FTD-MT- 64-156

# TRANSLATION

BUILDING STRUCTURES FROM ALUMINUM ALLOYS
(COLLECTION OF ARTICLES)



## FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

FTD-MT- 64-156

# EDITED MACHINE TRANSLATION

BUILDING STRUCTURES FROM ALUMINUM ALLOYS (COLLECTION OF ARTICLES)

English Pages: 379



PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.



Date 27 July 1965

Akademiya Stroitel'stva i Arkhitektury SSSR

Tsentral'nyy Nauchna-Issledovatel'skiy Institut
Stroitel'nykh Konstruktsiy

# STROITEL'NYYE KONSTRUKTSII IZ ALYUMINIYEVYKH SPLAVOV

Pod obshchey redaktsiyey
d-ra tekhn. nauk prof. S. V. Taranovskogo

Gosudarstvennoye Izdatel'stvo
Literatury Po Stroitel'stvu Arkhitekture
i Stroitel'nym Materialam

Moskva-1962

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

| Block | Italic | Transliteration | Block | Italic | Transliteration |
|---|---|---|---|---|---|
| А а | *А а* | A, a | Р р | *Р р* | R, r |
| Б б | *Б б* | B, b | С с | *С с* | S, s |
| В в | *В в* | V, v | Т т | *Т т* | T, t |
| Г г | *Г г* | G, g | У у | *У у* | U, u |
| Д д | *Д д* | D, d | Ф ф | *Ф ф* | F, f |
| Е е | *Е е* | Ye, ye; E, e* | Х х | *Х х* | Kh, kh |
| Ж ж | *Ж ж* | Zh, zh | Ц ц | *Ц ц* | Ts, ts |
| З з | *З з* | Z, z | Ч ч | *Ч ч* | Ch, ch |
| И и | *И и* | I, i | Ш ш | *Ш ш* | Sh, sh |
| Й й | *Й й* | Y, y | Щ щ | *Щ щ* | Shch, shch |
| К к | *К к* | K, k | Ъ ъ | *Ъ ъ* | " |
| Л л | *Л л* | L, l | Ы ы | *Ы ы* | Y, y |
| М м | *М м* | M, m | Ь ь | *Ь ь* | ' |
| Н н | *Н н* | N, n | Э э | *Э э* | E, e |
| О о | *О о* | O, o | Ю ю | *Ю ю* | Yu, yu |
| П п | *П п* | P, p | Я я | *Я я* | Ya, ya |

* <u>ye</u> initially, after vowels, and after ъ, ь; <u>e</u> elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

FOLLOWING ARE THE CORRESPONDING RUSSIAN AND ENGLISH

DESIGNATIONS OF THE TRIGONOMETRIC FUNCTIONS

| Russian | English |
|---|---|
| sin | sin |
| cos | cos |
| tg | tan |
| ctg | cot |
| sec | sec |
| cosec | csc |
| sh | sinh |
| ch | cosh |
| th | tanh |
| cth | coth |
| sch | sech |
| csch | csch |
| arc sin | $\sin^{-1}$ |
| arc cos | $\cos^{-1}$ |
| arc tg | $\tan^{-1}$ |
| arc ctg | $\cot^{-1}$ |
| arc sec | $\sec^{-1}$ |
| arc cosec | $\csc^{-1}$ |
| arc sh | $\sinh^{-1}$ |
| arc ch | $\cosh^{-1}$ |
| arc th | $\tanh^{-1}$ |
| arc cth | $\coth^{-1}$ |
| arc sch | $\mathrm{sech}^{-1}$ |
| arc csch | $\mathrm{csch}^{-1}$ |
| rot | curl |
| lg | log |

## ANNOTATION

In articles of collection there is correlated native and foreign experience in application of contemporary aluminum alloys as building material, and there are presented data on actual performance of elements of structures, articles, and parts from this material. In collection there is considered contemporary state of question, and field of application of aluminum alloys in construction is determined; experience in designing, manufacture, assembling, and exploitation of structures is illuminated; there are given examples of native structures planned and build with application of aluminum alloys; there are given the aspects of technical modes of designing of building structures from these alloys and main problems of scientific research works on application of aluminum alloys in construction.

This book is designed for engineer-builders, production workers and designers, workers of building materials industry, workers of scientific research institutes, and also for post graduates and students of technical institutes.

PREFACE

Under conditions of construction carried out in USSR application of new, light building materials, an important place among which is occupied by aluminum alloys, is acquiring great value.

It is natural, therefore, that subject "Building Structures From Aluminum Alloys" is included in plan of the most important scientific research works of state construction in USSR.

Coordination of all scientific research works on this subject is entrusted to Central Scientific Research Institute of Building Structures (TsNIISK) ASIA USSR.

At regular coordination conference at TsNIISK, which took place in March 1960 under acting chairmanship of member of ASIA USSR B. I. Belyayev, a resolution was taken about publication of collection of articles reflecting results of collective work on this subject conducted according to coordination plan in a number of scientific research, planning, industrial organizations, and in faculties of technical colleges.

In this collection there are included works presented during 1960 to TsNIISK for publication.

Board of Central Scientific Research
Institute of Building Structures.

MT-64-156
Building Structures from Aluminum Alloys
(Collection of Articles), GSI, Moscow,
1961.
Pages: Cover - 339

# BASIC PROBLEMS IN PREPARATION FOR BROAD APPLICATION OF ALUMINUM ALLOYS IN CONSTRUCTION

Dr. Tech. Sciences, Professor S. V. Taranovskiy

## 1. Introduction

Program of Communist Party of Soviet Union, accepted by XXII Congress of Communist Party among a number of other problems of party, provides for further rapid increase of the production of metal. Especially to be accelerated is production of light, nonferrous, and rare metals, output of aluminum will be significantly increased, as will its application in electrification, machine building, construction, and in everyday life.

Basic merits of aluminum alloys as building materials are its lightness, strength, high technological effectiveness, durability, and good appearance.

Certain disadvantage of aluminum and aluminum alloys* is lowered, as compared to steel, value of modulus of longitudinal elasticity, which shows up negatively during calculations for resistance and increases deformation of structures and elements from aluminum alloys. This peculiarity of aluminum alloys must be in all possible ways considered during designing.

However, lowered elastic modulus of aluminum alloys evokes decrease of secondary stresses during change of temperature or settling of supports in static,

*In the future commercial aluminum and aluminum alloys will be conditionally united under the general designation "aluminum alloys."

indeterminable systems and improvement of ability of structure to withstand dynamic and, especially, seismic influences.

Aluminum alloys first found application in construction in the last century - initially as decorative material and material for unloaded or slightly loaded articles, but starting approximately from the Thirties of this century - also load-bearing structures.

At present the United States expend on construction per year nearly 20%, and England, FRG, and France expend nearly 6% of total consumption of aluminum for this purpose.

In USSR industrial output of aluminum began only in Thirties of this century. In spite of intensive growth of native aluminum industries, great needs for this material in a number of branches of People's Economy until now led to limited application of aluminum alloys in construction.

Specific character of aluminum alloys as building material requires serious preparation for wide application of them in construction in connection with the most immediate problem of creation of structures, articles, and parts meeting high technical standard.

A future problem will be rapid rate of quantitative growth of building structures from aluminum alloys. High technical level of created structures, articles, and parts (in the future combined under general designation of structures) requires:

a) thorough study and enlistment of everything useful that gave and gives application of aluminum alloys in other fields, for instance in aviation and shipbuilding;

b) use of the quite broad foreign experience in application of aluminum alloys in construction,

c) use of native experience of scientific research works on designing and manufacture of steel building structures.

Relatively little practical experience of number of native scientific research, design, and industrial organisations, and also faculties of technical colleges shows, however, that points enumerated in pars. "a", "b," and "c" are insufficient.

Actually, the greatest experience in application of structures from aluminum alloys is in aviation. However, building structures differ radically from those of aviation in degree of longevity, character of loads, structural forms, and necessity of techno-economic comparison with other building materials.

Experience in application of aluminum alloys in shipbuilding is considerably less than in aviation, but it deserves attention during development of technology of welding of building structures.

Use of broad foreign experience in application of aluminum alloys in construction requires specially critical reference to this source for possibility of use of all that is useful and relative to our conditions.

Use of experience in designing of steel structures is one of the powerful means of preparation for broad application of aluminum alloys in construction.

However, it is absolutely necessary here to thoroughly consider difference of physico-mechanical parameters of aluminum alloys and steel, peculiarities of manufacture of semi-finished products, assemblies and structures, distinction in exploitational characteristics, and also techno-economic factors.

In connection with limited possibilities of use of above-mentioned data for broad preparation for application of aluminum alloys in construction of absolute necessity are development of scientific research works, experimental and real designing, creation of an industrial basis for manufacture of structures from aluminum alloys, collection and correlation of data on exploitation of these structures, and more precise definition of field of their application on the basis of analysis of their techno-economic characteristics.

At present, as a result of correlation conducted in USSR of collective work on application of aluminum alloys in construction, it is possible to bring in initial results and to outline the most important avenues of continuation of this work.

## 2. Selection of Brands of Aluminum Alloys and Types of Joints for Building Structures

### a) Material for Structures

In all countries building structures are made from aluminum alloys of different brands.

Properties of these alloys are less stable than for structural steels, inasmuch as modernization is being conducted of existing alloys, and new brands of alloys are being created.

Only with growth of scale of application of aluminum alloys in construction are there created brands intended chiefly for application in construction.

Basic requirements set forth for aluminum alloys as building material are:

1) high technological effectiveness, ensuring receipt of semifinished products of necessary form;

2) high technological effectiveness of resolution of joints;

3) longevity of material (in durability);

4) longevity of external appearance of structures;

5) high strength of basic material;

6) high strength of joints;

7) relatively low cost of material (semifinished products),

8) relatively low cost of manufacture of building structures from aluminum alloys.

Enumerated requirements, however, are incompatible; principal and determining of them are shown in pars. 1, 3, 7, and 8. Therefore, depending upon purpose of structure in TU SN [Technical Specs and Construction Norms] 113-60 there is provided for application of different aluminum alloys.

Thus, for structures combining functions of enclosing and load bearing (coverings of buildings in the form of shells, roof and wall panels, stained glass panels, sashs, etc.), basic attention should be allotted questions of resistance to corrosion. Questions of strength of material have less value here.

In conformity with this there are recommended in this case deformed alloys of systems: aluminum-manganese; aluminum-magnesium; and aluminum-magnesium-silicon.

Basic calculated resistances to extension, compression, and bend of these alloys constitute 24-66% of basic calculated resistance for steel of brand of St. 3.

For load-bearing, welded structures there should, naturally, be applied welded aluminum alloys possessing sufficiently high strength properties. To these belong certain alloys of system aluminum-magnesium, and alloys of systems aluminum-magnesium-silicon and aluminum-zinc-magnesium.

Basic calculated resistances of these alloys constitute 67-119% of basic calculated resistance of steel of brand St. 3. Finally, for load bearing, riveted sturctures there are recommended alloys of systems aluminum-magnesium-silicon and aluminum-copper-magnesium (duralumin). Basic calculated resistances of these alloys constitute 76-138% of calculated resistances for steel of brand St. 3.

It is necessary to note that strength characteristics of aluminum alloys applied in construction depend on a number of factors. They are:

a) type, brand, and state of alloy;

b) type, form, and dimensions of semifinished products;

c) presence and thickness of plated layer,

d) presence of copper in alloys of type AV (aluminum-magnesium-silicon);

e) increase of temperature (over 50°), etc.

Enumerated factors, naturally, to a different degree appear in different alloys.

The clearest example of influence of form and dimensions of semifinished products can be thermally hardened alloy V92-T of system aluminum-zinc-magnesium, for which basic calculated resistance for rolled sheets constitutes 1700 kg/cm$^2$, and for extruded profiles and tubing - 2500 kg/cm$^2$.

Questions of general appraisal of contemporary aluminum alloys as material are illuminated in this collection in two articles.

The first of these articles, that by Dr. of Tech. Sciences I. N. Fridlyander, contains general consideration of contemporary aluminum alloys, in the first place the deformed, with introduction of new data on these alloys necessary for builders.

Besides deformed aluminum alloys, in article there are also considered cast alloys, baked aluminum powders and alloys, and foamy aluminum.

Second article, by N. M. Edel'man, engineer, is devoted to consideration of foreign and native aluminum alloys for construction.

In examining of native aluminum alloys the most attention is allotted new alloys of system aluminum-magnesium-silicon, including alloys AD31, AD33.

Content of these articles facilitates problems of selection of brands and states of aluminum alloys for building structures of different purpose.

Article by workers of All-Union Scientific Research Institute of Transport Construction L. P. Shelestenko, Cand. of Tech. Sciences and Yu. M. Nagevich, engineer, contains results of investigations conducted in TsNIISK [Central Scientific Research Institute of Communications], of Mintransstroy of physico-mechanical properties of aluminum alloys designed chiefly for load-bearing, bridges structures. In this article there is made comparison of primary diagrams of compression and extension.

Questions of comparison of mechanical characteristics of aluminum alloys under extension and compression are illuminated also in article by Yu. S. Mkrchants, engineer, ( TsNIISK, ASiA and USSR).

As a result of investigations conducted in 1959-1960 in TsNIISK by author of article on an original device, there were revealed certain divergences in magnitudes of limits of proportionality and conditional yield point in samples from alloy D16-T under extension and compression, which requires use of diagram of compression for exact solution of problems of stability.

b) Joints

Practice of aircraft building gives little data for resolution of joints of building structures from aluminum alloys, owing to insufficiency of data welding and absence of broad experience in setting of rivets of large diameters. In this sense the experience of shipbuilding may be more useful for building structures.

The most complicated problem for welded joints is creation fo full value, in strength, butt weld, inasmuch as until now the strength of butt welds for all weldable aluminum alloys was lowered as compared to strength of basic material. Complicated also are the establishment and decrease of width of zone of thermal influence.

These difficulties are in significant measure based on specific character of influence of heating on aluminum alloys, especially the thermally hardened.

Setting of cold rivets of large diameter also evokes production complications.

The noted difficulties are gradually decreasing, which is promoted not only by development of basic forms of joints (welding, riveting, and bolts), but by introduction of new joints, for instance high-strength bolts, bolts with squeeze rings, etc.

Essence of bolts with squeeze rings, sometimes called lock bolts abroad, consists in separation of bolt into two parts (Fig. 1): stem with head and locking (squeeze ring). The stem part can be made of high-strength alloys or of steel (with protective coverings against corrosion), whereas squeeze ring is made of ductile, light alloy.

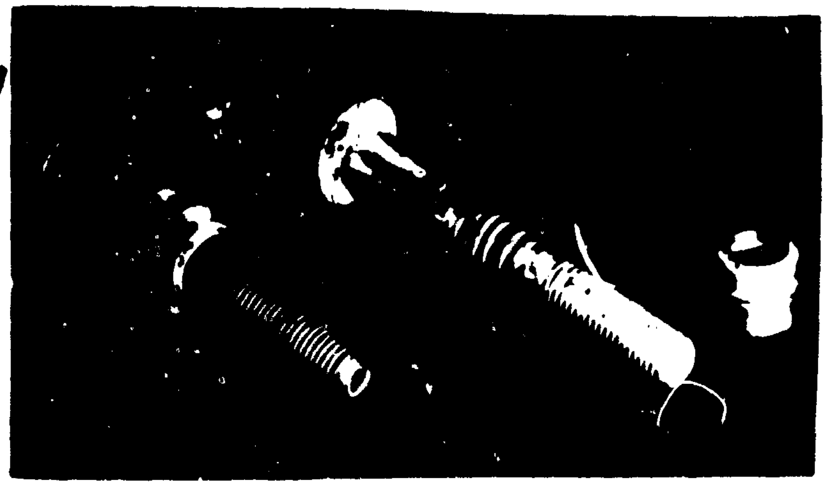

Fig. 1. Bolt with squeeze ring (lock bolt).

Setting of bolts with squeeze rings is carried out with help of light tightening gun, which is activated by pneumatic drive, consisting of compressor and flexible hose.

Sequence of operations in installation of bolt with squeeze ring is shown in Fig. 2.

At present bolts with squeeze rings are prepared in this country with diameter to 10 mm with tendency toward increase of this diameter to 12-14 mm.

As compared to rivets made from aluminum alloys, bolts with squeeze rings ensure increase of their load-bearing ability to resist shear and breaking away of head.

Comparison of certain strength characteristics of material and joints from aluminum alloys (according to TU SN 113-60) with those of steel (according to NiTU 121-55) is given in Table 1 for welded structures and in Table 2 for riveted structures.

Comparison of load-bearing ability of riveted joints in structures from aluminum alloys with riveted joints of steel structures made from St. 3 with rivets of St. 2 (rivet), is presented in Table 2.

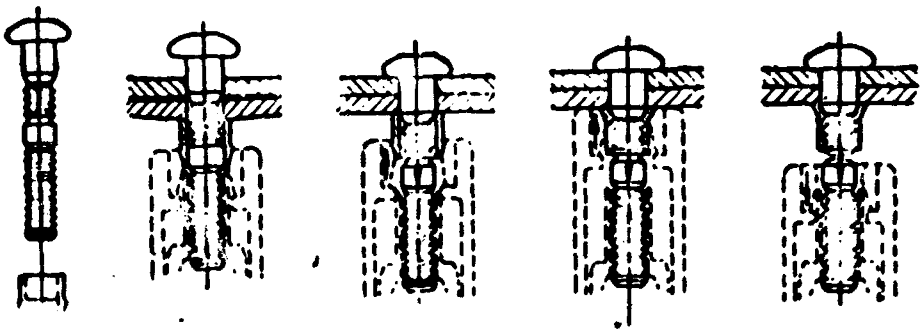

Fig. 2. Sequence of operations in installation of bolts with squeeze rings.

Table 1. Comparison of Strength Characteristics of Material and Joints of Welded Structures from Aluminum Alloys with Those of Steel.

| Characteristic | Brand and state of aluminum alloys for welded structures | | | | | |
|---|---|---|---|---|---|---|
| | | | | | V92-T | |
| | AMg6 | AMg61 | AD33-T1 | AV-T1 | Sheet | Extruded Profile |
| Basic calculated resistance R (to extension, compression and bend): | | | | | | |
| in kg/cm$^2$. . . . . . . | 1400 | 1800 | 1600 | 1700 | 1700 | 2500 |
| in % of R for steel of brand of St. 3 . . . . | 67 | 86 | 76 | 81 | 81 | 119 |
| Calculated resistance for butt weld in structures from aluminum alloys | | | | | | |
| in kg/cm$^2$. . . . . . . | 1300 | 1600 | 1000 | 1100 | 1500 | 1500 |
| in % from calculated resistance for butt weld in steel structures (St. 3) and on electrodes of type E34. . . . . . | 100 | 123 | 77 | 85 | 115 | 115 |
| The same, with electrodes of type E42 and E42A and automatic welding under layer of flux. . . . . . . . . . . | 62 | 76 | 48 | 52 | 72 | 72 |

Table 2. Comparison of Strength Characteristics of Material and Joints of Riveted Structures from Aluminum Alloys with Those of Steel

| Characteristic | Brands and state of aluminum alloys for riveted structures | | | |
|---|---|---|---|---|
| | AD33-T1 | AV-T1 | D1-T | D16-T |
| Basic calculated resistance R (to extension, compression, and bend); in kg/cm$^2$ . . . . . . . . . . . . . . | 1600 | 1700 | 1600-2100 | 2400-2900 |
| in % of R for steel of brand St. 3; | 76 | 81 | 76-100 | 114-138 |
| Calculated resistance to shear R of rivets from alloy D18P; in kg/cm$^2$; . . . . . . . . . . . . . | 1100 | 1100 | 1100 | 1100 |
| in % of calculated resistance to shear B of rivets from steel of brand St. 2 (rivet); | 61 | 61 | 61 | 61 |
| The same, from alloy V65: in kg/cm$^2$; . . . . . . . . . . . . . | 1450 | 1450 | 1450 | 1450 |
| in % of calculated resistance to shear B of rivets from steel of brand Sta 2 (rivet); | 81 | 81 | 81 | 81 |
| Calculated resistance to crumpling B of rivets in structures from aluminum alloys: in kg/cm$^2$; . . . . . . . . . . . . . | 2400 | 2400*/2700 | 2900 | 3900 |
| in % calculated resistance to crumpling B of rivets in structures from steel of brand St. 3. | 57 | 57/64 | 69 | 93 |

*In numerator for alloy with copper content to 0.1%; in denominator for alloy with copper content >0.1%.

Above mentioned data on materials and joints allow us to make following conclusions.

1. Calculated resistances of aluminum alloys intended for welded building structures from aluminum alloys constitutes 67-119% with respect to R for St. 3. However, calculated resistances of butt welds not exceed 76% of calculated resistances of butt welds in steel structures welded by electrodes of types E42 and E42A, and automatically under layer of flux in structures from steel of brand St. 3.

2. Calculated resistances of aluminum alloys intended for riveted building structures from aluminum alloys constitute 76-138% with respect to R for St. 3. However, calculated resistances of rivet joints to shear constitute 61-81%, and to crumpling 57-93% of corresponding calculated resistances of rivet joints from St. 2 (rivet), in structures from St. 3.

3. For broad preparation for application of aluminum alloys in load-bearing structures the measures enumerated below are absolutely necessary:

a) perfection and wide introduction into practical use of new brands of aluminum alloys possessing higher calculated resistances in basic material and especially in joints; an example can be one of the measures outlined for organization of production of materials and articles for construction of World-wide Exhibition in Moscow in 1967, which anticipated creation of weldable aluminum alloy of high strength for large-span, load-bearing structures and for space structures, combining load-bearing and enclosing functions; calculated resistance of new material is contemplated within limits of 2400-3000 kg/cm$^2$ with calculated resistance of butt weld within limits of 2000-2500 kg/cm$^2$;

b) All possible reduction of quantity of joints by means of increase of dimensions of extruded, rolled, and shape-formed elements in both area of cross section and in width, height, and length;

c) search for structural forms allowing us to dispose joints in less stressed places, thereby ensuring full value use of calculated resistances of basic metal;

d) parallel with further improvement of first rate welded and riveted joints it is necessary in all possible ways to continue work of perfecting of other forms of joints, including bolts of various type, glued, etc.

4. Principal technical documents on above-mentioned questions must be "Technical Specs of Designing of Structures from Aluminum Alloys" (SN 113-60), and also technical specs on materials for building structures, to be complied in 1961.

Further technical progress toward improvement of basic material and especially of joints should be quickly reflected in form of supplements to indicated technical specs.

Questions of role of joints in structures from aluminum alloys are illuminated in number of articles of this collection.

Article by workers of NII [Scientific Research Institute] of bridges at Leningrad Institute of Railroad Transportation Engineers (LIIZhT) Yu. P. Satayev, and cand. Tech. sciences and A. A. Savel'yev, engineer is devoted to riveted joints. In article there are given results of investigations conducted in NII of bridges at LIIZhT on cold riveting of load-bearing structures from aluminum alloys.

Article by I. V. Levitanskiy, engineer (MISI [Moscow "Order of the Red Banner of Labor" Construction Engineering Institute] im. Kuybyshev) contains data from theoretical and experimental investigations of nodal joints of tubular aluminum girders. Works were conducted by the author (post graduate of MISI) jointly with GPI [State Planning Institute] Proektstal'konstruktsiya.

Article by N. I. Novozhilova, cand. of tech. sciences (NII of brigdes at LIIZhT) illuminates results of investigations conducted at NII of bridges on determination of vibration resistance of riveted joints. Author offers values of coefficients $\gamma$ of lowering of allowed stresses for elements working under sign-alternating and variable loads of span structures of bridges and other load-bearing structures made from aluminum alloys.

## 3. Manufacture of Semifinished Products and Structures from Aluminum Alloys

Development of aluminum industry is determined by general problems of national-economic plan, taking construction into account as one of basic long-term consumers of a large quantity of aluminum alloys.

Output of semifinished products, sometimes specially called rolling, is also organized in interests of all consumers of aluminum alloys. Existing catalogs of extruded profiles are gradually expanding. However, builders are making their demands, volume of which, naturally, will increase with expansion of application of aluminum alloys in construction.

Such requirements include:

a) perfection and introduction of special assortment of profiles for construction, including the extruded, shape-formed, and profiles bent from sheets;

b) perfection of technical documents for designing of special profiles, not included in assortment.

This work is conducted, basically, by forces of NII on construction of Ministry of Construction of RSFSR and by organizations,

c) the fastest output of profiled sheets with height of corrugation on order of 100-200 mm and with different corrugation contour; extremely important for builders in output of elements bent to large radius.

Questions of production of semifinished products necessary for builders, although sometimes slowly, however, are being solved in interests of builders. However, even the little native experience testifies to deficiencies that worsen properties of structures from aluminum alloys (small length of semifinished products and requirements presented to specifications of technology of manufacture for increase of minimum thickness of extruded profiles).

The most difficult today is question of manufacture of building structures from aluminum alloys. As it is known, at present building structures from aluminum alloys are made either in steel fabrication factories, or in factories of aviation industry.

Successful example of first trend is the manufacture in 1959 at Chelyabinsk metal fabrication factory im. S. Ordzhonikidze of 30 sets of prefab-collapsible grain elevators for virgin lands, planned by GPI Promzernoproyekt with participation of a number of organizations.

A number of structures from aluminum alloys are made at Sokolovskiy metal fabrication factory of Ministry of Construction of RSFSR. Separate structures are manufactured by forces of scientific research and design institutes.

Distribution of orders for building structures of aviation factories evokes a number of inherent dificulties.

In connection with this an indispensable condition for broad preparation for application of aluminum alloys in construction is creation of industrial power specially intended for manufacture of building structures from aluminum alloys.

Such an industrial basis should provide high-quality manufacture of all necessary building structures from aluminum alloys intended for scientific and experimental investigations and also for practical (in first years, essentially, experimental) construction.

Amassed experience of manufacture of building structures from aluminum alloys will allow us qualitatively to work out necessary technical specifications for manufacture of building structures from aluminum alloys and thereby to supplement and develop the presently existing GPI Promstal'konstruktsiya, GPI Proektstal'-konstruktsiya, and TsNIISK ASiA project of instruction in manufacture and assembling of building structures from aluminum alloys.

In article by A. G. Immerman, Cand. of Tech. Sciences (NII on construction of Minstroy of RSFSR) there is expounded method of compiling the assortment, developed with respect to specific properties of aluminum alloys and peculiarities of production from them of pressed profiles. Article contains data on draft of assortment intended for use in designing of load-bearing structures from aluminum alloys recommended by TU SN 113-60.

In spite of comparative simplicity of manufacture of profiles and many possibilities of technology of pressing, presence of assortment of general-usage profiles will positively influence development of structures from aluminum alloys.

Among a number of other questions in article there is given method of construction of nomographs, allowing us to quickly select efficient cross sections of centrally compressed rods, in which there is completely utilized the load-bearing ability both with respect to total and local stability.

Questions of manufacture of building structures from aluminum alloys are partially illuminated also in a number of other articles of this collection.

## 4. Resistance of Aluminum Alloys to Corrosion

Necessary durability of aluminum alloys requires their high resistance to corrosion. Available data on this question have to be divided into two groups, the first of which provide for preservation of necessary durability, and second-preservation of both durability and appearance of the structure.

High durability of structures, articles, and parts from aluminum alloys with correct selection of brands of alloys with regard for medium in which they will be exploited can be attained in a number of cases without special measures of protection against corrosion, because of natural formation on surface of aluminum alloys of protective oxidized film.

Analysis of foreign source material on corrosion of building structures from aluminum alloys shows that corrosion of aluminum alloys quickly dies down in time, which leads, for instance, to a situation in which depth of corrosion after first year of exploitation is equal to depth of corrosion for subsequent 19 years.

In Fig. 3 there are given data on depth of affection by corrosion of a foreign alloy comparable approximately to native alloy AMts after twenty-years period of exploitation in costal (marine), industrial, and tropical regions.

As can be seen from Fig. 3, maximum depth of affection after 20 years in costal (marine) region constituted 0.2 mm.

Durability of structures and articles from aluminum alloys in a number of cases exceeds by several times the durability of steel structures; as examples of this are upper bonds and roofing of reservoirs for sulfurous oil, application of aluminum alloys in gas conduits in the presence of sulfurous gas, etc.

At the same time there are a number of aggressive media (chiefly alkali), where application of aluminum alloys should be excluded.

Thus, it is necessary to study thoroughly favorable and unfavorable factors for application of aluminum alloys by condition of protection of their durability, which should be carried out by means of analysis of foreign data and by making of special investigations organized in Union of Soviet Socialist Republics, for instance in YuzhNII [Southern NII] ASiA Ukraninain SSR.

So far as preservation of appearance of aluminum alloys and avoiding of even slight corrosion (as factor disturbing this appearance) is concerned, the complex of measures, of both technological and exploitational nature, should be thoroughly worked out and checked under actual conditions of exploitation.

On the whole it is necessary to note that in the overwhelming number of cases the stability of aluminum alloys has been increased.

Question of corrosion resistance of aluminum alloys is continuously the center of attention in organizations developing aluminum alloys. Here it is considered, for instance, absolutely rational to obtain even a slight lowering of strength properties at the expense of increase of corrosion resistance of alloy. An example of this is limitation of copper content in alloy AV-T, given in TU SN 113-60, leading to increase of corrosion resistance through lowering of calculated resistances by approximately 100 kg/cm$^2$, and also the intended transition from alloy AV-T1 to alloy AD33-T1 with problem of increase of corrosion resistance through certain lowering of calculated resistances.

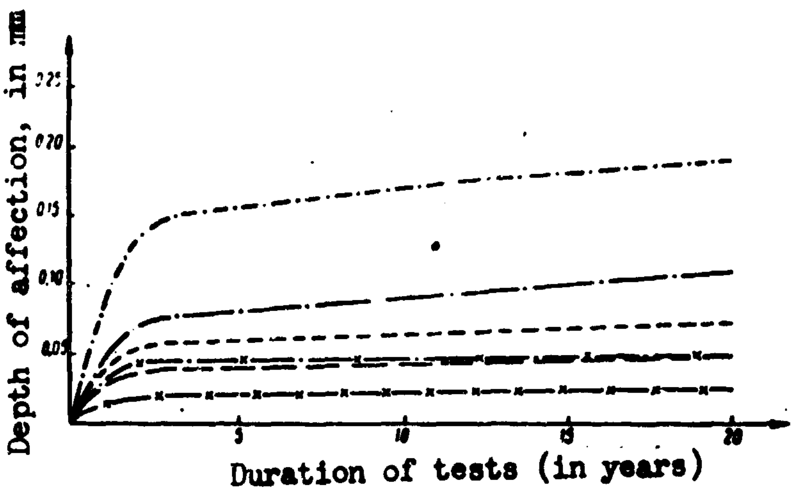


Fig. 3. Characteristic of corrosion resistance of aluminum alloys

| | | |
|---|---|---|
| ---- | mean value | costal region |
| -·-·- | maximum value | |
| — — — | mean value | industrial region |
| —▮—▮— | maximum value | |
| – x – | mean value | tropical region |
| –·–x– | maximum value | |

High resistance of aluminum alloys to corrosion allows us to apply minimum thicknesses of semifinished products from aluminum alloys.

1.5 mm-for load-bearing elements located inside building and for elements protruding to exterior;

3 mm-for structures in open air (with the exception of projecting elements);

0.3 mm-for roofing and wall panels with appropriate form of profile ensuring stability of section.

Questions of corrosion resistance of aluminum alloys in building structures are illuminated in article by workers of YuzhNII ASiA Ukrainian SSR Yu. N. Tikenko, Cand. of Tech. Sciences and V. Ya. Flaks, engineer. In article there is given foreign data on corrosion resistance of aluminum alloys and also initial results of broad research started in YuzhNII on corrosion resistance of native aluminum alloys during their exploitation under conditions of metallurgical factories and in atmosphere of industrial city.

## 5. Certain Peculiarities of Calculation of Structures from Aluminum Alloys with Respect to Ultimate Strains (Deflections) and to Stability

Value of modulus of longitudinal elasticity of aluminum alloys lowered as compared to steel, increases significance of check of structures from aluminum alloys for ultimate strains, total and local stability. One of the most important questions of designing is determination of ultimate strains (deflections) of bent elements.

For the purpose of limitation of number of cases of calculation of bent elements for deflections and thereby more rational use of material during calculation of strength in structures from aluminum alloys, TU SN 113-60 has developed this question more specifically, in particular, there are allowed larger values of ultimate strains than in NiTU 121-55 for steel structures.

Thus, for instance, in SN 113-60 there are given delfection norms for elements of framework, roof panels, suspended ceilings and wall panels, which were not in NiTU 121-55. Ultimate deflections for roof panels and suspended ceilings have been determined at 1/150 (1/25) of span, and wall panels - at 1/125 (1/100) of span, where figures in parentheses are magnitudes allowed when there is a foundation, including experimental construction.

We must note that tendency of increase of ultimate strains is common for structures from aluminum alloys, therefore, with development of these structures one should expect further increase of ultimate deflections of bent elements.

Question of check of total stability of girders in TU SN 113-60 has been developed in sufficient detail. In particular, in Tables 19 and 20 of Technical Specs there is given data on the biggest ratios of free length of compressed boom $\underline{l}$ to its width b, in which there is not required check of stability of welded, pressed (Table 19), and riveted (Table 20) girders in dependence not only on place of application of load, brands of alloys and their states, but also on ratio of total height of beam to its width. Permissible ratios $\underline{l}$ : b in structures from aluminum alloys, are understandably less than for steel structures.

Check of local stability of walls of girders is also made in structures from aluminum alloys under more rigid requirements.

In detail in TU SN 113-60 there are considered questions of relationships of dimensions centrally compressed and compressed flexed elements.

Here there are determined permissible ratios of rated height $h_0$ or average diameter D of tubing to corresponding thickness $\delta$, depending upon calculated flexibility $\lambda$ and also on magnitude of ultimate overhangs of flange plates and shelves of compressed, compressed flexed, and bent elements both in the absence and in the presence on overhangs of thickenings (bulbs).

Low value of modulus of longitudinal elasticity is reflected also on values of coefficients $\varphi$, of buckling of centrally compressed elements. Comparison of the latter with corresponding values for steel structures is presented in Fig. 4.

Relatively low values of coefficients $\varphi$ for aluminum alloys led to necessity of reduction of allowed limits of flexibility of compressed elements (as compared to steel elements). It is necessary, however, to stipulate that for purpose of best use of material, flexibility of principal compressed elements from aluminum alloys does not usually have to exceed 50-60.

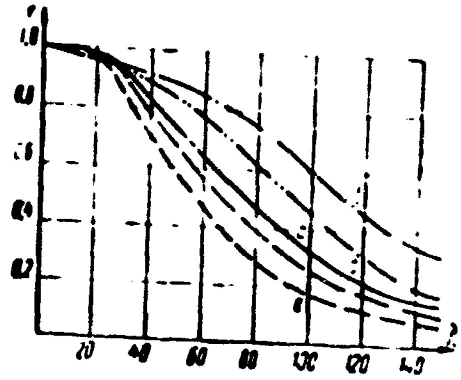

Fig. 4. Values of coefficients $\varphi$ and ultimate bend strengths of principal compressed elements

a - a - from aluminum alloys; b - b - from steel

Special designations:

| | |
|---|---|
| ———— | AMg6-M; |
| — — — | AV-T |
| - - - - - - | D16-T |
| -·-·-·- | St. 3 |
| -··-··-·- | NL2 (15 KhSND). |

Large number of articles in this collection are devoted to theoretical and experimental investigations of actual work of material, separate elements, articles, and structures.

Two articles are devoted to questions of calculation of stability. The first of them - by Dr. of Tech. Sciences B. M. Broude and G. M. Chuvikin, Cand. of Tech. Sciences (TsNIISK ASiA USSR) - contains basi of certain methods of calculation of stability given in TsNIISK ASiA USSR, which are given in TU SN 113-60. Here, there are included questions of eccentric compression, bend-twist form of loss of stability, axial compression, overall stability of girders, and local stability of walls on beams.

Second article - by workers of NII construction of Ministry of Construction of RSFSR A. G. Immerman, Cand. of Tech. Sciences and V. S. Moskvitin, engineer -

is devoted to more precise definition of local stability of angular profiles from alloy D16-T. In article, on the basis of theoretical prerequisites and conducted experimental investigations, there are made recommendations for assignment of overhang of corner flanges (both the usual and also those with thickenings - bulbs). Obtained data are designed for use both in designing of elements and also during composition of assortment.

In article by A. Kh. Khokharin Cand. of Tech. Sciences (TsNIISK ASiA USSR) there are illuminated results of investigations of work of rods under central compression. Obtained results are compared with those given in TU SN 113-60.

In article by B. G. Bazhonov, engineer (TsNIISK) there are given results of experimental investigations conducted on eccentrically compressed rods of rectangular and H-shaped sections from aluminum alloy AV-T1. In article there is given also a method of approximation of solution of problem of stability of eccentrically compressed rod for the same forms of cross section. There is given also comparison of theoretical values of critical forces determined with help of offered method of approximation, with results of experiments.

Here we can refer to above-mentioned works on actual work of joints.

Article by Yu. S. Mkrchanets, engineer (TsNIISK) is devoted to analysis of investigations conducted by him at TsNIISK of actual work of I-beams under influence of concentrated static loads.

Author, on the basis of analysis and modernization of existing theoretical assumptions and on numerous experimental investigations conducted by him of series of beams, studied questions of local stability of walls, distribution of stresses in elements of beams, overall and local deformations, and also values of ultimate strains of beams.

Correlation of practice of experimental and practical designing of structures from aluminum alloys should be subject of special investigation.

In this collection five articles are devoted directly to structures from aluminum alloys.

Article by K. D. Fink, engineer (EKB [Experimental Designers Bureau] at ASiA USSR) is devoted to designing of certain type of roof and wall panels, developed at EKB with participation of TsNIISK.

Article by V. N. Spirov, engineer (Moscow) gives data on designing and manufacture of building structures and articles from aluminum alloys. Such structures and articles include wall panels, windows and doors, partitions and stained glass panels, and roof and suspended ceilings.

In article by G. D. Popov, engineer (GPI Proektstal'konstruktsiya) [State Planning Institute for Steel Construction] there is given data from planning department of this institute on structures from aluminum alloys, including span of 90 m, in which as load-bearing structures there are used jointless archs.

Article by Yu. S. L'vov, engineer (GPI Giproavtotrans) [State Planning Institute auto Transportation] is devoted to first permanent highway bridge with span structure from aluminum alloys, developed in this organization.

In article by B. A. Speranskiy, Cand. of Tech. Sciences (Ural Polytechnical Institute] and F. F. Tamplon, engineer (NII on construction in Sverdlovsk) there are given results of initial research in prestressed girders from aluminum alloys.

On the whole, contents of first issue of the collection and planned future issues provides for both correlation of works conducted according to coordinate plan and formulation of subsequent new problems, solution of which will facilitate preparation for wide application of aluminum alloys in construction:

1) creation of a special industrial base for manufacture of structures;

2) further increase of resistance of aluminum alloys to corrosion;

3) significant increase of strength properties of basic metal and especially of joints intended for load-bearing structures;

4) expansion of theoretical and experimental works on questions of

calculation and designing;

5) development of structural forms of buildings and structures which, to the highest degree, reflect specific character of aluminum alloys;

6) establishment of cost of both semifinished products from aluminum alloys and also for manufacture of structures from them;

7) more precise definition of range of application of aluminum alloys with respect to prices, which will provide maximum technical progress in manufacture of semifinished products and structures from aluminum alloys.

# CONTEMPORARY ALUMINUM ALLOYS

Dr. of Tech. Scien es I. N. ridlyander

Aluminum has for a long time occupied place of second (after iron) metal. Production of aluminum is still many times lower than that level which has been attained in field of steel, but ra e of growth of production of aluminum is many times higher.

Rapid growth of production oi aluminum is caused both by properties of the pure metal and also especially by that complex of important qualities which different alloys possess, that are based on aluminum. During the last few years development of new aluminum alloys has been intensely conducted in many countries, and this has been fruitful. Possiblities in this respect are still far from relaised, and one should expect in future the creation of new, still more interesting alloys.

Before Second World War the basic alloying additions to aluminum alloys were magnesium, copper, and silicon (separately and in different combinations). Using various combinations of these additions, there were created magnalium (Al-Mg alloys), Silumin (Al-Si alloys, when necessary - with additions of copper and magnesium), duralumin (alloys of Al-Cu-Mg system), and also a group of forging alloys on a base of Al-Mg-Si system and Al-Mg-Si-Cu (AK5, AK6, AK8). In majority of these alloys there was introduced also maganese or its analog chromium (and later, zirconium). Role of small additions of these elements, especially in deformed alloys, is extraordinarily great, and it is possible to say that in certain respects it is still not clear. With manganese, chromium, and zirconium there is connected appearance of press-effect in pressed, semifinished products. These additions render very great influence on transverse properties of articles, disintegration rate of solid solutions, hardenability of articles, processes of recrystallization, and on appearance of coarse-grained structure.

In war and especially in postwar years there became intensely more familiar a new group of alloys, in composition of which as the most important alloying element there was introduced zinc (V95, V96, V94, V93, and V92).

At last, there were recently discovered, and they are obtaining even greater value, two groups of alloys, basic alloying components of which are oxygen ($Al_2O_3$), the so-called baked aluminum powder (SAP), and lithium in combination with cadmium in presence of copper and manganese (alloy VAD23).

It is necessary to emphasize that in creation of new alloys a decisive role is played not by added elements themselves, but by those chemical compounds which appear in alloy during alloying of aluminum. These chemical compounds or phase-strengtheners, interacting with solid solution, evoke hardening of alloys during heat treatment and render decisive influence on strength, ductility, and corrosion resistance of alloys. At the same time of extraordinarily important value are forms, dispersion, nature of distribution of phases-strengtheners, and also composition, structure, and properties of solid solution. Experience shows that maximum hardening during heat treatment of aluminum alloys is attained when phase-strengthener has in its own composition not less than two foreign (besides aluminum) atoms. Such phases are $Mg_2Si$ in Al-Mg-Si system (alloys AD31, AD33, AV), $MgZn_2$ and T, $Al_2Mg_3Zn_3$ in Al-Zn-Mg-Cu system (alloys V95, V96, V94, V93, and V92); $S(Al_2CuMg)$ in Al-Cu-Mg system (alloys D16, D18, AK4, AK4-1), phase $W(Al_xMg_ySi_zCu_u)$ in Al-Si-Mg-Cu system (alloys AK6 and AK8). At the same time, phases $CuAl_2$ and

$Al_3Mg_2$ (binary alloys Al-Cu) and Al-Mg (magnalium) evoke significantly less hardening. Discovery of new phase able to cause significant effect of hardening or appearance of other interesting properties each time constitutes definite, important stage in development of aluminum alloys.

Aluminum alloys are used in annealed and naturally or artificially aged states. Depending upon phase-strengthener, the properties of alloys change. Thus, in Al-Mg system mechanical properties of alloys in all states of heat treatment are practically equal. Phase S (Al-Cu-Mg system) evokes significant increase of strength after natural aging; artificial aging does not evoke additional, noticeable increase of strength or can even lead to certain lowering of it. Phases containing silicon and zinc (for instance, $Mg_2Si$ and $MgZn_2$) lead to significant effect of natural aging and to additional, large increase of strength after artificial aging. All phases of system Al-Cu-Mn and Al-Cu-Li possess very small effect of natural aging and huge effect of artificial aging. All these peculiarities of alloys must be considered during development of technological processes connected with their application. Described distinctions concern characteristics of strength. However, in all cases artificial aging leads to sharp increase of yield point, considerable increase of ratio $\sigma_{02}:\sigma_b$ and to significant lowering of elongation. In spite of lowering of elongation, alloys is artificially aged state can experience signigicant deformations without rupture, and they are fully applicable to structures. Regarding corrosional stability, in principle it is possible to ascertain that with proper selection of conditions of artificial aging, corrosion resistance of artificially aged alloys is no worse than corrosion resistance of naturally aged alloys.

1. <u>Deformed Aluminum Alloys and Certain Peculiarities of Their Application</u>

Deformed aluminum alloys can be divided into following groups:

a) pure Al;

b) Al-Mn alloys;

c) Al-Mg alloys (magnalium);

d) Al-Mg-Si alloys;

e) Al-Zn-Mg alloys (Cu);

f) Al-Cu-Mg alloys;

g) Al-Mg-Si-Cu alloys;

h) Al-Cu-Mn alloys (Li, Cd);

To Al-Mg-Si system belong alloys AD31, AD33, and AV. Alloy AV is sometimes called an avial.

In bygone times this alloy had large value for aviation, as a result of which it obtained the name "aviation aluminum" - avial. Now the role of this alloy in aviation is small, and this term is an anachronism.

In application of structural aluminum alloys one should consider some of their peculiarities, distinguishing them from steel. These, first of all are lowered values of elongation and impact toughness. For structural aluminum alloys the characteristic values of impact toughness are of the order of 1-2 kgm/cm$^2$ in longitudinal direction and 0.4-1 kgm/cm$^2$ in transverse (with respect to fiber) direction. Nonetheless, not one case of brittle fracture of a structure from deformed aluminum alloys after entire time of their exploitation was noted. These alloys are practically not inclined to brittle fracture, nor to cold brittleness, therefore, they can be with absolute calm applied with shown characteristics of impact toughness. However, if structure experiences direct (without damping) impact loads, additional tests have to be conducted.

Concept of satisfactory ductility (determined in practice basically by elongation) underwent long evolution. Up to 1940-1943 it was considered obligatory that average elongation be on order of 12-20%. Later, in connection with development of stronger alloys, this average elongation was lowered to 8-12%, and then (especially for rods, forgings, and stampings) -- to 3-6%. At the same time minimum assurable elongation was lowered from 10 to 6% for pressed articles, form 13-15 to 7-6% for sheets, and to 6-2% (depending upon direction of cutting of samples) for big forgings and stampings, and also for massive profiles. At present there is being realized lowering of assurable elongation for sheets and profiles from specially strong alloys to 2-3%. In spite of such comparatively low elongation, aluminum alloys work quite satisfactorily in structures. Prolonged tests showed that there is no direct connection between values of elongation, structural strength, or vibration strength of material. Moreover, by direct experiments on alloys of type V95 it was shown that with increase of temperature of artificial aging elongation of alloy is sharply lowered, and its resistance to vibration loads increases. Furthermore, its resistance to stress corrosion is immeasurably improved.

Therefore, alloy V95 can not be applied in naturally aged state (with elongation on order of 20%), and it should be used in structure only in artificially aged state (with elongation on order of 4-10%). Rivet alloy V94 is upset only after aging at sufficiently high temperature, as a result of which elongation of alloy is lowered. In naturally aged state (elongation of 20-25%) alloy V94 cracks during riveting. Artificially aged alloys V95 and V96 allow additional pressing by means of rolling to 20-25%, which confirms their good efficiency in artificially aged state with comparatively low elongation.

Together with that, some minimum of elongation is necessary. In rods, forgings, stampings, and profiles elongation in width and especially in height of articles with incorrect method of their manufacture can approach zero values. Big articles of similar type have to be tested in three mutually-perpendicular directions. In any of these directions elongation should be no lower than 1.5-2%. When necessary, elongation in transverse direction may be raised by means of application of the proper deformation diagram. Together with elongation, because of improvemnt of technology of production of semifinished products, corrosion resistance of articles may also be considerably improved.

Considerable attention should be given to any kind of structural heterogeneities, first of all to stratifications, inclusions of intermetallic compounds, and to coarse-grainedness, in particular macrocrystalline ferrule.

Stratifications, constituting local disturbances of continuity of metal, are met most frequently in forgings, stamping, pressed articles, and plates; they sometimes appear also in sheets. Area of stratifications can reach tens, and sometimes hundreds of square millimeters. They are always disposed with fiber and little affect unit properties, but weaken material in direction perpendicular to plane of bedding of stratifications. Stratifications, as a rule, are well revealed by ultrasonics, therefore, critical articles have to pass ultrasonic inspection. Slag inclusions worsen corrosion properties of articles, spoil their appearance, and lower vibration strength in thin sections.

In certain alloys there are easily formed coarse intermetallic compounds, constituting, as a rule, compounds of aluminum with manganese, chromium, iron, vanadium, or titanium. In semifinished products they are disposed in the form of separate points or lines. Inclusions of intermetallic compounds worsen transverse mechanical properties and corrosion resistance of material and spoil its appearance.

In articles from aluminum alloys there sometimes appears coarse grain. It, in general, weakly affects mechanical properties, corrosion resistance, and vibration strength of material, but worsens its decorative appearance; on sheets, pipes, and profiles in the presence of coarse grain there appear roughness and motley colored tints. On pressed articles coarse grain is revealed in the form of so-called macrocrystalline ferrule, which is sharply outlined and clearly segregated from remaining section. Macrocrystalline ferrule is allowed by present technical specs. However, it is necessary to consider its negative sides-it spoils appearance, is more easily inclined to overheating than basic material; during cold-water quenching from upper limit of temperature (within limits of instruction on heat treatment) inside ferrules there appear cracks, strength of ferrule is lower than strength of basic material by 4-8 kg/mm$^2$.

Stratification, slag inclusions, inclusions of intermetallic compounds, coarse-grainedness, and macrocrystalline ferrule in case of need can be regulated under special technical conditions.

a) Aluminum and Alloy of Aluminum with Manganese

Commercial aluminum is alloy of aluminum with constantly present impurities of iron and silicon (sometimes copper, magnesium, titanium, sodium, and others). The purer the aluminum, the higher its corrosion resistance. Aluminum is applied both in annealed and cold-worked states. This is excellent corrosion-resisting material, possessing good weldability, but poor machinability. Aluminum is very receptive to color anodizing. It can be applied in all those cases where its strength turns out to be sufficient.

High strength is possessed by alloy of aluminum with manganese (AMts alloy). Alloy AMts with respect to weldability, corrosion resistance, and machinability, is very near to aluminum, but in respect to color it looks worse.

b) Alloys of Aluminum with Magnesium (Magnalium)

Alloys of aluminum with magnesium (magnalium) possess (with correctly designed technology of production of semifinished products) high strength. They find wide and various application. During the last few years, composition of wide-spread brands of these alloys has been definitized and new brands have been created. It is assumed that at the end of this work there will have been obtained a number of alloys of magnalium type, in which content of magnesium changes continuously from 0.5-1.8% in AMg1 alloy, to 5.8-6.8% in AMg6 alloy, and possibly to 8-9% in new alloys of this group.

Alloy AMgl possesses high corrosion resistance, polishability, and reflectivity. Following the example of German Democratic Republic, content of chromium in AMgl alloy (and also in more alloyed alloys AMg2, AMg3, and AMg5) is limited to 0.05%. In this case this entire group of alloys AMgl, AMg2, AMg3, and AMg5 is well adapted to color anodizing, and it is excellent structural and decorative material. In order to distinguish magnalium with limited content of chromium, special marking will be introduced for them.

In structural alloys AMg5-V and AMg6-T a big complication is evoked by appearance in the structure of inclusions of intermetallic compounds of complex composition (aluminum with manganese, titanium, chromium, vandium, iron, and zirconium - depending upon presence of these elements in alloy). Intermetallic compounds act like sharp cuts, they worsen corrosion resistance and decorative appearance of material; permissibility of them should be thoroughly checked in each separate case. It has been shown that intermetallic compounds containing vanadium and zirconium are especially easily formed; titanium readily forms intermetallic compounds where content of it in alloy is more than 0.1%. Therefore, in alloy AMg6-T titanium content has been lowered to 0.02-0.1% and it was given a new brand name AMg6 (without T), and in alloy AMg5-V - vanadium will be substituted for titanium (0.02-0.1%), and alloy will also assume brand name AMg5 (without T).

Solubility of magnesium in aluminum decreases considerably with decrease of temperature (from 15-17% at 450° to 2% at room temperature); however, decomposition of solid solution in this system occurs extremely slowly. Therefore, for instance, alloy AMg6, quanched from temperature of 400-430° in water or slowly cooled in air, has practically the same mechanical properties, i.e., does not possess effects of heat treatment (effect of quenching and effect of aging). Therefore, these alloys are slightly weakened with welding, and attenuation factor for welding is near to one.

Solid solution of magnesium in aluminum in alloy AMg6 at room temperature is unstable and supersaturated, and with passage of time gradually decomposes, with singling out of smallest inclusions of $Al_3Mg_2$ phase. Decomposition is more rapid, the greater the content of magnesium in aluminum and the higher the temperature of holding. Alloys AMg1, AMg2, AMg3, and also the workable alloy AMg4 are not inclined to decomposition. Alloys AMg5 and AMg6 do not decompose at temperatures of holding up to 30-40°, but with increase of temperature to 60-70° and holdings for several hundreds and thousands of hours, their decomposition is quite intense. Decomposition in interval 60-70° (and up to 150-200°) leads to formation of continuous bead chains of $Al_3Mg_2$ compounds along grain boundaries. Owing to different of potentials of solid solution and compound there occurs fast destruction of grain boundaries, and strength of material and its plasticity drop catastrophically.

Thus, buoys from alloy AMg6, floating for year in Black Sea in Gelendzhik region, turned out to be severely damaged and less long-lasting than buoys made of alloy D16.

In order to avoid unfavorable influence of low-temperature heatings, alloys AMg5 and AMg6 must be annealed at a temperature of 300-350°; here solid solution of magnesium in aluminum also decomposes, but $Al_3Mg_2$ compounds falls out in the form of separate, comparatively large inclusions, isolated from each other (partially on boundaries, partially inside grains).

Similar, isolated particles only faintly worsen corrosion resistance of alloy. Therefore, over conditions of annealing alloys AMg5 and AMg6 there should be strict control in all those cases when in process of exploitation of structures there is possible low-temperature heating (thus, for example, in southern latitudes structures are easily heated to 60-80° under the influence of solar rays). Control is further complicated by the fact that test of alloy for mechanical properties does not give indications of how given conditions were sustained; exact answer can be obtained by control of corrosion behavior of alloy after heating (for instance, for 10 hours at 150°). Probably, appraisal is possible of state of alloy by level of electrical resistance, but this method is still undeveloped.

In use of sheets from alloys of magnalium type significant additional strengthening can be obtained as a result of cold hardening of material (Table 1).

Table 1. Properties of Cold-Worked Sheets from Alloy AMg6

| (a) Процент нагартовки | $\sigma_b$ in kg/mm$^2$ | $\sigma_{0.2}$ in kg/mm$^2$ | $\delta$ in % |
|---|---|---|---|
| 0 | 32 | 17 | 24 |
| 5 | 35 | 22,5 | 19 |
| 10 | 37 | 29,5 | 13 |
| 15 | 39 | 32 | 10 |
| 20 | 40 | 34 | 9 |
| 30 | 42 | 36 | 7 |

KEY: (a) Percent of cold-working.

Weakening of zone of welded seam during use of welded material is compensated by local thickening of weld zone, created by means of rolling of sheets with flange on butts or by other methods.

As a result of previously conducted works and those investigations which will be carried out in 1961-1962, there is possible the use of alloys of magnalium type, and reliability of their application may be significantly increased. Summarizing what has been said, it is possible to note that from corrosion point of view alloys of magnalium type all the way up to alloy AMg4 require less attention to method of their manufacture than do alloys AMg5 and AMg6, which can be applied only with reliable realization of required conditions of annealing. For color anodizing the most suitable alloys are those with limited chromium content.

c) Alloys of Al-Mg-Si Type

Alloys of Al-Mg-Si type during the last few years have attained very great value as structural and decorative material. In properties they strongly differ from magnalium. Alloys of Al-Mg-Si are strengthened by $Mg_2Si$ phase, provoking significant effect of quenching, of natural, and especially of artificial aging. Thus, for instance, one of alloys of this group - alloy AV - has, in annealed state, strength of not more than 15 $kg/mm^2$, in naturally aged state - not less than 20 $kg/mm^2$, and after artificial aging - not less than 30 $kg/mm^2$. These alloys are easily subjected to any kind of cold bends, stamping, deep drawing, and so forth in annealed state. Material is comparatively little strengthened and allows significantly larger drawings than alloys AMg5 and AMg6, which are quickly riveted during cold deformation. However, great effect of heat treatment peculiar to alloys Al-Mg-Si is eliminated through welding, and material in zone of seam is strongly weakened. In naturally, and especially in artificially aged state Al-Mg-Si alloys have high yield point, by which they favorably differ from magnalium.

Corrosion resistance of Al-Mg-Si alloys strongly depends on relationship between concentration of magnesium and silicon. Good corrosion resistance is possessed by those alloys in which this relationship is such that all the silicon completely leaves formation of $Mg_2Si$ compounds. As soon as excess silicon appears in structure, corrosion resistance of alloys worsens sharply. Excess magnesium enters into solid solution with aluminum and does not lower corrosion resistance. Introduction of copper into Al-Mg-Si alloys worsens their corrosion behavior in proportion to copper content. At present in Al-Mg-Si system there are three industrial alloys: AD31, AD33, and AV*.

At present we are improving composition of alloy AD35: Mg 0.4-1.4%;

*See article by N. M. Edel'man, included in this collection.

Si 0.6-1.5%; Mn 0.4-1%. Heightened content of manganese in this alloy retards growth of grains. At the same time this alloy possesses high strength and corrosion resistance, and for all these reasons it is promising for construction.

d) Alloys of Al-Zn-Mg (Cu) Type

The strongest aluminum alloys belong to systems Al-Zn-Mg and Al-Zn-Mg-Cu. Development of alloys of this group and their adoption in serial production at first caused great difficulties connected with inclination of alloys to stress corrosion and cracking of ingots during continuous casting. Gradually these difficulties were surmounted. It was shown that inclination to formation of cracks during casting depends on relatioship of content of impurities in aluminum of iron and silicon. If iron in alloy is more plentiful than silicon, practically no cracks are formed. Therefore, when necessary, into alloy there is specially introduced a small quantity of iron. More precise determination of composition of alloy, as regards impurities and improvement of technology of casting allow, us to obtain ingots of very large dimensions without cracks.

With passage of time we have managed also to find compositions of alloys and conditions of aging corresponding to them, ensuring reliable corrosion behavior of material.

Ternary alloys Al-Zn-Mg containing more than 7-8% total of zinc and magnesium with significant excess of zinc over magnesium, are inclined to stress corrosion. This inclination is removed by small addition of copper, not forming new phases but changing composition of solid solution in favorable direction.

First representative of alloys of Al-Zn-Mg-CU system-alloy V95 - contains: zinc 5-7%, magnesium 1.8-2.8%, copper 1.4-2%, manganese 0.2-0.6%, chromium 0.1-0.25%. According to different data, additions of chromiun and manganese are necessary for increase of corrosion resistance of alloys. Role of chromium especially emphasized in the United States; there it is pointed out that only with help of chromium is it possible to ensure satisfactory corrosion resistance of high-strength alloys of this system.

However, in our country there have been created and successfully exploited two high-strength alloys of this system-alloys V94 and V93, containing neither chromium nor manganese nor other analogously active elements. For alloys V93, V95, and V96 artificial aging is mandatory. In naturally aged state all of them have unsatisfactory corrosion behavior.

Alloy V92 stands alone. It will be described below.

From alloy V95 there are prepared sheets, profiles, forgings, and stampings. Strength of articles from this alloy (with fibers) is on level of 52-60 kg/mm$^2$, yield point 44-55 kg/mm$^2$, elongation 6-12%. General corrosion resistance of alloy is inversely proportional to content in alloy of copper. Therefore, in general corrosion resistance alloy V95 is higher than alloy D16. For riveted structures and buildings alloy V95 can be considered as very acceptable material in the form of sheets and pressed articles.

However, during planning and manufacture of structures from alloy V95 it is necessary to prevent appearance of concentrators of stresses (in the form of sharp cuts, sharp corners with very small radii, and so forth).

Alloy V96 in the form of pressed semifinished products is 10% stronger than alloy V95. Sheets from alloy V96 do not have special advantages over sheets from alloy V95.

Alloy V94 is intended for manufacture of rivets working against shear or crumpling. Minimum guaranteed resistance to shear of rivet wire is 29 kg/mm$^2$, but in process of riveting resistance to shear is increased. Now the possibility is being studied of increase of guaranteed resistance to shear of rivet in upset form up to 31 kg/mm$^2$. Alloy V94 can be upset at any time after quenching (in contrast to certain rivet aluminum alloys which it is possible to upset only for a limited time after quenching), but which requires observance of certain precautions during riveting.

Rivets from alloy V94 possess reliable corrosion resistance and can be applied in building structures. New alloy V93 possesses guaranteed strength in three directions — 48 kg/mm$^2$; from it, it is possible to prepare forgings and stampings of different dimensions, including big ones. The alloy is water quenched at a temperature of 70–80°, and during subsequent machining it is little deformed. Therefore, parts can be completely mechanically processed and then hardened, which in a number of cases presents greater technological conveniences.

Weldable alloy V92 differs from all above described alloys of Al–Zn–Mg–Cu system. For increase of general corrosion resistance no copper is included in it; content of magnesium exceeds content of zinc; number of alloying elements is lowered.

Alloy V92 belongs to self-hardening alloys, i.e., it is hardened with air cooling, and then ages naturally or artificially. This ability considerably decreases weakening of weld zone as a result of heating during welding, and it also allows us to obtain a stronger seam. Natural aging of alloy V92 continues for a very prolonged time (up to 3 months). Basic increase of strength is attained during first month, additional — up to 3 months; aging gives additional increase of strength of 2-3 kg/mm$^2$. Alloy V92 is also subjected to artificial aging; approximate process of aging is 100°-96 hours. Properties of alloy V92 to significant degree depend on degree of deformation and form of semifinished products. For assurance of satisfactory properties, degree of deformation during pressing should not be less than 93-97%. For fulfillment of this condition it is necessary to watch both factory suppliers and customers.

From alloy V92 there are poured ingots of the largest diameters. Also case are flat ingots of the largest cross sections. Therefore, the required degree of deformation can always be attained. It is necessary also to note that plates

Table 2. Mechanical Properties of Semifinished Products from Alloy V92, Depending upon Conditions of Aging

| (a) Вид полуфабрикатов | (b) Размеры и степень деформации полуфабрикатов | $\sigma_b$ in kg/mm² | | | (q) $\sigma_{0,2}$ in kg/mm² при режиме старения | | | δ in % | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (c) 1 неделя 20% | (d) 1 месяц 20% | (e) 96 час. 80% | (c) 1 неделя 20% | (d) 1 месяц 20% | (e) 95 час. 80% | (c) 1 неделя 20% | (d) 1 месяц 20% | (e) 96 час. 80% |
| (f) Катаные листы | δ=2–10 мм | 37—38 | 39—41 | 42—45 | 20—23 | 22—25 | 29—32 | 19—21 | 17—20 | 14—16 |
| (g) плиты | δ=20–50 мм | 40—41 | 43—45 | 44—45 | 23 | 23—26 | 29—32 | 18—19 | 17—18 | 17—18 |
| (h) Прессованная полоса | (m) 40×320 мм. Степень деформации 88 % | 37 | 41 | 44 | 20 | 22 | 30 | 15 | 17 | 12 |
| (i) То же | (n) 12×200; 20×200; 10×120; 25×180; 50×90. Степень деформации 96% | 41—45 | 42—46 | 45—48 | 31 | 31—34 | 33—36 | 11 | 12 | 10—12 |
| (j) Прессованный пруток | (o) Диаметр 50 мм. Степень деформации 93% | 43 | 45 | — | 31 | 32 | — | 12 | 11 | — |
| (k) Прессованные профили | (p) Степень деформации 94—97% | 41—47 | 43—48 | — | 31—33 | 32—33 | — | 12 | 10 | — |
| (l) То же, с тонкой стенкой | (i) То же | — | 39—42 | 48 | 25—27 | 35 | — | 15—18 | 12 | - |

KEY: (a) Form of semifinished products; (b) Dimensions and degree of deformation of semifinished products; (c) week; (d) month; (e) hours; (f) Rolled sheets; (g) Rolled plates; (h) Pressed strip; (i) The same; (j) Pressed rod; (k) Pressed profiles; (l) The same, with thin wall; (m) Degree of deformation of 88%; (n) Degree of deformation 96%; (o) Diameter 50 mm. Degree of deformation 93%; (p) Degree of deformation 94–97%; (q) Method of aging.

of considerable thicknesses have to be prepared not from flat, but from round ingots by means of forging then to final dimension by forging into billet and subsequent rolling. Only in this case are we able to ensure overall high level of properties and, in particular, satisfactory properties througnout thickness of plate. Alloy is inclined to press-effect; in extruded articles its strength and yield point are considerably higher than in sheets and rolled plates; therefore, alloy V92 is very profitable to apply in the form of extruded profiles, plates, and panels. Alloy satisfactorily undergoes forging and stamping.

Alloy V92 possesses good overall corrosion resistance under atmospheric conditions and during submersion in sea water both in naturally and also in artificially aged states. It behaved well in pipelines during annual tests in different soils. Prolonged heatings at 70-80° and artificial aging worsen resistance of alloy V92 to stress corrosion. However, it is possible to rely on fully satisfactory behavior of alloy under actual conditions of exploitation of building structures.

Properties of semifinished products from alloy V92 are given in Table 2. On alloy V92 there has been accumulated considerable experience in welding; there has been made, in particular, the important conclusion that alloy V92 welds well by argon arc process. At present alloy V92 is undergoing extensive technological, exploitational, and corrosion testing in a number of structures and buildings.

e) Alloys of Duralumin Type (of Al-Cu-Mg system)

The duralumin alloys are those of Al-Cu-Mg system; the most important of them are alloys D1 and D16; as rivet alloys there are applied D18, V65, and D19. Recently there has been developed weldable alloy M40, belonging to this system.

Industrial alloys by relationship between copper and magnesium are disposed in following order:

| Alloy | Ratio Cu: Mg |
|---|---|
| B65 . . . . . . . . . . . . | 19.0 |
| D18 . . . . . . . . . . . . | 7.4 |
| D1 . . . . . . . . . . . . | 6.35 |
| D16 . . . . . . . . . . . . | 2.76 |
| D19 . . . . . . . . . . . . | 1.7 |
| VD17 . . . . . . . . . . . | 1.32 |

In general we note that by the measure of decrease of this ratio, the corrosion resistance of alloys is increased. Semifinished products from alloy D16 have ultimate strength of 40-48 kg/mm$^2$, yield point of 28-40 kg/mm$^2$, resistance to shear -- 25-27 kg/mm$^2$, elongation of 12-20%.

With overhardening of sheets and profiles from alloy D16 (and of other alloys hardened by heat treatment) their strength, and especially yield point, drops by 1-3 kg/mm$^2$. This phenomenon is caused by fact that values guaranteed by technical specs of ultimate strength and yield point are ensured by application of drawing of semifinished products after hardening. Consumers do not produce drawing, and corresponding effect of hardening is lowered.

Together with hardened and naturally aged sheets (of brand D16-T) there are supplied cold-worked sheets (D16A-TN). Cold hardening is done by means of cold rolling in quenched state; degree of cold hardening constitutes 6-7%. With cold hardening to 6-7% (to a still larger degree than with drawing) there is increased ultimate strength and especially yield point with certain lowering of elongation. Cold worked sheets can be applied in those cases when sheets in process of manufacture of structures are not subject to significant deformations.

The greatest hardening of sheets from alloy D16 can be achieved by applying still greater cold hardening -- on order of 20% (D16A-T1-N1). Such cold hardening allows us to increase strength of sheets from alloy D16A-T as compared to the usual by 6 kg/mm$^2$. Subsequent artificial aging for 10 hours at 130° ensures approximately the same level of elongation as for sheets of D16A-TN.

Thin sheets from alloy D16 in avoidance of through diffusion of copper in plating layer (which leads to lowering of corrosion resistance and impairment of appearance) must have plating of relatively large thickness.

Strength of pressed articles from alloy D16 can exceed strength of sheets by 4-8 kg/mm$^2$. Intensity of presses-effect depends on cross section of pressed articles; it appears more strongly on large thicknesses. Therefore, in technical specs there is provided increase of strength and yield point of profiles with increase of thickness of wall. However, recent investigations showed that with proper control of composition of alloy D16 and methods of pressing it is possible on thin profiles to obtain ultimate strength of not less than 48 kg/mm$^2$ and yield point of not less than 34 kg/mm$^2$ with assured elongation of order of 7%. These properties are provided by special technical methods for procurement of profiles from alloy D16 with wall thickness of more than 2 mm.

From rivet alloys of duralumin type alloys D18 and V65 have wide application for room temperature, while alloy D19 is used for heightened temperatures. Rivets from alloys D18 and V65 are upset in aged state, i.e., at any time after quenching. Alloy D19 can be upset for 2-6 hours after quenching (the greater the diameter of wire, the less is the time permissible for riveting). However, in corrosion resistance alloy D19 significantly exceeds alloy V65.

Of considerable interest is weldable alloy M40. The alloy is forged, rolled, extruded, and satisfactorily welded by all forms of welding. Plated sheets from alloy M40 have strength on order of 39 kg/mm$^2$, $\sigma_{0.2}$ = 25 kg/mm$^2$, $\delta$ = 18%. Strength of extruded profiles is 43 kg/mm$^2$, conditional yield point is 32 kg/mm$^2$, elongation is 13%. Strength of sheets with thickness of 2 mm, welded by argon arc automatic welding, is equal to 32-34 kg/mm$^2$. Resistance to shear and break-away of welded points considerably exceeds corresponding characteristics for alloy D16. At present there is also being investigated weldable variety of alloy D16.

f) Alloys of Al-Mg-Si-Cu System

To alloys of this system belong alloys AV (when this alloy has copper), AK6, and AK8. All of them have identical concentration of magnesium and silicon and, in ascending order from alloy AV to alloy AK8, increasing copper content. In accordance with increase of copper content strength of alloys grows, and ductility and corrosion resistance are lowered. Basic assignment of alloys AK6 and AK8, and partially of alloy AV is forging. From these alloys it is possible to pour ingots of the largest diameters, and there can be obtained large dimension forgings and complex forms of stampings.

Alloys of Al-Mg-Si-Cu system age naturally and artificially. Natural aging is evoked by S phase, the same that acts in alloy D16; artificial aging -- by phase containing silicon $Mg_2Si$ and W. Alloys Ak6 and AK8 are used chiefly in artificially aged state. They have high strength and high yield point with considerable ductility. Artificially aged alloy AK6 possesses the same strength as alloy D1, but has supplanted the latter as forging alloy, since it possesses better casting and forging properties.

In general, we note that alloy AK6 is very successful alloy for application in the form of forgings and stampings of average strength.

Widely used for manufacture of loaded forgings and stampings of heightened strength is alloy AK8. However, alloy AK8 is capricious under heat treatment, it has narrow permissible interval during heating before quenching, which, in practice, quite often leads to burning of parts or to another defect, the so-called "etch effect", appearance of chains of intermetallic compounds on grain boundaries. Recently AK8 has been replaced by alloy V93, having higher strength, higher corrosion resistance, and considerable ductility.

It is necessary to note that alloy AK8, sometimes called superduralumin, thus, characterizing it as representative of alloys of aluminum-copper-magnesium system. However, after artificial aging there are more common traits between alloys AK8 and AK6, than between alloys AK8 and D16. Therefore, it is more correct to refer alloys AK8 and AK6 to aluminum-magnesium-silicon-copper system.

### g) Alloys of Al-Cu-Li-Cd-Mn System

In 1957 a very promising discovery was made of new phases-strengtheners possessing ability not only to create high strength at room temperature, but also to a significant degree to preserve it up to 200°.

In development of these investigations there was developed alloy VAD23, containing 4.9-5.8% Cu, 0.4-0.8% Mn, 101.4% Li, 0.1-0.25% Cd, and up to 0.15% Ti. Alloy VAD23 in strength characteristics at room temperature exceeds alloy V95, and at a temperature of 180-200°, after multi-thousand [hour] holdings is approximately of the same strength as alloy D1 at room temperature (Table 3). Alloy VAD23 has 4-5% lower specific gravity than alloy V95, and its elastic modulus is 6-8% higher than elastic modulus of all other aluminum alloys.

Table 3. Comparative Mechanical Properties of Alloys VAD23, D16, and V95 (Pressed Rods)

| (a) Сплав | (b) Температура испытаний в град | (c) Время выдержки в час. | $\sigma_b$ in kg/mm² | $\sigma_{0.2}$ in kg/mm² | $\delta$ in % | $E$ in kg/mm² |
|---|---|---|---|---|---|---|
| VAD23 | 20 | — | 63 | 57 | 5 | 7600 |
| | 180 | 100 | 47 | 45 | 4 | 6700 |
| | 200 | 100 | 39 | 36 | 3 | 6500 |
| | — | 1000 | 30 | — | 10 | — |
| D16 | 20 | — | 53 | 39 | 10 | 7200 |
| | 180 | 100 | 36 | — | 12 | — |
| | 200 | 100 | 32 | — | 14 | 6100 |
| | — | 1000 | 25 | 19 | 16 | — |
| V95 | 20 | — | 62 | 57 | 5 | 7000 |
| | 200 | 100 | 19 | — | 12 | 5050 |
| | — | 1000 | 10.5 | 9 | — | — |

KEY: (a) Alloy; (b) Temperature of tests, in deg; (c) Time of holding, in hours.

Alloy VAD23 is absolutely immune to stress corrosion. General corrosion resistance of alloys VAD23 and D16 is, practically, quite close. In quenched and naturally aged state semifinished products from alloy VAD23 are well suited to any kind of bending operation. Inasmuch as strengthening of alloy in process of natural aging is extremely small, bending operations can be done at any time after quenching (but before artificial aging).

In artificially aged state there should be produced comparatively small deformations. Alloy VAD23 is expedient to apply where there is possible prolonged heating of structures to comparatively high temperatures (up to 180-200°) or where maximum strength and rigidity at normal temperatures are needed.

### h) Founding Aluminum Alloys

Founding aluminum alloys have to fill molds well and not to give cracks, friability, or bubbles during crystallization. All these qualities of founding alloys are obtained only when they are sufficiently eutectic.

Therefore, all good founding alloys contain corresponding concentration of elements forming eutectoid. But purely eutectic alloys have low strength. For increase of strength in alloys there are introduced components entering in solid solution and forming phases that are able in process of aging to fall from solid solution and strengthen alloy.

There are applied both binary and also more complex founding aluminum alloys. Among the binary alloys one should note alloys of aluminum with silicon, aluminum with copper, and aluminum with magnesium. Alloys of aluminum with copper have lowered corrosion resistance.

Alloys of aluminum with silicon (Silumin) possess excellent founding properties, however, their strength is comparatively low, elongation low and their structure coarse, For improvemnt of mechanical properties and structure coarse.

Silumins are modified by means of introduction of sodium into liquid melt.

For further increase of mechanical properties of Silumins, into them there are introduced magnesium and copper (separately or together). In this case Silumins obtain ability to be strengthened by heat treatment. Content of copper and magnesium is chosen so as to cause maximum strengthening after heat treatment but so that this does not lead to formation of fragile eutectoids (for instance, Al Si $Mg_2Si$). For assurance of sufficient ductility content of silicon in complex Silumins is decreased in comparison with binary Silumins. Complex Silumins are inclined to formation of gas porosity, for removal of which there is used method of crystallization under pressure.

The binary Silumins having industrial value include alloy AL2; the ternary Silumins, Al-Si-Mg, are alloys AL4 and AL9. Separately cast samples from alloy AL2 have strength of not less than 15-16 kg/mm$^2$. with elongation of not less than 2-4%. Alloys AL4 and AL9 -- cast in chill mold and thermally treated - possess strength of not less than 20-24 kg/mm$^2$ with elongation of more than 2-4%.

Small addition of beryllium to AlMgSi alloys gave good results -- alloy VAL2. The alloy contains 6-8% silicon, 0.3-0.6% magnesium, and 0.5-0.8% beryllium. Ultimate strength of alloy VAL2 constitutes 26 kg/mm$^2$, yield point -- 22 kg/mm$^2$, elongation -- 2%. In founding properties alloy VAL2 is not inferior to alloys AL4 and AL9. Deficiency of the alloy is presence in its composition of expensive beryllium, also requiring observance of certain safety measures.

Alloys based on systems Al-Si-Cu and Al-Si-Cu-Mg (alloys AL6, AL3, and AL5) possess satisfactory founding properties, however, castings from them are distinguished by great gas porosity. For increase of density of castings liquid metal is refined. All these alloys do not require modification, which is their important technological advantage. In strength Silumins containing copper are close to Al-Si-Mg alloys, but their ductility is considerably lower. Introduction of copper leads also to impairment of corrosion resistance of alloys.

Binary aluminum-copper alloys are in founding properties worse than binary Silumins. They are strengthened by heat treatment and have greater hot strength than binary Silumins. Development of these alloys is progressing in two directions:

1) by means of introduction into their composition of magnesium (here S phase is formed) and combined additions of nickel, maganese, and chromium (alloys AL7 and AL1);

2) by means of increase of copper content and introduction into alloy of manganese and titanium (here the Al-Cu-Mn phase is formed -- alloy AL19).

Both of these groups of alloys have large interval of crystallization, and are inclined to appearance of friability and hot cracks. In founding properties they are inferior to alloys of Silumin type. However, their properties of hot strength, and for alloy AL19 of strength, are significantly better; therefore, for the last few years they have found wide application.

Development and adoption of alloy AL19 were significant achievements in field of founding aluminum alloys. Alloy contains 4.5-5.3% copper, 0.6-1% manganese, and 0.25-0.45% titanium. Quenched and artificially aged alloy (T5 method) ensures strength of samples separately cast in earth of not less than 34 kg/mm$^2$ elongation of not less than 4%. Alloy welds well, as do alloys D20 and M40. It also machines well. Corrosion resistance of alloy AL19 is lowered also, as is the case of other aluminum alloys containing significant concentrations of copper.

Good corrosion resistance and significant strength belong to binary alloys of aluminum with magnesium (alloy AL8) and to more complex alloys of aluminum with magnesium and additions of silicon (alloys VI11-3 and AL13).

Alloy AL8 possesses wide interval of crystallization and is inclined to be friable. Thanks to large content of magnesium, the alloy readily oxidizes: moreover, in castings, especially in massive ones, there appears so-called black fracture, leading to significant decrease of strength and elongation. Addition of 0.02-0.03% beryllium decreases inclination of alloy to oxidation.

Alloy AL8 is strengthened by heat treatment which consists of heating to 430°, holding at this temperature for 15-20 hours and water or oil cooling; essentially, heat treatment is reduced to homogenizing (levelling) annealing.

With correct processing alloy AL8 has strength in separately cast samples of not less than 28 kg/mm$^2$ and elongation of not less than 9%.

In alloy VIl1-3 obligatory elements are beryllium and titanium. Additions of beryllium decrease oxidation of alloy during melting and casting. Titanium promotes crushing of grain. Silicon (0.8-1.2%) improves founding properties of alloy, where its corrosion resistance is not lowered. Tightness of castings from alloy VIl1-3 is high. Alloy is especially useful for pressure casting. In alloy AL13 magnesium content is lower by approximately 2 times over alloys AL8 and VIl1-3; therefore strength of alloy is lower (on order of 15 kg/mm$^2$), but less also is its inclination to oxidation and better technological properties.

Heat treatment of alloy AL13 is usually not done.

The interesting achievements are in field of founding alloys of Al-Zn-Mg system. These alloys are quenched with comparatively slow cooling (for instance, with air cooling). On base of Al-Zn-Mg system there has been developed alloy VL15, possessing satisfactory founding properties, significantly exceeding in strength the founding alloys used without heat treatment, and which is not inferior in strength to many heat treated founding alloys.

Alloy VL15 contains 3.5-4.2% zinc, 1.5-2% magnesium, 0.2-0.5% manganese, and 0.1-0.2% titanium. Its strength is 23 kg/mm$^2$, elongation is 3%. As all alloys of Al-Zn-Mg system, alloy VL15 quickly loses strength during heatings. In corrosion resistance it exceeds founding alloys containing copper.

Alloy VL15 is expedient to apply in those cases when it is desirable to avoid heat treatment, special complexities during casting, and when average strength and sufficient corrosion resistance are required.

2. SAP's (Baked Aluminum Powders) and SAS's (Baked Aluminum Alloys)

All thermally processed metallic alloys are strengthened with help of smallest particles, chemical compounds, or intermediate phases falling from supersaturated solid solution. If in process of heatings the particles are enlarged, strength of alloys is lowered -- alloy "overages" or is annealed. Necessary prerequisite for strengthening of thermally processed alloys is insolubility in the basic metal of those additions, which henceforth, forming suitable compounds and falling from hardened, supersaturated solid solution, will be called strengthening of alloy. This condition (solubility and formation of suitable phases) significantly narrows possibility of creation of new alloys with desirable properties. In principle, a new means of obtaining alloys with the sought properties is that of baked aluminum powder (SAP) and baked aluminum alloys (SAS). In this case also, strengthening of material is attained by the smallest particles. They are, however, introduced into structure of basic metal not from supersaturated solid solution but by combined chemico-mechanical means.

Process of obtaining an SAP is briefly as follows: liquid aluminum is atomized and then crushed in ball mills; here there are formed thin films of aluminum, thickness of which is less than 1μ. Similar aluminum powder explodes upon contact with air. Therefore, breaking is done in neutral medium, for instance in atmosphere of nitrogen. To the nitrogen is added a small quantity of oxygen; with this there occurs oxidation of the powder (laminae of aluminum are covered with a still thinner film of aluminum oxide). Subsequently, powder is pressed (it is subjected to heating, pressure, and deformation); there are formed briquettes, from which are obtained pressed and rolled articles, sheets, foil, rods, profiles, forgings, and stampings. Externally they do not differ from the usual aluminum alloys.

Initial laminae of aluminum, covered with oxide film, are turned, deformed, and ground; the oxide film bursts. After respective heatings, and sufficient degree of deformation structure of SAP looks like a solid, light matrix of aluminum in which there are interspersed smallest particles of aluminum oxide. In dimensions they are close to those particles which in thermally strengthened aluminum alloys fall from supersaturated, solid solution in process of aging.

Therefore, particles of aluminum oxide in SAP are also able to evoke strenthening of aluminum, as, let us say, do the intermediate phases of chemical compound $CuAl_2$ in alloy D1. However, compound $Al_2O_3$ has at the same time indisputable advantage over compound $CuAl_2$. $Al_2O_3$ is melted at immeasurably higher temperature than $CuAl_2$; therefore it ensures much higher hot strength of aluminum than alloy D1. SAP can work at temperatures of 500-550°, which are absolutely unacceptable for other aluminum alloys. Furthermore, $CuAl_2$ particles coagulate (are enlarged) significantly faster than $Al_2O_3$ particles. As a result, strength of alloy D1 with increase of time of holding at heightened temperatures is quickly lowered. Article made from SAP is comparatively slightly reduced in strength after holding for thousands, tens of thousands, and hundreds of thousands of hours.

Particles strengthening during aging, as a rule, evoke appearance of unfavorable difference of potentials and worsen corrosion resistance of aluminum. In SAP this negative defect is practically absent and corrosion resistance of SAP is the same as and for aluminum.

At last, in process of melting, casting, and crystallization, and then subsequent recrystallization, in structure of aluminum alloys there appears a whole series of nonmetallic contaminations, inclusions of intermetallic compounds, and regions of recrystallization; and strength and corrosion resistance of structures are noticeably lowered. In the SAP all these unfavorable factors are excluded.

Consequently, SAP should be applied where structures are heated to 300-500°, where there is required combination of sufficient strength and good corrosion resistance, and where it is necessary to exclude influence of coarse-structure heterogeneities.

From SAP it is possible to prepare sheathing, power set, honeycomb panels, pistons, helicopter blades, pipes, and so forth. Properties of SAP depend on content of aluminum oxide in initial powder. With increase of quantity of aluminum oxide in initial aluminum, strength, stress-rupture strength, and hardness increase, and ductitity and specific conductance are lowered. Strength of pressed rods in increased from 7-8 (for pure aluminum) up to 40-44 kg/mm$^2$; hardness $H_B$ is increased from 20-25 to 120 kg/mm$^2$; elongation is lowered to 5%. At 500° SAP has short-term strength of order of 12-14 kg/mm$^2$ and stress-rupture strength of order of 5-7 kg/mm$^2$. At present in industrial adoption is alloy SAP1 (with aluminum oxide content of 6-11 %). Sheets, profiles, and forgings from SAP1 have strength of 31-35 kg/mm$^2$, yield point of 19-25 kg/mm$^2$, and elongation of 2-8%. SAP1 is welded by resistance welding. Recently it was found that SAP1 subjected to special treatment can successfully be welded by argon arch welding also. As a result of this treatment, strength of SAP1 drops by 2-3 kg/mm$^2$, and elongation is noticeably increased.

Along with alloy SAP1 there is being adopted SAP2, containing 11-16% aluminum oxide. Semifinished products from SAP2 have strength of 40-44 kg/mm$^2$, yield point of 24-26 kg/mm$^2$ and elongation of 2-3%.

On the same principle SAP it is also possible to obtain baked aluminum alloys; here it is possible to introduce into alloy significant quantities of insoluble elements in the form of the finest, evenly-distributed particles, for instance, up to 10% iron. Furthermore, it is possible in such a way to avoid those structural heterogeneities of which we spoke earlier.

In particular, helicopter blades made from baked alloy AD33 will probably, possess more uniform structure than the same blades obtained from ingots.

Recently, there was offered SAS1-Alloy with very high silicon content and certain other additions. SAS1 differs in sharply lowered coefficient of linear expansion ($15 \times 10^{-6}$ instead of $22 \times 10^{-6}$ for aluminum), sufficient strength (25 $kg/mm^2$), and high elastic modulus (on order of 10,000 $kg/mm^2$).

Study of SAP and SAS has just begun. Their possibilities are still by far unrealized.

## 3. Foam Aluminum

A big achievement in technology of production of aluminum articles is the obtaining of foam aluminum. In principle, process of manufacture is simple. Liquid aluminum is passed through a screw device, reminiscient of a meat-grinder, in which it is mixed with powder of titanium hydride. Hydride is decomposed, releasing large quantity of hydrogen bubbles. Titanium liberated in the reaction is assimilated by the aluminum. The foamed, intensely aerated mass is quickly poured in molds and congeals before bubbles of hydrogen can manage to separate out. There is formed a cellular mass with specific gravity equal to 0.5-0.6 or even 0.3 $g/cm^3$. Pores are closed, therefore foam aluminum floats on water. Material is easily cut, soldered, and welded. Properties of foam aluminum are given in Table 4.

Table 4. Properties of Foam Aluminum

| Удельный вес в $г/см^3$ (a) | Предел прочности при сжатии в $кг/см^2$ (b) | Ударная вязкость в $кгм/см^2$ (c) | Модуль упругости при сжатии $E \cdot 10^3$ в $кг/см^2$ (d) |
|---|---|---|---|
| 0,3 | 35 | 3 | 17 |
| 0,4 | 65 | 4 | 26 |
| 0,5 | 110 | 5 | 35 |

KEY: (a) Specific gravity in $g/cm^3$; (b) Ultimate compressive strength, in $kg/cm^2$; (c) Impact toughness, in $kgm/cm^2$; (d) Elastic modulus during compression, $E \times 10^3$, in $kg/cm^2$.

Foam aluminum works well under compression, therefore it can be used as filler, for instance, in exchange for honeycomb panels, manufacture of which is rather complicated and very time-consuming. Foam aluminum is an excellent heat- and soundproofing material. Manufacture of foam aluminum may be set up in any factory where, besides bars and ingots, it is also possible to obtain parts of complex form from it.

# ALUMINUM ALLOYS IN CIVIL CONSTRUCTION

N. M. Edel'man, Engineer

For the last few years, aluminum alloys have found ever wider application in civil construction.

Low specific gravity, good corrosion resistance, high mechanical properties not inferior to properties of separate semifinished products of steel, good appearance, and possibility of application of different decorative and protective coverings and finishings (anodizing of different colors and tinits, ematol, enameling etc.) make alloys from aluminum a new, progressive material in civil construction.

Some such alloys, obtaining wide application both in this country and especially abroad, are alloys of AlMgSi system.

In Soviet Union alloys of this system are known under brands AD31, AD33, and AV.

In America -- representatives of alloys of this system are alloys 6061, 6062, 6063, and 6151.

In England -- alloys 9 (Noral 50S*); 19 (Noral 51S), 20 (Noral 65S), and

*In England, as in many other foreign countries, different firms supply material with different specifications. Thus, for instance, by specification B. S. (British Standard) alloy of composition 0.4-0.9% Mg and 0.3-0.7 Si has brand 9, and by Noral specification -- 50S.

30 (Noral B51S).

In FRG - alloys AlMgSi0, 5, AlMgSi1, and AlMgSi1, 5.

In Canada - Alcan: 50S, 51S, 65S, etc.

Wide application of alloys of this system is due to their high ductility, corrosion resistance, good decorative appearance, and satisfactory weldability.

In Table 1 there are given chemical composition and typical values of mechanical properties of alloys of AlMgSi system, applied in different countries (in state of full heat treatment; quenching plus artificial aging).

From data of Table it is clear that certain alloys of AlMgSi system in different countries have practically the same chemical composition and the same value of mechanical properties.

Thus, for instance, in all shown countries there is low-component alloy composed of 0.4-0.9% Mg and 0.2-0.7% Si. This alloy, both here (AD31) and abroad, is applied in civil construction, basically, in the form of pressed profiles for window frames, doors, partitions, and so forth.

Alloy of this composition has average strength, high ductility (thanks to high ductility of alloy in state there can be made profiles very complex forms from it), good corrosion resistance, capability for anodizing, and satisfactory weldability.

In the United States, England, Canada, and Soviet Union there is alloy of composition 0.8-1.2% Mg, 0.4-0.8% Si, 0.15-0.4% Cu, and 0.15-0.35% Cr.

Composition of this alloy corresponds to original American alloy 6061. All other alloys of this composition are its analogs.

Alloy 6061, having in America the widest application of all alloys of AlMgSi system, is used for manufacture of all forms of semifinished products (sheets, profiles, pipes, rods, strips, plates, wire, etc.). This alloy is applied in load-bearing structures where there must be high corrosion resistance, as, for

Table 1. Chemical Composition and Mechanical Properties of Aluminum Alloys of AlMgSi System

| (a) Страна | (g) Марка сплава | (h) Химический состав в % | | | | | | (i) Типичные механические свойства | | | (j) Вид полуфабрикатов |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mg | Si | Cu | Cr | Mn | (p) Ti не более | $\sigma_b$ в (o) кг/мм² | $\sigma_{0,2}$ в кг/мм² | $\delta$ в % | |
| (b) Советский Союз | (n) АД31 | 0,4—0,9 | 0,3—0,7 | 0,1 | 0,1 | 0,1 | 0,15 | 24 | 21 | 10 | (k) Листы, профили |
| | (n) АД33 | 0,8—1,2 | 0,4—0,8 | 0,15—0,4 | 0,15—0,35 | — | 0,15 | 30—32 / 32 | 25—26 / 26 | 14—16 / 12—14 | (k) Листы / Профили |
| | (n) АВ | 0,45—0,9 | 0,5—1,2 | 0,2—0,6 | (m) Хром или марганец в количестве 0,15—0,35 | — | — | 32—34 / 32—36 | 23—25 / 25—30 | 14—16 / 12—14 | (k) Листы / Профили |
| (c) Соединенные Штаты | 6061 | 0,8—1,2 | 0,4—0,8 | 0,15—0,4 | 0,15—0,35 | 0,15 | 0,15 | 32 | 28 | 12—17 | (k) Листы, профили |
| | 6062 | 0,8—1,2 | 0,4—0,8 | 0,15—0,4 | 0,04—0,14 | 0,15 | 0,15 | 32 | 28 | 17 | (k) Профили |
| | 6063 | 0,45—0,9 | 0,2—0,6 | 0,1 | 0,1 | 0,1 | 0,1 | 24,5 | 21,5 | 12 | . |
| | 6151 | 0,45—0,8 | 0,6—1,2 | 0,35 | 0,15—0,35 | 0,2 | 0,15 | 33,5 | 30 | 17 | (l) Поковки |
| (d) Англия | 9(Noral50S) | 0,4—0,9 | 0,3—0,7 | 0,1 | — | 0,3 | 0,3 | 25 | 19 | 13 | (k) Профили |
| | 19 Noral51S) | 0,4—1,5 | 0,6—1,3 | 0,1 | 0,1 | 0,2 | 0,3 | 31,5 | 28,5 | 9 | . |
| | 20(Noral65S) | 0,8—1,2 | 0,4—0,8 | 0,15—0,4 | 0,15—0,35 | 0,15 | 0,3 | 33 / 31,5 | 28 / 27 | 12 / 10 | (k) Листы / Профили |
| | 30(NoralB51S) | 0,4—1,5 | 0,6—1,3 | 0,1 | 0,3 | 0,4—1 | 0,3 | 34,5 / 33 | 29,5 / 30 | 12 / 13 | (k) Листы / Профили |
| (e) ФРГ | AlMgSi0.5 | 0,4—0,9 | 0,3—0,8 | <0,1 | <0,05 | 0,1 | <0,2 | 23 | 20 | 12 | (k) Профили |
| | AlMgSi1 | 0,5—1 | 0,6—1,1 | <0,1 | 0,05 | 0—0,8 | <0,2 | 32 | 29 | 10 | . |
| | AlMgSi1,5 | 0,6—1,4 | 0,6—1,6 | 0,1 | 0—0,3 | 0,6—1 | 0,2 | 34 | 30 | 8—10 | . |
| (f) Канада | Alcan50S | 0,45—0,85 | 0,3—0,6 | 0,1 | 0,1 | 0,1 | 0,1 | 23 | 20 | 12 | (k) Профили |
| | AlcanB51S | 0,4—0,8 | 0,7—1,3 | 0,1 | — | 0,4—0,8 | 0,2 | 33 | 30 | 12 | . |
| | Alcan65S | 0,8—1,2 | 0,4—0,8 | 0,15—0,4 | 0,15—0,35 | 0,15 | 0,15 | 32 / 31,5 | 28 / 29,5 | 12 / 15 | (k) Листы / Профили |

KEY: (a) Country; (b) Soviet Union; (c) United States; (d) England; (e) FRG; (f) Canada; (g) Brand of alloy; (h) Chemical composition in %; (i) Typical mechanical properties; (j) Form of semifinished products; (k) Sheets, profiles; (l) Forgings; (m) Chromium and manganese in amount; (n) AD31, AD33, AV; (o) in kg/mm$^2$; (p) no more than.

instance, in bridge building, in railroad transportation (for bodies of trucks, frames of railroad trucks, railroad cars), in construction of Civic buildings, and so forth.

In Soviet Union, the United States, England FRG, and other countries there is alloy of composition 0.45-1% Mg 0.5-1.2% Si (native alloy AV, with different additions of [illegible], Mn, and Cr.

Alloy of this composition possesses somewhat higher strength characteristics as compared to above-mentioned alloy 6061, however, its corrosion resistance is significantly lower.

Therefore, in the United States this alloy found application only in forgings and stampings for which questions of corrosion resistance are not limiting, thanks to sizable dimensions of articles.

Here in Soviet Union from alloy AV there are prepared all forms of semi-finished products. Alloy of composition 0.4-1.5% Mg, 0.6-1.6% Si, and 0.4-1% Mn exists in England (alloy 30), in FRG (AlMgSi1, 5), in France (ASG), and in other countries. According to data from these countries. it is known that the alloy has the highest mechanical properties, as compared to other alloys of AlMgSi system. From alloy of shown composition there are prepared all forms of semi-finished products. The alloy has good corrosion resistance, weldability, and capability for anodizing.

In Soviet Union an alloy of this composition is in stage of investigation.

In connection with development of trade between countries there has arisen necessity of establishment of a single international standard for alloys of Al-Mg-Si system.

In Table 2 there is given chemical composition of offered alloys.

Table 2. Chemical Composition of Alloys of Al-Mg-Si System

| № п/п | (a) Тип сплава | (b) Химический состав в % | | | | | | | (c) Модифицирующие элементы |
|---|---|---|---|---|---|---|---|---|---|
| | | Cu | Mg | Si | Fe | Mn | Zn | Cr | |
| 1 | SiMg | 0,1 | 0,4—1,4 | 0,6—1,6 | 0,5 | 0,4—1 | 0,2 | 0,3 | |
| 2 | MgSi | 0,1 | 0,4—0,9 | 0,2—0,7 | 0,5 | 0,3 | 0,2 | 0,1 | Ti+Zn=0,2 |
| 3 | MgSi | 0,15—0,4 | 0,8—1,2 | 0,4—0,8 | 0,7 | 0,15 | 0,15 | 0,15—0,35 | |

KEY: (a) Type of alloy; (b) Chemical composition, in %; (c) Modifying elements.

From given data it is clear that alloy No. 2 in chemical composition corresponds to native alloy AD31, and alloy No. 3 - to alloy AD33. Alloy of composition No. 1, as we noted above, at present is in stage of investigation.

Thus, for needs of civil construction at present in Soviet Union from alloys of AlMgSi system there can be recommened alloys AD31, AD33, and AV.

Standard alloy AV has been known in Soviet Union since 1935, and it was included in All-Union Government Standard; its properties have been studied in considerable detail, and they are given in appropriate reference books.

Alloys AD31 and AD33, know` earlier under brands A\Ch (AD31) and AMK (AD33), not standardized, their properties up to now had been studied insufficiently, Articles from these alloys made by metallurgical factories were supplied according to STU [Tech. Specs], as a rule, without test of mechanical properties.

In 1959 for alloys AD31 and AD33 there were composed certificates No. 4?5 (for AD31) and No. 496 (for AD33). Below we shall give properties of these alloys.

## 1. Alloy AD31

Properties. Characteristic peculiarities of this alloy are average strength, high ductility, good appearance of semifinished products (especially after

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*Investigation of properties of alloys AD31 and AD33 was conducted by the author jointly with Z. I. Starostina and Ye. A. Gubareva.

mechanical polishing), and good corrosion resistance (for manufacture of articles for decorative purposes with especially good surface polish of metal, as, for instance, for watch cases it is recommended to use alloy of composition: 0.55-0.9% Mg, 0.4-0.5% Si, 0.05% Cu, and 0.12 Fe).

From the alloy there can be prepared both pressed, semifinished products, profiles, rods, strips, pipes, and also sheets. Pressed articles and sheets material from alloy AD31 have the same values of mechanical properties.

Alloy - thermally strengthened (temperature of quenching 520±5°, temperature of aging 160°, time of holding during aging 12-16 hours). Strengthening has place both in process of natural and also of artificial aging.

Strengthening of alloy at room temperature is most intense during first 30 minutes and is concluded, basically, after 10 days. Further increase of time of holding to 2 months practically does not change properties of alloy (Table 3).

**Table 3. Influence of Natural Aging on Mechanical Properties of Alloy AD31**

| (a) Время выдержки в час. | (b) $\sigma_b$ в кг/мм² | (b) $\sigma_{0,2}$ в кг/мм² | (c) δ в % | (a) Время выдержки в час. | (b) $\sigma_b$ в кг/мм² | (b) $\sigma_{0,2}$ в кг/мм² | (c) δ в % |
|---|---|---|---|---|---|---|---|
| 0 | 11,5 | — | 29,2 | 24 | 20,3 | 8 | 26 |
| 30 (min) | 16,8 | 5,6 | 31,1 | 48 | 20,5 | 8,6 | 26,2 |
| 1 | 17,3 | 6,2 | 30,3 | 96 | 20,6 | 9 | 26,2 |
| 2 | 17,8 | 6,3 | 28,9 | 120 | 21 | 9,3 | 26,4 |
| 3 | 18,5 | 6,5 | 28 | 144 | 21,4 | 9,7 | 26,5 |
| 4 | 18,6 | 6,8 | 27 | 240 | 21,6 | 10 | 26,5 |
| 6 | 19,3 | 7,3 | 26,7 | 360 | 21,5 | 9,8 | 26 |
| 8 | 19,7 | 7,8 | 26,7 | 720 | 21,6 | 10 | 25,5 |
| 12 | 20 | 8,2 | 26,4 | 1440 | 21,5 | 9,8 | 25,5 |

Note: Test of mechanical properties was made on samples of laboratory manufacture. Mechanical properties of semifinished products of alloy AD31-T, prepared under industrial conditions are the following, $\sigma_b$ = 16 to 18 kg/mm², $\sigma_{0.2}$ = 9 to 10 kg/mm², and δ = 20 to 25%.

KEY: (a) Time of holding, in hours; (b) in kg/mm²; (c) in %.

The highest values of mechanical properties of material of alloy AD31 are attained after artificial aging.

Mechanical properties of pressed and rolled semifinished products at a temperature of 20° are presented in Table 4.

Table 4. Mechanical Properties of Alloy AD31 (after Artificial Aging)

| (a) Механические свойства сплава | $E$ | $G$ | $\mu$ | $\sigma_p$ | $\sigma_{0.2}$ | $\sigma_b$ | $\delta$ | $\psi$ | $\tau_{cp}$ | $H_B$ | $\sigma_{-1}$* | $a_н$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (d) в кг/мм² | | | (d) в кг/мм² | | | (e) в % | | (d) в кг/мм² | | | (f) в кгм/см² |
| (b) Типичные | 7100 | 2700 | 0,31 | 14 | 21 | 24 | 10–12 | 50 | 15 | 80 | 9 | 4 6 |
| (c) Гарантируемые | — | — | — | — | 15 | 20 | 10 | — | — | — | — | |

*Fatigue limit $\sigma_{-1}$ was determined with cantilever bending of revolving, round, smooth sample on base of 20 million.

KEY: (a) Mechanical properties of alloy; (b) Typical; (c) Guaranteed; (d) in kg/mm$^2$; (e) in %; (f) kgm/cm$^2$

Values of mechanical properties of pressed and rolled semifinished products are practically not changed in their length and width in case of sheet material (Table 5).

Welding of semifinished products. Alloy AD31 welds well by resistance (spot and roll) welding and satisfactorily by argon arc and gas welding.

It is known that alloys of AlMgSi system (AD31, AD33, AV) have great inclination to formation of crystallization cracks during argon arc and gas welding when welding rod having composition of basic material is used. Coefficient of crack formation K in this case reaches 50–60%. Ultimate strength of welded seam constitutes 60–70% of ultimate strength of basic material.

Application of welding rod AK (Al–5% Si) significantly lowers inclination of alloys to formation of crystallization cracks—practically to 10–20%. Strength of welded seam, as in case of use of welding rod of basic composition, also constitutes 60–70% of strength of basic material.

Subsequent quenching and aging of welded joints (if heat treatment is

Table 5. Mechanical Properties of Pressed and Rolled Semifinished Products From Alloy AD31 in Artificially Aged State in Length and Cross Section

| Form of semi-finished product | Place of cutting of sample | Mechanical properties: Longitudinal direction | | | Transverse direction | | |
|---|---|---|---|---|---|---|---|
| | | $\sigma_b$, kg/mm² | $\sigma_{0.2}$, kg/mm² | $\delta$, % | $\sigma_b$, kg/mm² | $\sigma_{0.2}$, kg/mm² | $\delta$, % |
| Profile PS100-10 No. 1, corner (25X25X X2 mm) | Outlet end | 24<br>23.7 | 21<br>20.8 | 11.5<br>12.4 | — | — | — |
| | Middle | 23.6<br>23.9 | 20.4<br>20.1 | 12<br>11.5 | — | — | — |
| | Shrink-hole | 23.9 | 20.1 | 11.5 | — | — | — |
| Profile 2 | Outlet end | 24<br>24.2 | 21<br>21.3 | 11.6<br>11.1 | — | — | — |
| | Middle | 24.2<br>24.3 | 21.7<br>21.1 | 11.8<br>12.5 | — | — | — |
| | Shrink-hole | 24.3 | 21.1 | 12.5 | — | — | — |
| Profile 3 | Outlet end | 23.9<br>24.4 | 20.8<br>21.4 | 10.4<br>11.2 | — | — | — |
| | Middle | 24.1<br>24.2 | 20.8<br>21.2 | 12.3<br>12 | — | — | — |
| | Shrink-hole | 24.2 | 21.2 | 12 | — | — | — |
| Strip 40X320 mm $\delta$ = 5 mm | Outlet end | 24.5 | 19.3 | 20.5 | 24.5 | 18.5 | 20.5 |
| | Shrink-hole | 24.9 | 19.8 | 20 | 24.5 | 19.1 | 20.5 |
| Strip 40X X3[illegible] mm $\delta$ = 6 mm | Outlet end | 25.2 | 20.8 | 18.5 | 25 | 20.[illegible] | 18.5 |
| | Middle | 24.8 | 20 | 20 | 24.5 | 20 | 19.5 |
| Sheet $\delta$ = 2 mm | — | 25.5 | 22 | 13 | 26 | 21.8 | 12.2 |
| Sheet $\delta$ = 6 mm | — | 25 | 21 | 14 | 25 | 20.8 | 13.5 |

Note: Profiles PS100-10 had length of 6–7 m. From outlet end at distance of 200 mm for test there were taken first five samples of l = 210 mm. Subsequent samples were test at each 400–500 mm.

possible) increase strength of seam practically to 90–95% of $\sigma_b$ of basic material.

In civil construction, where in many cases the assurance is necessary of good decorative appearance of structure, application of welding rod AK during welding is not always desirable since welded seam after anodizing has dark color, and in this case structure must be painted. If elements of the structure can be welded on butt-welding (as for example, parts of stained glass panels), it is necessary to use machines ensuring good-quality seam without application of fluxes and addition material. Such butt-welding machines at present in Soviet Union are coming into use (Ye. O. Paton Institute); production and application of them must be speeded up.

In Table 6 there are given results of tests of mechanical properties of welded joints of sheet material of alloy AD31*, welded by automatic argon arc welding with infusible electrode.

Table 6. Mechanical Properties of Welded Joints of Sheet Material of Alloy AD31

| (a) Состояние материала | (b) Вид полуфабриката | (c) $\sigma_b$ в кг/мм² с усилением | (d) Угол загиба в град. | (i) $a_к$ в кгм/см² |
|---|---|---|---|---|
| После сварки (e) | Лист δ = 2 мм (f) | 17 | 85 | 0,5 |
| | Профиль-полоса 7,5 × 80 мм | 18 | 66 | 0,5 |
| После термической обработки (закалка + искусственное старение) (g) | Лист (h) | 26,5 | 61,5 | 0,45–1,5 |

KEY: (a) State of material; (b) Form of semifinished pact; (c) in kg/mm² with strengthening; (d) Angle of bend, in degrees; (e) After welding; (f) Sheet δ = 2. Profile strip 7.5x80 mm; (g) After heat treatment (quenching = artificial aging); (h) Sheet; (i) in kgm/cm².

*Welding of semifinished products of alloy AD31 was done by Yu. P. Arbuzov and M. N. Naumova.

Corrosion resistance of semifinished products* was tested on samples prepared from sheets and pressed, semifinished products for general corrosion and under conditions of stress corrosion.

Test for general corrosion resistance was conducted under conditions of full submersion in 3% solution of NaCl with addition of 0.1% $H_2O_2$ for 3 months. Appraisal of corrosion resistance in this case was made according to loss of mechanical properties as a result of corrosion. Stress corrosion test was conducted on corrosion wheel under conditions of variable submersion in 3% solution of NaCl on samples in form of loop from sheet material with thickness of 1.5 mm and on samples "forks," prepared from pressed strip of dimension 7.5 x 80 mm (samples for corrosion tests were cut in transverse direction). In Table 7 there are given results of three-month tests of sheet and pressed materials of alloy AD31 under conditions of full submersion in 3% solution of $NaCl+0.1H_2O_2$ (in table there are given mean values from five samples).

For comparison this table there are given data on test of alloy AV, containing copper at upper and lower limits.

As follows from presented data, semifinished products from alloy AD31 have good corrosion resistance, significantly higher, as compared to corrosion resistance of semifinished products from alloy AV.

In Table 8 there are given results of annual test of alloy AD31 under atmospheric conditions in industrial area.

Consequently, semifinished products from alloy AD31 also possess good corrosion resistance under atmospheric conditions.

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*Investigation of corrosion resistance of alloy AD31 was conducted by Ye. I. Burova and L. I. Agapova.

Table 7. Comparison of Mechanical Properties of Alloys AD31 and AV

| (a) Марка сплава | (b) Вид полуфабриката | (c) Механические свойства до коррозии | | (d) Механические свойства после коррозии | | (e) Потери механических свойств в % | |
|---|---|---|---|---|---|---|---|
| | | (i) $\sigma_b$ в кг/мм² | $\varepsilon$ в % (j) | (i) $\sigma_b$ в кг/мм² | $\varepsilon$ в % (j) | $\Delta\sigma_b$ | $\Delta\varepsilon$ |
| AD31 | (f) Листы $\delta = 2$ мм | 25,7 | 16,3 | 26 | 13,6 | 0 | 16,5 |
| | (g) Прессованный пруток диаметром 20 мм | 23,6 | 17,2 | 23,3 | 18,2 | 1,2 | 0 |
| AV | (h) Лист $\delta = 2$ мм . . (Cu = 0,2%) | 37,5 | 16 | 35,5 | 5,4 | 5,5 | 66 |
| | (h) Лист $\delta = 2$ мм (Cu = 0,5 %) . . . | 39,2 | 18 | 34,4 | 2,8 | 12 | 84 |

KEY: (a) Brand of alloy; (b) Form of semifinished product; (c) Mechanical properties before corrosion; (d) Mechanical properties after corrosion; (e) Losses of mechanical property in %; (f) Sheets $\delta$ = 2mm; (g) Pressed rod with diameter of 20 mm; (h) Sheet $\delta$ = 2 mm. (i) in kg/mm²; (j) in %.

Table 8. Influence of Corrosion on Mechanical Properties of Alloy AD31

| (a) Вид полуфабриката | (b) Механические свойства до коррозии | | (c) Механические свойства после коррозии | | (d) Потери в % | |
|---|---|---|---|---|---|---|
| | (g) $\sigma_b$ в кг/мм² | $\varepsilon$ в % (h) | (g) $\sigma_b$ в кг/мм² | $\varepsilon$ в % (h) | $\Delta\sigma_b$ | $\Delta\varepsilon$ |
| (e) Лист $\delta = 2$ мм . . . . . . . . | 26,6 | 14,7 | 26,5 | 13,6 | 0,3 | 7,4 |
| (f) Прессованный пруток диаметром 20 мм . . . . . . . . | 24,4 | 17,6 | 24,4 | 16,5 | 0 | 6,2 |

Key: (a) Form of semifinished product; (b) Mechanical properties before corrosion; (c) Mechanical properties after corrosion; (d) Losses in %; (e) Sheet $\delta$ = 2 mm; (f) Pressed rod with diameter of 20 mm; (g) in kg/mm²; (h) in %.

Alloy AD31, as all alloys of AlMgSi, is not inclined to stress corrosion. Samples made from sheets $\delta$ = 2mm and pressed strips with dimension 7.5x80 mm with stood stress without failures for more than a year.

Ductility of alloy at temperature of pressure treatment of 480-510° is high. Machinability in state T and T1 is satisfactory, in annealed state — unsatisfactory.

## Physical Properties

| | |
|---|---|
| Specific gravity . . . . . . . . . . . . . . . . . | 2.71 $g/cm^3$ |
| Coefficient of linear expansion ( $\alpha \cdot 10^{-6}$ ): | |
| at 20-100° . . . . . . . . . . . . . . . . . | $23.4 \ 10^{-6}$ |
| " 20-200° . . . . . . . . . . . . . . . . . | $24.3 \ 10^{-6}$ |
| " 20-300° . . . . . . . . . . . . . . . . . | $25.8 \ 10^{-6}$ |
| " 20-400° . . . . . . . . . . . . . . . . . | $26.7 \ 10^{-6}$ |
| " 100-200° . . . . . . . . . . . . . . . . | $25.3 \ 10^{-6}$ |
| " 200-300° . . . . . . . . . . . . . . . . | $28.2 \ 10^{-6}$ |
| " 300-400° . . . . . . . . . . . . . . . . | $29.9 \ 10^{-6}$ |
| Thermal conductivity at 20-400° . . . . | 0.45 cal/cm sec deg |
| Heat capacity at 100-400° . . . . . . . . | 0.22-0.25 cal/g deg |
| Specific electrical resistance . . . . | 0.0344 ohm $mm^2/m$ |

Application. Alloy AD31 may be widely used in civil construction, where there are required average strength, good ductility, corrosion resistance, and good decorative appearance.

In civil construction alloy AD31 is most widely used in the form of pressed semifinished products for window frames, doors, partitions, risers, and so forth.

## 2. Alloy AD33

Properties. Alloy AD33 of AlMgSi system has composition: 0.8-1.2% Mg, 0.15-0.4% Cu, 0.4-0.8% Si, 0.15-0.35% Cr, up to 0.15% Ti, and possesses average strength and good corrosion resistance in humid and marine atmospheres.

From the a loy there can be prepared all forms of semifinished products. Alloy is thermally hardened (temperature of quenching is 520±5°, temperature of aging 160°, time of holding during aging 16-20 hours). Alloy is hardened both in process of natural and also in process of artificial aging.

Increase of strength characteristics at room temperature, basically, is terminated by 10-15 days. Further increase of time of holding to 2 months practically does not change properties of alloy (Table 9).

The highest values of mechanical properties are reached by material of alloy AD33 after artificial aging (see Table 10).

<u>Welding of semifinished products.</u> Alloy AD33* welds well by resistance (roll and spot) welding and satisfactorily by argon arc and gas welding.

Table 9. Influence of Natural Aging on Mechanical Properties of Alloy AD33

| (a) Время выдержки в час. | (d) $\sigma_b$ в кг/мм² | (d) $\sigma_{0,2}$ в кг/мм² | (e) $\delta$ в % |
|---|---|---|---|
| 0 | 18,1 | — | 27,7 |
| 30 (мин.) (b) | 20 | 6,4 | 28,4 |
| 1 | 20,3 | 7,1 | 29,1 |
| 3 | 20,7 | 7,5 | 28 |
| 4 | 21,4 | 7,6 | 27 |
| 6 | 21,6 | 8,5 | 26 |
| 8 | 22,4 | 9 | 26 |
| 12 | 22,8 | 9,5 | 25,8 |
| 24 | 23,8 | 10 | 26 |
| 48 | 25,7 | 11 | 26,5 |
| 96 | 25,2 | 11,5 | 26,5 |
| 120 (5 сут.) (c) | 25,5 | 11,7 | 27 |
| 144 (6 сут.) | 26,2 | 11,6 | 27 |
| 240 (10 сут.) | 26,3 | 12 | 26,2 |
| 360 (15 сут.) | 27,1 | 12,1 | 27,1 |
| 480 (20 сут.) | 27 | 12 | 27,2 |
| 720 (30 сут.) | 27,1 | 12,3 | 27,3 |
| 1440 (60 сут.) | 27 | 12,5 | 26,3 |

Note: Test of mechanical properties was made on samples of laboratory manufacture. Semifinished products of alloy AD33 prepared under industrial conditions in naturally aged state have following typical mechanical properties: $\sigma b$ = 23 kg/mm², $\sigma_{0.2}$ = 14 to 15 kg/mm², $\epsilon$ = 15 to 20%.
KEY; (a) Time of holding in hours; (b) min; (c) days; (d) in kg/mm²; (e) in %.

In Table 11 there are given results of tests of mechanical properties of welded samples of sheet material of alloy AD33 ( $\delta$ = 2 mm) welded by automatic argon arc welding with infusible electrode.

From given data it follows that alloy AD33 in state of welding has ultimate strength equal to 60% of strength of basic material.

*Investigation of weldability of alloy AD33 was conducted by Yu. P. Arbusov and M. N. Naumova.

Table 10. Mechanical Properties of Pressed and Rolled Semifinished Products from Alloy AD33 after Artificial Aging at a Temperature of 20°

| (a) Механические свойства сплава | $E$ (d) в кг/мм² | $G$ | $\mu$ | $\sigma_p$ (d) в кг/мм² | $\sigma_{0,2}$ | $\sigma_b$ | $\delta$ (e) в % | $\psi$ | $\tau$ (d) в кг/мм² | $H_B$ | $\sigma^*_{-1}$ | $a_K$ в кгм/см² (f) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (b) Типичные | 7100 | 2700 | 0,31 | 18 | 25—27 | 30—32 | 12—15 | 25 | 19 | 90—100 | 11 | 3 |
| (c) Гарантируемые . . | — | — | — | — | 23 | 27 | 10 | — | — | — | — | |

*Fatigue limit was determined with cantilever bend of revolving, round, smooth sample on base of 20 million cycles.

KEY: (a) Mechanical properties of alloy; (b) Typical; (c) Guaranteed ; (d) in kg/mm²; (e) in %; (f) in kgm/cm².

Table 11. Mechanical Properties of Welded Samples form Sheet Material of Alloy AD33

| (a) Состояние материала | $\sigma_b$ в кг/мм² (m): с усилением (b) | со снятым усилением (c) | в наплавленном металле (d) | в зоне сплавления (e) | (f) Угол загиба в град. | (g) Ударная вязкость в кгм/см²: в наплавленной зоне (h) | в зоне сплавления (e) | (i) Примечание |
|---|---|---|---|---|---|---|---|---|
| (j) После сварки . . . | 21 | 20 | 21 | 22 | 67,5 | 1,4 | 1,9 | (l) Листы сваривались присадочной проволокой АК (Al—5%Si) |
| (k) После термической обработки (закалка + искусственное старение). . . . | 34 | 32 | 34 | — | 68,5 | — | — | |

KEY: (a) State of material; (b) With strengthening: (c) With removed strengthening; (d) In fused metal; (e) In zone of alloying; (f) Angle of bend in degrees; (g) Impact toughness in kgm/cm²; (h) In fused zone; (i) Note; (j) After welding; (k) After heat treatment (quenching + artificial aging); (l) Sheets were welded by welding rod AK (Al—5% Si); (m) in kg/mm².

After heat treatment ultimate strength significantly increases and practically attains strength of basic material. Ductility of alloy (angle of bend) is not changed.

Corrosion resistance of semifinished products (sheet $\delta$ = 2mm and pressed profile) of alloy AD33 was also tested for general corrosion under conditions of stress corrosion.*

In Table 12 there are given results of three-month tests of sheet and pressed material for general corrosion under conditions of full submersion in 3% solution of NaCl + 0.1% $H_2O_2$ in comparison with standard alloy AV, containing copper content at upper and lower limits.

Table 12. Influence of Corrosion on Mechanical Properties of Alloy AD33

| (a) Марка сплава | (b) Вид полуфабриката | (c) Механические свойства до коррозии | | (d) Механические свойства после коррозии | | (e) Потери механических свойств в % | |
|---|---|---|---|---|---|---|---|
| | | (h) $\sigma_b$ в $кг/мм^2$ | (i) $\delta$ в % | (h) $\sigma_b$ в $кг/мм^2$ | (i) $\delta$ в % | $\Delta\sigma_b$ | $\Delta\delta$ |
| AD33 | (f) Лист $\delta$ = 2 мм . . . . | 30,4 | 17,3 | 30,1 | 16,8 | 0,9 | 2,3 |
| | (g) Профиль ПС754-2 . . | 32 | 16,4 | 31,5 | 15,4 | 1,5 | 6,1 |
| AV | (f) Лист $\delta$ = 2 мм . . . . | | | | | | |
| | Cu = 0,2% . . . . . | 37,5 | 16 | 35,5 | 5,4 | 5,5 | 66 |
| | Cu = 0,5% . . . . . . | 39,2 | 18 | 34,4 | 2,8 | 12 | 84 |
| | (g) Профиль ПС754-2 . . | 35 | 14,6 | 29,7 | 2,7 | 15,1 | 81,5 |

KEY: (a) Brand of alloy; (b) Form of semifinished product; (c) Mechanical properties before corrosion; (d) Mechanical properties after corrosion; (e) Losses of mechanical properties in %; (f) Sheet $\delta$ = 2 mm; (g) Profile PS754-2; (h) in $kg/mm^2$; (i) in %.

From given data it follows that corrosion resistance alloy AD33 is good and significantly higher than corrosion resistance of standard alloy AV.

Investigation of alloy under conditions of stress corrosion showed that alloy AD33, as other alloys of AlMg Si system (AV, AD31), is not inclined to stress control.

All test samples were found after annual test to be withour failure.

Application. Alloy AD33, because of all its characteristics, can be widely used in civil construction, where there are required average strength, good

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*Investigation of corrosion resistance of sheets of alloy AD33 was conducted by Ye. I. Burova and L. I. Agapova; investigation of corrosion resistance of pressed profiles by — S. M. Ambartsumyan.

ductility and corrosion resistance, and also in humid and marine atmospheres.

## Physical Properties

Specific gravity 2.71 $g/cm^3$

Coefficient of linear expansion ($\alpha \cdot 10^{-6}$);

| | |
|---|---|
| at 20-100° | 23.2 $10^{-6}$ |
| " 20-200° | 24.1 $10^{-6}$ |
| " 20-300° | 25 $10^{-6}$ |
| " 100-200° | 25.1 $10^{-6}$ |
| " 200-300° | 26.7 $10^{-6}$ |

| | |
|---|---|
| Thermal conductivity at 20-300° | 0.34-0.41 cal/cm sec deg |
| Heat capacity at 100-300° | 0.225-0.25 cal/g deg |
| Specific electrical resistance | 0.438 ohm $mm^2/m$ |

# INVESTIGATION OF PHYSICO-MECHANICAL PROPERTIES OF ALUMINUM ALLOYS D1-T, D16-T, AMg61, and D16-A(g/k)

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Availability of data on mechanical properties of aluminum alloys is necessary condition for development of corresponding norms and methods of calculation of structures.

Data available in literary sources insufficiently illuminate these properties. Thus, for instance, there is usually not given such important data as primary diagrams of compressions, limits of proportionality, and compressive yield point, extremely necessary during the analysis of questions of overall and local stability of structures.

As it is known, normative and calculated resistances are usually taken to standardized, as identical during extension and compression, and if for steel, there are known bases for this, then with respect to aluminum alloys the possibility of such assumption requires special experimental check.

Of indubitable practical interest are values of coefficient of homogeneity for aluminum alloys, obtained on the basis of experimental data, at least in the very first approximation. As it is known, at present for all aluminum alloys this coefficient is taken, conditionally, as equal to 0.85.

This work had as its purpose the establishment of values of indices of physico-mechanical properties of alloys D1-T, D16-T, AMg61, and D16-A(g/k) and on this basis the illumination to a certain extent of above-mentioned questions.

Alloy D16-A(g/k) was tested in this case optionally for the purpose of study, mainly, of change of mechanical properties in relation to thickness of sheet.

Work has done in laboratory of norms for designing and testing of bridges of TsNIIS* [Central Scientific Research Institute of Communications].

## 1. Substance and Method of Investigation

In considered alloys there were studied following mechanical properties: limit of proportionality, yield point, ultimate strength, elastic modulus, specific elongation, and reduction of area, with receipt of primary diagrams of tension and compression for different profiles of each alloy.

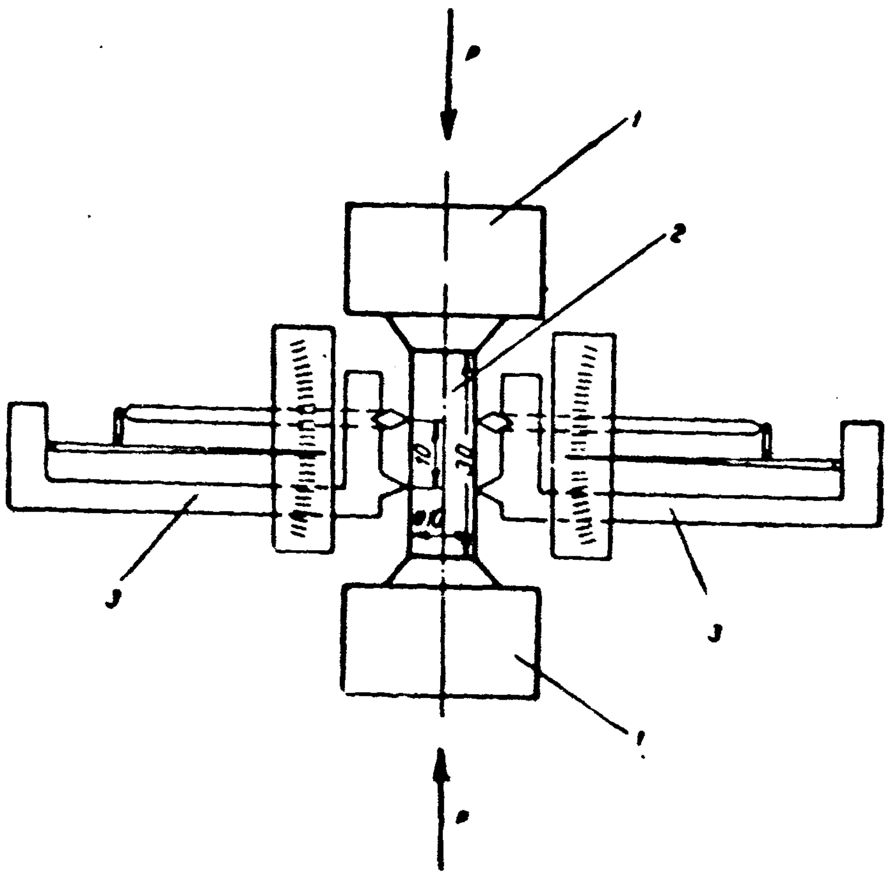

Fig. 1. Diagram of layout of crusher of testing machine
1 — punch; 2 — crusher; 3 — tensometer

*Yu. A. Dobrovol'skiy, engineer, participated in carrying out of experiments.

For study of these properties there were made tests of standard samples for extension and crushers for compression. The samples were prepared from different profiles. Samples were prepared in quantity sufficient for judgement about changeability of properties of alloys, depending upon form of profile, direction of rolling, thickness of rolled sheets, position through cross section and length of profile.

For the purpose of study of homogeneity of mechanical properties through length of profile billets for samples and crushers were taken in several (3-5) dispersed cross sections, divided through length of profile into approximately equal parts.

Billets for crushers were usually disposed side by side with billets for standard samples, for the purpose of best comparability of results of tests for tension and compression.

For tensile tests there were applied flat samples, conforming to requirements of GOST [All-Union Government Standard].

Billets were taken form profiles along length of profile, while those from sheets — both with and across direction of rolling.

Preparation of samples from profiles and sheet metal was executed with such calculation that their surface layer remained untouched.

For compression tests there were applied crushers having form of cylinder with diameter of 10 mm and height of 30 mm.

Cutting of billets for crushers was done on milling machine, but crushers themselves were turned on lathe.

Crushers were prepared from profiles with longitudinal orientation of axis, and from sheets — both with longitudinal and with transverse orientation of axis of rolling.

Tests of samples for axial extension were made on 50-ton testing machine.

Tests of crushers for axial compression were made on 4-ton testing machine

(Fig. 1).

Measurement of deformations (strains) was made by mechanical tensometers on 1 cm base.

During tensile tests four tensometers were set up at the center (through length of sample) of section, while during compression tests -- two tensometers faced each other at the center (through height of crusher) of section.

Loads were applied to sample in consecutive steps, starting from conditional zero, i.e., during tensile tests -- from load of 625 kg, and for compression -- from load of 50 kilograms.

## 2. Results of Tensile Tests

Tensile properties of alloys were determined in accordance with requirements of All-Union Government Standard 1497-42.

Primary tensile diagrams were constructed on coordinates $\sigma - \varepsilon_p$. Magnitude of relative elongation $\varepsilon_p$ was found as arithmetical mean from readings of four tensometers. Typical tensile diagrams are shown in Fig. 2.

Limit of proportionality was determined also as conditional, the stress at which deviation from linear dependence between stresses and strains attained such magnitude that tangent of angle formed by strain curve with axis of stresses is increased by 50% of its initial value.

The values found by results of tensile tests for mechanical properties - limit of proportionality, yield point, ultimate strength, and their ratios are given in Table 1.

Having examined these data, the following judgement can be made about changeability of mechanical properties of tested alloys.

For all profiles of alloy D1-T these data vary within considerable limits; for instance, difference between least and the greatest values of limit of proportionality constitutes 35%, for yield point -- 30%, and for ultimate stength 16%.

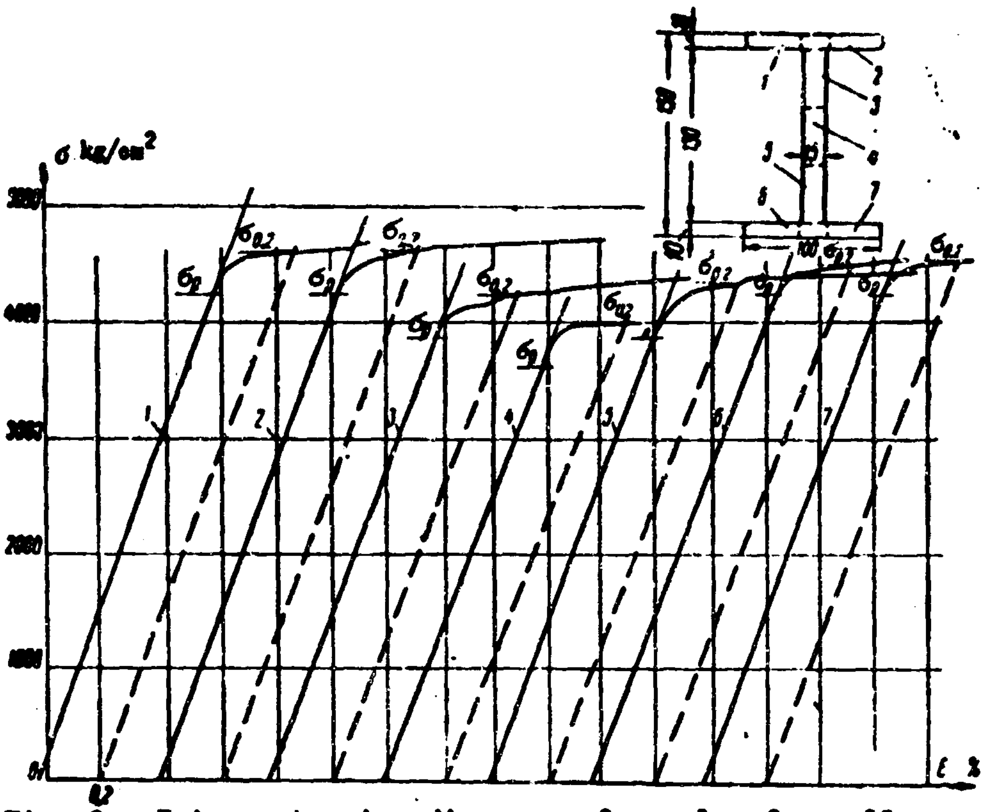

Fig. 2. Primary tension diagrams of samples from alloy D16-T.

Data in Table 1 show that mechanical properties of alloy D16-T undergo significant changes both within limits of one profile and also in relation to form of the latter. In this case difference between least and the greatest values for limit of proportionality constitutes 46%, yield point — 36%, and ultimate strength - 27%.

From alloy AMg61 difference between least and the greatest values of limit of proportionality constitutes 16%, yield point - 15%, and ultimate strength - 11%; as we see, this difference is comparatively small.

Comparing values given in Table 1 for mechanical properties for sheets of different thickness from alloy D16-A(g/k), we note presence of significant changeability of properties.

With increase of thickness of sheets there is observed no definite regularity in change of limit of proportionality.

The same may be said about ultimate strength, if we compare its arithmetical mean values, which are given in Table 1.

Arithmetical mean value of yield point decreases with increase of thickness

## Table 1. Mechanical Properties of Metal of Samples from Aluminum Alloys

| Brand of alloy and assortment | [illegible] kg/cm² — Proportionality $\sigma_p$ | Yield $\sigma_{0.2}$ | Strength $\sigma_b$ | Ratio $\frac{\sigma_p}{\sigma_{0.2}}$ | Ratio $\frac{\sigma_{0.2}}{\sigma_b}$ | Arithmetical mean [illegible] kg/cm² — [illegible] | [illegible] | [illegible] $\sigma_b$ | Arithmetical mean — [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alloy D1-T** | | | | | | | | | | | |
| I-beam 90×10+ +2×90×15 | 2580–3340 | 3420–4290 | 4460–4770 | 0,60–0,86 | 0,73–0,91 | 2910 | 37[illegible] | [illegible] | 0,81 | 0,78 | 11 |
| Angle 90+90×10 | 2800–3200 | 3450–4700 | 4530–4750 | 0,76–0,88 | 0,75–0,79 | 2650 | 3570 | [illegible] | [illegible] | [illegible] | 9 |
| " 75+75×10 | 2720–3400 | 3650–3840 | 4600–4900 | 0,74–0,9 | 0,76–0,8 | [illegible] | 3720 | 4770 | 0,75 | [illegible] | 12 |
| Channel 100×5+ +2×70×5 | 2220–2800 | 2960–3080 | 4110–4230 | 0,75–0,91 | 0,72–0,73 | 2530 | 3020 | 4160 | 0,73 | 0,83 | 20 |
| I-beam 150×15+ +2×100×14 | 3230–3620 | 3600–4000 | 4530–4900 | 0,90–0,91 | 0,78–0,82 | 3470 | 3850 | 4730 | 0,81 | 0,91 | 21 |
| **Alloy D16-T** | | | | | | | | | | | |
| I-beam 150×15+ +2×100×14 | 3[illegible]30–4250 | 4000–4600 | 4950–5500 | 0,91–0,93 | 0,81–0,84 | 3940 | 4270 | 5100 | 0,83 | 0,92 | 21 |
| T-beam 100×15+100×12 | 3400–[illegible] | 3800–5100 | 5100–5920 | 0,83–0,95 | 0,74–0,93 | 3760 | 4320 | 5420 | 0,79 | 0,92 | 20 |
| Angle 200+75×[illegible] | 2700–3020 | 3130–3550 | 4300–5000 | 0,80–0,88 | 0,73–0,73 | 2915 | 3370 | 4130 | 0,73 | 0,87 | 20 |
| " 100+70×[illegible] | 2760–3010 | 3870–4300 | 4870–5150 | 0,66–0,76 | 0,78–0,84 | 2900 | 4050 | 5050 | 0,8 | 0,72 | 10 |
| " 90+90×10 | 2800–3870 | 3730–4270 | 4850–5500 | 0,75–0,94 | 0,73–0,78 | 3300 | 3970 | 5200 | 0,76 | 0,83 | 8 |
| **Alloy AMg6** | | | | | | | | | | | |
| Strip 120×12 | 2120–2470 | 2600–2890 | 3660–3880 | 0,82–0,86 | 0,71–0,75 | 2270 | 2750 | 3780 | 0,73 | 0,82 | 14 |
| Channel 140×5+ +2×58×12 | 2070–2320 | 2750–3070 | 3780–4100 | 0,75–0,76 | 0,73–0,75 | 2160 | 2890 | 3970 | 0,73 | 0,75 | 12 |
| **Alloy D16-[illegible] (a/s)** | | | | | | | | | | | |
| Sheet δ = 10 mm with rolling | 1000–1170 | 1520–1720 | 2390–2540 | 0,66–0,68 | 0,64–0,68 | 1065 | 1625 | 2180 | 0,66 | 0,66 | 7 |
| The same, across rolling | 970–1150 | 1525–1650 | 2230–2380 | 0,64–0,7 | 0,68–0,69 | 1060 | 1590 | 2270 | 0,69 | 0,67 | 5 |
| Sheet δ = 16 mm with rolling | 700–1120 | 1350–1550 | 2220–2500 | 0,52–0,72 | 0,61–0,62 | 910 | 1460 | 2330 | 0,62 | 0,64 | 8 |
| The same, across rolling | 770–1150 | 1370–1520 | 2070–2220 | 0,56–0,75 | 0,66–0,69 | 910 | 1450 | 2150 | [illegible] | 0,65 | 6 |
| Sheet δ = 20 mm with rolling | 1120–1300 | 1500–1600 | [illegible]–2420 | 0,73–0,81 | [illegible]–0,66 | 1210 | [illegible] | 2370 | [illegible] | 0,78 | 6 |
| The same, across rolling | 1080–1200 | 1450–1620 | 2040–2270 | 0,73–0,74 | 0,71–0,72 | 1130 | [illegible] | [illegible] | 0,72 | 0,73 | 6 |
| Sheet δ = 30 mm with rolling | 950–1000 | 1320–1370 | [illegible]–2720 | 0,72–0,73 | 0,39–0,51 | [illegible] | [illegible] | [illegible] | [illegible] | 0,73 | 7 |
| The same, across rolling | 920–1020 | 1370–1420 | 2650–2700 | 0,67–0,72 | 0,51–0,53 | 950 | [illegible] | [illegible] | [illegible] | 0,70 | 7 |

of sheets by 17% with rolling and by 12% across rolling.

We must note also the comparatively insiginificant difference of arithmetical values of mechanical properties for samples with and across rolling.

Of interest is character of change of considered properties of alloys in respect to position of sample in cross section of profile.

As experimental data show, for I-beam profile of alloy D1-T mechanical properties through section can differ among themselves by up to 2 kg/mm$^2$, while values of these properties for flanges is higher than for a wall.

For I-beam profile from alloy D16-T mechanical properties for flanges are somewhat higher than for walls (Fig. 2). In Table 2 there are given for this profile limits of change, in different sections, of arithmetical mean values of mechanical properties for wall and flanges.

Table 2. Change of Mechanical Characteristics by Section of I-beam Profile from Alloy D16-T (in kg/cm$^2$)

| (a) Механические свойства | (b) Пределы изменения среднеарифметических значений механических свойств | |
|---|---|---|
| | (c) стенка | (d) полки |
| (e) Предел пропорциональности . . . | 3 790—3 960 | 3 810—4 250 |
| (f) „ текучести . . . . . . . . . | 4 060—4 200 | 4 200—4 560 |
| (g) „ прочности . . . . . . . . . | 4 990—5 070 | 5 100—5 520 |

KEY: (a) Mechanical properties; (b) Limits of change of arithmetical mean values of mechanical properties; (c) Wall; (d) Flanges; (e) Limit of proportionality; (f) Yield point; (g) Ultimate strength.

For tee and angle profiles from alloy D16-T and for channel profile from alloy AMg61 mechanical properties through section are changed immaterially (up to 4% for D16-T).

Comparison of values of mechanical properties of alloys D1-T, D16-T, and AMg61 for different sections of one and the same profile showed that these properties are practically identical through length of article.

In Table 3 there are given values of yield point for these alloys, obtained as a result of statistical treatment of experimental data.

Table 3. Values of Tensile Yield Point (in $kg/mm^2$)

| (a) Характеристика | (b) Марка сплава | | |
|---|---|---|---|
| | (f) Д1-Т | (f) Д16-Т | (g) АМг61 |
| (c) Среднее статистическое значение | 35,08 | 39,76 | 27,6 |
| (d) Среднее квадратичное отклонение | 3,3 | 4,36 | 1,18 |
| (e) Минимальное вероятное значение | 25,18 | 26,68 | 24,06 |

Key: (a) Characteristic; (b) Brand of alloy; (c) Average statistical value; (d) Root-mean-square deviation; (e) Minimum probable value; (f) D1-T, D16-T; (g) AMg61.

Minimum probable value of yield point given in Table 3 was found as difference of its average statistical value minus three root-mean-square deviations (standard).

Taking normative resistance for alloy D1-T equal to 23 $kg/mm^2$ and minimum probable value of yield point equal to 25.18 $kg/mm^2$, we find that coefficient of homogeneity in its accepted sense is very high (1.09), which can be explained, apparently, by evident limitedness of experimental data used in this case during statistical treatment.

Of the 79 tested samples of alloy D16-T only two have yield point equal to its minimum value according to technical specs AMTU 258-55, i.e., 31 $kg/mm^2$. There were no tested samples with yield point of less than 31 $kg/mm^2$.

Taking normative resistance for alloy D16-T is equal to 31 $kg/mm^2$ and minimum probable value of yield point is equal to 26.68 $kg/mm^2$, we obtain coefficient of homogeneity equal to 0.86. We obtain comparatively low coefficient even without calculation of minus allowances for rolling.

For all samples from alloy AMg61 yield point turned out to be higher than

Table 4. Values of Mechanical Characteristics from Results of Tensile Tests

| Brand of alloy and assortment | Elastic modulus E in m/cm$^2$ | | | Specific elongation $\epsilon$ in % | | | Reduction of area $\epsilon$ in % | | |
|---|---|---|---|---|---|---|---|---|---|
| | Limits | Arithmetical mean profile | Arithmetical mean alloy | Limits | Arithmetical mean for profile | Arithmetical mean for alloy | Limits | Arithmetical mean for profile | Arithmetical mean for alloy |
| **Alloy D1-T** | | | | | | | | | |
| I-beam 150×15+2×100×14 . . . . | 700—775 | 737 | 737 | 6,7—14,2 | 11,31 | 11,31 | 10,5—20 | 15,2 | 15,2 |
| **Alloy D16-T** | | | | | | | | | |
| I-beam 150×15+2×100×14 . . . | 687—780 | 744 | | 5—13,7 | 9,5 | | 8,5—20 | 13,3 | |
| T-beam 100×16+100×12 . . . . . . . | 712—812 | 764 | | 6,58—15,42 | 11,6 | | 7,5—19 | 11,2 | |
| Angle 203+75×20 . . . . . . | 762—800 | 778 | 770 | 5,71—14,4 | 11,6 | | 6—14,5 | 11,3 | 13 |
| " . 106+70×16 . . . . . . . . . | 750—800 | 782 | | 7,45—13,76 | 11,2 | | 13—17,5 | 15,4 | |
| " . 90+90×10 . . . . . . . . . . | 712—812 | 766 | | 7,9—13,7 | 12 | 11 | 11—16 | 13,8 | |
| **Alloy AMg-61** | | | | | | | | | |
| Strip 120×12 . . . . . . . . . . | 725—775 | 750 | 767 | 9,1—12,4 | 11 | | 11—19 | 14,6 | 16,3 |
| Channel 140×6+2×58×12 . . . . | 755—810 | 783 | | 8,4—18,8 | 11 | | 13—23,5 | 18,1 | |

22 kg/mm$^2$, i.e., higher than its minimum value shown in technical specs VTU 1524-56.

Minimum probable value of yield point for this alloy was found equal to 24.06 kg/mm$^2$, i.e., somewhat larger than normative resistance (22 kg/mm$^2$).

It is obvious that these experimental data are clearly insufficient for determination of coefficient of homogeneity of alloy AMg61, even in the very first approximation.

Values found by results of tensile of elastic modulus, specific elongation, reduction of area for considered alloys are given in Table 4.

From table it follows that values of elastic modulus change within comparatively narrow limits. Thus, for instance, for alloy D1-T difference between its least and greatest value constitutes nearly 11%, for alloy D16-T-15%, for alloy AMg61-11%.

Results of statistical treatment of experimental values of elastic modulus and specific elongation are given in Table 5.

Table 5. Results of Statistical Treatment of Experimental Values of Elastic Modulus and Specific Elongation

| (a) Характеристика | (b) E в т/см² для сплавов | | | (f) δ в % для сплавов | | |
|---|---|---|---|---|---|---|
| | (g) Д1-Т | (g) Д16-Т | (h) АМг61 | (g) Д1-Т | (g) Д16-Т | (h) АМг61 |
| (c) Среднее статистическое значение . | 737 | 770 | 767 | 11,3 | 10,8 | 10,7 |
| (d) Среднее квадратичное отклонение | 16,75 | 25,61 | 22,9 | 2,07 | 2,18 | 1,44 |
| (e) Минимальное вероятное значение . | 686,75 | 693,17 | 698,3 | 5,09 | 4,26 | 6,38 |

Key: (a) Characteristic; (b) E in m/cm$^2$ for alloys; (c) average statistical value; (d) Root-mean-square deviation; (e) Minimum probable value; (f) in % for alloys; (g) D1-T, D16-T; (h) AMg61.

In Fig. 3 there are presented typical fractures of samples having different thickness of all tested alloys.

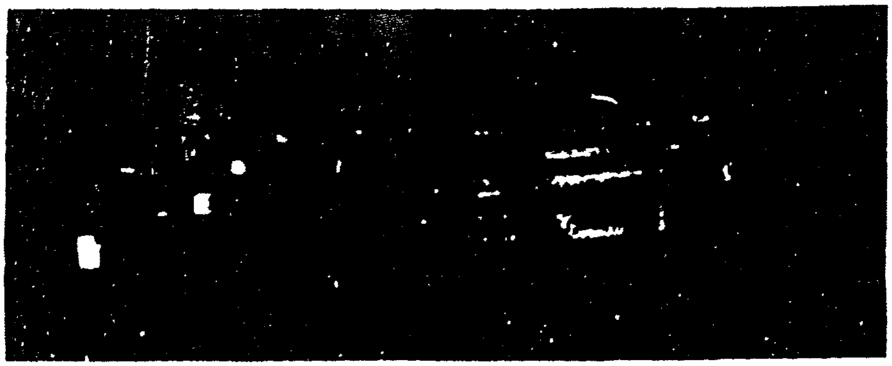

Fig. 3. Fractures of samples during tensile tests.

In all cases failure occurred in working part. Yield plane constituted nearly 45° to longitudinal axis of sample.

## 3. Results of Compression Tests

Tests were designed to establish possible peculiarities of work of aluminum alloys under compression, as compared to work under tension.

Primary diagrams of compression were constructed on coordinates -- $\epsilon_c$ .
Magnitude of $\epsilon_c$ was arithmetical mean, according to readings of two tensometers.

Mechanical properties under compression were determined by analogy with those for tension (Fig. 4).

Values found from results of compression tests of limit of proportionality, yield point, and elastic modulus are given in Table 6.

Considering these data, following judgement about character of their changeability can be made.

Limits of variation of values of mechanical properties for all tested alloys differ among themselves rather considerably, approximately in the same amounts as in case of tension. Thus, for instance, for alloy D1-T difference between least and the greatest values of yield point for all tested profiles constitutes 38%, for alloy D16-T -- 42%, for alloy AMg61 -- 22%. Approximately within the same significant amounts the values of limit of proportionality vary also (for alloy D1-T difference between its extreme values for all profiles constitutes 40%, for alloy D16-T-52%, for alloy AMg61-19%).

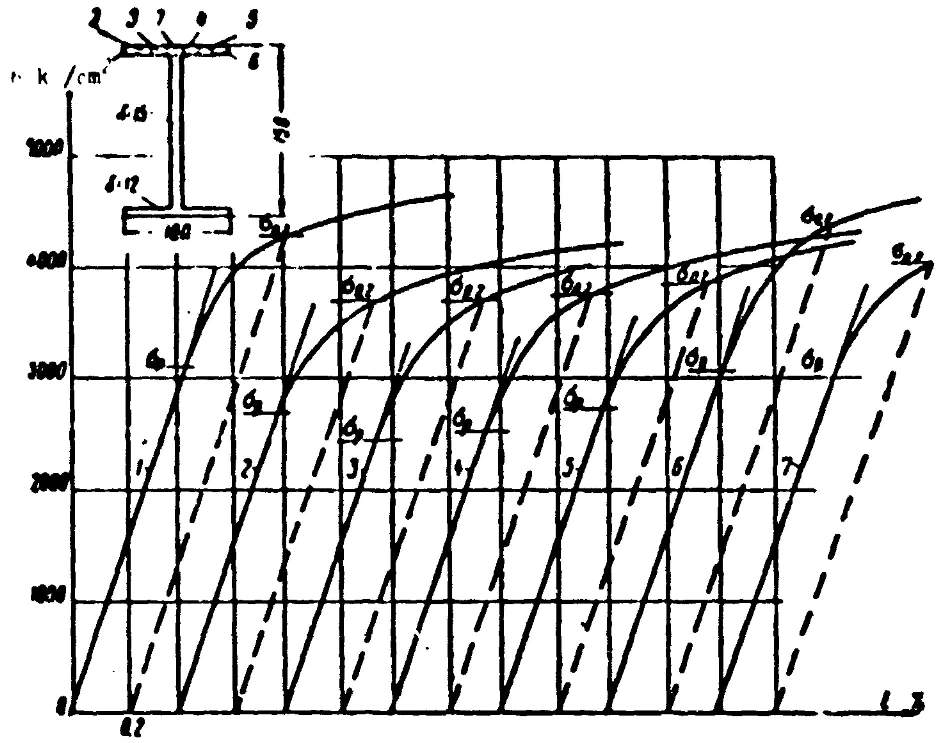

Fig. 4. Primary diagrams of compression of crushers from alloy D16-T.

Comparing data given in Table 6 for alloy D16-A(g/k), obtained on samples with and across rolling, we note almost total absence of any essential difference between them.

Comparison made of values of mechanical properties for different sections of one and the same profile showed that these properties are practically identical through length of profile.

On I-beam profile limit of proportionality and yield point for cruchers prepared from flanges of profile are noticeably larger than values corresponding to them for crushers made from walls. This difference for alloy D1-T reaches 15%, for alloy D16-T-18%. The greatest values of limit of proportionality and yield point are for those of crushers, billets for manufacture of which were disposed at edges of flanges and in places of juncture of flanges with wall.

Table 6. Values of Mechanical Characteristics from Results of Compression Tests

| Brand of alloy and assortment | Limit of proportionality $\sigma_p$ in kg/cm$^2$ | Yield point $\sigma_{0.2}$ in kg/cm$^2$ | $\frac{\sigma_p}{\sigma_{0.2}}$ | Aritmetical mean limit of proportionality $\sigma_p$ | Aritmetical mean limit of field $\sigma_{0.2}$ | Arithmetical mean ratio $\frac{\sigma_p}{\sigma_{0.2}}$ | Arithmetical mean modulus E in m/cm$^2$ | Quanity of crushers |
|---|---|---|---|---|---|---|---|---|
| Alloy D1-T | | | | | | | | |
| I-beam 90x10+2x90x15 | 2140–2560 | 3180–3680 | 0.67–0.7 | 2460 | 3455 | 0.71 | 780 | 20 |
| Angle 90+90x10 . . . . | 2020–2540 | 3040–3600 | 0.66–0.7 | 2360 | 3210 | 0.73 | 735 | 18 |
| " 75+75x10 . . . . | 2200–2640 | 3200–3100 | 0.69–0.71 | 2420 | 3350 | 0.72 | 776 | 11 |
| Channel 100x5+2x50x5 . | 1260–1510 | 2140–2520 | 0.59–0.6 | 1390 | 2330 | 0.6 | 758 | 24 |
| I-beam 150x15+2x100x12 | 1750–2570 | 2820–3700 | 0.62–0.69 | 2100 | 3200 | 0.66 | 762 | 84 |
| Alloy D16-T | | | | | | | | |
| I-beam 150x15+2x100x12 | 2130–3320 | 3230–4380 | 0.66–0.76 | 2530 | 3650 | 0.7 | 761 | 105 |
| T-beam 100x16+100x12 . | 2510–3690 | 3530–4380 | 0.71–0.84 | 3000 | 3800 | 0.79 | 785 | 36 |
| Angle 203+75x20. . . . | 1770–2820 | 2540–3690 | 0.7–0.76 | 2150 | 3000 | 0.72 | 769 | 23 |
| " 106+70x16. . . . | 2380–2760 | 3400–3920 | 0.7–0.71 | 2600 | 3650 | 0.71 | 773 | 18 |
| " 90+90x10 . . . . | 2360–2910 | 3220–3950 | 0.73–0.74 | 2600 | 3540 | 0.74 | 778 | 22 |
| AMg-61 | | | | | | | | |
| Strip 120x12. . . . . | 1230–1310 | 1950–2120 | 0.57–0.62 | 1240 | 2040 | 0.63 | 725 | 12 |
| Channel 140x6+2x58x12 | 1260–1510 | 2140–2510 | 0.59–0.61 | 1400 | 2330 | 0.6 | 753 | 24 |
| Alloy D16-A(g/k) | | | | | | | | |
| Sheet δ=10 mm with rolling. . . . . . . . | 1150–1230 | 1480–1500 | 0.77–0.82 | 1210 | 1500 | 0.81 | 717 | 6 |
| The same across rolling | 1160–1220 | 1520–1560 | 0.76–0.78 | 1190 | 1540 | 0.77 | 758 | 6 |
| Sheet δ=16 mm with rolling. . . . . . . . | 840–1220 | 1330–1460 | 0.63–0.83 | 960 | 1370 | 0.7 | 772 | 8 |
| The same across rolling | 720–920 | 1270–1330 | 0.57–0.69 | 840 | 1300 | 0.65 | 797 | 6 |
| Sheet δ=20 mm with rolling. . . . . . . . | 1020–1300 | 1460–1560 | 0.7–0.84 | 1210 | 1490 | 0.81 | 783 | 6 |
| The same across rolling | 1060–1290 | 1470–1520 | 0.72–0.85 | 1170 | 1490 | 0.79 | 797 | 6 |
| Sheet δ=30 mm with rolling. . . . . . . . | 970–1040 | 1380–1420 | 0.7–0.74 | 1020 | 1390 | 0.73 | 740 | 8 |
| The same across rolling | 1020–1070 | 1390–1440 | 0.73–0.74 | 1030 | 1420 | 0.73 | 760 | 6 |

Considering values given in Table 6 of ratio $\frac{\sigma_p}{\sigma_{0.2}}$, we note that these data (with slight exception) are changed within comparatively moderate limits, especially in the same profile. Difference between the greatest and least values of this ratio for alloy D1-T for all tested profiles constitutes 12%, for alloy D16-T-21%, for alloy AMg61-8%.

Arithmetical mean values of elastic modulus (Table 6) for all tested alloys and profiles are changed within comparatively narrow limits: from 717 to 797 t/cm$^2$.

All experimental values of yield point, just as during tension, are significantly higher than magnitude 23 kg/mm$^2$, taken as normative resistance for alloy D1-T.

In Table 7 there are given values of compressive yield point of this alloy, obtained as a result of statistical treatment of experimental data.

Table 7. Values of Compressive Yield Point (*in kg/mm$^2$)

| (a) Характеристика | (b) Марка сплава | | |
|---|---|---|---|
| | D1-T | D16-T | AMg61 |
| (c) Среднее статистическое значение . | 32,4 | 35,6 | 21,7 |
| (d) Среднее квадратичное отклонение . | 2,28 | 3,61 | 1,87 |
| (e) Минимальное вероятное значение | 26,2 | 24,77 | 16,09 |

KEY: (a) Characteristic; (b) Brand of alloy; (c) Average statistical value; (d) Root-mean-square deviation; (e) Minimum probable value.

From Table 7 it follows that minimum probable value of compressive yield point of alloy D16-T is equal to 24.77 kg/mm$^2$, i.e., less than magnitude 26.68 kg/mm$^2$ — its value during tension (Table 3).

Attempt in this case to determine coefficient of homogeneity, as ratio $\frac{24.77}{31} = 0.8$, already gives magnitude which is considerably less than its value 0.85, accepted in technical specs (without calculation of minus allowances for

for rolling).

Minimum probable value of compressive yield point of alloy AMg61 is found equal to 16.09 kg/mm$^2$ (Table 7).

Attempt in this case to determine coefficient of homogeneity gives us a value equal to $\frac{16.09}{19} = 0.85$ (also without calculation of minus allowances for rolling).

### 4. Comparison of Results of Tensile and Compression Tests

For the purpose of clarity of comparison of properties of alloys obtained during tensile and compression tests, in Fig. 5 there are presented (for samples and crushers from I-beam profile of alloy D1-T) primary diagrams of tension and compression in superposition, and also diagram of cutting of profile through length and cross section.

In cut of profiles, to each sample for tension there corresponded three samples for compression. Therefore, to each diagram of tension there correspond three diagrams of compression.

Comparing these diagrams, one should first of all note considerable difference in nature of their contour. If diagrams of tension have comparatively small transition curves from limit of proportionality to yield point, then on diagrams of compression these curves are very well-developed.

As a rule, yield point and especially limit of proportionality during compression are significantly less than during tension.

For alloy D1-T average statistical values of limit of proportionality during compression and tension are equal respectively to 25.52 and 29.7 kg/mm$^2$, and their ratio is equal to $\frac{25.52}{29.7} = 0.86$. Average statistical values of yield point for compression and tension are equal respectively to 32.6 and 35.08 kg/mm$^2$, and their ratio is equal to $\frac{32.6}{35.08} = 0.93$.

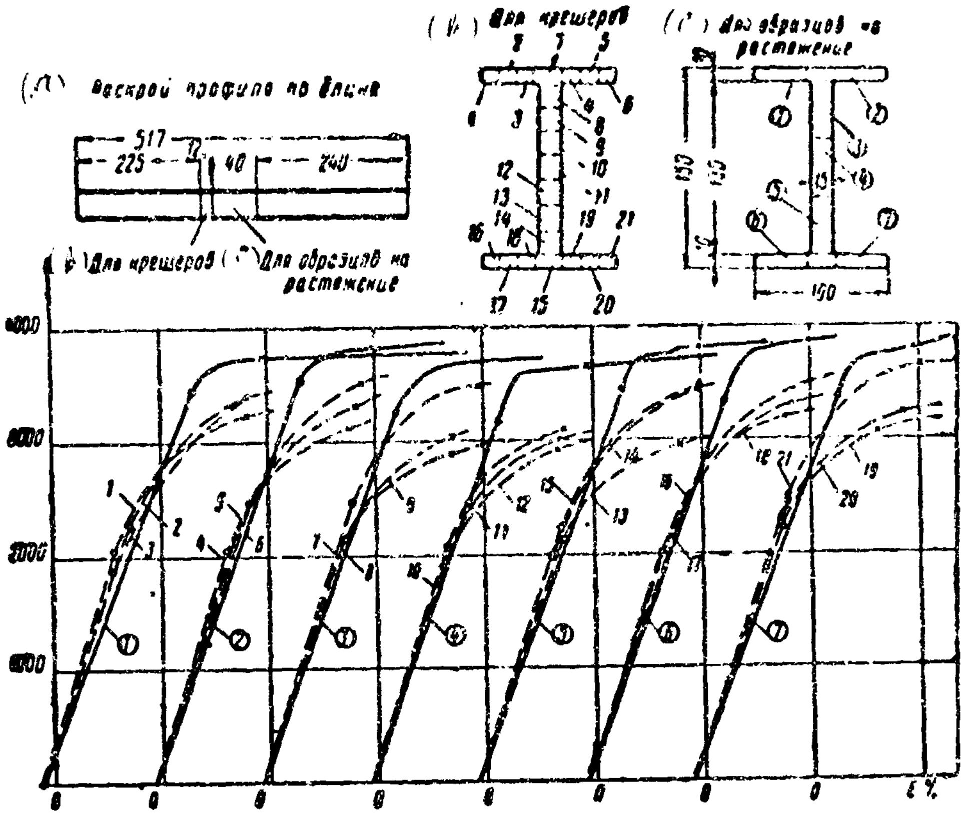

Fig. 5. Comparison of primary diagrams of compression and tension for alloy D1-T.

Special Designation

——— tension; --------- compression; O —— limit of proportionality; x—— yield point

KEY: (a) Cut of profile through length; (b) For crushers; (c) For tensile samples.

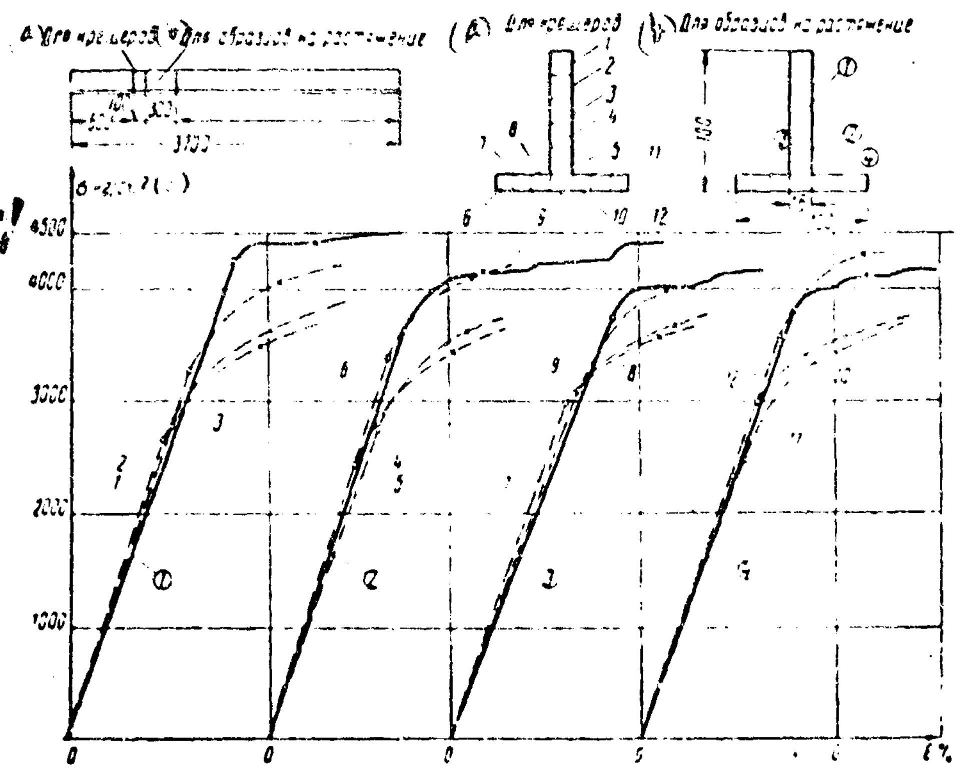

Fig. 6. Comparison of primary diagrams of compression and tension for alloy D16-T

Special designations: see Fig. 5

Key: (a) For crushers; (b) For tensile samples; (c) kg/cm$^2$.

As we see, difference is quite substantial, especially for limits of proportionality.

Comparing average statistical values of elastic modulus for compression and tension, respectively equal for allov D1-T to 762 and 737 t/cm$^2$, we find their ratio is equal to $\frac{762}{737}$ = 1.03, i.e., elastic moduli for compression and tension are practically identical.

In Fig. 6 there are presented (for samples and crushers from tee profile of alloy D16-T) primary diagrams of tension and compression in superposition. Comparing th⋅⋅e diagrams, we note the same essential difference in character of their outline as in preceding case.

For given alloy average statistical values of limit of proportionality for compression and tension respectively are equal to 25.52 and 33.79 kg/mm$^2$, and their ratio is equal to $\frac{25.52}{33.79}$ = 0.76.

Average statistical values of yield point for compression and tension respectively are equal to 35.6 and 39.76 kg/mm$^2$, and their ratio is equal to $\frac{35.6}{39.76}$ = 0.89.

As we see, in this case difference, especially for limits of proportionality, is also quite considerable.

Average statistical values of elestic modulus for alloy D16-T for compression and tension give us ratio $\frac{773}{770}$ = 1.

Comparison of primary diagrams of compression and tension for identical samples of alloy AMg61 leads to analogous results.

For this alloy average statistical values of limit of proportionality for compression and tension respectively are equal to 13.4 and 22.13 kg/mm$^2$, and their ratio is equal to $\frac{13.4}{22.13}$ = 0.61.

Average statistical values of yield point for compression and tension for given alloy respectively are equal to 21.7 and 27.6 kg/mm$^2$, and their ratio is equal to $\frac{21.7}{27.6} = 0.79$.

Elastic moduli for compression and tension of alloy AMg61, as those of alloys D1-T and D16-T, are practically identical.

Alloy D16-A(g/k) differs in properties from remaining alloys. Comparison of primary diagrams of compression and tension of this alloy shows that they are not essentially different.

Identity of results of tests for tension and compression of alloy D16-A(g/k) indicates also the fact that above-stated considerable difference of mechanical properties of alloys D1-T, D16-T, and AMg61 for compression and tension is not result of influence of form of test samples (for tension - flat sample, and for compression - crusher) or their scale factor (flat sample was incommensurably larger than crusher).

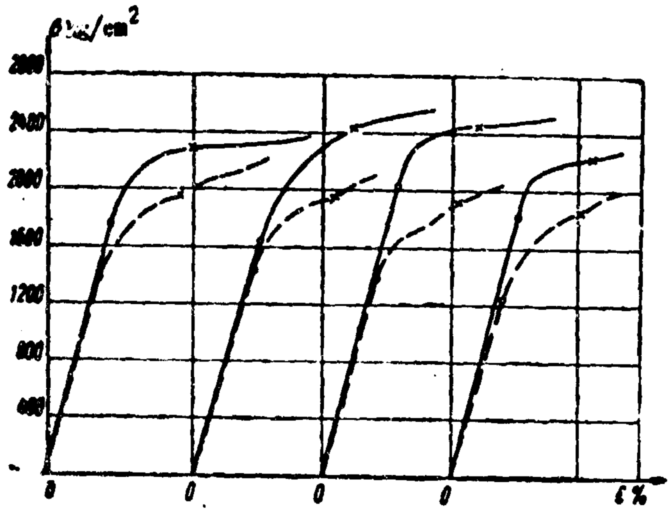

Fig. 7. Comparison of primary diagrams of compression and tension for alloy AMg61.

Special designations: see Fig. 5.

Nonetheless, for the purpose of additional check of method used in this work of compression tests there were specially conducted following experiments, having only procedural value.

From billet of each alloy initially there was turned round rod with diameter of 1 cm, and then part of it was cut into crusher, and others went to sample for tension. Thus, these test samples differed only by length, which for crusher was 2-3 times less than for tension sample.

For the purpose of close identity of conditions of test crusher and sample were tested on the same universal 4-ton to machine with use of the same tensometers for measurement of strains.

Such tests were conducted for alloys D1-T (I-beam), D16-T (I-beam), and AMg61 (channel) with the following results.

For clarity in Fig. 7 there are presented obtained primary diagrams of tension and compression for alloy AMg61, as before in super position. Comparing these diagrams, we arrive at results presented earlier.

In this case arithmetical mean values of ratios of limits of proportionality and yield points for compression and tension for alloy AMg61 were found respectively equal to 0.76 and 0.75.

Analogous results, agreeing with those presented earlier, were obtained and for alloys D1-T and D16-T.

In order of development of such procedural tests there were also conducted following experiments.

An I-beam was taken, 90x10+2x90x15, from alloy D1-T and subjected to compression tests - in one case as whole profile with flexibility on order of 15 (all four samples), and in other - in the form of crushers. In first case of compressive strains of whole profile were measured with special strain gauge on 15 cm base on four fiber boards (two on wall, and two on opposite flanges of I-beam).

Relative compressive strain of profile was found as arithmetical mean magnitude from four readings of strain gauge.

Method of tests of crushers was same as before.

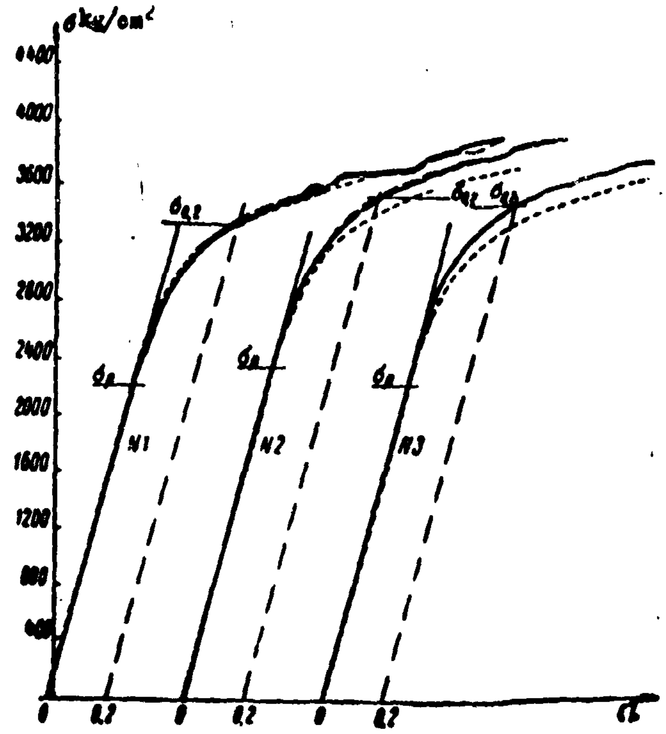

Fig. 8. Comparison of primary diagrams of compression of whole profile and crushers.

Special designations;

——————— instruments are fixed on wall of profile;

- - - - - - - - - instruments are fixed on flanges of profile;

. . . . . . . . . average of five crushers from flanges.

Primary diagrams of compression obtained as result of such tests (in one case of whole profile, but in other - of crushers) are presented in Fig. 8 in superposition.

Comparing these diagrams, it may be concluded that they are very similar to one another.

## 5. General Conclusions

On the basis of obtained results of study of physico-mechanical properties for tension and compression of aluminum alloys we can make following general conclusions.

1. Aluminum alloys of brands D1-T, D16-T, and AMg61, when working under tension and compression, both in elastic and in elastic-plastic stages possess

sufficiently high mechanical properties, from the point of view of requirements demanded of metal of load-bearing structures, including span structures of bridges.

2. Ration of average statistical values of limit of proportionality of yield point for alloys D1-T, D16-T, and AMg61 for tension are respectively equal to 0.82, 0.86, and 0.78.

3. Ratio of average statistical values of yield point to ultimate strength for tension for alloys D1-T, D16-T, and AMg61 are respectively equal to 0.79, 0.77, and 0.73.

4. Average statistical value of specific elongation for alloys D1-T, D16-T, and AMg61, respectively equal to 11.31, 10.8, and 10.7, are somewhat less than magnitudes standardised by effective All-Union Government Standards (respectively 12.1 and 12), with the exception of alloy D16-T.

5. Average statistical values of elastic modulus for tension for alloys D1-T, D16-T, and AMg61, respectively equal to 737, 770, and 767, are close to those values standardised by corresponding TU's [Tech. Specs].

6. Primary diagrams of compression differ considerably, according to the nature of their contour, from corresponding diagrams of tension. If diagrams of tension have comparatively small transition curves from limit of proportionality to yield point, then these curves for compression are very well-developed.

7. Yield point and especially limit of proportionality for compression of alloys D1-T, D16-T, and AMg61 are significantly lower than for tension.

Ratio of average statistical values of limit of proportionality for compression and tension for given alloys is respectively equal to 0.86, 0.76, and 0.61.

Ratio of average statistical values of yield point for compression and tension for these alloys is respectively equal to 0.93, 0.89, and 0.79.

8. Coefficient of homogeneity, determined as ratio of minimum probable

value of yield point to normative resistance, is found for alloy D16-T equal to 0.86, without calculation of minus allowances for rolling, which indicates necessity of carrying out further investigations.

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INVESTIGATION OF MECHANICAL PROPERTIES OF CERTAIN ALUMINUM ALLOYS UNDER TENSION AND COMPRESSION

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## 1. Aims and Method of Investigation

Aim of these investigations was to clarify possible peculiarities of work of aluminum alloys D16-T and AMg6 under tension and compression on the basis of obtaining diagrams of work of material, determination of certain mechanical characteristics of it, and comparison of obtained data.

The mechanical characteristics subjected to determination included conditional yield points $\sigma_{0.2}$, limits of proportionality $\sigma_p$, and moduli of longitudinal elasticity E for tension and compression, and also ultimate strength $\sigma_b$ and specific elongations $\epsilon$ for tension. Here compression is designated by superscript "c" and tension by "p."

As material for investigations there were taken sheets with thickness of 6 mm from aluminum alloys of brands D16-T and AMg6.

All samples intended for tests for both tension and compression were cut, as far as possible, from the same places from sheets with direction of rolling.

Mechanical properties of sheets under tension were determined on standard flat samples, prepared according to All-Union Government Standard 1497-42, and they were tested by usual method, which did not present great difficulties.

However, determination of the same properties of sheets under compression presented certain difficulty, since during test it was necessary to somehow prevent lateral buckling of thin sample, which required development of special attachment for tests.

As a result of consideration of different methods of solution of analogous problems offered by a number of authors,* for solution of problem on hand there was designed special attachment, general view of which, together with test sample and instruments attached to it, is shown in Fig. 1,a, and schematic drawing-in Fig. 1,b. As can be seen from Fig. 1,b, test sample 7 is disposed between steel elements 1 and 2, fastened together by two clamps consisting of transverse strips 3 and 4 and thin screws 5. Degree of clamping of steel elements 1 and 2 to test sample 7 was regulated with help of two thumb screws 6, screwed into transverse strips of clamps 3.

Before testing of sample guide elements of attachment with help of these screws were clamped to sample in such a way that between sample and guides there remained no opening, but at the same time so that it was possible freely, without special effort, to move guides along sample. With help of these screws in process of entire tests of sample there was attained a position of guide elements, which, at first, did not allow test samples to bend and, secondly, did not prevent their expansion in transverse direction, when sample was subjected compression.

In these tests there were used samples of two types, with dimensions 6x12x55 mm and 6x20x68 mm and there were used two different attachemnts. Attachment for test of samples of second type differed in that on its guides 1 and 2 along longitudinal axis there was a groove, allowing us to glue on both sides of test sample electrical detectors for the purpose of control of stable state of sample

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*Structural Engineer, vol. XXXV, No. 5, May 1957, p. 176-189.

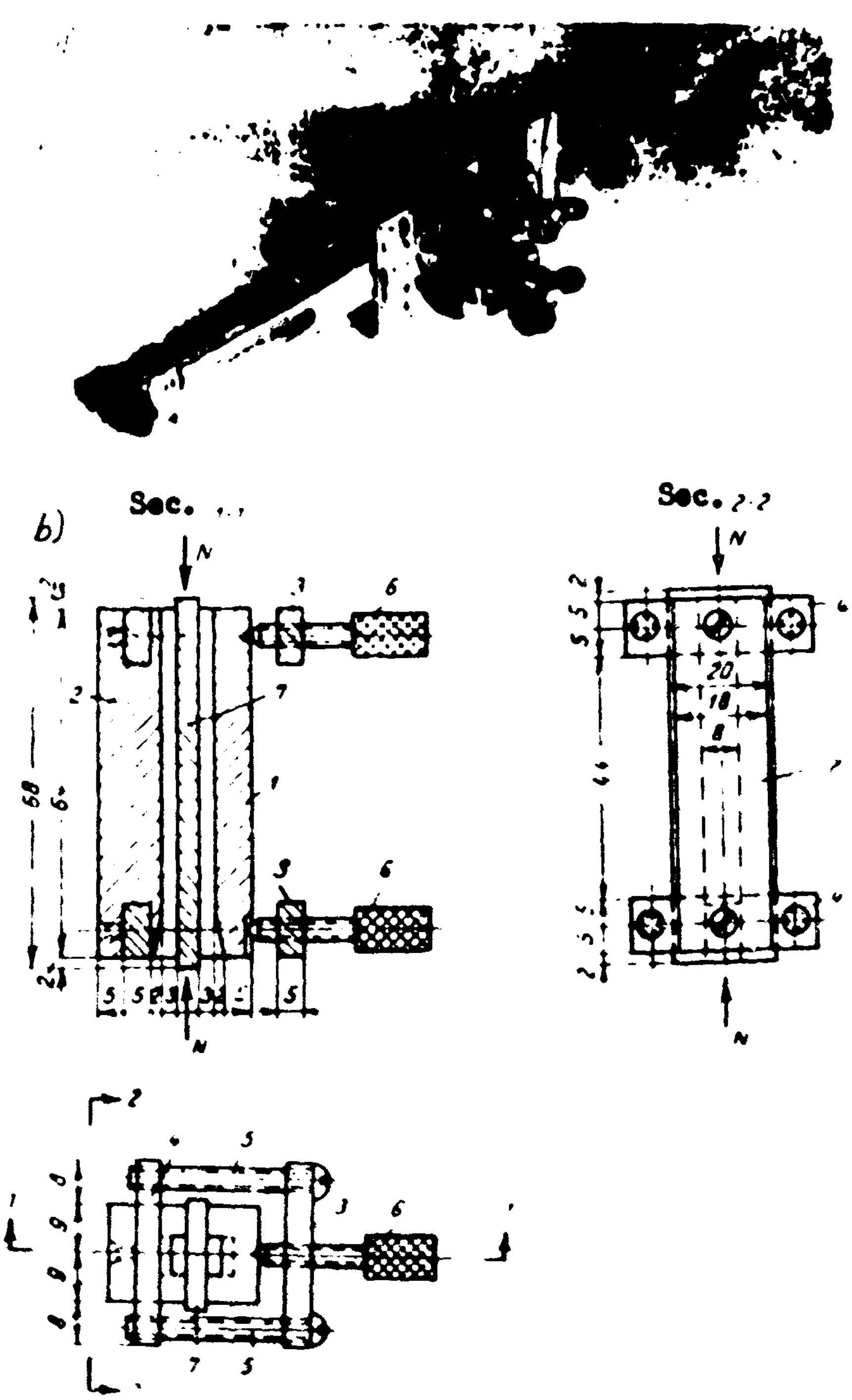


**Fig. 1. Attachment for test of samples from thin sheets for compression.**

a—general view; b—diagram; 1 and 2 — guide elements; 3 and 4 — clamp stripes; 5 — screws; 6 — clamp screws; 7 — test sample.

during test.

For more convenient fastening of tensometers on edges of test samples the latter were made 2 mm wider than guide elements.

During tests, two mechanical tensometers were used with base of 20 mm.

For the purpose of reduction of frictional forces to minimum, appearing between sample and guides, sliding surfaces of the latter were preliminarily lubricated with liquid graphite grease. For judgement about magnitude of these forces we determined magnitude of effort necessary for shift of these guides along sample at different stages of loading.

Thusly conducted preliminary tests showed that frictional forces appearing during test of sample, of which we spoke above, constituted not more than 1% of magnitude of load applied to sample.

All tests of samples (both for tension and compression) were conducted on the same testing machine, a 10-ton "Shopper" press.

## 2. Results of Tests

As a reult of tests of 70 samples for tension and compression from alloys D16-T and AMg6, we obtained primary diagrams of work of these materials, for which after appropriate treatment we found average curves of tension and compressions, shown in Fig. 2,a, b.

Fig. 2, a, shows diagrams of tension and compression for sheets from alloy D16-T, where both graphs for clarity are shown in combined form. From this figure it is clear that curves of tension and compression do not coincide, which is especially noticeable on section of nonelastic deformations. However, noncoincidence of curves of tension and compression is also observed on elastic section, where compression curve is slightly curved, which tension curve here is almost rectilinear. As compared to tension curve, transition in region of nonelastic deformations for compression curve has smoother character, and this curve is disposed on section of diagram above $\sigma_{0.2}$, at somewhat larger angle of inclination to axis of abscissas than tension curve.

For sheets from alloy AMg6 average curves of tension and compression, although they had certain differences, expressed mainly in non-coincidence of both curves in region of nonelastic deformations and in somewhat larger angle of slope of a curve of compression higher than conditional yield point, nevertheless this non-coincidence was so insignificant that upon superimposing them the diagrams almost merged (Fig. 2,b).

Mechanical characteristics of samples from alloys D16-T and AMg6 obtained from primary diagrams of work of material under tension and compression are given in Table 1, from which it is clear that these characteristics for both alloys have certain variations. For alloy D16-T limits of variations $\sigma_p^p$ constitute 30.2 to 31.3 kg/mm$^2$; $\sigma_{0.2}^p$ = 34.9 to 35.2 kg/mm$^2$; $\sigma_b$ = 48.4 to 49 kg/mm$^2$; $E^p$ = 7,200 to 7,500 kg/mm$^2$ and $\varepsilon$ = 15 to 17.5%.

During compression, mechanical properties of this alloy vary within limits: $\sigma_p^c$ = 27.2 to 29 kg/mm$^2$; $\sigma_{0.2}$ = 33.1 to 33.8 kg/mm$^2$, and $E^c$ = 7,200 to 7,600 kg/mm$^2$.

For alloy AMg6 values of $\sigma_p^p$ vary within limits 15.2 to 17 kg/mm$^2$; $\sigma_{0.2}^p$ = 16.7 to 19.3 kg/mm$^2$; $\sigma_b$ = 35.8 to 39.3 kg/mm$^2$; $E^p$ = 7,100 to 7,400 kg/mm$^2$, and $\varepsilon$ = 19.1 to 23.4%.

During compression, limits of variations of $\sigma_p^c$, $\sigma_{0.2}^c$ and $E^c$ constitute respective values: 15.3 to 16.7 kg/mm$^2$, 17.5 to 18.6 kg/mm$^2$, and 6,950 to 7,350 kg/mm$^2$.

Obtained data show that mechanical characteristics of sheets from both alloys during tension and compression vary within very narrow limits and are rather stable.

Ratio $\frac{\sigma_p}{\sigma_{0.2}}$ and $\frac{\sigma_{0.2}}{\sigma_b}$ for alloy D16-T during tension are changed respectively within limits 0.87–0.89 and 0.72–0.73, and limits of variations $\frac{\sigma_p}{\sigma_{0.2}}$ during compression constitute 0.82–0.86, i.e., this ratio is approximately equal to analogous during tension.

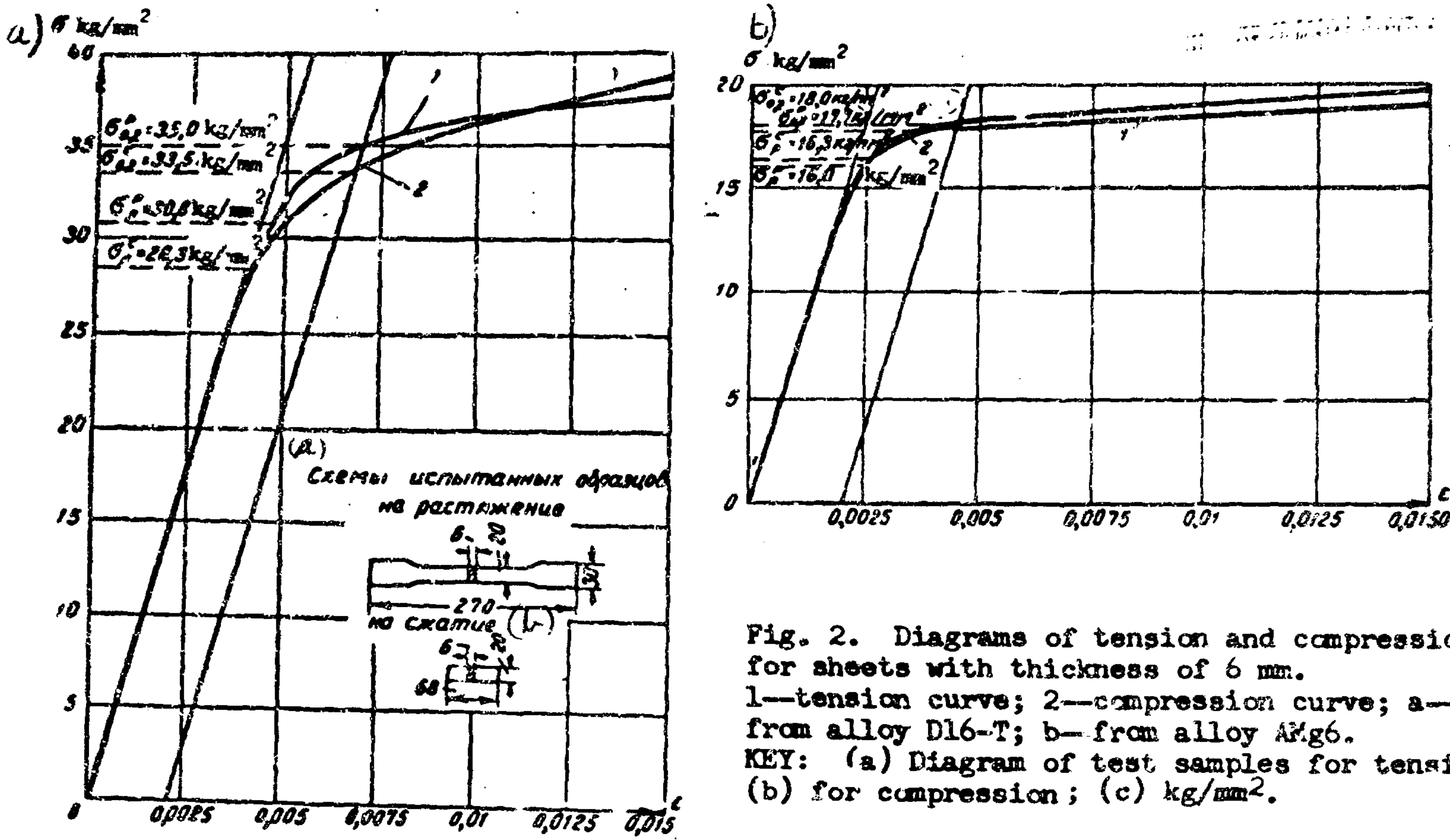


Fig. 2. Diagrams of tension and compression for sheets with thickness of 6 mm.
1—tension curve; 2—compression curve; a—from alloy D16-T; b—from alloy AMg6.
KEY: (a) Diagram of test samples for tension; (b) for compression; (c) kg/mm².

Table 1. Mechanical Properties of Material with Thickness of 6 mm from Aluminum Alloys D16-T and AMg6

| (a) № образцов | $\sigma_p$ | | $\sigma_{0,2}$ | | $\sigma_b$ | $E$ | | $\delta_{10}$ в % (g) |
|---|---|---|---|---|---|---|---|---|
| | в кг/мм² | | | | | | | |
| | (b) растяжение | (c) сжатие | (b) растяжение | (c) сжатие | (b) растяжение | (b) растяжение | (c) сжатие | (b) растяжение |
| (d) Сплав Д16-Т | | | | | | | | |
| 1 | 30,2 | 29 | 34,9 | 33,7 | 48,5 | 7 400 | 7 300 | 16,6 |
| 2 | 30,6 | 27,2 | 35 | 33,2 | 49 | 7 350 | 7 500 | 15 |
| 3 | 30,7 | 28,6 | 35 | 33,8 | 48,4 | 7 250 | 7 600 | 15 |
| 4 | 30,8 | 28 | 35 | 33,4 | 48,6 | 7 100 | 7 600 | 17,3 |
| 5 | 30,9 | 28,5 | 35 | 33,1 | 48,9 | 7 300 | 7 300 | 16,7 |
| 6 | 30,9 | 28,7 | 35 | 33,6 | 48,8 | 7 500 | 7 500 | 16,2 |
| 7 | 31,3 | 28,3 | 35,2 | 33,6 | 48,8 | 7 200 | 7 200 | 16,2 |
| (e) Средние значения | 30,8 | 28,3 | 35 | 33,5 | 48,7 | 7 300 | 7 430 | 16,2 |
| (f) Сплав АМг6 | | | | | | | | |
| 1 | 17 | 16,6 | 19,3 | 17,9 | 39,3 | 7 200 | 7 000 | 23,4 |
| 2 | 16,8 | 16,5 | 18,6 | 17,8 | 41,4 | 7 200 | 7 200 | 20,8 |
| 3 | 16,4 | 16,7 | 17,6 | 18,4 | 36,8 | 7 250 | 7 250 | 23,3 |
| 4 | 15,5 | 16,6 | 17,1 | 18,6 | 36,4 | 7 150 | 7 000 | 23,4 |
| 5 | 15,4 | 16,4 | 16,7 | 18 | 35,8 | 7 000 | 7 350 | 19,1 |
| 6 | 15,2 | 15,8 | 17,1 | 17,8 | 36,3 | 7 100 | 7 100 | 20,8 |
| 7 | 15,4 | 15,3 | 17,5 | 17,5 | 37,4 | 7 400 | 6 950 | 22,5 |
| (e) Средние значения | 16 | 16,3 | 17,7 | 18 | 37,6 | 7 200 | 7 140 | 21,9 |

Note: Magnitudes of $\sigma_p$ were determined according to All-Union Government Standard 1497-42.
KEY: (a) No. of samples; (b) Tension; (c) Compression; (d) Alloy D16-T; (e) Mean values; (f) Alloy AMg6; (g) in %.

For alloy AMg6 ratios $\frac{\sigma_p}{\sigma_{0,2}}$ and $\frac{\sigma_{0,2}}{\sigma_b}$ during tension are changed respectively within limits 0.88-0.89 and 0.47 -0.49, and limits of change $\frac{\sigma_p}{\sigma_{0,2}}$ during compression constitute 0.87-0.91, i.e., just as for alloy D16-T, this ratio is approximately equal to analogous ratio during tension.

Comparison of mechanical characteristics of one and the same material during tension and compression shows that ratios $\frac{\sigma_p^c}{\sigma_p^p}$, $\frac{\sigma_{0,2}^c}{\sigma_{0,2}^p}$, and $\frac{E^c}{E^p}$ on the average constitute 0.94, 0.96, and 1.02 for sheets from all~y D16-T, and 1.02, 1.01, and 0.99 for alloy AMg6.

From ratios it is clear that values of $\sigma_p$ and $\sigma_{0,2}$ during compression turn out to be somewhat smaller than during tension for alloy D16-T, and they are approximately equal for alloy AMg6. Values of moduli of longitudinal elasticity during tension and compression for alloy D16-T, just as for alloy AMg6 are approximately equal.

## 3. Conclusions

Conducted investigations of mechanical properties of sheets from aluminum alloys D16-T and AMg6 allow us to note the following.

1. Comparison of diagrams of work of material of sheets from alloy D16-T during tension and compression shows that these diagrams differ in character somewhat among themselves, and that this distinction is most noticeable on section above limit of proportionality, where transition of compression curve in region of nonelastic deformations is smoother than for tension curve. Curves of tension and compression have analogous character for sheets from alloy AMg6, with the difference that distinction between them is very small.

2. Values of limits of proportionality and fluidity during compression turn out to be somewhat smaller than during tension for alloy D16-T and approximately equal for alloy AMg6. Values of moduli of longitudinal elasticity during tension and compression for alloys D16-T and AMg6 are approximately equal.

3. With accurate solution of problems of stability of various elements of structures from such alloys, such as D16-T, for instance, differ from each other, for obtaining of more correct result one should use diagrams of compression of applied material, but not those of tension.

4. For obtaining of clearer picture of changeability of mechanical properties of applied alloys in respect to influence of different factors, investigation of questions posed must be continued.

# CORROSION RESISTANCE OF ALUMINUM ALLOYS IN BUILDING STRUCTURES

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Increase of longevity of buildings and structures and, in particular their corrision resistance is one of basic problems of contemporary construction.

Application of aluminum alloys in construction, together with reduction of weight of structures, opens up broad possibilities of increase of their corrosion resistance and longevity.

It is necessary to consider that corrosion resistance of aluminum alloys, as of metals in general, is not their absolute property, but depends on a whole series of factors.

Among them, in the first place, one should mention chemical composition and heat treatment of alloys, their state of strain, character and composition of corrosive medium, contacts with other materials, etc.

Study of these questions involves a number of problems, upon solution of which effectiveness of use of aluminum in construction depends.

In this article there are given available data on corrosion of aluminum alloys in building structures and also results of corrosion tests conducted at Yush NII on aluminum alloys under conditions of service of building structures of metallurgical factories and in the atmosphere of the industrial city.

## 1. Data on Corrosion of Aluminum Alloys in Building Structures

Aluminum is one of those metals possessing high chemical activity. It enters easily into reaction with oxygen, forming aluminum oxide $Al_2O_3$. But namely, thanks to its heightened oxidizability, aluminum obtains high corrosion resistance in the whole series of corrosive media.

Oxide film forming on surface of aluminum has tight structure and good cohesion with metal. Thickness of film oxidized under usual conditions constitutes 0.01-0.02 $\mu$.

It is necessary to note that oxide films are formed also on other metals, in particular on steel but they have much smaller thickness (0.001-0.002 $\mu$), are porous, and do not possess protective properties.

Presence of oxide film ennobles aluminum, increasing its electrode potential in neutral media from - 1.66 to - 0.5v.

Starting with electrochemical characteristics of aluminum, of danger to it is galvanic corrosion in contact with many metals possessing more positive electrode potentials than aluminum. Copper belongs in the first rank of such metals.

With iron a great danger is present by contacts of aluminum - magnesium alloys, especially with heightened magnesium content. Alloys of duralumin type, because of presence in them of copper, in a number of media have electrode potential close to that of iron, and therefore contacts with iron are less dangerous for them.

Contact of different aluminum alloys can sometimes present danger, owing to difference in their potentials. Thus, for instance, potential difference in solution of NaCl aluminum alloys with 10% Mg and duralumin can reach up to 0.28 v. Upon contact of two brands of duralumin corrosion, is possible if amount of copper in them differs by 2.5 % [1].

However, presence on aluminum alloys of oxidized film significantly decreases difference in their potentials, but in strongly corrosive media destruction of protective oxidized film is possible, and this must be taken into account.

Aluminum under many conditions has electrode potentials close to those of zinc and cadmium, which eliminates danger of contact corrosion.

Presence in aluminum of impurities, and also inclusion in its alloys, for increase of mechanical properties, of alloying additions, magnesium and chromium, besides maganese, usually decreases corrosional resistance of aluminum.

This is explained by the fact that alloying elements disturb completeness of continuous and uniform oxide film, which is peculiar to pure aluminum, while in case of beginning of corrosion they accelerate it, acting as cathodes of corrosion elements.

Especially unfavorable influence on resistance of aluminum to corrosion is rendered by additions of iron and copper.

Iron and copper have at normal temperature low solubility in aluminums and form with it intermetallic compounds $FeAl_3$ and $CuAl_2$, which possess more positive potential than aluminum and, consequently, are strong cathodes, paired with which aluminum (anode) is quickly destroyed. Therefore, if high resistance to corrosion is necessary, iron content in aluminum must not exceed 0.4 %, and that of copper - 0.05 %.

These limitations have been introduced into many norms of foreign countries (FRG, the United States) on application of aluminum alloys in building structures.

Magnesium in content up to 3.5-[illegible].5 % does not lower corrosional resistance of aluminum, since it, like aluminum, is able to form protective oxide film.

When magnesium content is higher than shown limits, it will form with aluminum the intermetallic compound $Al_3Mg_2$, which, separating out on grain boundaries, may cause intercrystaline corrosion under certain conditions.

Besides chemical composition, corrosion resistance of aluminum alloys is to a significant degree influenced by heat treatment. Usually, all non-heat-treated alloys possess higher corrosion resistance than alloys subjected to heat treatment.

Corrosion resistance of alloys strengthened by heat treatment depends to high degree on form and conditions of treatment.

Thus, alloys subjected after quenching to artificial aging possess lower corrosion resistance than alloys that are naturally aged.

Certain aluminum alloys have sensitivity to corrosion cracking, i.e., to corrosion damage with simultaneous action of tensile stresses and corrosive medium.

Such alloys include alloys of Al-Mg system with heightened magnesium content ( > 5-6 %) and of Al-Zn-Mg-Cu system.

Investigations conducted recently by I. N. Fridlyander and others on alloys of Al-Zn-Mg-Cu system (V95, V94), allowed them to obtain, with correct combination in alloy of concentrations of zinc, magnesium, and copper and optimum conditions of artificial aging, articles possessing sufficiently high resistance to stress corrosion [2].

Depending upon chemical composition and heat treatment, aluminum alloys by their corrosion resistance can usually be divided into two groups: the first group includes alloys of system Al-Mn and Al-Mg; the second group - alloys of Al-Mg-Cu and Al-Zn-Mg-Cu.

First group includes alloys of brands AMts, AMg, AMg3, AMg5, and AMg6, not containing copper; second - D1, D16, V95 - with copper. Alloys of first group have the highest corrosion resistance.

Alloy of Al-Mg-Si system of brand AV (avial) contains copper in small quantity (0.2-0.6%). In quenched and natural aged state this alloy in corrosion resistance is close to alloys of first group. In case of artificial aging, for alloy AV because of presence of copper, there appears inclination to intercrystalline corrosion. Therefore in case of artificial aging copper content in avial alloy, for obtaining of sufficient corrosion resistance should be limited to 0.05-0.1%.

Furthermore, it is desirable also that ratio of silicon to magnesium in alloy be as small as possible.

Corrosion resistance of aluminum and its alloys in different corrosive media depends on stability in these media of oxidised film of $Al_2O_3$.

In alkali media there occurs destruction of oxidised film with formation of soluble aluminate.

Therefore, for aluminum alloys, unlike for instance, those of steel, contacts with wet concrete and plastering solution are dangerous.

In contact with dry concrete and plaster aluminum alloys are not usually subject to corrosion [3].

In medium of sulfurous compounds - sulfurous anhydride, hydrogen sulfide - oxidised film on aluminum possesses rather high stability.

Dry sulfurous gas, as tests in Institute of Physical Chemistry of Academy of Sciences of USSR showed, is not dangerous for aluminum alloys [4].

Only during relative humidity higher than 70-80 % does corrosion of aluminum alloys increase with increase of $SO_2$ content.

The majority of aluminum alloys is quite stable in atmosphere of hydrogen sulfide and its mixtures with air and steam [5].

Of significant interest for building structures is atmospheric corrosion of aluminum and its alloys, since the greater part of buildings and structures is subjected during exploitation to atmospheric influences.

Tests of aluminum alloys in atmospheric conditions have been conducted in USSR during the last few years at corrosion stations of Academy of Sciences of USSR and in a number of other scientific research organisations.

Investigations of corrosion resistance of aluminum alloys in atmospheric conditions have been conducted for 20 years in the United States by American Society for Testing Materials (ASTM) at nine stations (four in industrial, three in Marine, and two in rural areas) [6]; by Aluminum Company of America (ALCOA) at seven stations (three in industrial and four in Marine areas) [7]; by National Bureau of Standards (NBS) at three stations [8].

In Figs. 1, 2 and in Tables 1, 2 there are given certain results of corrosion tests of aluminum alloys in atmospheric conditions obtained by ASTM and ALCOA.

As can be seen from given graphs and tables, corrosion of aluminum alloys sharply attenuates with time. Thus, after first year, for aluminum alloys depth of penetration of corrosion was approximately equal to depth of penetration after subsequent 19 years.

Total depth of corrosion after 20 years in industrial atmosphere constituted on the average 0.2-0.25 mm, and in Marine -0.2-0.3 mm. Loss of strength for samples with thickness of 1.6 mm did not exceed 6-11 %, while for steel under analogous conditions there were such losses already after first year.

Aluminum alloys 2S, 3S, 4S, 52S, and A54S, close to native alloys Al, AMts, AMg, and AMg3, in industrial atmosphere showed approximately identical degree of corrosion. Alloys 53S-T6, 61S-T6, 63S-T6, close to alloy AV, had under these conditions somewhat larger corrosion losses.

Fig. 1. Maximum depth of corrosion of aluminum alloys 2S, 3S, 4S in Marine and industrial atmosphere [9].
1) Marine (Point Judith); 2) Industrial (New Kensington); 3) Marine (Georgetown).
KEY: (a) Maximum depth of damages in mm; (b) Duration of test in years.

In Marine atmosphere aluminum-magnesium alloys were better behaved.

In general, aluminum alloys show higher corrosional resistance in industrial atmosphere than in Marine.

Higher corrosiveness of Marine atmosphere is explained by presence in it of chlorine ions, which can penetrate through protective oxidized film of $Al_2O_3$ and destroy aluminum.

Corrosion tests of aluminum alloys in different atmospheric conditions for shorter period of time (2-5 years) were conducted in Italy, England, Canada, and other countries [10], [11].

Table 1. Corrosion of Aluminum Alloys 2S and 3S After 20 Years According to Tests by ASTM Samples with Thickness of 0.87 mm

| Type of atmosphere | Place | Conditions of tests | Maximum depth of corrosion in mm | | Rate of corrosion in mm/per year | | Loss of strength in % |
|---|---|---|---|---|---|---|---|
| | | | 2S | 3S | 2S | 3S | 3S |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| Industrial | Altoona | On roof of building of railroad station | 0.28 | 0.19 | 0.014 | 0.009 | 18 |
| | New York | Roof of telephone laboratory on West street | 0.21 | 0.16 | 0.011 | 0.008 | 10 |
| Marine | La Jolla | Wind from sea, sea stormy, dense fogs | 0.35 | 0.26 | 0.018 | 0.013 | 20 |
| | Sandy Hook | Station on end of cape jutting into bay. Wind from bay | 0.23 | 0.08 | 0.012 | 0.004 | 6 |
| Rural | Phoenix | Dry, semiarid region | 0.02 | 0.01 | 0.001 | 0.0005 | 2 |
| | State College | Clean rural region, there are no industrial contaminations | 0.09 | 0.06 | 0.005 | 0.003 | 2 |

Table 2. Corrosion of Certain Brands of Aluminum Alloys, According to Tests by ALCOA Samples with Thickness of 1.6 mm

| Type of atmosphere | Place | Conditions of tests | Indices of corrosion | After 1 year | | | After 20 years | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 2S, 3S, 4S | 52S, A54S | 53S-T6, 61S-T6, 63S-T6 | 2S, 3S, 4S | 52S, A54S | 53S-T6, 61S-T5, 63S-T6 |
| Industrial | New Kensington | Roof of aluminum laboratory, nearby there is exhaust pipe from analytical laboratory | Maximum depth of corrosion in mm | 0,06 | 0,05 | 0,1 | 0,12 | 0,1 | 0,2 |
| | | | Rate in mm/year | 0,06 | 0,05 | 0,1 | 0,006 | 0,005 | 0,01 |
| | | | Loss of strength in mm | 1 | 1 | 2 | 7 | 3 | 7 |
| Marine | Point Judith | 100 m inland. Wind from ocean, salty sprays, fogs. | Maximum depth in mm | 0,12 | 0,05 | 0,1 | 0,2 | 0,1 | 0,18 |
| | | | Rate in mm/year | 0,12 | 0,05 | 0,1 | 0,01 | 0,005 | 0,009 |
| | | | Loss of strength in % | 1,5 | 1 | 3 | 9 | 6 | 11 |

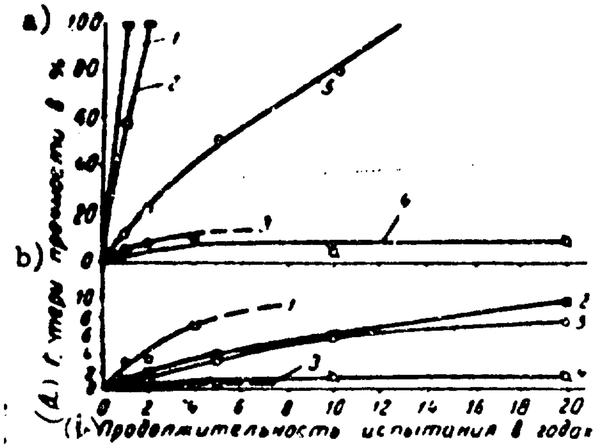


Fig. 2. Average corrosion losses of strength of samples with thickness of 1.6 mm from aluminum alloys 2S, 3S, 4S (b) and low-carbon steels (a) in Marine and industrial atmospheres [7]. Marine atmosphere: 1) Kure Beach, 30 m from shore; 2) Point Judith 100 m from shore; 3) Miami Beach 100 m from shore; 4) Georgetown 2,500 m from shore: industrial atmosphere; 5) New Kensington.
KEY: (a) Losses of strength in %; (b) Duration of test in years.

Tests by Milan Institute of Nonferrous Metals of about 10 brands of aluminum alloys in four types of industrial atmosphere showed significant superiority of aluminum alloys over steel [10]. Losses of strength of samples with thickness of 1.5 mm from alloys AG 2.5 and AM1.2 (close to native brands AMg and AMts) after 2 years of tests near chemical factory in atmosphere contaminated with nitrogenous and ammonium fumes and sulfurous anhydride constituted 2-3 %; and steel samples — 30 %. For alloy AG5, containing nearly 5 % Mg, losses of strength under these conditions were greater than for other alloys.



Fig. 3. Appearance of corrugated sheets from aluminum alloy VA60 (a) and galvanized steel (b) after 3 years of tests in atmosphere of chemical factory [11].

In general, least corrosion losses under all conditions during test in Italy were observed for pure aluminum and for its alloys AG2.5, AM1.2, and ASO.4G (close to AMg, AMts, and AV).

Tests in Italy also confirmed fading of corrosion of aluminum alloys with time.

Extensive tests of aluminum alloys for the purpose of their application as roofing on chemical factories were conducted in England.

In Fig. 3 there is shown appearance of corrugated sheets from aluminum alloy VA 60 and galvanized steel after 3 years of tests in atmosphere of chemical factory, contaminated with ammonia and sulfurous gas [11]. As can be seen on photograph, galvanized sheet corroded right through, while sheet of aluminum alloy is in good condition.

Tests in England led to conclusion that period of service of unprotected aluminum roofing with thickness of 0.7 mm under the heaviest corrosion conditions of chemical factory will be not less than 7 years, whereas roofing from galvanized steel under such conditions will serve no more than 2 years.

Besides the designated tests, very valuable data on corrosion resistance of aluminum was obtained as a result of inspections made in various countries of existing aluminum structures exploited for prolonged period without any protection.

To the longest-standing known examples of service of aluminum in atmospheric conditions belong parts of Washington Monument in the United States (1884) and statue of Eros in London (1893), made from case aluminum of low purity. Inspection of Washington Monument in 1934, i.e., after 50 years of service, showed that aluminum detail is in good condition [12]. Statue of Eros, in spite of corrosive atmosphere of London has also kept well in the city to this time [13].

In literature there is also brief mention of roof of warehouse building from sheet aluminum with thickness of 0.5 mm, existing in rural locality for more than 100 years [14].

Of significant interest are the two following examples of long-standing service of aluminum, since this is one of first sufficiently detailed inspections of application of aluminum for purely structural purposes: cornice of an apartment building in Montreal (1896) [15] and roof of a church in Rome (1897) [16].

In Table 3 there are given results of inspection of these structures and also a number of other structures raised later at different times.

From data in Table 3 it is clear that rate of corrosion of aluminum and its alloys after 40-50 year period in atmosphere of industrial cities constituted 0.003-0.004 mm/year. After shorter period of time, especially in first year, rate of corrosion is significantly higher and reaches 0.05-0.1 mm/year.

First criteria of corrosion on structure from aluminum alloys can appear after relatively short interval of time. Thus, from experience of construction in England there are known cases, when in industrial atmosphere of Manchester aluminum structures after just 2 months were covered with considerable quantity of corrosion pits. Subsequently conducted inspections, after each 6 months and tests of samples of structures did not show increase of depth of corrosion or lowering of strength properties [20].

Experience of exploitation of building structures from aluminum alloys abroad shows that their corrosion is frequently more intense in places which are poorly ventilated, are not washed by rain, and where there is large accumulation and retention of dust.

Incorrect application of aluminum alloys in building structures can sometimes lead under corrosive conditions to significant corrosion.

Thus, for instance, during construction of roof for building of gas purification shop of one of chemical factories in Liverpool, a sheet with thickness of 0.7 mm from aluminum - manganese alloy was placed on steel rafter girder without any insulation. After 4 years at place of contact of aluminum roof with steel girder then was revealed damage of aluminum sheet through its entire thickness, whereas on other sections of roof maximum depth of corrosion did not exceed 0.2 mm [18]. However, with correct application of aluminum alloys, they, under many industrial conditions, have sufficiently high corrosion resistance without any protection.

This was confirmed on many structures, built in recent years where unprotected

## Table 3. Corrosion of Aluminum and its Alloys in Building Structures According to Results of Inspections

| Designation of structure | Location | Date of building | Date of inspection | Period of exploitation before inspection in years | Material | Type of structure | Initial thickness of elements in mm | Conditions of exploitation | Maximum depth of corrosion in mm | Average rate of corrosion in mm | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Apartment building | Montreal (Canada) | 1896 | 1944 | 48 | Aluminum (99.4 %) | Roof, smooth sheet | 0,7 | City atmosphere | 0,15 | 0,003 | [15] |
| Church of San Gioccin | Rome (Italy) | 1897 | 1937 | 40 | Aluminum (99.3 %) | The same | 1,3 | The same | 0,15 | 0,0038 | [16] |
| Apartment building | Sidney (Australia) | 1900 | 1937 | 37 | Aluminum (99.2 %) | Roof, corrugated sheet | 0,7 | City and marine atmosphere | 0,13 | 0,0035 | [15] |
| Government building | St. Ives (England) | 1937 | 1950 | 13 | Noral 51S | Window frame | * | Marine atmosphere | 0,16 | 0,012 | [15] |
| Building of laboratory | Banbury (England) | * | * | 10 | 3S | Roof | * | Rural atmosphere | 0,076 | 0,0076 | [15] |
| Compressor factory named after Walter Ulbricht | German Democratic Republic | 1945 | 1957 | 12 | AlCuMg colored | Rafter girder | * | Flue gasses, steam, condensate | Corrosion is absent | | [17] |
| Oil refinery | Lancashire (England) | 1947 | 1954 | 7 | 3S; 1.2 % Mn | Roof and load-bearing structures of canopy | * | Industrial atmosphere | On upper side of roof there is no damage, on lower - shallow pitting | | [18] |
| Gas factory | Sevenoaks (England) | 1948 | 1952 | 4 | N3 | Roof | 0,7 | The same | 0,12 | 0,03 | [19] |
| | | | | | NG10 | Rafter girders | 4,3—6,3 | | 0,435 | 0,11 | |
| Gas purification plant | Liverpool (England) | 1950 | 1954 | 4 | 3S | Roof, corrugated sheet | 0,7 | Emissions from coke bank and coke-slaking tower | 0,2 | 0,05 | [18] |
| Chemical factory | England | * | * | 3 | 3S; 1.2 % Mn | Roof | * | Industrial atmosphere | 0,15 | 0,05 | [18] |

* No information.

structures from aluminum alloys of avial type and those of plated duralumin did not show criteria of corrosion after first years. Among them: are bridges in Scotland (Pitloch), Canada (Arvida) and FRG (Dusseldorf), hangars at London airport, transformer substation in New Zealand (Heywood), and many others.

In Table 4 on the basis of analysis of data of numerous tests and inspections of existing structures built abroad mean values are given of rate of corrosion for aluminum alloys and steel under different atmospheric conditions.

Table 4. Average Rates of Corrosion for Aluminum Alloys and Steel in mm/year Under Different Atmospheric Conditions

| (a) Материал | (b) Продолжительность наблюдения | (c) Тип атмосферы | | |
|---|---|---|---|---|
| | | (d) сельская | (e) индустриальная | (f) морская |
| (g) Алюминиевые сплавы | (i) Первый год | 0,05 | 0,1 | 0,15 |
| | (j) Последующие годы | 0,003 | 0,003 | 0,003 |
| | (k) Среднее за 10 лет | 0,0076 | 0,013 | 0,018 |
| (h) Сталь | (l) То же | 0,038 | 0,13 | 0,05 |

KEY: (a) Material; (b) Duration of observation; (c) Type of atmosphere; (d) rural; (e) industrial; (f) Marine; (g) Aluminum alloys; (h) Steel; (i) First year; (j) Subsequent years; (k) Average for 10 years; (l) The same.

From values given in Table 4 it is clear that rate of corrosion of aluminum alloys in different atmospheres differs only in initial period, but then becomes constant for all types of atmospheres. Rate of corrosion of aluminum alloys is lower than rate of corrosion of steel in industrial atmosphere by 10 times, in rural - by 5 times, in Marine - by 3 times.

Above-mentioned survey shows peculiarity of corrosion behavior of aluminum alloys under different conditions, rate of their corrosion in building structures and superiority in corrosion resistance over steel.

However, data existing at present on corrosion of aluminum alloys does not embrace the whole variety of corrosive media in which building structures can be exploited. Furthermore, available foreign data, undoubtedly, require checks under our conditions for native materials.

Below there are described corrosion tests conducted at YuzhNII [Southern Scientific Research Institute] of aluminum alloys under natural conditions.

## 2. Methods and Carrying out Corrosion Tests of Aluminum Alloys Under Natural Conditions

Corrosional tests have purpose of establishment of amount of corrosion of native brands of aluminum alloys in conditions of service of building structures of metallurgical factories and in atmosphere of industrial city, selection of best material in corrosion resistance, determination of minimum permissible thicknesses of structures from condition of corrosion, etc.

Investigated are corrosion properties of aluminum alloys of systems aluminum - manganese (AMts), aluminum - magnesium (AMg6), aluminum - magnesium - copper (D16), and also steel of brand of St 3.

Tests are made on sheet semifinished products with thickness in the main of 3 mm. Furthermore, sheets are being tested of smaller thicknesses (1.5 and 1 mm), but results on them are still unavailable.

Sheets from alloy D16-T are being tested both with protective plating of aluminum with thickness of 0.1-0.12 mm on each side of sheet and also without it. Unprotected sheets from D16-T, and also from AMg6 have industrial plating with thickness of 0.03 mm on each side of sheet. Indicated industrial plating serves basically for easing of production of rolling articles from alloys with large content of magnesium and copper and does not have protective aims. Sheets from alloy AMts had no plating.

Initial data about investigated materials are given in Table 5.

Table 5. Initial Data on Investigated Sheet, Semifinished Products from Aluminum Alloys and Steel

| (a) Сплавы | (b) Термическая обработка | (c) Химический состав в % | | | | | | (d) Механические свойства | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mg | Mn | Cu | Si | Fe | Ti | предел прочности $\sigma_{пч}$ в кг/мм² (e) | предел текучести $\sigma_т$ в кг/мм² (f) | относительное удлинение ε в % (g) |
| AMts-M | Отжиг (h) | Следы (i) | 1,32 | Следы | 0,23 | 0,57 | — | 13 | 7 | 36 |
| AMg6-M | " | 6,7 | 0,65 | " | 0,38 | 0,22 | 0,06 | 37 | 17 | 22 |
| D16-T | Закалка и естественное старение (j) | 1,2 | 0,71 | 4,5 | 0,26 | 0,36 | — | 50,5 | 34,5 | 16 |
| D16-T (плакированный) (k) | То же (l) | 1,24 | 0,8 | 4,6 | 0,32 | 0,3 | — | 48,5 | 33 | 18 |
| ST3 (мартен. спокойная) (m) | В состоянии прокатки (n) | C 0,18 | 0,5 | S 0,024 | 0,18 | P 0,048 | — | 50,5 | 31 | 25 |

KEY: (a) Alloys; (b) Heat treatment; (c) Chemical composition in %; (d) Mechanical properties; (e) ultimate strength $\sigma_{пч}$ in kg/mm²; (f) yield point in kg/mm²; (g) specific elongation in %; (h) Annealing; (i) Traces; (j) Quenching and natural aging; (k) (plated); (l) The same; (m) St 3 (open-hearth furnace, dead melt); (n) In rolled state.

Test are conducted on samples in the form of rectangular plates of 150 X 100 mm cut from sheets in direction across rolling.* Surface of samples was not subjected to additional treatment and had natural state, obtained after rolling. Before testing, samples were degreased in acetone and alcohol.

As basic indices of corrosion there were take: losses of mechanical properties ($K_\sigma$, $K_\varepsilon$), of weight ($K_g$), and depth of penetration of corrosion ($K_h$).

Loss of mechanical properties due to corrosion was found to be

$$K_\sigma = \frac{\sigma_0 - \sigma_1}{\sigma_0} 100\% ; \quad K_\varepsilon = \frac{\varepsilon_0 - \varepsilon_1}{\varepsilon_0} 100\% .$$

*Besides shown type of samples, at present there are being tested samples with welded joints in strain state (in contact with steel). However, results of tests of these samples will be obtained later.

where $K_\sigma$ and $K_\epsilon$ - losses of ultimate strength and specific elongation in %;

$\sigma_0$ and $\epsilon_0$ - ultimate strength in kg/mm$^2$ and specific elongation in % metal in initial state;

$\sigma_1$ and $\epsilon_1$ - ultimate strength in kg/mm$^2$ and specific elongation in % metal after corrosion tests.

Ultimate strength ($\sigma_0$) and specific elongation ($\epsilon_0$) of metal in initial state were established from average of tests of 18-20 transverse samples taken from different points through length and width of sheet. Here root - mean - square deviation for sheets from different alloys constituted: for ultimate strength 0.4-1.6 %, for yield point 1.2 - 4 %, for specific elongation 5-16 %.

Thus, the stables of mechanical properties of material is ultimate strength, changes of which were taken as one of basic indices of corrosion resistance.

Mechanical properties of metal after corrosion were determined by means of tensile test of no less than three standard samples of 150 x 20 mm dimension cut from already corroded plate. Breaking load pertained to initial; before corrosion section of sample, i.e., "conditional" ultimate strength was determined.

Losses of weight were calculated by the formula

$$K_g = \frac{g_0 - g_1 + \Delta g_1}{g_0 F} \text{ г}/\text{м}^2,$$

$$K_g = \frac{g_0 - g_1 + \Delta g_1}{g_0} 100\%,$$

where $K_g$ - loss of weight in g/m$^2$;

$g_0$ - weight of sample in initial state in g;

$g_1$ - weight of sample after removal of products of corrosion in g;

$\Delta g_1$ - loss of weight of basic metal in solution for removal of products of corrosion in g;

F - total surface area of sample in m$^2$.

Removal of products of corrosion was done by chemical method in solutions:

1) for aluminum alloys - 200 ml $H_3PO_4$ + 80 g $Cr_2O_3$ per liter of water;

2) for steel - 10 % $H_2SO_4$ + 1 % formalin.

Temperature of solutions - room; time of stay in solution of samples from aluminum alloys was 2 hours; samples of steel - from 3 to 5 hours, depending upon degree of corrosion of sample. Losses of weight of basic metal ($\Delta g1$) constituted on the average: for aluminum alloys 0.01 g/hour; for steel 0.1 g/hour, which did not exceed 5 % of losses of metal from corrosion. Weighing of samples from aluminum alloys was done with accuracy up to 0.0001; samples of steel - to 0.01.

Depth of penetration of corrosion was determined by following methods:

1) through losses of weight ($K_{hg}$);

2) through losses of strength ($K_{h\sigma}$);

3) by direct measurements ($K_h$)

$$K_{hg} = \frac{1}{1000} \cdot \frac{K_g}{\gamma} \text{ мм},$$

where $K_g$ - loss of weight in g/m²;

$\gamma$ - specific gravity in g/cm³ (for all aluminum alloys 2.7; for steel 7.85);

$\frac{1}{1000}$ - conversion factor from m and cm to mm;

$$K_{h\sigma} = \frac{1}{2} \cdot \frac{\Delta \sigma}{\sigma_0} h \text{ мм},$$

where $\Delta\sigma$ - losses of ultimate strength in kg/mm²;

$\sigma_0$ - ultimate strength of metal in initial state, in kg/mm²;

h - initial thickness of sample in mm;

1/2 - coefficient signifying loss of thickness on one side of sample.

Direct measurement of depth of corrosion damage was made with help of an indicator adapted for this purpose with value of each division of 1 $\mu$.

Besides above-indicated basic indices of corrosion, there was determined also variation factor of distribution of corrosion by the formula

$$K = \frac{K_g}{K_\sigma},$$

where $K_g$ - loss of weight of sample in %.

$K_\sigma$ - loss of ultimate strength of sample in %.

With continuous, uniform corrosion coefficient K should be near to one.

In case of continuous, nonuniform or localized corrosion the more value of coefficient K differs from 1, the more nonuniform is character of corrosion.

Indices of corrosion were taken as average from two identical samples.

Corrosion tests are being conducted at two metallurgical (Zaporozh'ye Krivoy Rog) and one by-product (Krivoy Rog) factory and in atmosphere of an industrial city (Khar'kov).

In different workshops of the indicated factories there were set up test stands to which were fastened samples of investigated metals. Stands consist of wooden lattices with dimensions 1.4 X 1.1 m or 1.2 X 0.9 m, which are mounted on existing building structures or on special supports. The lattices are disposed both vertically and at an angle to horizon (30 and 60°).

In Fig. 4 there is shown general view of two such stands. Each sample is fixed on stand with help of four porcelain isolators (rollers) in grooves of which it fits. Thus, reliable bracing and insulation of samples are assured.

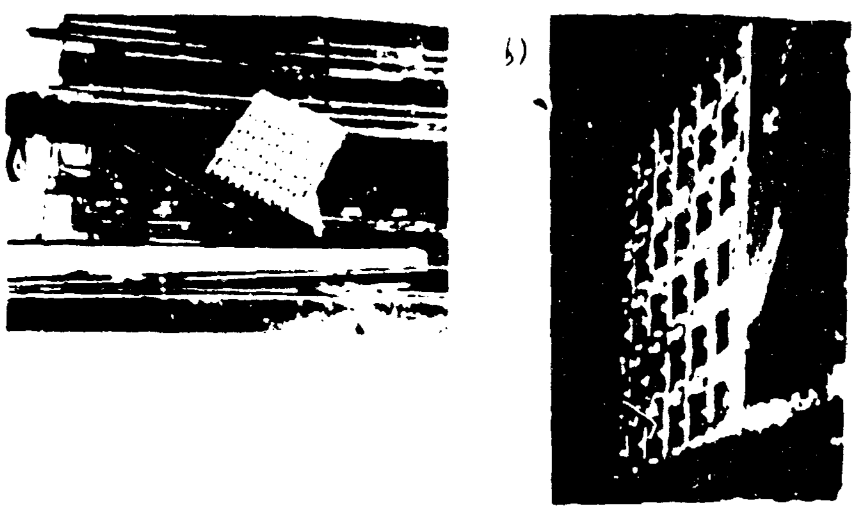

Fig. 4. General view of two stands of YuzhNII for corrosion tests.
a) stand No. 9 on gantry crane of slag - granulation basin;
b) stand No. 1 on rafter girder of building of pickling section of cold rolling workshop.

Metallurgic and by-product coke factories, thanks to their large dimensions and various forms of production, have very different character and composition of corrosive medium. Therefore, during selection of places for carrying out corrosion tests we strove to embrace the most characteristic exploitational media, and also those places which are of interest from the point of view of application of aluminum alloys.

All stands under test conditions can, in the first place, be combined in two groups: in open atmosphere and inside buildings.

In Tables 6 and 7 there are given places of installation of test stands and brief characteristic of area of carrying out of tests.

As can be seen from Table 6, tests simulate general factory atmospheric conditions in region of blast furnace and open-hearth shops, the recovery shop, and also in microcosms with considerably local corrosive emissions - coke-slaking tower, slag-granulation basin.

Table 6. Places of Carrying out of Corrosion Tests by YuzhNII under Atmospheric Conditions of Metallurgical and By-product Coke Factories and of the Industrial City

| No. of stand | Place of test | Place of installation of stand | Slope of stand to horizon in degrees | Orientation of upper plane of stand | Brief characteristic of test conditions |
|---|---|---|---|---|---|
| 12 | Krivoy Rog, by-product coke factory | Column of scaffold for slime settling tank of coke-slaking tower No. 1 | 90 | Northeast | Systematic sprays of water from coke-slaking tower. In atmosphere there were found sulfurous gas, hydrogen sulfide, and ammonia |
| 13 | The same | Gas conduit support of sulfate section of recovery shop | 90 | Southeast | Near pit containing salts of ammonium, hydrogen sulfide, and cyanides, next to it is located the saturator |
| 9 | Krivoy Rog, metallurgical factory | Girder of gantry crane of slag granulation basin | 60 | Southwest | Water vapors from basin during pouring of molten slag. Atmosphere contains sulfurous gas, hydrogen sulfide, and ore dust from sintering shop next door. |
| 8 | The same | Console of ore-loading crane No. [illegible] on coke-bank side | 30 | Northeast | One hundred meters from coke-slaking tower and coke bank. Wind carries drops of water from coke-slaking tower and gases from coke bank, coke and iron-ore dust |
| 7 | Zaporozh'ye metallurgical factory | Console of ore-loading crane No. 2 on coke-bank side | 90 | North | Conditions close to conditions of stand No. 8, but less corrosive, because of great distance from coke shop |
| 5 | The same | Light tower of open-hearth shop | 60 | • | Smoke from open-hearth furnaces |
| 14 | Khar'kov, industrial region | Roof of YuzhNII building | 45 | South | On roof there emerge chimneys of boiler room and exhaust from analytical laboratory. Next to it there is located a refractory materials factory |

Table 7. Place of Carrying out of Corrosion Tests by YuzhNII was Inside Industrial Buildings of Metallurgical Factory

| No. of stand | Factory | Place of installation of stand | Slope of stand to horizon, degrees | Brief characteristic of test conditions |
|---|---|---|---|---|
| 11 | "Krivorozhstal'" | Roof joints of casting yard of blast furnace No. [illegible] | 90 | Sulfurous gas, emitted during removal from blast furnace of cast iron and slag, and ore dust |
| 3 | "Zaporozhstal'" | Rafter girder of mixer building | 60 | Heightened temperature, sulfurous gas, and graphite dust |
| 4 | The same | Rafter girder of stockyard | 60 | Locomotive smoke, sulfurous gas, charging and scrap dust |
| 2 | • | Rafter girder above finishing cribs of thin-sheet shop | 90 | Heightened temperature, dust consisting, basically, of iron cinder |
| 1 | • | Rafter girder above pickling baths of cold-rolling shop | 90 | Heightened humidity, sulfuric acid vapors |

Test inside buildings include five forms of production, where along with such serious, from the point of view of corrosion of metals, conditions as casting bed, pickling section, there were chosen places with less corrosiveness of intrashop medium -- mixer, thin-sheet shop.

Installation of samples from aluminum alloys of brands AMts, AMg6, D16, and steel of brand St3 was done in period from 15 September through 3 October 1958.

Total duration of corrosion tests was fixed at 3 years, with determination of indices of corrosion after each year.

First lot of samples was removed from stands in period from 5 through 25 August 1959, i.e., almost eleven months after their installation. At the same time there were set up additional samples from alloys AMg, AMg5v, and AV, for which results will be obtained late.

Below then are given results of first year of corrosion tests of aluminum alloys AMts, AMg6, and D16.

## 3. Results of Annual Corrosion Tests

Investigated aluminum alloys after eleven months of tests under all (with some exception) conditions had corrosion damage. Only on stand inside rolling shop (above mills) had samples kept initial surface state. Inside building of stockyard and mixer corrosion damage was on lower side of sample, but upper side had kept its initial state.



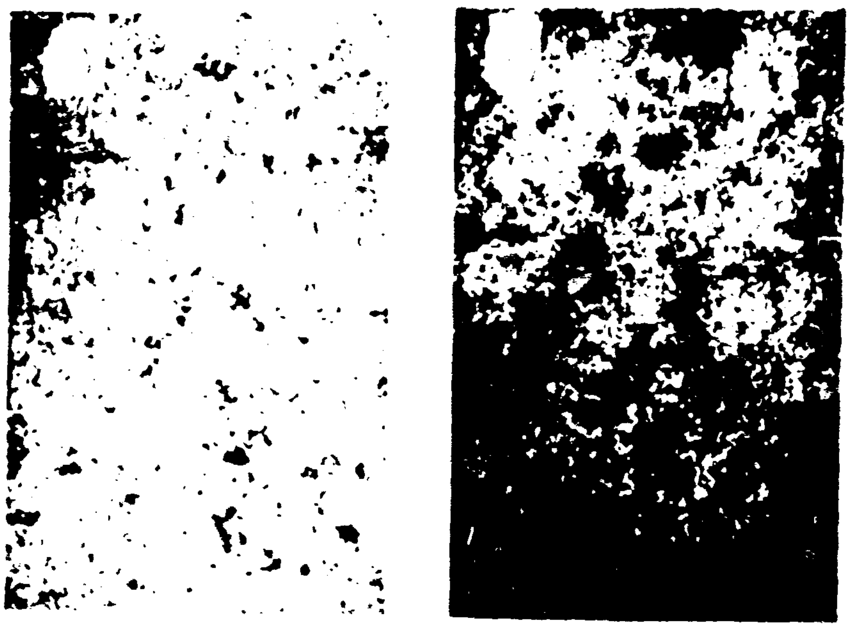

Fig. 5. Damage to upper (a) and lower (b) sides of plate from alloy D16-T with protective plating under heavy corrosion conditions. One may see greater damage to lower side of sample as compared to upper.

Aluminum alloys AMts-M, AMgб-M, and D16-T (the latter with plating) under all conditions revealed localized corrosion.

Alloy D16-T, depending upon conditions of tests, had both solid (stands No. 12, 9, 8) and localized corrosion.

In Table 8 there are given dimensions of corroded surface of samples in percentages of their total surface area.

In Fig. 5 there is shown state of surface of one of tested samples under the most serious corrosion conditions.

Table 8. Percentage of Corroded Surface in Relation to Total Area of Samples from Aluminum Alloys and Steel After Eleven Months of Tests Under Natural Conditions

| Alloys | Number of stand 12 | 9 | 8 | 7 | 13 | 5 | 14 | 11 | 1 | 4 | 3 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMts-M | 50<br>55 | 40<br>50 | 35<br>40 | 8<br>15 | 12<br>18 | 3<br>5 | 8<br>10 | 35<br>45 | 32<br>45 | 0<br>20 | 2<br>20 | 0<br>0 |
| AMg6-M | 40<br>50 | 35<br>40 | 30<br>30 | 6<br>10 | 8<br>12 | 1<br>3 | 6<br>10 | 25<br>35 | 32<br>40 | — | 0<br>10 | 0<br>0 |
| D16-T | 100<br>100 | 90<br>100 | 90<br>100 | 12<br>22 | 16<br>26 | 1<br>4 | 30<br>55 | 95<br>95 | 90<br>90 | 0<br>50 | 0<br>2 | 0<br>0 |
| D16-T (plated) | 35<br>55 | 45<br>65 | 20<br>50 | 8<br>12 | 6<br>12 | 0<br>4 | 6<br>9 | 35<br>45 | 35<br>45 | 0<br>6 | 0<br>3 | 0<br>0 |
| St. 3 | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | 0<br>80 | 2<br>4 | 0<br>0 |

Note: In upper line there are given data pertaining to upper side of plate, in lower - to lower side.

From values given in Table 8 and also from Fig. 5 it is clear that lower side of plates was corroded 25-30% more than upper. This may be explained by the fact that although lower side of sample was in lesser degree subject to atmospheric influences (rain, dust), the drying of moisture on it occurs more slowly and usually more dust accumulates, which is less removed by wind and rain than that on upper side. All this creates favorable conditions for more intense corrosion on lower side of sample.

Inside stockyard and mixer the worse state lower side of sample is caused by the fact that with slanted disposition of samples on these stands the lower side was subjected to direct influence of corrosive agents rising from beneath (locomotive smoke, gasses).

Each alloy displays its own peculiar type of corrosion damage which, with little exception, is kept under all conditions.

Thus, alloy AMts-M corrodes, basically, in the form of separate dots and "worm holes"; in area of coke-slaking tower there is revealed pitting (Fig. 6, a).

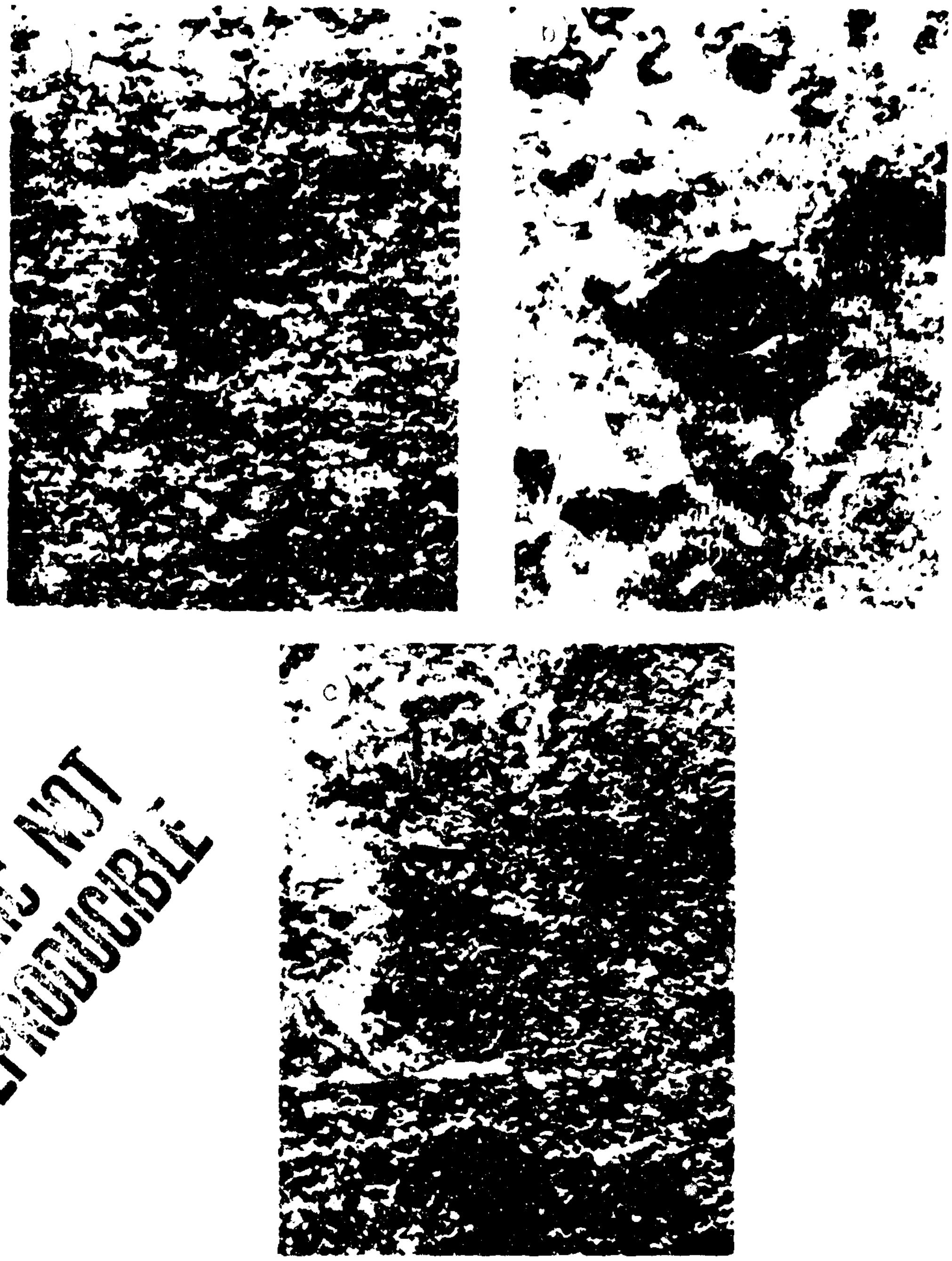



Fig. 6. Form of corrosion damage to sheets from different aluminum alloys (greatly magnified)
a) AMts-M: damage in the form of dots "worm holes" and pitting; b) D16-T with protective plating: destruction of plating (one can see shallow, honeycomb structure of surface of basic metal); c) AMg6-M with industrial aluminum plating - swelling of surface.

Surface of samples from alloy AMg6-M is covered with swellings, having oval or winding outline in plan. Beneath swellings there are usually revealed crater-like depressions in metal (Fig 6. c).

Samples from alloy D16-T have dots and "worm holes"; with solid corrosion their surface takes on a shallow honeycomb pattern.

Destruction of plating layer on alloy D16-T has character of dots and "worm holes," under severe conditions - spots, surface of which has, as and for unplated alloy, shallow, honeycomb structure (Fig. 6b ).

Different character of corrosion damage on surface of investigated alloys may be explained by the following.

As it was noted above, sheet, semifinished products from alloy AMg6 have industrial aluminum plating with thickness of 0.03 mm on each side of sheet. In an electrochemical sense plating on alloy AMg6 is cathode. This means that during penetration of corrosive agents through the microcracks always available in plating, corrosion damage occurs through core of sheet, and corrosion products formed here swell plating layer.

With respect to alloy D16-T aluminum plating is anode, and during corrosion processes, it, being destroyed, protects basic metal. Therefore corrosion damage on alloy with protective plating had character of dots and patches with maximum depth equal to thickness of plating layer. Only with great area of destruction of plating (patch with diameter of 3-4 cm) did its protective action fail, and corrosion started to spread to interior of basic metal.

Steel samples tested in parallel with aluminum had, basically, solid, uniform corrosion. Under conditions of coke-slaking tower on steel samples there were found separate, deep corrosion pits.

Quantitative indices of corrosion of aluminum alloys and steel are loss of weight and mechanical properties; depth of penetrations are given in Tables 9-11.

In examining quantitative indices of corrosion, in the first place, one should note that all of them do not identically characterize corrosion resistance of aluminum alloys.

Thus, for instance, under conditions of stand No. 8 losses of weight for alloys AMts-M and D16-T are equal, while loss of strength for first alloy turned out to be 2.5 times more than for second. There is also a difference in depth of corrosion, determined through losses of weight and strength, and by direct measurements.

All this is explained by the fact that corrosion of aluminum alloys has mainly a localized character, therefore during appraisal of their corrosion resistance in reference to building structures, we must take this as an index of corrosion.

Corrosion resistance of aluminum alloys in building structures is most correctly estimated by loss of strength and depth of corrosion, determined by direct measurements.

Table 9. Losses of Weight of Aluminum Alloys and Steel Due to Corrosion After 11 Months.

| | Kg in g/m2 | | | | | Kg in % | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of stand | AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 | AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 |
| 12 | 134 | 105 | 248 | 87 | 2 930 | 3,6 | 2,8 | 6,6 | 2,3 | 25,8 |
| 9 | 109 | 62 | 76 | 67 | 2 510 | 2,9 | [illegible] | 2 | 1,7 | 22 |
| 8 | 69 | 50 | 78 | 35 | 2 505 | 1,9 | [illegible] | 2,1 | 0,9 | 22,4 |
| 7 | 11 | 7 | 9 | 9 | 1 263 | 0,3 | 0,2 | 0,3 | 0,2 | 11,3 |
| 13 | 13 | 11 | 13 | 8 | 760 | 0,4 | 0,3 | 0,4 | 0,2 | 6,6 |
| 5 | 4 | 5 | 2 | 3 | 575 | 0,1 | 0,2 | 0,1 | 0,1 | 5,2 |
| 14 | 24 | 23 | 22 | 18 | 615 | 1 | 0,6 | 0,6 | 0,5 | 5,9 |
| 11 | 115 | 140 | 92 | 97 | 408 | 3,1 | 3,7 | 2,5 | 2,5 | 3,7 |
| 1 | 59 | 55 | 94 | 42 | 387 | 1,6 | 1,5 | 2,5 | 1,1 | 3,6 |
| 4 | 20 | — | 16 | 9 | 253 | 0.3 | — | 0,2 | 0,1 | 1,1 |

For steel corrosion weight losses, strength, and thickness usually agree quite well among themselves; therefore each of them can separately characterize its corrosion resistance.

It is necessary also to consider that loss of strength is relative index, since it is obtained on samples having certain thickness. With identical degree of corrosion, samples of large thickness will have smaller losses of strength, proportional to increase of thickness of sample.

Table 10. Losses of Mechanical Properties of Aluminum Alloys and Steel Due to Corrosion After 11 Months in %

Thickness of Samples 3 mm

| No. of stand | Ultimate Strength $K_\sigma$ in %: AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 | Specific elongation $K_\varepsilon$ in %: AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 10,5 | 14,2 | 17,2 | 4,3 | 31,4 | 45 | 43 | 58 | 33 | 56 |
| 9 | 9,3 | 14,5 | 2,3 | 1,1 | 26,4 | 52 | 46 | 3 | 19 | 32 |
| 8 | 6,9 | 9,4 | 2,7 | 1 | 23,7 | 32 | 31 | 17 | 3 | 25 |
| 7 | 4,6 | 4 | 2.6 | 1,5 | 10,4 | 8 | 14 | 4 | 9 | 12 |
| 13 | 4,7 | 3,6 | 2,8 | 0,7 | 7,7 | 8 | 18 | 20 | 6 | 2 |
| 5 | 2,9 | 3,4 | 2,3 | 1,7 | 6,7 | 2 | 6 | 3 | 3 | 3 |
| 14 | 5,1 | 5,2 | 2,6 | 1 | 8,6 | 8 | 20 | 1 | 4 | 4 |
| 11 | 9,9 | 11,4 | 3,4 | 1 | 6.2 | 20 | 17 | 40 | 33 | 8 |
| 1 | 6,5 | 5,5 | 3,3 | 3 | 5,4 | 0,5 | 14 | 8 | 29 | 8 |
| 4 | 4,5 | -- | 2,2 | 0,6 | 1,6 | 4 | - | 5 | 3 | 4 |

Table 11. Depth of Penetration of Corrosion for Aluminum Alloys and Steel After 11 Months of Tests Under Natural Conditions, in mm

| No. of stand | By loss of weight: AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 | By loss of strength: AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 | Direct measurements of damage, top of plate: AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 | bottom of plate: AMts-M | AMg6-M | D16-T | D16-T (plated) | St. 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 0,05 | 0,04 | 0,09 | 0,03 | 0,37 | 0,16 | 0,21 | 0.26 | 0,06 | 0,47 | 0,45 | 0,28 | 0,11 | 0,07 | 0,7 | 0,55 | 0,35 | 0,15 | 0,08 | 0,8 |
| 9 | 0,04 | 0,02 | 0,03 | 0,02 | 0,32 | 0,14 | 0,22 | 0,03 | 0,02 | 0,40 | 0,4 | 0,16 | 0,02 | 0,09 | 0,2 | 0,45 | 0,19 | 0,04 | 0,09 | 0,3 |
| 8 | 0,02 | 0,02 | 0,03 | 0,01 | 0,33 | 0,1 | 0,14 | 0,04 | 0,02 | 0,35 | 0,24 | 0,18 | 0,03 | 0,09 | 0,3 | 0,4 | 0,2 | 0,03 | 0,09 | 0,3 |
| 7 | 0,004 | 0,005 | 0,003 | 0,003 | 0,16 | 0,07 | 0,07 | 0,04 | 0,02 | 0,16 | 0,02 | 0,1 | 0,02 | 0,08 | 0,1 | 0,25 | 0,13 | 0,03 | 0,08 | 0,15 |
| 13 | 0,005 | 0,004 | 0,005 | 0,003 | 0,1 | 0,07 | 0,07 | 0,04 | 0,01 | 0,12 | 0,01 | 0,11 | 0,02 | 0,07 | 0,03 | 0,15 | 0,12 | 0,03 | 0,08 | 0,08 |
| 5 | 0,002 | 0,002 | 0,001 | 0,001 | 0,07 | 0,04 | 0,04 | 0,03 | 0,03 | 0,10 | 0,005 | 0,005 | 0,01 | 0,005 | 0,03 | 0,03 | 0,05 | 0,01 | 0,05 | 0,06 |
| 14 | 0,012 | 0,008 | 0,008 | 0,007 | 0,09 | 0,08 | 0,08 | 0,04 | 0,02 | 0,13 | 0,01 | 0,005 | 0,02 | 0,06 | 0,12 | 0,17 | 0,2 | 0,02 | 0,07 | 0,15 |
| 11 | 0,042 | 0,05 | 0,03 | 0,04 | 0,05 | 0,15 | 0,17 | 0,05 | 0,02 | 0,09 | 0,2 | 0,17 | 0.005 | 0,08 | 0,06 | 0,28 | 0,19 | 0,05 | 0,03 | 0,07 |
| 1 | 0,021 | 0,02 | 0,04 | 0,02 | 0,05 | 0,1 | 0,08 | 0,05 | 0,05 | 0,08 | 0,04 | 0,14 | 0,03 | 0,07 | 0,1 | 0,06 | 0,12 | 0,04 | 0,03 | 0,12 |

Data given in tables show that corrosion losses of aluminum alloys to great degree depend on conditions of test. Thus, in different places in atmosphere of of metallurgical factory ratios of maximum and minimum corrosion losses, on the average, for all aluminum alloys were equal: for strength, to 5, and for weight, to 35.

Ratio of corrosion losses of aluminum alloys AMts-M, AMg6-M, D16-T under identical conditions constituted by weight 1.3-2.3 to one, by strength 1.5-2 to one. Under conditions of stands No. 9, 8, and 11 ratios in losses of strength were larger and reached up to 3.4-6.3 to one.

The greatest losses of strength were shown by all aluminum alloys in area of coke-slaking tower (10. 5-17.2 %), the least - in area of open-hearth shop (2.3-3.4 %).

Inside pickling section, and especially in casting yard, corrosion losses were comparatively high, and they exceeded losses under a number of atmospheric conditions.

Corrosion losses in city atmosphere turned out to be no less than losses in certain places in atmosphere of metallurgical factory, for instance in region of open-hearth shop.

During comparison of corrosion resistance of different aluminum alloys it is clear that resistance is not always identical, and that it depends on conditions of tests. Only alloy D16-T with protective plating showed least corrosion losses under all conditions. Among the remaining alloys no one was superior under all conditions and in all indices.

Thus, under strongly corrosive conditions at coke-slaking tower the biggest losses were for alloy D16-T, then there followed alloys AMg6-M and AMts-M. Under remaining conditions in losses of strength alloys were disposed most frequently in following manner: the biggest - for alloy AMg6-M, then followed AMts-M and D16-T.

By weight losses order of disposition of alloys was usually inverse. Only inside casting yard for alloy D16-T did weight and strength indices of corrosion turn out to be less than for remaining alloys.

Peculiarity in corrosion behavior of different brands of aluminum alloys may be explained by following circumstances.

In the first place, it is necessary to note the influence of industrial plating on alloys D16-T and AMg6-M on their corrosion resistance.

One may assume that industrial plating on alloy D16-T in some degree rendered protective action, at least in first period of tests.

Corrosion on alloy D16-T, thanks to presence of industrial plating, had more frequently surface, rather than deep-seated character. This indicated the fact that samples from alloy D16-T with the biggest losses of weight often had least losses of strength.

Indices in this respect are values of coefficient of uniformity of corrosion ($K=\frac{K_r}{K_s}$) for different aluminum alloys. Thus, average magnitude of coefficient of uniformity of corrosion for alloy D16-T constituted 0.52 (with separate values, close to 0.8), for alloy AMts-M - 0.23, and for alloy AMg6-M - 0.18. For steel these values constituted, on the average 0.85.

On corrosion of aluminum alloys influence was rendered by presence in dust of metallurgical factory of iron-ore particles in the form of iron oxides.

Iron oxides, on sample in layer of dust, can render influence on course of corrosion processes, emerging as cathode particles. Under such conditions corrosion for alloy D16-T, which has, as compared to other alloys, a more positive potential, should be the least.

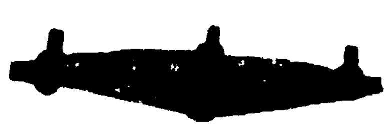

Fig. 7. Corrosion of aluminum alloy AMts-M in contact with steel under severe corrosive conditions.

Possibly, therefore, under conditions of casting yard, where in solid crust of dust existing on samples there was revealed significant quantity of magnetite $Fe_3O_4$ (40 %), large losses of weight were displayed by alloys with more negative potential (AMg6, AMts).

Of interest are results of test of certain samples from aluminum alloys which were in contact with steel.

Under conditions of stand No. 12 plate from alloy AMts in contact with steel plate was bent by accumulated products of corrosion (Fig. 7), which consisted, basically, of aluminum hydroxide. Surface of sample from alloy AMts adjacent to steel sample corroded considerably, while surface of steel plate remained almost untouched by corrosion. Loss of weight of sample of AMts turned out to be 5 times more than loss of weight of the same sample without contact with steel.

Loss of weight of steel contact plate was 3 times less than for sample without contact.

On remaining stands where there were exposed samples and where external medium was less corrosive (stands No. 2, 7, 13, and 14) upon visual inspection there were revealed no distinctions in them from ordinary samples.

On the basis of obtained results of tests, after 11 months it was possible to derive average rate of corrosion of rolled sheets from aluminum alloys after first year under different conditions (Table 12).



Table 12. Mean Value of Corrosion Losses After First Year of Rolled Sheets From Aluminum Alloys and Steel With Thickness of 3 mm Under Different Conditions

| Nature of conditions | Losses of strength in % | | | | | Depth of penetration in mm | | | | | Ratio of losses of steel to aluminum alloys | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aluminum alloys | | | | Steel | Aluminum alloys | | | | Steel | | |
| | AMts | AMg6 | D16-T | Average | St. 3 | AMts | AMg6 | D16-T | Average | St. 3 | in strength | in depth |
| Atmospheric conditions of metallurgical factory with considerable discharge of moisture, sulfurous gas, and ore dust | 10 | 14 | 8 | 10 | 30 | 0.4 | 0.2 | 0.06 | 0.2 | 0.5 | 3 | 2.3 |
| General factory and city atmosphere | 5 | 5 | 3 | 4 | 9 | 0.01 | 0.07 | 0.02 | 0.03 | 0.1 | 2.2 | 3.3 |
| Inside shop buildings with considerable discharge of moisture, sulfurous gas, and dust | 9 | 9 | 4 | 7 | 6 | 0.1 | 0.15 | 0.01 | 0.09 | 0.06 | 0.9 | 0.7 |

In comparison of corrosion resistance of aluminum alloys with steel it is clear that all aluminum alloys in most cases are superior in corrosion resistance to structural steel.

Relationship between corrosion losses of aluminum alloys and steel is not constant, but it is significantly changed, depending upon nature of corrosive medium.

Thus, for instance, losses of strength of alloy D16-T were less than losses of strength of steel in area of granulation pit by 11.5 times; in atmosphere of open-hearth shop by 2.9 times; inside casting yard by 1.8 times.

Average corrosion losses for all aluminum alloys under atmospheric conditions were approximately 3 times less than for steel.

Inside industrial buildings superiority of aluminum alloys over steel was less.

Results of first year of tests are, of course, insufficient for final conclusions concerning corrosion resistance of aluminum alloys, since their has not been definitized character of development of their corrosion in respect to time.

But already on the basis of available data, taking into account data of other investigations for a more prolonged period, it is possible to establish, for instance, permissible thicknesses of roofs from aluminum alloys for separate buildings of metallurgical factories. Thus, thickness of roof where its exploitation is to extend for 25 years may be found from Table 13.

Table 13. Permissible Thicknesses of Roofs from Aluminum Alloys in mm

| Casting bed of blast furnace | Main building of open-hearth shop | Rolling shop | |
|---|---|---|---|
| | | above mills | above pickling baths |
| 2-2.5 | 1.2-1.5 | 0.6-0.7 | 0.7-0.8 |

Table 14. Economic Effectiveness of Replacement of Steel Exterior Roofing of Industrial Buildings of Principal Workshops of Metallurgical Factory by Roofing from Aluminum Alloys, in 1960 Prices (According to Factory "Zaporozhstal'")

| Designation of workshops and buildings | Area of roof in m² | Period of service of roof in years | | Capital expenditures on roofing in thousands of rubles | | | | Savings in thousands of rubles | | Period of return of aluminum roof in years |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Steel with thickness of 2 mm | Aluminum with thickness of 1.5 mm | Steel | | Aluminum | | Overall | Per year | |
| | | | | In single replacement | By the end of service of aluminum roof | In single replacement | Savings in thousands of rubles | | | |
| Blast furnace shop | | | | | | | | | | |
| Buildings and galleries of casting machines. . . . | 3 200 | 3 | 25 | 131.5 | 1 052 | 179 | 179 | 873 | 35 | 4.1 |
| Open-hearth shop | | | | | | | | | | |
| Main body. . . . . . . . | 32 500 | 2 | 25 | 1335.4 | 16 020 | 1 816 | 1 816 | 14 204 | 588 | 2.7 |
| Mixer. . . . . . . . . . | 2 960 | 3 | 25 | 121.7 | 974 | 165 | 165 | 809 | 33 | 4.1 |
| Slabbing shop | | | | | | | | | | |
| Storehouses for slabbing mill and scrap bays . . . | 28 400 | 5* | 40 | 584 | 4 672 | 793 | 793 | 3 879 | 98 | 6.9 |
| Soaking pits . . . . . . | 14 000 | 5* | 40 | 288 | 2 304 | 391 | 391 | 1 913 | 48 | 6.9 |
| Thin-sheet workshop | | | | | | | | | | |
| Building of workshop. . . | 61 500 | 5* | 40 | 1 864 | 10 112 | 1 717 | 1 717 | 8 395 | 210 | 6.9 |
| | | | | | | | Total. | 30 073 | 944 | — |

*50% of roofing is replaced.

1. Labor-consumption of installation is taked, conditionally, the same as for steel roofing, although in reality it will be less.

Using advantage in corrosion behavior of aluminum alloys over steel, there can ever at present be realized significant economic effect.

Thus, for instance, tabulation of capital expenditures for 25 years per 1 $m^2$ of exterior roof of an industrial building made of steel and aluminum showed that initial cost per 1 $m^2$ of roof of aluminum was 40% higher than cost per 1 $m^2$ of steel roof; but after 25 years cost per 1 $m^2$ of aluminum roof becomes 6 times less than cost of steel.

Replacement of steel roof by roof from aluminum alloys may be very effective in already existing industrial buildings.

Analysis conducted jointly with factory "Zaporozhstal'" showed that with total replacement of steel roof of industrial buildings of principal workshops of factory by roof of aluminum alloys, cost of the latter is completely recompensed depending upon degree of corrosiveness of medium, in approximately 3-7 years, and the economy thus obtained, distributed evenly through whole period of service of aluminum roof, will constitute, per factory, nearly 1 million rubles per year at 1960 prices (Table 14).

Given examples show just how effective can be application of aluminum alloys in a whole series of cases, thanks to extension of period of service of structures and to lowering of operating expenditures. Here we did not consider economy realized through decrease of weight of structures.

With lowering of cost of aluminum, effect from its application in our country will grow.

## 4. Conclusions

Results given in present article of first year of corrosion tests allow us to make following, preliminary conclusions.

1. Magnitude of corrosion losses of sheets from aluminum alloys AMts-M, AMg6-M, and D16-T, and also disposition of alloys by corrosion resistance in metallurgical factories are not constants, but to large degree depend on composition and character of corrosive medium in separate places of indicated factories.

2. Is least corrosion losses under conditions of metallurgical factories were for sheets from alloy D16-T with protective plating of aluminum.

Remaining alloys in order of decrease of corrosion losses were most frequently disposed in following manner; D16-T, $AM_{ts-M}$ and AMg6-M.

3. Corrosion resistance of aluminum alloys in building structures should be estimated by losses of strength and depth of penetration of corrosion, determined by direct measurements. Weight losses due to corrosion for aluminum alloys unlike those of steel, are not representative in this respect.

4. Advantage of aluminum alloys in corrosion resistance over steel in metallurgical factories is greater in open atmospheric conditions than inside industrial buildings.

5. Structures from aluminum alloys in the whole series of corrosive media of metallurgical factories can be quite long-lasting without any protection.

Thickness of roof of buildings of principal workshops of metallurgical factories, based on its exploitation for no less than 25 years, may be taken as equal to 0.6-0.7 to 2-2.5 mm, depending upon corrosiveness of industrial conditions.

6. Application of aluminum alloys in roofs of buildings of metallurgical factories is at present already economically profitable, because of extension of period of service of roof and lowering of operating expenditures.

7. For final conclusions concerning corrosion resistance of investigated aluminum alloys it is necessary to obtain results of corrosion tests after long period of time (3-5 years).

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18. "Revue de l' Aluminum," 1957, 249.

19. "Metallurgia," 1953, V. 47, No. 283.

20. "Metal Industry," 1949, V. 74, No. 15.

4) stresses obey identical dependence $\sigma(\varepsilon)$, both during tension and compression,

5) stresses grow monotonically;

6) tangential stresses are not considered;

7) axis of beam does not twist.

Weinhold, for construction of tables not depending on yield points of different grades of aluminum alloys, uses following dimensionless parameters.

Relative stress

$$\bar{\sigma} = \frac{\sigma}{\sigma_T}$$

($\sigma_T$ - yield point)

specific conditional elongation

$$\bar{\varepsilon} = \frac{\varepsilon}{\varepsilon_T} = \frac{\varepsilon E}{\sigma_T}.$$

Relative critical stress

$$\bar{\sigma}_k = \frac{\sigma_k}{\sigma_T}.$$

Relative flexibility

$$\bar{\lambda} = \frac{\lambda}{\lambda_d},$$

where $\lambda_d$ is determined from expression

$$\sigma_T = \frac{\pi^2 E}{\lambda_d^2}.$$

Hence $\bar{\lambda} = \frac{\lambda}{\pi}\sqrt{\frac{\sigma_T}{E}}$.

Relative curvature

$$x = \frac{h}{\rho} \cdot \frac{E}{\sigma_T} = \bar{\varepsilon}_d - \bar{\varepsilon}_z,$$

where $\varepsilon$ - specific elongation;

h - height of section;

$\rho$ - radius of curvature;

$$\bar{\varepsilon}_d = \frac{\varepsilon_d}{\varepsilon_T}; \quad \bar{\varepsilon}_z = \frac{\varepsilon_z}{\varepsilon_T};$$

$\varepsilon_d$, $\varepsilon_z$ - relative edge deformations respectively for concave and convex sides of beam.

Relative average compressing stress $\bar{\sigma}_a = \frac{N}{F} \cdot \frac{1}{\sigma_T}$ (F - area of section).

Relative edge compressing bend stress

$$\bar{\sigma}_b = \frac{M}{W_d} \cdot \frac{1}{\sigma_T}.$$

Here $W_d$ - moment of resistance of section for outer compressed fiber.

Relative compressing stresses $\bar{\sigma}_a$ and $\bar{\sigma}_b$ can be expressed as functions of $x$ and $\bar{\varepsilon}_z$:

$$\bar{\sigma}_a = f_1(x, \bar{\varepsilon}_z);$$
$$\bar{\sigma}_b = f_2(x, \bar{\varepsilon}_z).$$

After exclusion of $\bar{\varepsilon}_z$ from the latter of two equations, which is done graphically, there is obtained expression for so-called basic curves

$$\bar{\sigma}_b = f_3(x, \bar{\sigma}_a). \qquad (1)$$

Here $\bar{\sigma}_a$ is considered as parameter.

For aluminum alloys, primary diagram of which does not have yield points, conditional yield point is taken equal to stress corresponding to relative permanent set at 0.2 %. Limit of proportionality is taken by Weinhold, with allowance for all aluminum alloys equal to $\sigma_p = 0{,}5\sigma_T$.

In elastic region, where we apply Hooke's law, i.e., when

$$\bar{\sigma} \leqslant 0{,}5, \quad \bar{\varepsilon} = \frac{\varepsilon E}{\sigma_T} = \frac{\varepsilon E}{\sigma}\bar{\sigma} = \bar{\sigma}.$$

For elastic-plastic region ($\bar{\sigma} > 0{,}5$) there is taken following analytic expression (with transfer beginning of coordinates to point $\bar{\sigma}_p = \bar{\varepsilon}_p = 0{,}5$)

$$\bar{\sigma} - \bar{\sigma}_p = 0{,}70029 - 0{,}51718e^{-x} + 0{,}0218e^{-2x} - 0{,}29322e^{-3x} + 0{,}08831e^{-4x}. \qquad (2)$$

Here $x = \bar{\varepsilon} - \bar{\varepsilon}_p$;

$\bar{\sigma}_p$ and $\varepsilon_p$ - correspond to limit of proportionality.

At $\bar{\varepsilon} \to \infty$, $\bar{\sigma} \to$ 1.20029.

Values of $\bar{\sigma}$, calculated by formula (2), are given in Table 1.

Subsequently, Weinhold applied approximate graphoanalytical method of Rosh-Brunner, based on replacement of form of distortion of beam by half-wave of sinusoid and fulfillment of conditions of equilibrium of external and internal forces in middle section. Here there was used equation (1), which at given $\bar{\sigma}_a$ establishes dependence between moment of internal forces (or of magnitude proportional to it $\sigma'_b$) and curvature of axis.

As a result, for certain types of sections there were composed tables, and graphs were drawn for average relative critical stress $\bar{\sigma}_{cr} = \frac{N}{F_{br}} = \varphi_{ecc}$ depending upon relative flexibility $\bar{\lambda} = \frac{\lambda}{\pi}\sqrt{\frac{\sigma_T}{E}}$ and on relative eccentricity $m = \frac{aF}{W_d}$, where a - absolute eccentricity.

Table 1. Values of $\bar{\sigma}$ by Formula (2)

| $\bar{\varepsilon}$ | $\bar{\sigma}$ | $\bar{\varepsilon}$ | $\bar{\sigma}$ | $\bar{\varepsilon}$ | $\bar{\sigma}$ |
|---|---|---|---|---|---|
| <0,5 | $\bar{\sigma} = \bar{\varepsilon}$ | 2 | 1,0829 | 3,6 | 1,177 |
| 0,5 | 0,5 | 2,1 | 1,0945 | 3,7 | 1,1792 |
| 0,6 | 0,5921 | 2,2 | 1,1048 | 3,8 | 1,1812 |
| 0,7 | 0,6702 | 2,3 | 1,1141 | 3,9 | 1,183 |
| 0,8 | 0,7362 | 2,4 | 1,1225 | 4 | 1,1847 |
| 0,9 | 0,7927 | 2,5 | 1,13 | 4,1 | 1,1862 |
| 1 | 0,8412 | 2,6 | 1,1368 | 4,2 | 1,1875 |
| 1,1 | 0,8826 | 2,7 | 1,1428 | 4,3 | 1,1887 |
| 1,2 | 0,9183 | 2,8 | 1,1483 | 4,4 | 1,1898 |
| 1,3 | 0,9494 | 2,9 | 1,1533 | 4,5 | 1,1908 |
| 1,4 | 0,9763 | 3 | 1,1578 | 4,6 | 1,1917 |
| 1,5 | 1 | 3,1 | 1,1618 | 4,7 | 1,1925 |
| 1,6 | 1,021 | 3,2 | 1,1655 | 4,8 | 1,1932 |
| 1,7 | 1,0393 | 3,3 | 1,1689 | 4,9 | 1,1939 |
| 1,8 | 1,0554 | 3,4 | 1,1719 | 5 | 1,1945 |
| 1,9 | 1,0699 | 3,5 | 1,1746 | ∞ | 1,2003 |

By Weinhold there were obtained tables and graphs for idealized profile from two strips (without web), for rectangular section, and for tee section composed of two equally - bent angles. In last case there are considered eccentricities both on flange side and also on feather-side.

In SN 113-60 there are added tables for I-beam sections with eccentricity in plane of web plate or normal to it. For first case values of $\varphi$ were obtained as partial sum of values of $\varphi$ for rectangular section and idealized profile.

For second case values of m are multiplied by coefficient (in NiTU 121-55)

$$\eta = 0{,}775 + 0{,}0015\lambda \quad \text{when} \quad 20 \le \lambda \le 150 .$$

By thus modified values of m from Weinhold table for rectangular section there were obtained sought values of $\varphi$.

Here for all alloys there mean value $\lambda$, was taken, corresponding to alloy

AV-T1 for which

$$\eta = 0{,}775 + 0{,}0015\,\pi\sqrt{\frac{E}{2{,}1}}\,\bar{\lambda} = 0{,}775 + 0{,}086\,\bar{\lambda}.$$

Of interest is comparison of values of coefficients of $\varphi$, calculated by the formulas and tables of SN 113-60, with results of calculation for outer yield, for instance, by the Reinhold formula [5], which is reduced to following form:

$$\sigma + \sigma m \frac{1}{1 - \frac{\sigma}{\sigma_E}} = \sigma_T, \tag{3}$$

where $\sigma_E = \frac{\sigma_T}{\bar{\lambda}^2}$ -Euler stress.

Hence

$$\bar{\sigma} = 0{,}5\left(1 + \frac{1+m}{\bar{\lambda}^2}\right) - \sqrt{0{,}25\left(1 + \frac{1+m}{\bar{\lambda}^2}\right)^2 - \frac{1}{\bar{\lambda}^2}}. \tag{4}$$

We shall make comparison at m = 1. Results of comparison for rectangular sections are given in Table 2.

Table 2. Values of $\varphi_{ecc}$ in SN 113-60 and of $\bar{\sigma}$ by Formula (4) at m = 1

| $\bar{\lambda}$ | 0,4 | 0,6 | 0,8 | 1 | 1,2 | 1,4 | 2 | 2,4 | 2,6 |
|---|---|---|---|---|---|---|---|---|---|
| $\varphi_{ecc}$* | 0,685 | 0,582 | 0,49 | 0,411 | 0,345 | 0,291 | 0,181 | 0,137 | 0,12 |
| $\bar{\sigma}$** | 0,5 | 0,458 | 0,422 | 0,352 | 0,34 | 0,295 | 0,19 | 0,141 | 0,128 |
| $\frac{\varphi}{\bar{\sigma}}$ | 1,37 | 1,26 | 1,16 | 1,08 | 1,02 | 1 | 0,96 | 0,95 | 0,93 |

*In SN 113-60.
** By formula (4).

Thus, calculation of fiber yield (4) with low flexibilities gives excessive reserve, with high - there is no reserve for deflection. For other types of sections deflection without reserve (at m = 1) may be greater.

In case of change of bending moment through length of beam calculated moment is determined just as per NiTU 121-55 [1], with the exception of beams with hinge-supported ends, for which there are given more exact formulas, obtained on the basis of works of Ellis [6], Galambos and Ketter [7].

b) Bend-Twist Form of Buckling

Absence of theoretical and experimental materials for foundation of methods of check of strength of eccentrically- compressed beams from aluminum alloys, with respect to bend-twist form of buckling, compels us to use formulas given in technical specs on designing of steel structures [1]:

$$\frac{N}{c\varphi_y F} \leq R; \quad c = \frac{\beta}{1+\alpha m_x},$$

where $m_x$ - relative eccentricity

$\lambda_c$ - flexibility, at which in case of axial compression critical stress is equal to limit of proportionality, is determined by the formula

$$\lambda_c = \pi\sqrt{\frac{E}{\sigma_p}}. \quad (5)$$

Values of coefficient $\beta = \frac{\varphi_c}{\varphi_y}$ at $\lambda_y > \lambda_c$ and of flexibility $\lambda_c$ depend on mechanical characteristics of material.

For considered alloys, with the exception of V-TI and AD33-T1, limit of proportionality is taken equal to $\frac{2}{3}\sigma_T$.

Then

$$\lambda_c = \pi\sqrt{\frac{E}{\sigma_T}\cdot\frac{3}{2}} \approx 102\frac{1}{\sqrt{\sigma_T}}.$$

Here $\sigma_T$ is given in t/cm$^2$.

Values of $\varphi_c$ corresponding to flexibilities $\lambda_c$, are determined by table of longitudinal bend. The biggest values of coefficient c at $\lambda_y > \lambda_c$ corresponding to buckling in elastic region, are calculated by the formula of theory of thin-webbed beams [8], which in case of section with two axes of symmetry may be reduced to form

$$\left(\frac{M}{M_0}\right)^2 - \left(1 - \frac{N}{N_y}\right)\left(1 - \frac{N}{N_\omega}\right) = 0. \quad (6)$$

If we disregard member $\frac{N}{N_\omega}$, then equation (6) changes to equation of Timoshenko [9]:

$$\left(\frac{M}{M_0}\right)^2 + \frac{N}{N_y} = 1. \quad (7)$$

Here $M_0$ - critical moment during bend only;

$N_y$ - Euler force;

$N_\omega$ - critical force during purely twisting form of buckling.

Equation (7) may be written in the following form:

$$\left(\frac{N}{N_y}\right)^2 \beta^2 + \frac{N}{N_y} - 1 = 0,$$

where

$$\beta^2 = \frac{e_y^2 N_y^2}{M_0^2} = \frac{e_y^2 N_y}{r^2 N_\omega} = \frac{e_y^2}{\frac{I_\omega}{I_y} + \frac{I_k l^2}{I_y 2{,}6\pi^2}} \approx \left(\frac{e_y}{h}\right)^2 \frac{4}{1+0{,}1\alpha};$$

$$\alpha = 1{,}54 \frac{I_k}{I_y}\left(\frac{l}{h}\right)^2 \approx \left(\frac{l\delta_1}{bh}\right)^2\left(1 + \frac{h\delta^3}{2b\delta_1^3}\right). \quad (8)$$

Taking mean value $\frac{h\delta^3}{2b\delta_1^3}$ = 0.25, we obtain

$$\beta^2 = \left(\frac{e_y}{h}\right)^2 \frac{4}{1+\left(\frac{l\delta_1}{bh}\right)^2} \quad (9)$$

In Table 27 of SN 113-60 there are given values of coefficients $c = \frac{N}{N_y}$, calculated by formulas (9) and (8) at $\frac{l\delta_1}{bh}$ from 0.1 to 1.

In Table 24 of NiTU 121-55 [1] there are given values of c at mean value $\beta = 1{,}7\frac{e}{h}$, which corresponds to $\frac{l\delta_1}{bh}$ = 0.615.

Normative resistances of alloys AV-T1 and AD33-T1 are lower than limits of proportionality. On this basis it is possible to ignore influence of transition of stresses beyond the limits of proportionality and to determine coefficient c according to elastic stage of work, i.e., according to the table of maximum values (table 27 SN 113-60).

For beams of closed section, continuous either with planks or lattices, it is possible to disregard torsion and to take in formula (20) [1] $\alpha$ = 0.7 for all alloys, with the exception of AV-T1 and AD33-T1.

For alloys AV-T1 and AD33-T1 we may disregard check of plane of moment, taking c = 1.

In case of change of bending moment through length of beam in SN 113-60 there are kept recommendations of NiTU 121-55, but calculated moment is taken as not less than half of the biggest moment through length of beam. This limitation is introduced on the basis of works of Campus and Massonnet [10].

## 2. Axial Compr ssion

Owing to inevitable accidental eccentricities and initial distortions, centrally compressed beams are esentially compression - bent beams. Therefore, coefficients of longitudinal bend are calculated just as for eccentrically compressed beams. However, calculated load must also not exceed the Euler value, divided into additional safety factor, taken by us as equal to 1.3. Second check is conclusive with high flexibilities, when influence of eccentricity decreases.

Magnitudes of relative accidental eccentricities are taken according to French, English, and American data: for mild alloys AMts-M and AMg-M $m = 0.0075\lambda$ for remaining alloys $m = 0.003\lambda$ where $\lambda$ - the highest flexibility of beam.

Calculation of coefficients $\varphi$ was performed with help of above mentioned tables of $\varphi_{ecc}$ for rectangular section, and for alloys AMg, AV-T1, and D16-T - also for tee section with eccentricity on feather side. Results of calculations are given in Tables 3 and 4 and in Fig. 1* and 2.

Divergences in magnitude of coefficients $\varphi$, calculated for two types of sections (Fig. 1), do not exceed 8%. On this basis for all types of sections there are taken coefficients $\varphi$, calculated for rectangular sections, especially as they occupy intermediate positions between values of $\varphi$ of different types of sections.

With relatively high flexibilities check is conclusive without calculation of accidental eccentricities (due to Euler force). With safety factor, with respect to Euler force, equal to i.e., coefficient of longitudinal bend is

$$\varphi = \frac{\pi^2 E}{1.3\lambda^2 \sigma_T} = \frac{5320}{\lambda^2 \sigma_T}. \qquad (10)$$

In Table 5 there are given values of $\varphi$, calculated by formula (10).

Values of coefficients $\varphi$, calculated by formula (10) for alloys AMts-M and AMg-M $\lambda > 150$, are greater than values determined with respect to accidental eccentricities.

*In Fig. 1 upper curves (each pair) pertain to rectangular sections; lower - to tee.

Table 3. Values of λ, m, φ for Rectangular and Tee Sections of Alloys AMg, AV-T1, and D16-T

| (a) Class | $\bar{\lambda}$ | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.4 | 1.6 | 1.8 | 2 | 2.2 | 2.4 | 2.6 | 2.8 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMg | λ | 37,16 | 55,74 | 74,32 | 92,9 | 111,48 | 130,06 | 148,64 | 167,22 | 185,8 | — | — | — | — | — |
| | $m$ | 0,2788 | 0,4182 | 0,5576 | 0,697 | 0,8364 | 0,9758 | 1,1152 | 1,2546 | 1,395 | — | — | — | — | — |
| | $\varphi_{прям}$ (b) | 0,897 | 0,725 | 0,575 | 0,456 | 0,363 | 0,297 | 0,24 | 0,199 | 0,168 | — | — | — | — | — |
| | $\varphi_{тавр}$ (c) | 0,833 | 0,669 | 0,534 | 0,429 | 0,344 | 0,282 | 0,233 | 0,195 | 0,165 | — | — | — | — | — |
| AV-T1 | λ | 22,95 | 34,44 | 45,92 | 57,4 | 68,9 | 80,36 | 91,84 | 103,32 | 114,8 | 126,28 | 137,76 | 149,24 | 160,72 | 172,2 |
| | $m$ | 0,0688 | 0,1032 | 0,1376 | 0,172 | 0,2064 | 0,2408 | 0,2752 | 0,3096 | 0,344 | 0,3784 | 0,4128 | 0,4472 | 0,4816 | 0,516 |
| | $\varphi_{прям}$ (b) | 0,992 | 0,848 | 0,712 | 0,586 | 0,474 | 0,384 | 0,313 | 0,257 | 0,213 | 0,179 | 0,153 | 0,132 | 0,114 | 0,1 |
| | $\varphi_{тавр}$ (c) | 0,963 | 0,708 | 0,671 | 0,557 | 0,458 | 0,375 | 0,306 | 0,252 | 0,211 | 0,178 | 0,148 | | | |
| D16-T | λ | 18,88 | 28,32 | 37,76 | 47,2 | 56,64 | 66,08 | 75,52 | 84,96 | 94,4 | 103,84 | 113,28 | 122,72 | 132,16 | 141,6 |
| | $m$ | 0,566 | 0,085 | 0,1133 | 0,1416 | 0,167 | 0,198 | 0,227 | 0,255 | 0,283 | 0,3115 | 0,34 | 0,368 | 0,3914 | 0,4248 |
| | $\varphi_{прям}$ (b) | 0,998 | 0,859 | 0,724 | 0,598 | 0,487 | 0,394 | 0,322 | 0,264 | 0,219 | 0,183 | 0,155 | 0,134 | 0,117 | 0 102 |
| | $\varphi_{тавр}$ (c) | 0,978 | 0,819 | 0,681 | 0,569 | 0,473 | 0,385 | 0,315 | 0,26 | 0,216 | 0,182 | 0,156 | — | — | — |

KEY: (a) Alloy; (b) rectangular; (c) tee.

Table 4. Values of λ, m, and φ for Rectangular Section of Alloys AMts-M, AV-T, and AMg6-M

| Alloys | $\bar{\lambda}$ | 0.4 | 0.6 | 0.8 | 1 | 1.2 | 1.4 | 1.6 | 1.8 | 2 | 2.2 | 2.4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMts-M | λ | 41,6 | 62,4 | 83,2 | 104 | 124,8 | 145,6 | 166,4 | — | — | — | — |
| | φ | 0,312 | 0,468 | 0,624 | 0,78 | 0,936 | 1,092 | 1,248 | — | — | — | — |
| | $m$ | 0,884 | 0,71 | 0 56 | 0,442 | 0,355 | 0,284 | 0,231 | — | — | — | — |
| AV-T | λ | 29,76 | 44,64 | 59,52 | 74,4 | 89,28 | 104,16 | 119,04 | 133,92 | 148,8 | 163,68 | — |
| | $m$ | 0,0892 | 0,1338 | 0,1784 | 0,223 | 0,2674 | 0,3122 | 0,3558 | 0,4014 | 0,446 | 0,4906 | — |
| | φ | 0,98 | 0,834 | 0,693 | 0,567 | 0,458 | 0,37 | 0,301 | 0,247 | 0,207 | 0,174 | — |
| AMg6-M | λ | 26,24 | 39,36 | 52,48 | 65,6 | 78,72 | 91,84 | 104,96 | 118,08 | 131,2 | 144,32 | 157,44 |
| | $m$ | 0,0788 | 0,1182 | 0,1576 | 0,197 | 0,2364 | 0,2758 | 0,3152 | 0,3546 | 0,394 | 0,4334 | 0,4728 |
| | φ | 0,985 | 0,841 | 0,703 | 0,575 | 0,466 | 0,377 | 0,307 | 0,252 | 0,21 | 0,177 | 0,151 |

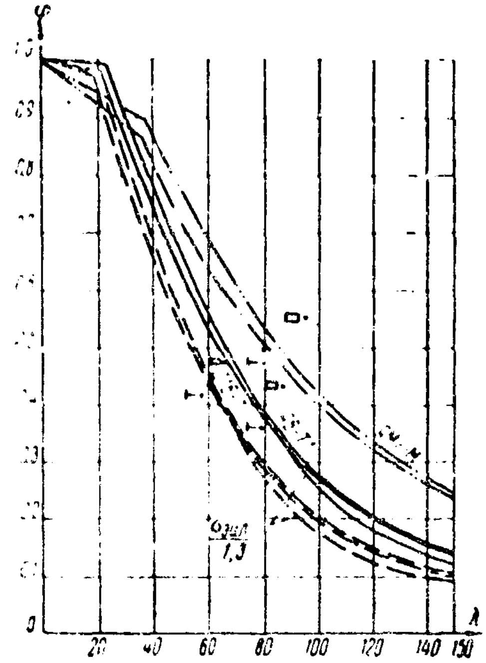


Fig. 1. Calculation of coefficient φ for alloys AMg-M, AV-T1, and D16-T.

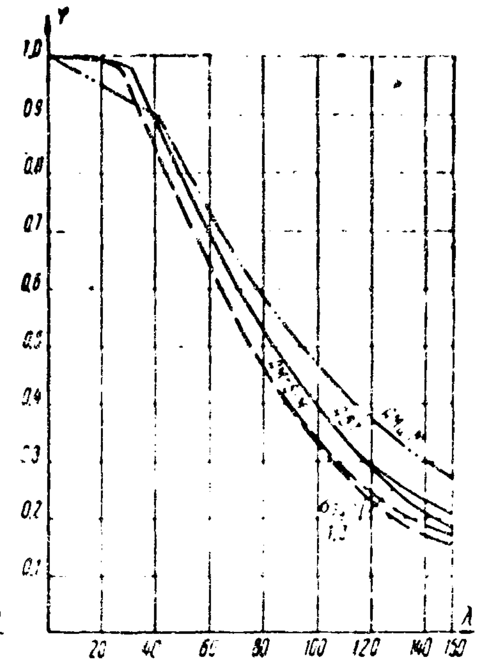


Fig. 2. Calculation of coefficient φ for alloys AMts-M, AV-T, and AMg6-M.

Table 5. Values of φ by Formula (10)

| (a) Сплавы | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
|---|---|---|---|---|---|---|---|---|---|
| AV-T | — | — | — | 0,408 | 0,335 | 0,263 | 0,241 | 0,208 | 0,161 |
| [illegible] | — | — | — | 0,332 | 0,273 | 0,23 | 0,196 | 0,169 | 0,147 |
| [illegible] | — | — | 0,345 | 0,28 | 0,23 | 0,194 | 0,165 | 0,143 | 0,124 |
| [illegible] | — | — | 0,312 | 0,252 | 0,208 | 0,175 | 0,15 | 0,129 | 0,115 |
| [illegible] | — | — | 0,286 | 0,231 | 0,19 | 0,16 | 0,136 | 0,118 | 0,103 |
| [illegible] | 0,352 | 0,268 | 0,2[illegible] | 0,171 | 0,142 | 0,118 | 0,101 | 0,087 | 0,076 |

KEY: (a) Alloys.

At $\lambda = 150$ for AMts-M $\frac{\varphi_{\text{Eul}}}{1.3} = 0.395 > 0.27$,

for AMg-M $\frac{\varphi_{\text{Eul}}}{1.3} = 0.295 > 0.235$.

By Figs. 1 and 2 there are determined coefficients φ, corresponding to whole values of λ.

## 3. Overall Strength Beams

Method of check of strength of beams is the same as for steel beams [1]. Values of coefficients ψ for beams of steel given in Table 9 of appendix IV [1], are calculated by the formulas and tables of S. P. Timoshenko [11] at E = 2100 t/cm$^2$ and $\sigma_T$ = - t/cm$^2$. Critical stresses are directly proportional to modulus of longitudinal elasticity, but values of coefficients ψ furthermore, are reciprocals of yield point.

Values of $\psi$, given for alloy D16-T, elastic modulus of which $E = 700$ t/cm$^2$ and conditional yield point $\sigma_T = 3.1$ t/cm$^2$, were obtained by multiplication of values of coefficients $\psi$ for steel by $\frac{700}{2100} \times \frac{2.4}{3.1} = 0.258$.

For other aluminum alloys values of $\psi$ are reciprocal to calculated resistances Ratio of shear modulus to modulus of longitudinal elasticity for steel is

$$\frac{G}{E} = \frac{1}{2(1+0{,}3)} = 0{,}385.$$

For aluminum alloys ratio $\frac{G}{E}$ may be taken equal to 0.375 [12].

Owing to insignificant difference of ratios $\frac{G}{E}$ we take formula for calculation of parameter $\alpha$ the same as for steel

$$\alpha = \frac{4GI_k}{EI_y}\left(\frac{l}{h}\right)^2 = 8\left(\frac{l\delta_1}{bh}\right)^2\left(1+\frac{d\delta^3}{b\delta_1^3}\right). \qquad (11$$

Stress, with respect to passage beyond the limits of proportionality ($\sigma_1$) is determined from expression analogous to formula of Yasinskiy [13]:

$$\frac{\sigma_1}{\sigma_T} = a - b\sqrt{\frac{E\sigma_T}{\sigma}}. \qquad (12$$

Here $\sigma$ - stress calculated without regard for influence of passage beyond the limits of proportionality.

Satisfying conditions

$$\frac{\sigma_1}{\sigma_T} = \frac{2}{3} \text{ when } \frac{\sigma}{\sigma_T} = \frac{2}{3};$$

$$\frac{\sigma_1}{\sigma_T} = 1 \text{ when } \frac{\sigma}{\sigma_T} = 4{,}5,$$

we obtain

$$\frac{\sigma_1}{\sigma_T} = 1{,}21 - 0{,}442\sqrt{\frac{\sigma_T}{\sigma}}. \qquad (13$$

Hence coefficient of decrease of modulus of longitudinal elasticity during passage beyond the limits of proportionality

$$\nu = \frac{\sigma_i}{\sigma} = \frac{(1{,}21-\sigma_1)^2\sigma_1}{0{,}442^2}. \qquad (14$$

Loss of strength of plane deformation of beams occurs under conditions of complex load: to bend in plane of the highest rigidity there are applied bend and torsion in plane of least rigidity. As experiments showed with samples from aluminum alloys [14], shear modulus at initial moment of twist has the same value as in elastic region.

If on this basis we take shear modulus as constant, then correction factor applied to magnitude of critical stress during passage beyond the limits of proportionality will be equal to

$$\vartheta = \sqrt{\nu}. \quad (15)$$

Substituting in equation (15) expression (14) and $\sigma_1 = \vartheta\sigma$, after transformations we obtain

$$\vartheta = \frac{(1.21\sigma^2 + 0.093) - \sqrt{(1.21\sigma^2 + 0.093)^2 - 1.464\sigma^4}}{\sigma^2}. \quad (16)$$

By formula (16) there were calculated values of $\vartheta$ and $\varphi_6' = \vartheta\varphi_6$, given in SN 113-60. Since for alloy AVT-1 and AD33-T1 limit of proportionality is near yield point, correction for passage beyond the limits of proportionality for them is not applied.

Table of the biggest ratios $\frac{l}{b}$, at which no check is required of strength of beams, was composed more specifically than corresponding table in NiTU 121-55. This allows us to make more beams, that do not require check of strength.

## 4. Check of Strength of Web Plates in Beams

Method of check of strength of web plates in beams from light alloys in principle does not differ from method presented in literature for strength of plates [15] in reference to steel beams. At the same time, this method differs from method recommended in NiTU 121-55, which is explained by certain peculiarities of stress-strain diagram in light alloys.

It is known that in majority of light alloys limit of proportionality $\sigma_p$ constitutes significantly smaller share of conditional yield point $\sigma_T$, than in steel. Thus, according to VIAM, [All-Union Scientific Research Institute of Aviation Materials] for AMg6 ratio $\sigma_p/\sigma_T$ constitutes from 0.45 (profile) to 0.71 (sheet). The same ratio for steel (St 3) varies from 0.85 to 0.9. It follows from this that in beams from light alloys check of strength should be made on the basis of real and not idealized diagram, taken during composition of corresponding section of "Technical Specs of Designing of Steel Structures" (NiTU 121-55).

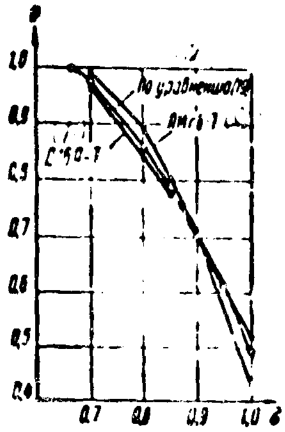

Fig. 3. Curves of $\vartheta$ for alloys AMg6 and D16-AT. KEY: (a) According to equation (19); (b) D16A-T; (c) AMg6-T.

For appraisal of influence of passage of stresses beyond the limits of proportionality in beams from light alloys there were used results of general Il'yushin – Stouell theory [16] for plates evenly compressed in one direction. In case of freely supported, infinitely long plate coefficient of decrease of critical stress with respect to limitless elastic plate is equal to

$$\vartheta_0 = \frac{E_s}{2E}\left(1 + \sqrt{\frac{1}{4} + \frac{3}{4}\cdot\frac{E_t}{E_s}}\right), \quad (17)$$

where $E_s$, $E_t$, $E$ – are respectively secant, tangential modulus, and modulus of longitudinal elasticity.

For infinitely long plate with fixed sides

$$\vartheta_1 = \frac{E_s}{E}\left(0{,}352 + 0{,}648\sqrt{\frac{1}{4} + \frac{3}{4}\cdot\frac{E_t}{E_s}}\right). \quad (18)$$

For plate with elastically pinched edges it is possible to take partial sum of expressions (17) and (18):

$$\vartheta = 0{,}5(\vartheta_0 + \vartheta_1).$$

On graph (Fig. 3) there are given curves of $\vartheta$, plotted alloys AMg6 (sheet) and D16-AT, according to VIAM. Here there is also plotted curve based on equation

$$\vartheta = \frac{1}{4}\left[2 + 9\bar{\sigma}(1 - \bar{\sigma})\right], \quad \frac{2}{3} \leqslant \bar{\sigma} < 1, \quad (19)$$

where $\bar{\sigma} = \sigma/\sigma_T$ – "dimensionless" stress. Formula (19) is recommended to be applied in practical calculations for all alloys, besides AV-T1 and AD33-T1, of which we shall speak below. Values of $\vartheta$, taken in SN 113-60 (Table 36) were calculated by the formula (19).

For transition from uniform compression to biaxial state of strain there is made provision: instead of magnitude $\bar{\sigma}$ to calculate dimensionless intensity of stresses $\bar{\sigma}_i = \sigma_i/\sigma_T$ at certain internal point of compressed zone. Such point in the absence of longitudinal rib is taken at distance of 2/3 of height of compressed zone from neutral axis.

$$\bar{\sigma}_i = \frac{1}{R}\sqrt{\left(\frac{2}{3}\sigma\right)^2 + 3\tau^2}. \tag{20}$$

Here $\sigma$ - calculated marginal normal stress, $\tau$ - calculated average tangential stress, but instead of $\sigma_i$ we substitute calculated resistance R.

In the presence of longitudinal rib at distance $b_1$ from calculated compressed margin of web plate $\bar{\sigma}_i$ is calculated at center of plate, located between rib and indicated margin

$$\bar{\sigma}_i = \frac{1}{R}\sqrt{\sigma^2\left(1 - \frac{b_1}{h_0}\right)^2 + 3(0,9\tau)^2}, \tag{21}$$

where $h_0$ - calculated height of web plate.

Values of $\bar{\sigma}_i > 1$ are considered impermissible in view of excessive development of plastic flows in web plate.

Let us assume that within limits of elasticity, check of strength is reduced to inequality

$$\Phi\left(\frac{\sigma}{\sigma_0}, \frac{\sigma_M}{\sigma_{M0}}, \frac{\tau}{\tau_0}\right) \leqslant m. \tag{22}$$

Here $\Phi$ - uniform function of first degree;

$\sigma_M$ - calculated normal stress, perpendicular to axis of beam;

$\sigma_0, \sigma_{M0}, \tau_0$ - critical values of one of stresses $\sigma$, $\sigma_M$ and in the absence of other two;

$m$ - coefficient, considering influence of initial distortion of web plate (in jib beams m = 0.9; in other beams m = 1).

If one were to assume proportional growth of all components of state of strain, then quality $1/\Phi$ constitutes safety factor. During transition beyond the limits of elasticity ($\bar{\sigma}_i > 2/3$) we make assumption that true safety factor decreases in ratio $\vartheta : 1$, where $\vartheta$ is by formula (19) as function of $\bar{\sigma}_i$. Check of strength takes form

$$\Phi\left(\frac{\sigma}{\sigma_0}, \frac{\sigma_M}{\sigma_{M0}}, \frac{\tau}{\tau_0}\right) \leqslant m\vartheta. \tag{23}$$

In certain cases, for instance during check of web plate strenghtened by longitudinal stiffener, function $\Phi$ is nonuniform polynomial; however, members of polynomial disturbing homogeneity are small compared to other members, therefore, condition (23) with certain degree of approximation may be used.

In alloys AV-T1 and AD33-T1 there is taken lowered value of normative resistance as a result of which these materials are used only within limits of elasticity, and for them one should always take $n = 1$.

For web plates strengthened only by transverse stiffeners:

$$\Phi\left(\frac{\sigma}{\sigma_0}, \frac{\sigma_M}{\sigma_{M0}}, \frac{\tau}{\tau_0}\right) = \sqrt{\left(\frac{\sigma}{\sigma_0} + \frac{\sigma_M}{\sigma_{M0}}\right)^2 + \left(\frac{\tau}{\tau_0}\right)^2}. \qquad (24)$$

As compared to formula (34) from NiTU 121-55, here under radical there is omitted member

$$\frac{1}{6}\cdot\frac{\sigma\tau}{\sigma_0\tau_0},$$

comparatively little affecting results.

Web plate is considered elastically pinched at webs and values $\sigma_0$, $\sigma_{M0}$, $\tau_0$ differ from corresponding magnitudes for steel web plates only by factor of 1/3, equal to ratio of elastic moduli of aluminum alloys and steel;

In case of web plate strengthened by longitudinal stiffener, during check of first plate (between compressed web and rib) there is taken

$$\Phi = \frac{\sigma}{\sigma_{01}} + \frac{\sigma_M}{\sigma_{M01}} + \left(\frac{\tau}{\tau_{01}}\right)^2. \qquad (25)$$

Expressions for $\sigma_{01}$, $\sigma_{M01}$ are somewhat definitized, as compared to formulas (43), (44) from NiTU 121-55.

Formula for calculation of second plate (between rib and stretched flange) remained the same as in NiTU 121-55).

Considerably more precise definition is introduced in method of determination of necessary moment of inertia of longitudinal rib. It consists in differentation of coefficients $c_1$ and $c_2$ in formula

$$J = \left(c_1 - c_2\frac{a}{h_0}\right)\frac{a^2}{h_0}\delta^3 \qquad (26)$$

(a - distance between transverse ribs; $\delta$ - thickness of web plate, which leads to decrease of J with increase of $b_1/h_0$ ($b_1$ - distance from compressed edge of web plate to rib).

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# EXPERIMENTAL INVESTIGATION OF LOCAL STRENGTH OF ANGULAR PROFILES FROM ALLOY D16-T

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Economy of profiles in significant degree depends on relationships of dimensions of their sides and thicknesses: the higher it is the thinner the flange can be made of elements working under compression and wall of elements working against bend. Magnitude of limiting ratio of width of wall or flange to thickness is determined by local strength. In spite of available investigations in this field, both in this country and abroad fully reliable recommendations for selection of this magnitude are lacking, especially if we have in mind big profiles from aluminum alloys for building parts.

In connection with this there was undertaken experimental investigation of local strength, results of which are used during development of assortment of profiles and have to be considered during designing of profiles for special purpose.

Investigation of strength of angular profiles from alloy D16-T had to give us possibility of more exact determination of dependence of critical stresses of local strength on ratio of width of flange to its thickness, to give us dependence between these ratios and flexibility of beams i.e., to establish connection between total and local strength to reveal influence of reinforcements of flanges of angles with thickenings (beads) on local strength of flanges, and to determine the most expedient dimensions and form of these beads.

For solution of these problems there were conducted three series of experiments, not counting preliminary series, which allowed us to establish optimum dimensions of samples. For obtaining by experimental means of dependence of critical stresses of local strength of equilateral angles without beads on ratio of width of flange to its thickness there were tested samples of first series.

In second series there were investigated samples with beads.

In third series we examined unequilateral angles without beads, with one bead on wide flange, and with beads on both flanges.

## 1. Material and Samples

In planning of investigation for tests there were required samples of various form and dimensions. To prepare them in appropriate factory by usual method - pressing - turned out to be difficult for organizational reasons.

Because of this, samples were prepared by means of machining on planing and milling machines for large profiles from alloy D16-T - angle 120 X 120 X 10 mm and angle 65 X 65 X 10 mm, which had characteristics:

ultimate strength . . . . . . . . . . . . . . . . . . 4880 kg/cm$^2$

conditional yield point . . . . . . . . . . . . . . 3770 kg/cm$^2$

specific elongation $\epsilon$ . . . . . . . . . . . . . . . . . . 12.6 %

modulus of longitudinal elasticity E . . . . . . . . .719,000 kg/cm$^2$

specific gravity $\gamma$ . . . . . . . . . . . . . . . . . . . 2.79 g/cm$^3$

According to analysis, chemical composition of alloy turned out to be the following (in %): copper 3.93, magnesium 1.1, manganese 0.61; impurities of silicon 0.5, the remainder aluminum; alloying additions and impurity of silicon - within limits of norm, according to All- Union Government Standard 4784-49.

For appraisal of influence of treatment on mechanical properties of material there were tested standard samples taken directly from prepared profiles. These tests confirmed complete invariability of magnitudes of conditional yield point and ultimate strength fixed for initial profile.

In first series we tested 23 equilateral angles with ratio $b_n/\delta$ from 4 to 33; maximum dimension of angle - 120 X 120 mm.

Samples of second series of experiments are shown in Fig. 1. Here, along with angles No. 101, having trapezoidal beads with thickness $3\delta$ and radii of curvature between flanges equal to $2\delta$ we tested profiles of assortment of British Aluminum Company (No. 103) with beads with thickness also of $2\delta$ and also two angles with round beads of different dimensions ($3\delta$ and $2.4\delta$ - Nos. 102 and 104); for comparison, one of angles was without beads.

All these angles had identical thickness $\delta$ and calculated width of flange, measured from internal face of flange to center of bead, but in one case (No. 103) - from center of bead to center of well-developed angle bracket.

After expediency was formed of application of trapezoidal bead, in given series there was tested still another series of samples with such beads at different values of ratio $b_n/\delta$ from 10 to 25. Total number of samples in this series constituted 18.

Third series constituted of 22 samples. Of them there were unequilateral angles without beads - 10 pieces, those with two beads - 8 pieces, with one bead - 4 pieces. Ratio of dimensions of sides was 2 : 3. Ratio $b_n/\delta$ was taken in limits from 7 to 25.

Each form of sample in all cases was prepared in two copies. Length of all samples on the basis of preliminary experiments was taken from such calculation that flexibility $\lambda$ was equal to 25. Since for equilateral angles without beads $i_{min}$ - 0.197 $b_n$ their length $\underline{l}$ - $5b_n$; for angles with beads $i_{min}$ - $0.234b_n$ and length $\underline{l}$ - $6b_n$

In all, more than 60 samples were tested.

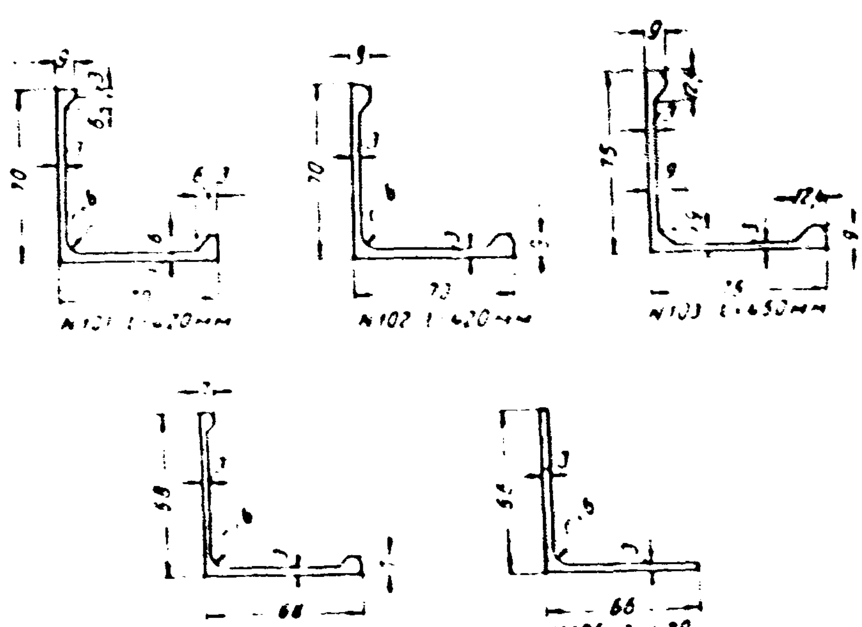

Fig. 1. Profiles of angles of second series of experiments.

## 2. Method of Carrying out Experiments

All experiments were conducted* on Amsler 200 ton press. Ends of samples were exactly perpendicular to longitudinal axis, polished, and well fitted to bearing discs of press. For control of centering and for establishment of critical force, to all samples there were glued electrical resistance detectors, readings of which were recorded by electronic strain meter EID-3, built by Central Scientific Research Institute of Aerohydrodynamics im. N. Ye. Zhukovskiy. Detectors were disposed in the middle of height of sample on each flange on both sides on feather or on bead and on back edge. For measurement of longidutinal deformation (convergence of bearing discs) there were applied in each experiment three indicators with divisions of 1/100 mm.

Control of centering was carried out by readings of detectors after application of small test load, which was then removed. After sample was finally set up, it was loaded. Degrees of loading decreased with approach toward expected critical force. Before buckling, and after it, (up to failure) degrees of loading constituted nearly 5 % of critical force. Before each stage of load, sample was held for 3-5 minutes, during which time readings were taken from instruments.

Ultimate stress was determined by indication of pointer on scale of press at moment of ceasing of further increase of load. We took as critical the force at which buckling started of flanges of angle. Beginning of buckling was established by graph of dependence of deformations of edge of flanges measured by detectors on load. Before buckling this dependence for each of detectors remains rectilinear; at moment of buckling of flange, on line there appears characteristic sharp break or distortion. Detector, which turns out to be on concave, compressed side of bulging flange shows, subsequently, rapid growth of deformations, while detector on convex side, conversely, records advancing unloading, and then sometimes extension also.

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*T. N. Livchak, junior scientific worker participated in carrying out of experimental investigation.

If on graph there appeared not sharp break, but smooth distortion, for determination of critical force we used method similar to that which is given in All-Union Government Standard 1497-42 for establishment of limit of proportionality for tensile test of metals: as critical force we took that at which tangent of angle of inclination of tangent to curve with axis of loads was changed by 50%.

Usually scattering of values of critical force from readings of detectors of one sample was small, and in calculation mean value was taken. Control of critical force was carried out with help of graphs of dependence of longitudinal deformation on load, fixed by readings of indicators.

Critical and limiting stresses $\sigma^0_{кр}$ and $\sigma^0_{пр}$ were determined by division of corresponding forces into area of section. Actual area of section was calculated according to weight of sample, its length, and specific gravity of given alloy. Width of flanges was measured by slide calipers, thickness of flanges and bead- with help of measuring plate and indicator. All measurements were taken in several places, and in calculation average magnitudes were taken.

During carrying out of experiments there was considered question of influence on critical force of small initial eccentricities of application of load, close to those which were considered during establishment of coefficient $\varphi$ for central compression in "Technical specs of designing structures from aluminum alloys" (SN 113-60).

Small irregularity in distribution of stresses on flanges (with exceeding of stress for free edge beyond stress on back edge) did not render great influence on magnitude of average critical stress, however, it was subsequently considered.

During test of corner profiles under compression, almost all samples suffered local buckling of flanges, which in form coincided with bend-twist buckling of sample on the whole.

## 3. Results of Experimental Investigations

Results of test of equilateral angles without beads, with beads of trapezoidal form, and also of unequilateral angles are shown in Fig. 2. In the figure there are plotted experimental values of critical stresses, depending upon ratios $b_0/\delta$ and $b_0'/\delta$ and also a number of curves (here:

$b_0 = b_1 - 0.5\delta$ for angles without beads,

$b_0' = b_n - 0.5\delta$ for angles with beads,

$b_n$ - full width of flange,

$\delta$ - thickness of wall;

for unequilateral angles as magnitude of $b_{\Pi}$ width was taken of large side).

Curve 1 gives us functional dependence of $\sigma_{\kappa p}$ on $b_0/\delta$ for equilateral angles without beads; it is plotted from known formula [1], determining critical stresses for plates with three hinge supported sides and a free fourth:

$$\sigma_{\kappa p} = \frac{k\pi^2 E}{12(1-\mu^2)}\left(\frac{\delta}{b_0}\right)^2 \alpha. \tag{1}$$

In this formula:

E - elastic modulus;

$\mu$ - Poisson's ratio, equal to 0.31;

$k = 0.42 + \left(\frac{b_0}{l}\right)^2$ - coefficent depending on length of plate $l$;

$\alpha$ - ratio of given modulus to usual one.

In drawing of curve value of k was taken equal to 0.42, which corresponds to plates of great length ($l > 16b_0$), for which critical stresses have minimum values and no longer depend on length. In connection with this during plotting of experimental points, experimental critical stresses were taken as factors of coefficients of k for plates of great and actual length, i.e., multiplied by $\frac{0.42}{k_{actual}}$.

Coefficient of $\alpha$ in elastic region is equal to one, and according to this value, by (1) there was plotted right section of curve. For nonelastic region it was determined approximately on the basis of analytic connection between it and critical stress [1]:

$$\alpha = \frac{\sigma_{\kappa p}(A-\sigma_{\kappa p})^2}{\pi^2 E \cdot B^2} \tag{2}$$

which is established with help of so-called rectilinear formula of critical stress of total strength for region between limit of proportionality $\sigma_p$ and yield point $\sigma_{0,2}$:

$$\sigma_{кр} = A - B\frac{l}{i}. \quad (3)$$

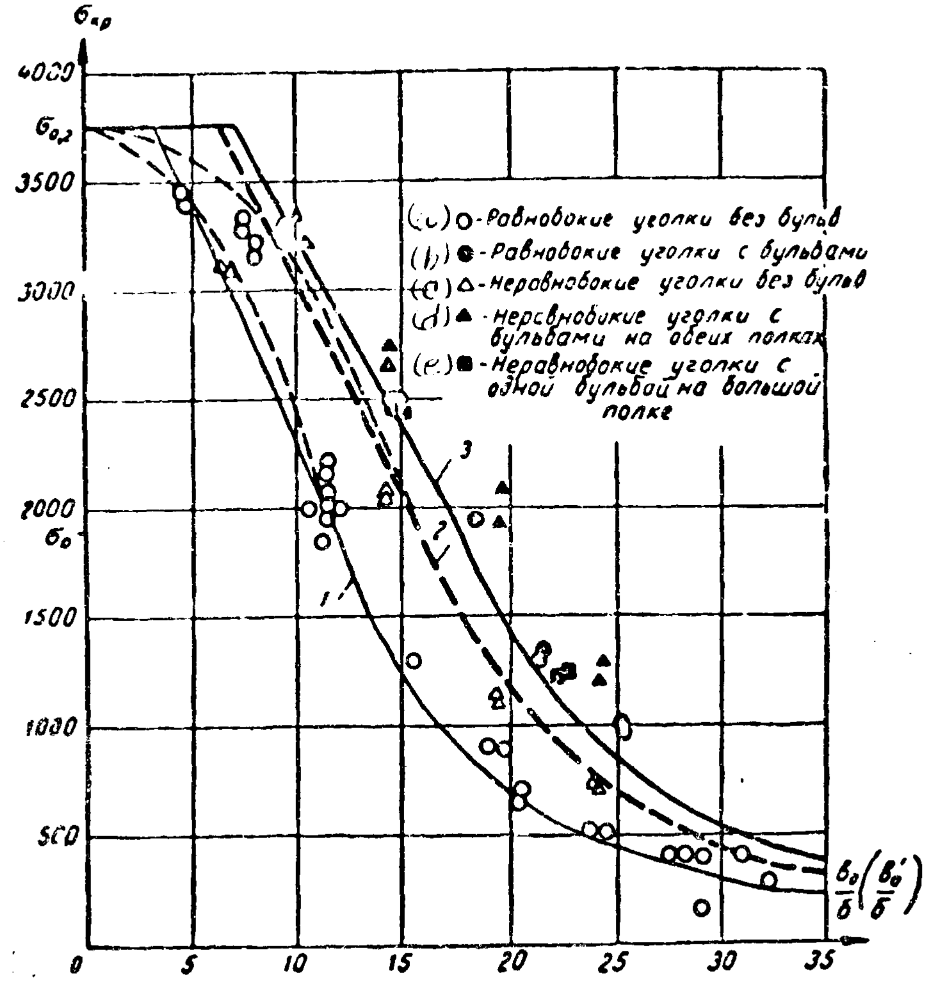


Fig. 2. Dependence of $\sigma_{кр}$ on ratio $b_0/\delta$ and $b_0'/\delta$ for angles from alloy D16-T (actual values of $\sigma_{0,2}$ = 3770 kg/cm²; E = 714,000 kg/cm²) 1) curve for equilateral angles without beads; 2) curve for equilateral angles with beads [taking into account formula (39) TU SN 113-60; 3) curve for equilateral angles with beads, taking into account their heightened resistance to torsion

KEY: (a) Equilateral angles without beads; (b) Equilateral angles with beads; (c) Unequilateral angles without beads; (d) Unequilateral angles with beads on both flanges; (e) Unequilateral angles with one bead on large flange.

Coefficients A and B were easy to determine having curve of dependence $\sigma_{кр}$ on $\frac{l}{i}$ from condition that at $\sigma_{кр} = \sigma_{0,2}$ flexibility is equal to known magnitude $\lambda_{0,2}$, and at $\sigma_{кр} = \sigma_p$ flexibility is equal to $\lambda_p$.

Such curve was plotted for alloy D16-T, from which there were made samples, taking into account its actual yield point and elastic modulus (curve 4 in Fig. 4). Critical stresses were obtained here by multiplication of conditional yield point by coefficients $\varphi$ ; the latter for given alloy were determined just as was done in TU, i.e., taking into account relative initial eccentricity $e_1 = 0.003\lambda$ .

Limit of proportionality $\sigma_p$ for aluminum alloys is usually taken equal to $0.5\,\sigma_{0.2}$ (the same ratio was also taken during composition of TU SN 113-60).

Under these conditions of values of A and B for alloy from which samples were made turned out to be equal respectively to 4700 and 55.5 kg/cm$^2$. For obtaining of section of curve beyond the limits of proportionality it was practically sufficient to find with help of formulas (1) and (2) the point corresponding to $b_0/\delta$ at $\sigma_{\kappa p} = \sigma_{0.2}$ and to connect it with point on curve at $\sigma_p = 0.5\,\sigma_{0.2}$ (when $\alpha = 1$ ); section of calculated values of $b_0/\delta$ at $\sigma_{0.2}$ to $b_0/\delta = 0$ was taken as horizontal (see Fig. 2.).

Curve of dependence of critical stresses on $b_0/\delta$ in nonelastic region can be plotted in the same way, using, instead of rectilinear formula (3), formula of square parabola

$$\sigma_{\kappa p} = C - D\left(\frac{l}{i}\right)^2. \tag{4}$$

Value of $\alpha$ in this case is expressed by formula

$$\alpha = \frac{\sigma_{\kappa p}(C - \sigma_{\kappa p})}{\pi^2 ED}. \tag{5}$$

Section of curve 1 plotted from these data in Fig. 2 is shown by dashed line.

In similar manner with use of formula (1) there are also plotted in Fig. 2 curves of critical stresses of local strength for angles with beads. Curve 2 was plotted according to TU SN 113-60 with respect to maximum ratio of width of flange with beads to thickness of angle by formula (39) of TU SN 113-60:

$$\frac{b'}{\delta} = \beta\sqrt{\frac{\beta + 0,3\left\{1 + c\left[1 + 4\left(1 - \frac{1}{\gamma}\right)^2\right]\right\}\gamma^4}{\beta + 2,35\,\gamma^4}} = k\beta, \tag{6}$$

where b' - width of flange measured from center of bead to face of adjoining flange,

$\beta = \frac{b}{\delta}$ ; b - maximum width of flange during given critical stress, measured from edge of given flange to face of that adjoining it in the absence bead;

$\gamma = \frac{D}{\delta}$; D - diameter of bead;

k and c - coefficients determined by Tables 41 and 42 of TU SN 113-60.

During construction of curve 2 (Fig. 2) according to known ratio $b'/\delta$ for given angle with bead from formula (6), we determined $b/\delta$*; then $\frac{b_0}{\delta} = \frac{b + 0.5\delta}{\delta}$ and by formula (1) we found corresponding $\sigma_{кр}$, which was critical stress for angle with bead.

During construction of curve 3 we used rough assumption that increase of critical stress of angle with beads, as compared to the same magnitude for usual angle, is proportional to ratio of their moments of inertia of free torsion ** $\eta = \frac{J'_к}{J_к}$, i.e., that critical stress for angle with beads is

$$\sigma'_{кр} = \sigma_{кр}\eta, \tag{7}$$

where $\sigma_{кр}$ - stress determined by formula (1).

During computation of $J'_{кр}$ sum was determined of moments of inertia of torsion of figures into which section of angle was approximately divided: two rectangles, circle inscribed at place of juncture of flanges, and two circles, diameter of which was equal to width of bead ($3\delta$).

With identical length of samples and with identical material, magnitude of $\sigma^0_{кр}\left(\frac{b'_0}{\delta}\right)^2$ is constant and does not depend on ratio $\frac{b'_0}{\delta}$; this ensues from structure of formula (1). Change of this magnitude depends on form of profile and dimensions of bead; it can serve as index of quality of section. Calculated values of $\sigma^0_{кр}\left(\frac{b'_0}{\delta}\right)^2$ for equilateral angles with different beads, shown in Fig. 1, are given in table.***

*With trapezoidal beads for D there was taken, in accordance with given experiments, width of beads.

**Actually, dependence between critical stresses for usual angles and those reinforced by beads is more complicated; however, for usual relationships $b_0$ and $\delta$ the taken approximation gives satisfactory result.

***During calculation of data of table, we took actual dimensions of profiles.

| (a) № образцо | 101 | | 102 | | 103 | | 104 | | 106 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | а | б | а | б | а | б | а | б | а | б |
| $\sigma^{0}_{кр}\left(\frac{b'_0}{\delta}\right)^2$ | 6,6·10[illegible] | 6,9·10[illegible] | 6,0·10[illegible] | 7,0·10[illegible] | 7,1·10[illegible] | 7,1·10[illegible] | 4,5·10[illegible] | 5,6·10[illegible] | 3,1·10[illegible] | 3,2·10[illegible] |

KEY: (a) No. of sample.

In Fig. 3 there are plotted experimental values of ratios $\sigma^{0}_{кр}/\sigma^{0}_{пр}$ at different $b_n\,\delta$ angles of all three series.

We made an attempt to compare limiting stresses of samples with those calculated by empirical formula of Needham [2], given by him for bent angles with free edges of flanges:

$$\sigma_{пр}=\frac{0{,}316\sqrt{\sigma_{0,2}\cdot E}}{\left(\frac{b_0}{\delta}\right)^{0,75}} \tag{8}$$

($b_0$ - distance from axis of adjoining flange to edge of that considered).

Formula gives us good results for angles without beads having flexibility close to that for which formula was obtained by the author ($\lambda = 20$).

On the basis of presented results it is possible to establish the following.

1. There were obtained experimental values of critical stresses of local buckling of equilateral angles without beads and with beads for wide range of ratios of width of flange to its thickness. Values of these stresses for angles without beads, basically, agree satisfactorily with theoretical data on strength of plates in elastic and nonelastic regions. Calculated estimate of critical stress of angles with beads may be done approximately by formula (7). Critical stresses for these angles, calculated according to TU SN 113-60 on maximum overhang of flanges, are found somewhat understated, as compared to experimental values.

2. Presence of beads, other things being equal, increases critical stress of local strength, drawing it to maximum, corresponding to ultimate load; however, actual ultimate load measured during experiments, as compared to load for

load for corresponding angle without beads, is changed immaterially. Thickness of beads has meaning: with its decrease, influence of beads on increase of critical stresses drops. Good results are obtained where beads have thickness of 3.

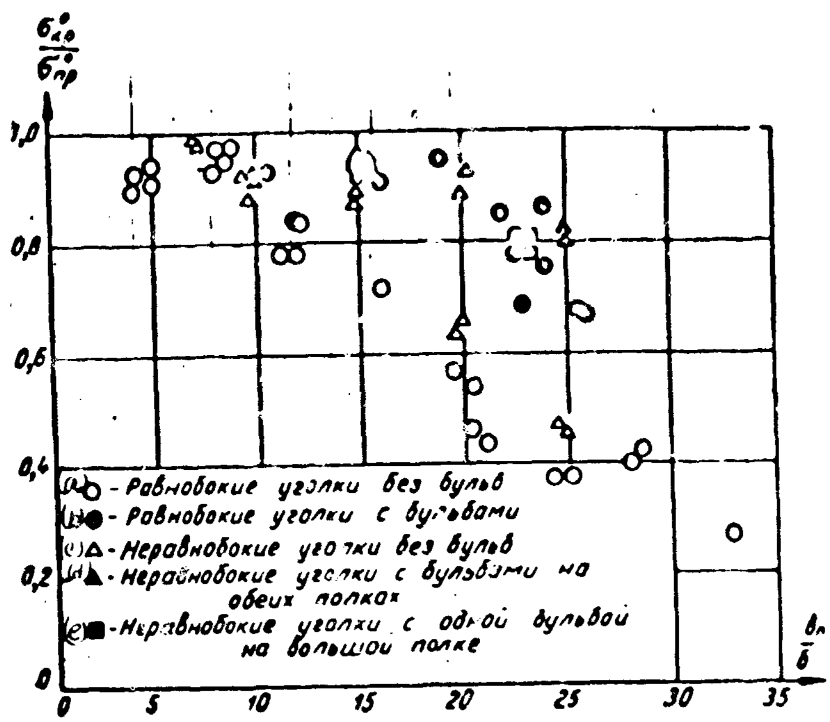


Fig. 3. Ratio $\frac{\sigma^0_{кр}}{\sigma^0_{кр}}$, depending upon $b_n/\delta$

KEY: (a) Equilateral angles without beads; (b) Equilateral angles with beads; (c) Unequilateral angles without beads; (d) Unequilateral angles with beads on both flanges (e) Unequilateral angles with one bead on large flange.

3. The highest characteristics f section belong to angles with trapezoidal beads with thickness of 3 $\delta$ and to angles with beads of assortment of British Aluminum Company.

Considering that the first are more convenient in a constructional sense (they have large width for placement of rivets), they should be given preference. Furthermore, angles with beads of British Aluminum Company also have large coefficient of fullness of section at identical thickness - smaller specific radius of gyration $i/\sqrt{F}$; this makes them less economical.

4. Unequilateral angles resist local buckling better than equilateral

having dimension of flange equal to dimension of large flange of unequilateral angle with identical thickness. This can be explained by the fact that small flange increases rigidity of fastening of large flange in place of their juncture. Unequilateral angles are profitably made with beads both on wide and on narrow flanges.

5. Ratios of critical stresses to limiting $\sigma^0_{кр}/\sigma^0_{пр}$ are changed in wide limits. For angles with thick walls they are close to one; with walls of average thickness, characteristic for majority of applied profiles, they constitute 0.6–0.8; for angles with very thin walls these ratios reach 0.3–0.4. Difference in stresses $\sigma^0_{кр}$ and $\sigma^0_{пр}$ for unequilateral angles is less than for unequilateral. Owing to intimacy of critical and limiting stresses in angles with beads, ratio $\sigma^0_{кр}/\sigma^0_{пр}$ is increased.

## 4. Practical Recommendations

Satisfactory coincidence of experimental and calculated values of critical stresses indicates definite reliability of accepted calculating methods. Using them, it is possible to make certain recommendations about assignment of dimensions of corner profiles in compressed beams.

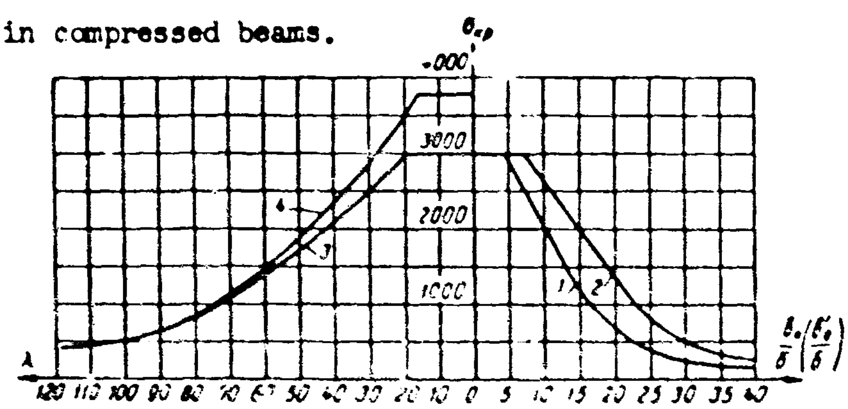


Fig. 4. Dependency between local and total strength for equilateral angles from alloy D16-T with standard indices ( $\sigma_{0.2}$ = 3000 kg/cm$^2$; E = 710,000 kg/cm$^2$)
1) curve of dependence of $\sigma_{кр}$ on $b_0/\delta$ for equilateral angles without beads;
2) curve of dependence of $\sigma_{кр}$ on $b_0'/\delta$ for equilateral angles with beads;
3) curve of critical stresses of total strength for alloy D16-T with standard indices of mechanical properties; 4) curve of critical stresses of total strength for alloy D16-T used in experiments.

In Fig. 4 shows combined graph of dependence of stresses on values of $\frac{b_n}{\delta}$ [for angles without beads - according to (1), and for angles with beads - from formula (7)] and $\lambda$ plotted for equilateral angles from alloy D16-T with standard indices of mechanical properties ( $\sigma_{0.2}$ = 3000 kg/cm$^2$; E = 710,000 kg/cm$^2$; A = 3910 kg/cm$^2$; B = 42.8 kg/cm$^2$). With help of this graph it is possible to establish connection between maximum ratios of width of flange to its thickness and flexibility $\lambda$ (Fig. 5, lines 1 and 2). Considering certain possible lowering of critical stress from initial eccentricity during construction of Fig. 5 we took for amount of overhand of flange its full width $b$.

In the same Fig. 5 for comparison we plotted dependencies of ratio $b_n/\delta$ on flexibility $\lambda$ given by norms of SN 113-60 (lines 3 and 4). It is possible to see that for low flexibilities norms allow somewhat larger overhangs of flanges, but for average, having the greatest practical value, and for high flexibilities, conversely, they give decreased value, decreasing thereby economy of sections.

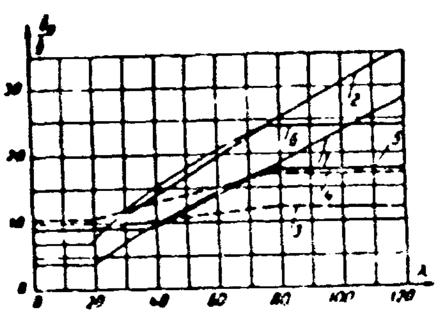

Fig. 5. Dependency of maximum overhangs $b_n/\delta$ for equilateral angles on flexibility $\lambda$.
1) graph for angles without beads, according to experiments; 2) the same with beads according to experiments; 3) the same without beads according to TU SN 113-60; 4) the same with beads, according to TU SN 113-60; 5) recommended graph for angles without beads 6) the same with beads.

For practical calculations it is possible to offer the following. Considering that in a number of experiments with equilateral angles without beads in nonelastic region the critical stresses turned out to be somewhat higher than those calculated (see Fig. 4), for low flexibilities magnitude of maximum overhangs of flanges of equilateral angles can be left the same as norms suggest. For equilateral angles with beads minimum values of overhangs (with low flexibilities) have to be left close to experimental values. They can be taken the same as for angles without beads. This corresponds to actual conditions of work: with thick flanges influence of beads on increase of $\sigma_{kp}$ is extremely slight. For average and high flexibilities maximum overhands of flanges can be taken according to experiments, straightening, for simplicity, the broken lines and making, according to constructional considerations, the values of $b_n/\delta$ at $\lambda > 76$ constants. Then for angles without beads we obtain Graph 5, and for angles with beads - Graph 6. From these graphs, as a result, there are obtained following values of maximum overhangs of flanges of equilateral angles from alloy D16-T, depending on flexibility of beam, at which local strength can be considered ensured:

Angles without beads

at $\lambda \leqslant 38$ $b_n/\delta = 9$

at $\lambda > 76$ $b_n/\delta = 17{,}5$

Angles with beads

at $\lambda \leqslant 23$ $b_n/\delta = 9$

at $\lambda > 76$ $b_n/\delta = 24$

For intermediate flexibilities maximum overhangs are determined either by graph of Fig. 5 or by linear interpolation. When at given flexibility there is applied angle having overhang greater than maximum the calculated resistance is determined with coefficient $\varphi$, corresponding not to actual flexibility of beam, but to flexibility corresponding to overhang taken $b_n/\delta$ and determined by graph of Fig. 5.

For instance, if with flexibility $\lambda = 20$ there is applied equilateral angle without beads with $b_n/\delta = 10$, then coefficient $\varphi$ is chosen not for flexibility $\lambda = 20$, but for flexibility $\lambda = 42$.

Indication of possibility of increase of overhang in understressed elements is given par. 76 of TU SN 113-60.

Literature

1. S. P. Timoshenko. Strength of elastic systems, State Technical Press, 1955.

2. R. A. Needham. The Ultimate Strength of Aluminum-Alloy Formed Structural Shapes in Compression, "Journal of the Aeronautical Sciences," No. 4, 1954.

EXPERIMENTAL-THEORETICAL INVESTIGATIONS OF CENTRALLY-COMPRESSED RODS FROM ALUMINUM ALLOYS

A. Kh. Khokharin, Cand. of Tech. Sciences

Tests conducted on centrally-compressed rods* from aluminum alloys had as their aim:

a) to obtain experimental appraisal of degree of conformity of actual load-bearing ability of elements working under central compression with that calculated determined in accordance with theoretical prerequisities** embodied in recommendations of technical specs (SN 113-60);

b) to study influence of form of cross section of rods on character of their deformation under critical loads.

Geometric characteristics of test samples and characteristics of material (D16-T) from which they were made are given in table.

Dimensions of cross sections of test samples conformed to specs for assurance of local strength of elements composing these sections.

All samples were prepared from pressed profiles supplied by metallurgical factories according to corresponding standards and technical specs and were

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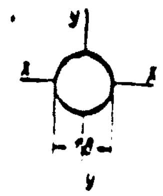
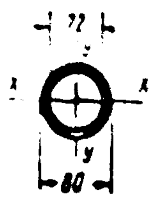
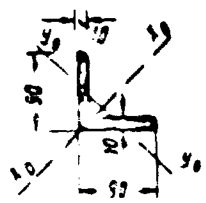
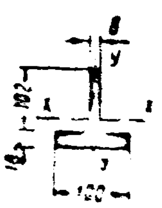
*Investigation of load-bearing ability of eccentrically-compressed rods is given in articly by B. G. Bazhanov.

**On theoretical prerequisities assumed on basis of recommendations SN 113-60, see article by B. M. Broude and G. M. Chuvikin in this collection.

Characteristics of Test Samples From Alloy D16-T and Critical Stresses for Them.

| (a) Форма сечения | (b) Характеристики образцов | | | | | | | (c) Опытные значения критических напряжений в кг/см² | | | | (e) $\sigma^{эк}_{кр}$ (средние значения) | (f) $\sigma^{т}_{кр}$ (теоретические значения) в кг/см² | $\frac{\sigma^{эк}_{кр}}{\sigma^{т}_{кр}}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $l_0$ в см | λ | F в см² | $I_y$ в см⁴ | $i_y$ в см | $\sigma_{0,2}$ в кг/см² | $\sigma_p$ в кг/см² | (d) № образца 1 | 2 | 3 | 4 | | | |
|  | 20,7 | 46 | 2,54 | 0,515 | 0,45 | 2690 | 1345 | 1570 | 1850 | [illegible] | — | 1703 | 1842 | 0,925 |
| | 28 | 62,2 | | | | | | 1496 | 1490 | 1416 | — | 1467 | 1545 | 0,95 |
| | 35 | 77,8 | | | | | | 1081 | [illegible] | 1081 | — | 1081 | 1165 | 0,927 |
| | 44 | 92,8 | | | | | | 708 | 826 | 826 | — | 787 | 741 | [illegible] |
| | 54 | 120 | | | | | | 512 | 512 | 512 | — | 512 | 493 | 1,04 |
| | 80 | 178 | | | | | | 2 | 197 | [illegible] | — | 203 | 224 | 0,91 |
|  | 81 | 30 | 9,55 | 69,7 | 2,7 | 3296 | 2560 | 3270 | 3170 | [illegible] | — | 3160 | 2875 | 1,1 |
| | 121,5 | 45 | | | | | | 2810 | 2720 | 2250 | — | 2589 | 2675 | 0,97 |
| | 162 | 60 | | | | | | 1860 | 1920 | 1805 | — | 1862 | 1975 | 0,945 |
| | 216 | 80 | | | | | | 1265 | 1185 | 1125 | 1120 | 1174 | 1174 | 1,056 |
| | 270 | 100 | | | | | | 950 | 948 | 855 | 1040 | 948 | 710 | 1,34 |
|  | 12,6 | 7 | 17,04 | 52,8 | 1,70 | 4205 | 3160 | 4050 | 4130 | — | — | 4050 | 4050 | 1,01 |
| | 52,3 | 29,7 | | | | | | 3350 | 3250 | — | — | 3300 | 3545 | 0,931 |
| | 78,3 | 44,5 | | | | | | 3140 | 3260 | 3080 | — | 3140 | 3220 | 0,975 |
| | 105,6 | 59,5 | | | | | | 2000 | 2400 | 2120 | — | 2173 | 2003 | 1,082 |
| | 139,1 | 79 | | | | | | 1380 | 1078 | 1272 | — | 1243 | 1137 | 1,093 |
| | 176,8 | 100,5 | | | | | | 890 | 1070 | 890 | — | 950 | 702 | 1,35 |
|  | 69,5 | 29 | 26,2 | 149,5 | 2,39 | 4180 | 3140 | 3280 | 3410 | 3120 | — | 3270 | 3545 | 0,922 |
| | 104 | 43,7 | | | | | | 2845 | 2880 | — | — | 2862 | 3165 | 0,904 |
| | 138,6 | 58 | | | | | | 2150 | 2110 | 1930 | — | 2135 | 2108 | 1,011 |
| | [illegible] | 77 | | | | | | 1340 | 1160 | 1560 | 1210 | 1318 | 1195 | 1,101 |
| | 230,5 | 96,5 | | | | | | 870 | 837 | 1082 | 1120 | 982 | 762 | 1,258 |

KEY: (a) Form of section; (b) Characteristics of samples; (c) Experimental values of critical stresses in kg/cm²; (d) No. of sample; (e) $\sigma^{expt.}_{crit.}$ (mean values); (f) $\sigma^{theor.}_{crit.}$* (theoretical values) in kg/cm².

DESIGNATIONS: в = in; кг = kg.

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*[Ed. Note: Throughout article superscripts эк and т = expt. and theoretical respectively, while subscript кр = critical].

accompanied by appropriate certificates. Cutting of samples from factory semifinished products was such that from each factory article there were prepared four rods of different length. From the same article there were prepared nine standard samples for tensile tests of material. Thus, twins of test samples of each flexibility were made from different semifinished products and had certain scattering in mechanical characteristics. Values of conditional yield points $\sigma_{0.2}$, shown in table, constitute averaged characteristics obtained from tests of the whole of standard samples of given profile. Limits of proportionality $\sigma_p$, shown in table, represent smallest values measured in tests of corresponding series of standard samples. Such values are taken with respect to fact that ratio of limit of proportionality to yield point during compression of material is lower than during extension. Here upper limit of ratio $\sigma_p:\sigma_{0.2}$ during compression turned out to be practically equal to lower limit of this ratio during extension of material.

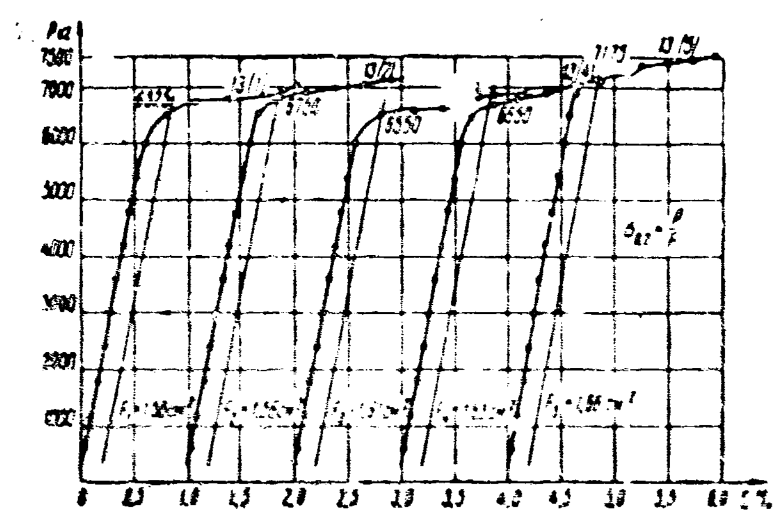

Fig. 1. Diagram of extension of material of test samples (alloy D16-T)
KEY: (a) Tension in kg.

Fig. 1 shows approximate character of diagrams of extension obtained during test of standard flat samples prepared from the same material as that of experimental rods. Tests were conducted by mechanical test section of Central Scientific Research Institute of Structural Parts. All flat samples failed usually along the line making angle of 30° with longitudinal axis of sample (with direction of effort) and with middle plane of sample after formation of slight neck (Fig. 2).

Tests of rods of tubular, tee, and corner profiles were conducted on 500-ton press calibrated with manometers in scales of 25, 50, 75, and 100 t. Pressure of press on sample was applied through special support parts, which consisted of two steel plates with dimension of 200 X 200 X 40 mm and a steel ball with diameter of 50 mm between them. Ball was fixed in spherical depressions with radius of 70 mm and depth of milled on centers of supporting plates 10 mm (Fig. 3).

One of plates of such balancer was fixed exactly at center of block of press, the other plate rested on milled face of test sample. For achievement of coaxial alignment of joints of upper and lower balancers with axis of loaded rod, plates of balancers resting on faces of tested rods had guide flanges with height of 8 mm. Position of these guides secured on plate determined position of center of gravity of profile exactly against center of spherical surface milled on other side of plate for support of ball and socket joint. Uniformity of distribution of pressure on butt section was attained by laying lead strips with 2mm thickness around perimeter of profile between butt sections of rod and bearing discs of balancers.



Fig. 2. Character of rupture of standard tension samples from alloy D16-T.

During test of rods of round cross section, support parts were made in the form of a head with knife-edge, secured on rod by screws in plane perpendicular to plane of support.

Loading in all tests was carried out by steps of 3-5 % of critical load on rod and was sustained at each stage for 8-10 minutes. During loading of rods there were taken measurements of stresses by mechanical lever tensometers, but displacements (deflections) - by deflectometers of N. N. Maksimov system in three sections through height of rod.

General view of installation of rods in press and diagram of arrangement of tensometers and deflectometeres by sections are shown in Fig. 4, a, b, c, d.

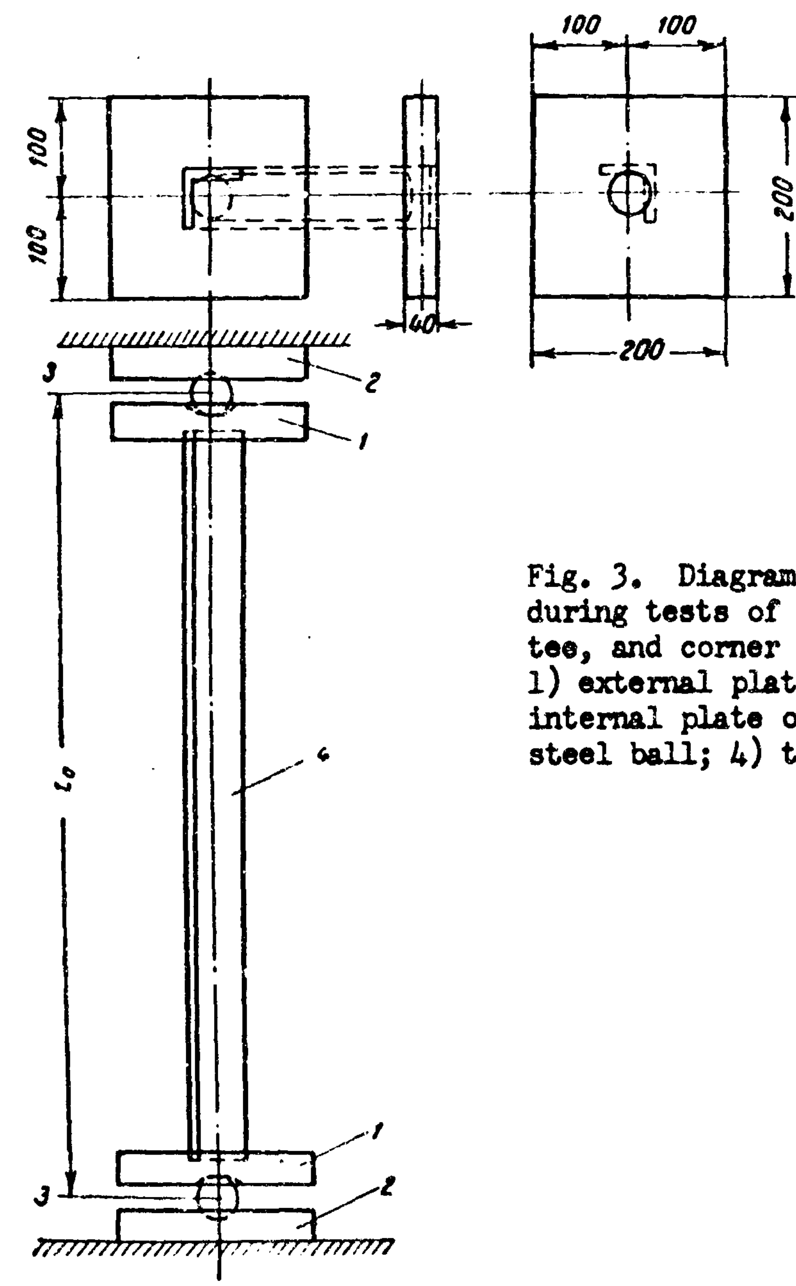


Fig. 3. Diagram of support balancers during tests of rods of tublar, tee, and corner profiles.
1) external plate of balancer; internal plate of balancer; 3) steel ball; 4) tested rod.

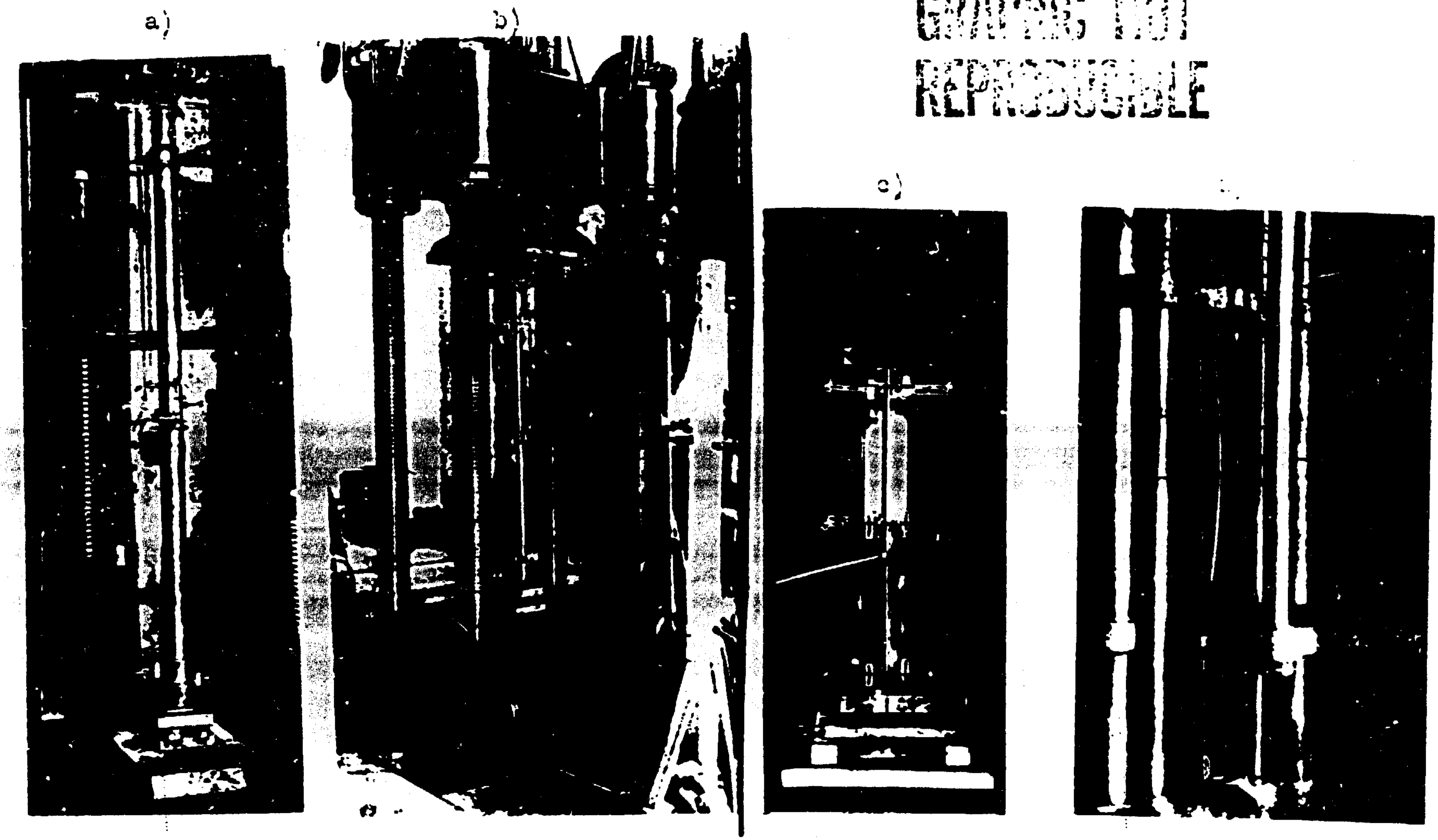


Fig. 4. General view of installation of rods in press with ball and socket joint of rods: a) tubular; b) corner; c) tee sections; d) with flat joint of rods of round section.

From measured deformations there were constructed graphs of dependencies of stresses $\sigma$ (P) and deflections y (P) on load. Samples of such graphs are shown in Figs. 5 and 6.

During all tests, graphs of total and local deformations of rod allowed us very exactly to determine critical load corresponding to moment of loss by rod of total strength. For critical load for rod there was taken load corresponding to continuous build-up of deformations (deflections) accompanied either by sharp drop of pressure in press or by smoother lowering of pressure (depending upon character of deformation of axis of rod and its cross section). On graph of deflections to this load there corresponds slanted section of curve y (P), asymptotically nearing horizontal line $P=P_{кр}$.

In table there are given experimental values of critical stresses $\sigma^{эк}_{кр}=P_{кр}:F$, equal to quotient of division of critical load by area of cross section of sample. In the same place these stresses are compared with theoretical values ($\sigma^{т}_{кр}$), calculated by the Euler formula:

$$\sigma^{т}_{кр}=\frac{\pi^2 E}{\lambda^2} \qquad (1)$$

within limits of its validity for given material, and by the formula of Yasinskiy - Tetmayer:

$$\sigma^{т}_{кр}=\sigma_{0,2}\left(1-\frac{\sigma_p}{\sigma_{0,2}}\right)\frac{1}{\pi}\sqrt{\frac{\sigma_p}{E}} \qquad (2)$$

for rods under stresses exceeding limit of proportionality of material.

During calculation of critical stresses by shown formulas, values of limits of proportionality of material given in table constituted: for round rods from pressed bars $\sigma_p = 0.5\ \sigma_{0,2}$, for rods from pressed pipes $\sigma_p = 0.78\ \sigma_{0,2}$ and for rods from tee and corner pressed profiles $\sigma_p = 0.75\ \sigma_{0,2}$, where $\sigma_{0,2}$ - conditional yield point, obtained from tests of standard samples.

For calculated free length of rods of tublar tee, and corner profiles there was taken their actual length, equal to distance between points of application of compressing forces to rod; for rods of round section free length was taken equal

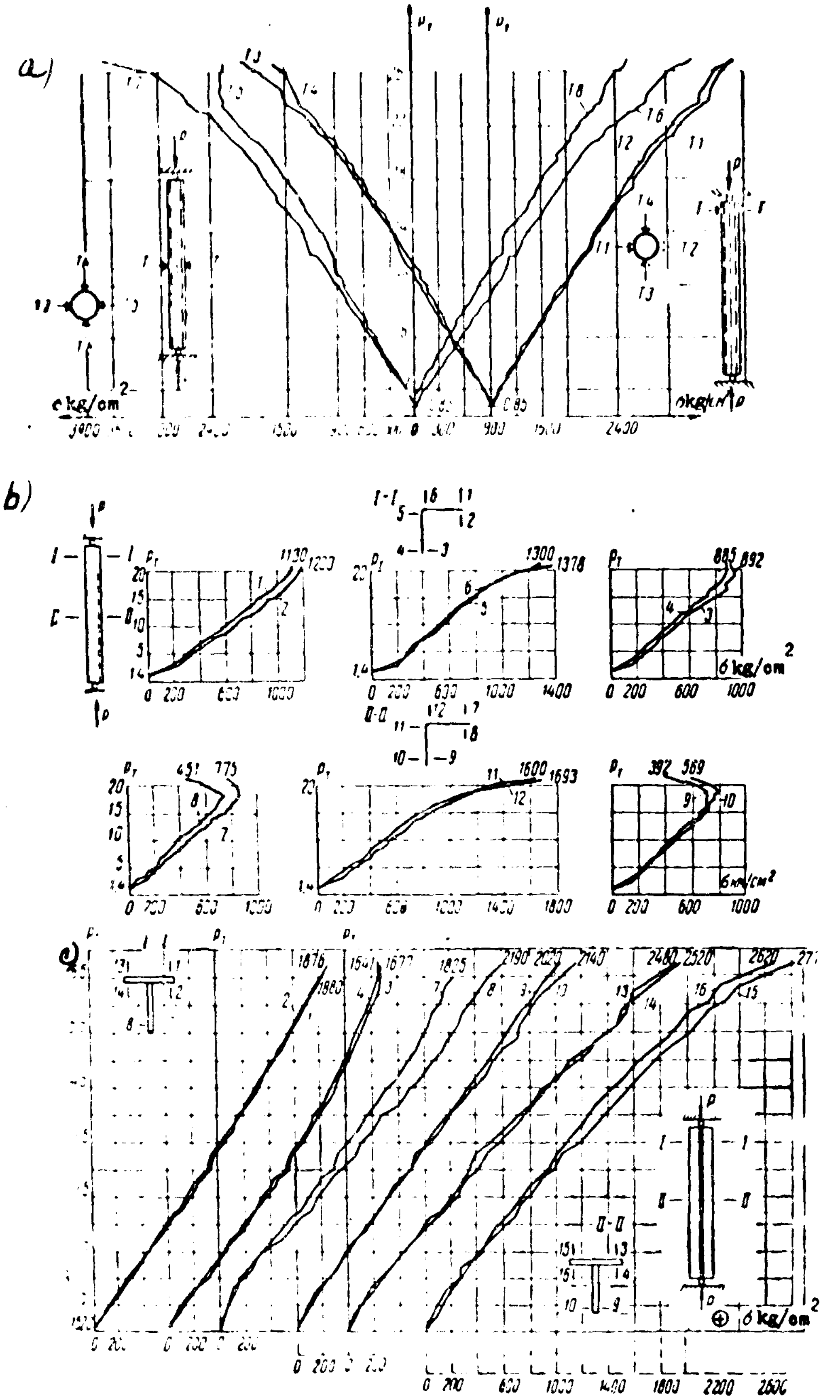

Fig. 5. Approximate graph of experimental dependence of stresses on load σ (P): a) tubular section; b) Angular section; c) tee section.

to distance between flat joints rigidly secured to rod in plane perpendicular to axis of hinge (see Fig. 4, d).

From data of table we notice that values of experimental critical stresses for each series of samples are quite close to theoretical values. Constructional corrections to mean values, as a rule, differ little from one. The biggest deviations are obtained for rods with flexibility of $\lambda = 100$, experimental values of critical stresses of which exceed by 29-35 % computed values calculated by the Euler formula. Exception for this flexibility constitutes rods of round cross section, for which $\sigma^{\text{эк}}_{\text{кр}}$ turned out to be practically equal to $\sigma^{\text{т}}_{\text{кр}}$. However, these results can not be considered representative inasmuch as test samples had significant initial distortions of axis (1/700-1/400) $l_0$, not coinciding, as a rule, with plane of hinge.

Deviations of the same order $\sigma_{\text{кр}}$ from $\sigma^{\text{т}}_{\text{кр}}$ were observed and on separate samples of other flexibilities, although mean value of experimental results in series on the whole were very close to those expected from calculation. The most coordinated results of tests were obtained for rods of closed tubular and solid round cross sections which are fully symmetrical. For rods of tee and corner profiles, axes of centers of gravity and centers of bend of cross sections of which do not coincide, there was obtained large scattering of values of experimental critical stresses within limits of each series of sample-twins. This condition is fully explicable, inasmuch as presence of least initial eccentricities of application of load or distortion of geometric axis of rod is more sharply manifested on character of work of such rods during longitudinal bend in comparison with rods having closed or solid, fully-symmetrical cross section.

In Fig. 7 on graph of $\sigma^{\text{т}}_{\text{кр}}$, based on formulas (1), (2) and the Engesser formula [4]

$$\sigma^{\text{т}}_{\text{кр}} = \sigma_{0.2} - \frac{\sigma_p(\sigma_{0.2} - \sigma_p)}{\pi^2 E}\lambda^2, \qquad (3)$$

are plotted experimental values of critical stresses for all tested rods.

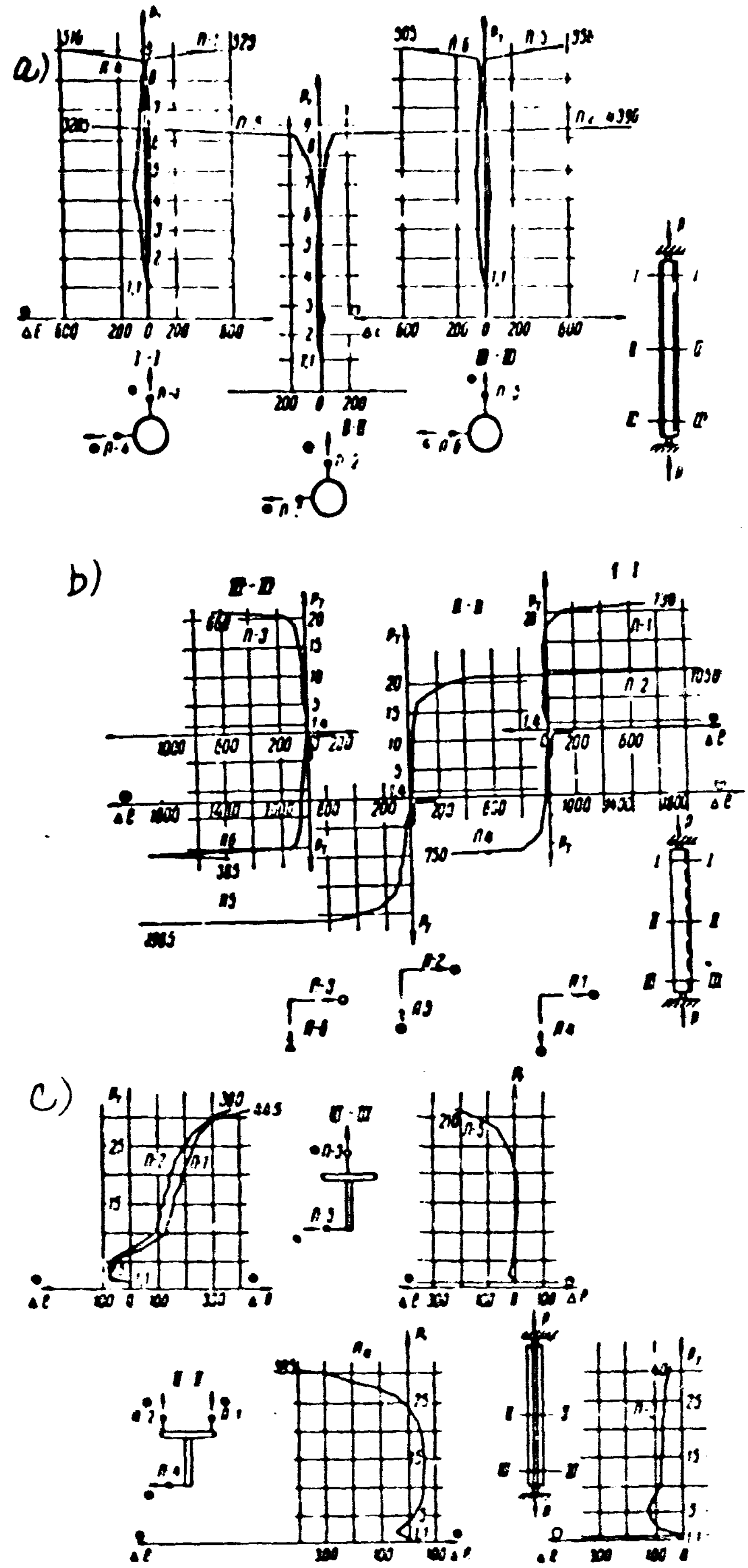

Fig. 6. Approximate graph of experimental dependence of deflections on load y (P): a) tubular section; b) angular section c) tee section.

As we see, experimental points lie basically above curve 1 and below curve 3 and straight line 2.

The closest approximation of experimental values to computed curves is noted for rods of average flexibilities bordering on maximum flexibility determined by condition (1). Exceeding of actual load-bearing ability beyond that calculated for rods with flexibility exceeding Euler's maximum flexibility for given material should be explained by influence of forces of friction appearing between ball and socket joints and bearing discs of balancers during deformation of axis of rod. As can be seen from Fig. 6, from first stages of loading of rod deflectometers mark deflection of its axis, as a result of which internal bearing discs of balancers turn relative to external plates.

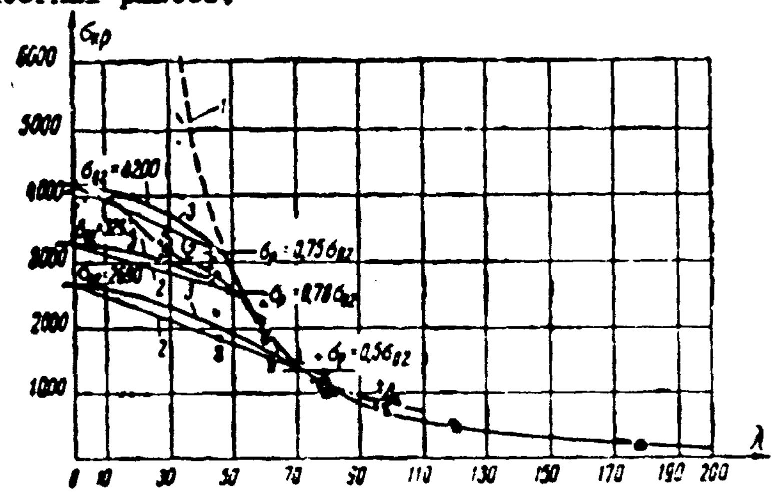


Fig. 7. Comparison of theoretical dependencies of critical stresses on flexibility of rods $\sigma^{T}_{кр}(\lambda)$ with experimental dependencies $\sigma^{эк}_{кр}(\lambda)$ 1) by the Eulet formula Euler's hyperbola $\sigma_{кр}=\frac{\pi^2 E}{\lambda^2}$; 2) by the Yasinskiy - Tetmayer formula; straight line of Yasinskiy Tetmayer $\sigma_{кр}=\sigma_{п.т}\times(1-a\lambda)$; 3) by the Engesser formula; (Engesser parabola $\sigma_{кр}=\sigma_{п.т}\times(1-a\lambda^2)$

Special designations;

• - round rod d = 18 mm; ○ - pipe, 80 X 72 X 4 mm; △ - angle, 90 X 90 X 10 mm; + - tee, 120 X 8 X 100 X 18 mm; —·— graph of average experimental values of •

During loading on rod close to critical, angle between bearing discs of balancers became noticeable to the eye (Fig. 8). If balls of support balancers had not been fixed in special spherical depressions milled in plates, then at such an angle of turn they would have skipped in direction of aperture of angle between bearing discs. Preservation of construction of balancer in such a form indicates presence of reactions holding ball between plates. These reactive forces form a pair of forces on ends of rod equivalent in action to certain pinching of ends of rod, decreasing its free length as compared to that taken in calculation.

Significant in this respect is the fact that with increase of flexibility of rods, difference is increased between actual load-bearing ability of rod and its computed value, while dispersion of experimental values of $\sigma^{эк}_{кр}$, obtained from tests of rods decreases independently of their form of cross section

Besides influence of terminal moments evoked by frictional force in support balancers there took place also initial eccentricities of application of compressing load on rods during their loading. Magnitudes of these eccentricites were revealed as a result of decomposition of curve of stresses measured by tensometers into components: $\sigma_N$ - from axial force and $\sigma_y$, $\sigma_x$ - from bending moments effective with respect to principal axes of cross section. From obtained stresses there were constructed graphs N (P), $M_x$ (P), and $M_y$ (P) of form shown in Fig. 9, which subsequently served as material for appraisal of character of work of rod under load and establishment of actual eccentricities of application of compressing force. They, showed in particular, that at each stage of loading force measured in section was equal (with deviations within limits $\pm$ 4-7 %) to force given by manometer, and that graphs of build up of bending moments in separate stages of loading in all cases had regularity close to linear, with certain deviations of particular values from averaged curve. However, such deviations should be considered inevitable, inasmuch as absolute value of increase of bend stresses at every stage of loading was commensurable with precision of measurement of stresses by tensometers (6-10 kg/cm$^2$, or 0.2-0.3 of one scale division).

Meanwhile, averaged curve of change of terminal moments indicated the fact that magnitude of initial eccentricity, expressing simultaneously eccentricity of application of compressing force and effect of pinching of rod by horizontal

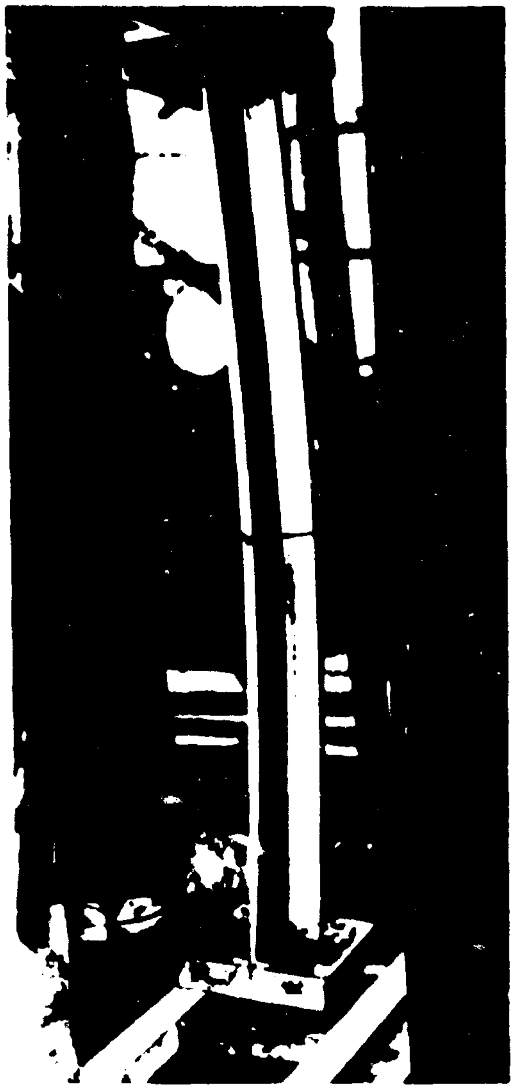

Fig. 8. Angle of rotation of bearing discs of balancer during load on rod is close to critical.

reactions, remained practically constant during whole process of loading.

By presence of these eccentricities in the first place should be explained lowering of actual load-bearing ability of rods with small flexibility, as compared to theoretical values determined by conditions (2) and (3).

In entire range of investigated flexibilities influence of form of cross section of rod showed up mainly on character of its deformations under load and in range of scattering of particular values of critical forces. Values of constructive corrections to mean values of critical stresses for all types of sections with corresponding flexibilities turned out to be practically identical.

It was noted, for instance, that upon achievement of critical forcerods of round and tubular sections lost load-bearing ability as a result of comparatively smooth build-up of deflections accompanied by intense build-up of fiber stresses. Sometimes such form of buckling preceded higher increase of deformations during stage of loading preceding critical force.

Rod under this load still kept stable equilibrium, and only further increase of load led to buckling, setting in, as and in first case, in form of flat bend of axis as a result of "smooth" build up of deflections. In both these cases exhausting of load-bearing ability was accompanied by drop of load at 20-30 % of critical.

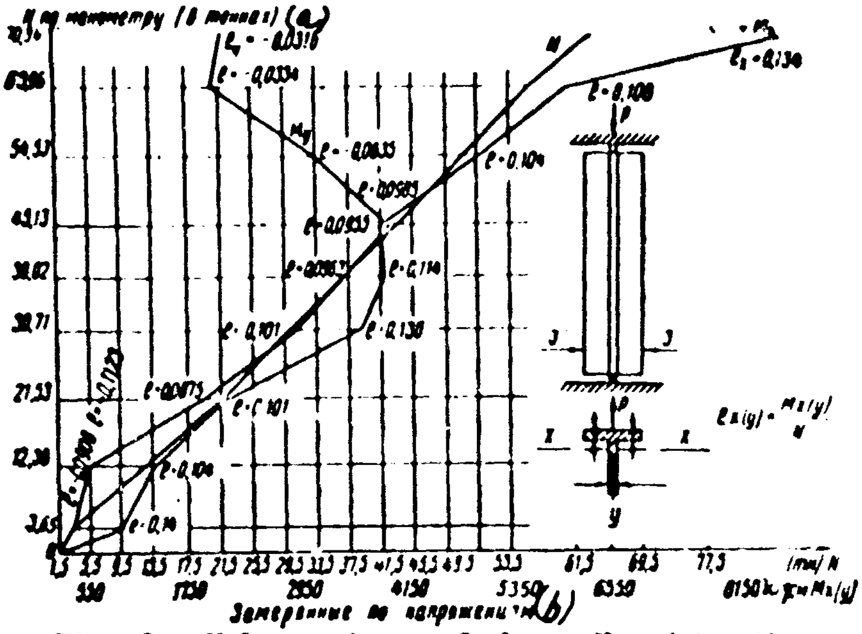

Fig. 9. Values of normal force N and bending moments $M_x$ and $M_y$, measured in cross sections at different stages of loading of rod.
KEY: (a) by manometer (in tons); (b) Measured at stresses.

Only in separate tests of this series of rods was there observed buckling in form of sharp end of axis (clap), accompanied by instantaneous drop of significant part (70–80 %) of load. In last cases critical load on rod was 10–20 % higher than load which was recorded for rods of the same flexibility, exhausting of load-bearing ability of which set in "smoothly." From 17 tests of rods of tubular section not once was there noted local deformations of cross section. Bent axis of rod always had flat character of elastic or elastic-plastic flow, disappearing almost completely upon removal of load.

During repeated loadings of these rods critical load for them constituted on the average nearly 80 % of critical load of first loading. Character of deformation during secondary loading was always smooth independently of character of deformation during first loading.

During tests of rods of corner profile, besides bend deformations, there were observed also criteria of twisting deformations. This appeared, in particular, in turn of internal bearing discs of balancers by angle up to 7–8° relative to one another and relative to initial position (Fig. 10). Nonetheless, of the 16 rods of

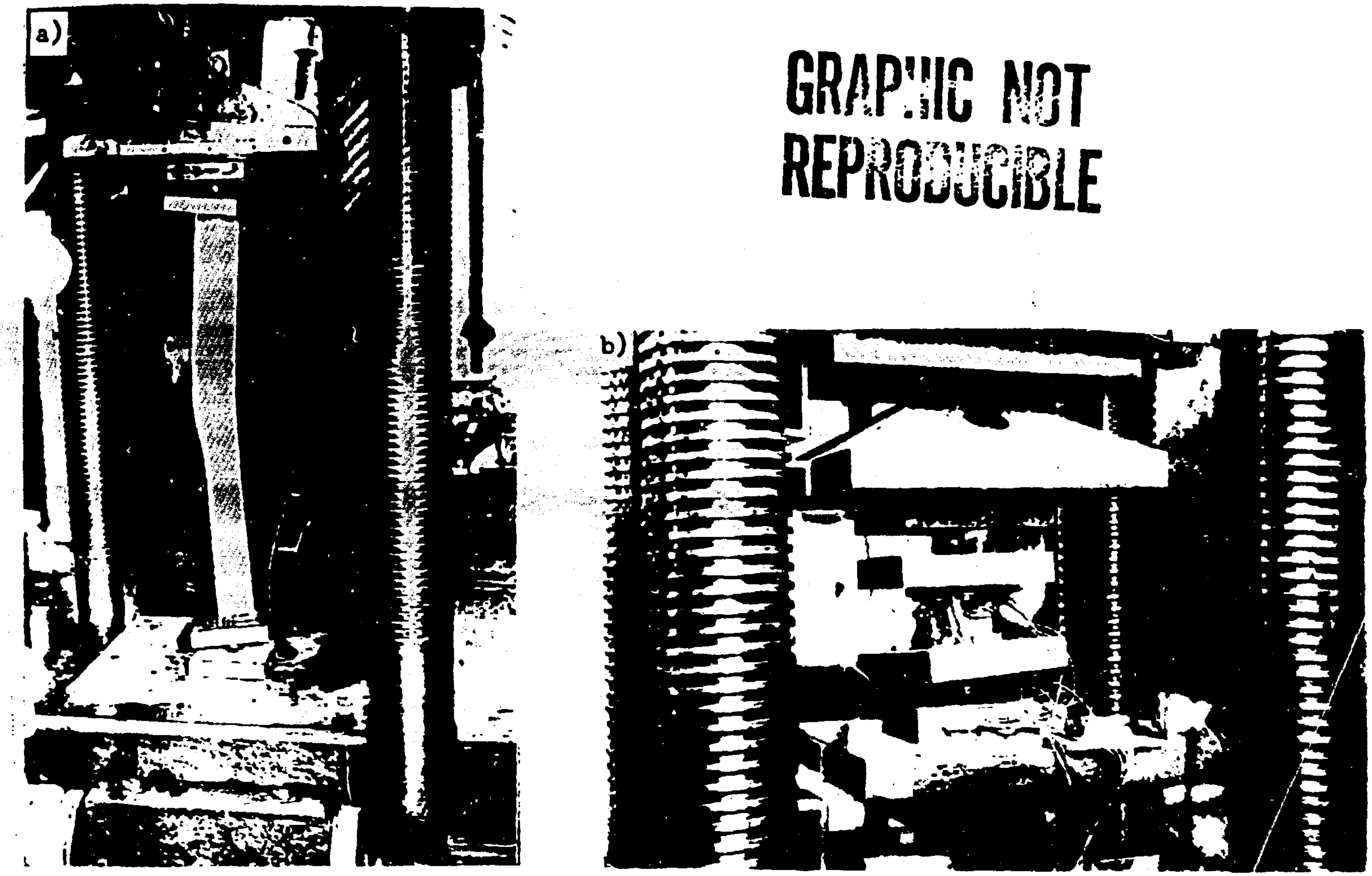


Fig. 10. Bend-twist form of loss of overall strength of rod of corner profile: a) flexibility $\lambda = 45$; b) flexibility $\lambda = 7$.

corner profile only in two cases at $\lambda = 100$ and $\lambda = 45$ was there buckling in plane of flange. In all other cases bend of rods of high flexibilities at moment of buckling is observed in plane of least rigidity with crushing of flanges in form shown in Fig. 11, a.

Form of deformation in these cases was, as a rule, symmetrical, and character of deformation - elastic or elastic-plastic. After removal of load, elastic axis of rod sometimes was straightened so much that readings of instruments recorded unobtrusive magnitudes of permanent deformations or their total absence. Mutual turn of bearing discs of balancers was especially noted during loading of rods of corner profile with flexibility $\lambda = 30$ and $\lambda = 45$. In both cases turn occurred instantly at moment of buckling; during stage loading of rods, turn of plates was not visually noted.

In the sense of appraisal of influence of torsion on load-bearing ability of centrally compressed rod of open profile the following three facts are interesting.

1. For two rods of corner profile with flexibility $\lambda = 30$ loss of load-bearing ability set in practically at the same load, but had externally excellent form. First rod during load P = 55.22 t at moment of buckling was bent and was turned around its own axis. Here bend of rod was not accompanied by clap. Second rod buckled during load P = 56.94 t in form of flat bend in that same plane $(y_0 - y_0)$ that was accompanied by clap. Unloading of rods during their deformation was unequal and constituted respectively 57 and 66 % of their critical loads, i.e., convergence of ends during deformation in first case was less than in second.

2. During loading of rods $\lambda = 45$, in two of three cases buckling of rods set in instantly and was accompanied by clap. And although values of critical forces in both cases were practically equal, form of deformation in one case was purely bend (P = 54.5 t - Fig. 11, b), in other case - bend-twist with noticeable turn of bearing discs (P = 53.5 t - Fig. 11, c). Drop of load in both cases constituted on the average 74 % of maximum value. Critical load for third rod

of this flexibility, of which set in the form of bend of axis in plane of least rigidity without clap, was equal to $P = 46.42$ t, i.e., 14% lower. Unloading during deformation of first loading in this case constituted 25 % in all of $P_{кр}$. During full unloading there were measured small, permanent sets, indicating on elastic-plastic character of work of rod under critical load. Ultimate load during repeated loading turned out to be equal to 75 % of critical force of first loading.



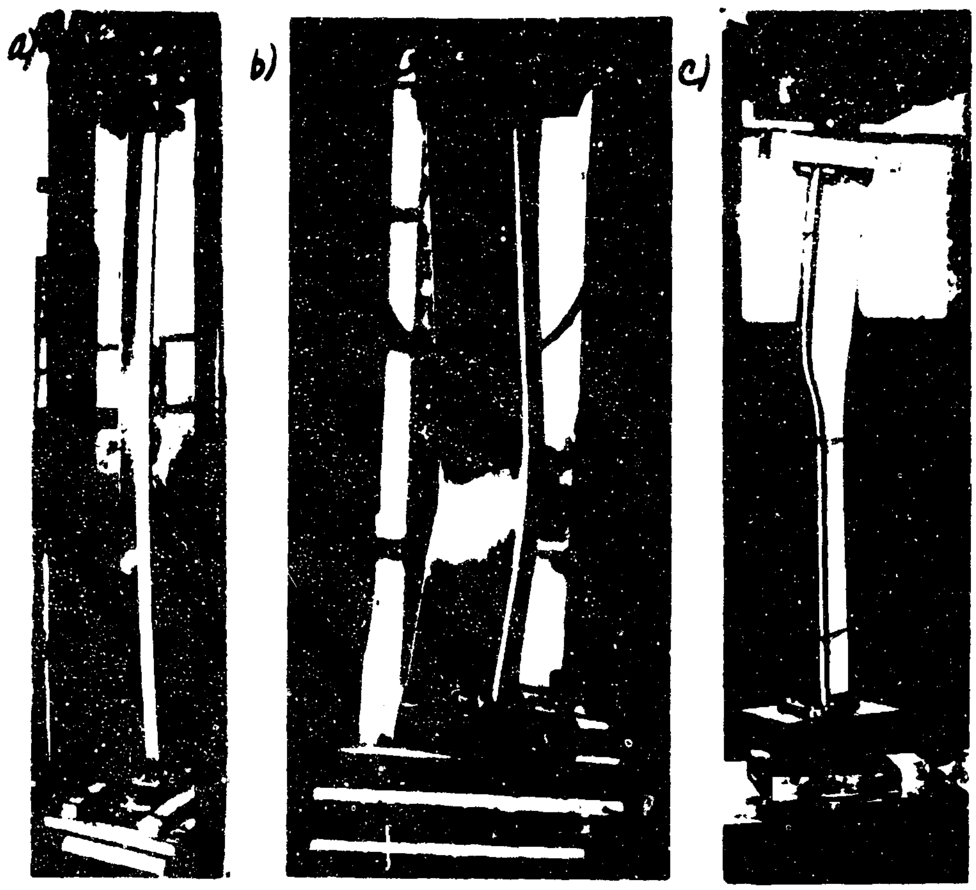


Fig. 11. Bend form of loss of overall strength with crushing of flanges of angle.
a) bend of rod with crushing of flanges ( $\lambda = 100$); b) bend in plane of flange ( $\lambda = 45$); c) bend-twist form ( $\lambda = 45$).

3. During loading of rods with flexibility $\lambda = 100$, two rods of the three had identical values of critical forces $P_{кр} = 15.57$ t with various forms of buckling: one rod was "smoothly" bent in plane of least rigidity, other was also "smoothly" bent, but in plane of flange. Turn of section around axis of rod in both cases was not observed. During deformation of rods there was noted identical

degree of unloading (25 % of $P_{kp}$). After full unloading of rods there were measured extremely small (within limits of accuracy of deflectometer) permanent sets, which fully corresponded to results of repeated loading, ultimate load for which constituted 93 % of critical load of first loading.

Buckling of third rod with the same flexibility set in during load $P_{kp}$ 21.11 t, i.e., 36% higher than for first two rods, and had character of instantaneous disturbance of stable equilibrium of rod. Character of deformation, bend in plane of least rigidity, was accompanied by clap and shallow crushing of flanges. After full unloading of rod, its axis was straightened completely. However, ultimate load of repeated loading was lower than during first loading. Presence of inconspicuous permanent sets of cross section and fastening supports lowered critical load on rod to value P = 15.65 t, equal to critical force for first two rods.

Thus, these observations allow us to conclude that influence of twisting deformations was not significant, determining load-bearing ability of centrally compressed rods, whereas scattering in values of critical forces with identical form of buckling indicates significant influence of initial eccentricities of application of load.

This conclusion is fully confirmed by results of tests of rods of tee section, when 15 rods tested there was not one case of buckling with any noticeable influence of twisting deformations.

All rods buckled severely in plane of least rigidity (in plane of flange, where bend of rods, as a rule, was accompanied by a jolt. There was a case of local buckling by wall during test of rod with flexibility $\lambda$ = 29 (Fig. 12). Local deformation of rods practically in all cases was elastic-plastic.

Both in rods with flexibility $\lambda$ = 96.5 and in rods with flexibility $\lambda$ = 30 there were noted insignificant permanent sets after unloading of rod and lowering of ultimate load during repeated loading, as compared to critical force of first loading. Character of deformations of rods during repeated loading was

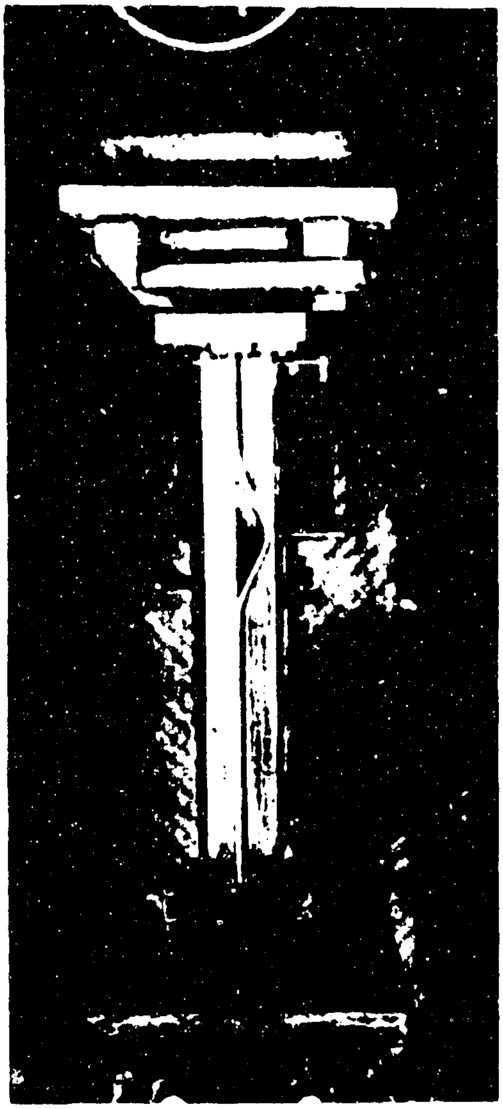

Fig. 12. Local buckling by wall during central compression of rod of tee section with flexibility ( $\lambda = 29$).

analogous to first loading, with the difference that bend of axis of rod upon achievement of critical force occured more smoothly.

Thus, results of tests of rods of four types of cross section confirmed possibility of acceptance of normative coefficients of longitudinal bend during central compression without regard for form of cross section of element.

Appraisal of conformity of actual load-bearing ability with respect to that calculated, determined according to second calculated limiting state, to equality

$$N = \varphi RF, \qquad (4)$$

may be done on the basis of comparison of graph of normative coefficients $\varphi$ [1] with actual values of ratios $\sigma^{эк}_{кр} : \sigma_{0,2} = \varphi$. Such comparison is shown in Fig. 13.

From Fig. 13 we notice that through entire extent of investigated flexibilities normative curve is within lower limits of experimental points, which with so insignificant a scattering of them is fully acceptable at present stage of mastering of this new material.

Here one should consider also the fact that actual values of relative eccentricities $e_1^*$ in all rods tested in this program were more than two times less than eccentricities taken during composition of table of normative values

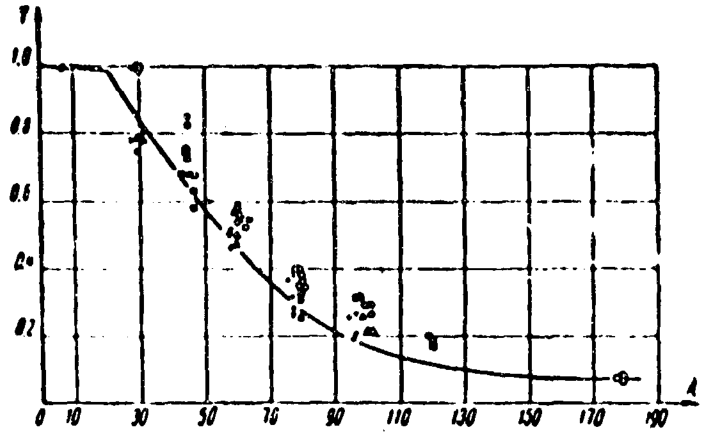


Fig. 13. Comparison of normative curve of coefficients of longitudinal bend of centrally compressed rods with experimental values of ratios $\sigma_{кр}^{эк} : \sigma_{0.2} = \varphi_{эк}$ .

Special designations:

△ - angle 90 X 90 X 10 mm; ○ - pipe, 80 X 72 X 4 mm; □ - rod, d = 18 mm; + - tee, 100 X 18 + 120 X 8 mm.

of coefficients of longitudinal bend $\varphi$, and in a number of cases less than eccentricities possible under actual conditions. Thus, for instance, average relative eccentricity for rods of tubular section with flexibility $\lambda = 45$ constituted $e_1' = 0.07$ and for tee rods of the same flexibility $e_1' = 0.04$ instead of $m = \frac{3}{1000}\lambda = 0.135$ - normative value of relative eccentricity for given grade of alloy.

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# LOAD-BEARING ABILITY OF ECCENTRICALLY COMPRESSED RODS FROM ALUMINUM ALLOY AV-T1

B. G. Bazhanov, Engineer

## 1. Introduction

In building structures there are applied aluminum alloys of different grades [1]. Stress-strain diagrams of these alloys beyond the limits of elasticity have curvilinear character and noticeably differ from each other in amount of hardening of material in plastic stage.

During calculation of rods from aluminum alloys for eccentric compression, application of different curves with complex analytical expression for approximation of diagram $\sigma - \varepsilon$ of each alloy leads to large number of labor-consuming computations, and does not give in final result formulas convenient for application.

For simplification of solution of this problem Weinhold in his works [5], [6] replaced diagram of all applied alloys by single, generalized curve having complex analytical expression, and developed method of dimensionless parameters, allowing use of this generalized curve during calculation of structures from any alloys. This method was used* during composition in TU SN [Tech. Specs. and Building Standards] 113-60 [1] of tables for coefficients $\varphi_{ecc}$. However, absence of

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*See article by B. M. Broude and G. M. Chuvikin in this collection.

experimental works on strength of eccentrically compressed rods from native alloys did not allow authors of technical specs recommended in TU SN 113-60 to estimate accuracy of method used in application to aluminum alloys. Besides this, comparison of generalized curve (Weinhold) and experimentally determined diagram $\sigma - \varepsilon$ of alloy AV-T1, plotted on one drawing (Fig. 1), indicates their essential distinction in plastic stage.

Solution of problem of strength of eccentrically compressed rods can be significantly simplified by putting in basis of this solution in place of curvilinear idealized diagram $\sigma - \varepsilon$ one composed of two slanted, straight lines (Fig. 2). Basic parameters of this idealized diagram are chosen on the basis of analysis of experimental diagram $\sigma - \varepsilon$ of investigated alloy. Thus, straight line OA with angle of inclination $\varphi$ (Fig. 2) corresponds to elastic stage of work of material; here $\tan \varphi = E$, where E - elastic modulus taken from experimental diagram.

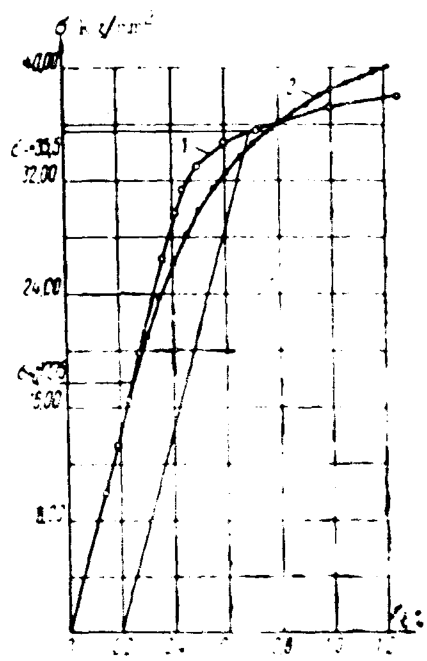

Fig. 1. Comparison of experimental diagram $\sigma - \varepsilon$ of alloy AV-T1 (1) with generalized curve of Weinhold (2).

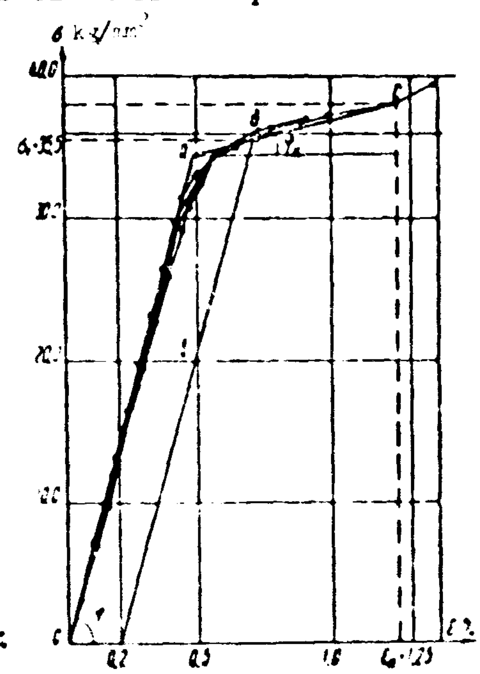

Fig. 2. Approximation of experimental diagrams $\sigma - \varepsilon$ of alloy AV-T1 with help of idealized diagram with linear hardening.

Angle of inclination $\varphi_k$ of straight line AC depends on nature of contour of experimental diagram in plastic stage, and for each alloy it has definite value; where $\tan \varphi_k = E_k$, where $E_k$ - tangent modulus taken from experimental diagram.

Furthermore, we draw slanted straight line AC through point B of experimental diagram $\sigma - \varepsilon$, yield point $\sigma_T$ for both diagrams.

On the basis of study of form of experimental diagrams $\sigma - \varepsilon$ of alloy AV-T1, depicted in Fig. 2, amount of linear hardening of material in plastic stage is taken equal to $\theta = \frac{E_K}{E} = 0.08$.

On the basis of results of experimental investigations conducted earlier in TsNIISK on eccentrically compressed rods from alloy D16-T, and from number of works [7] it is known that for rods from aluminum alloys to moment of loss of stability of deformation on compressed fibers of average section have insignificant magnitude ($\varepsilon$ = 0.8 to 1 %).

Considering these results, in present work approximation of experimental diagram is made in interval of deformations $\varepsilon$ = 0 to 1.25 %.

Experimental diagram $\sigma - \varepsilon$ was determined during test of flat samples from alloy AV-T1 for compression on a device developed in TsNIISK by Yu. S. Mrchanets engineer.* On this device there was conducted test of flat samples with dimension 5 X 12 X 55 mm cut from pressed profiles, from which there were prepared rods for eccentric compression tests. Mechanical characteristics of alloy AV-T1 obtained as a result of these tests are given in Table 1.

Table 1. Mechanical Characteristics of Samples from Alloy AV-T1

| (a) № образца | (b) Предел пропорциональности $\sigma_p$ в кг/мм² | (c) Условный предел текучести $\sigma_{0,2}$ в кг/мм² |
|---|---|---|
| 1 | 30,2 | 36 |
| 2 | 30,5 | 35,6 |
| 3 | 29,8 | 35,4 |
| 4 | 30,3 | 35,2 |
| 5 | 29,7 | 35,3 |

KEY: (a) No. of sample; (b) Limit of proportionality $\sigma_p$ in kg/mm²; (c) Conditional yield point $\sigma_{0.2}$ in kg/mm².

*Experimental determination of diagram of compression is described in this collection in article by Yu. S. Mkrchanets, engineer.

## 2. Theoretical Solution For Cases of Unilateral Yield

In this section there is considered strength in plane of bend of eccentrically compressed aluminum rods H - shape and rectangular sections.

As method of theoretical investigations we used method of two calculated sections developed by Dr. of tech. sciences A. V. Gemmerling [2].

Solution is approximate, since it is based on following assumptions:

a) flat form of bend is stable;

b) deformations through section are distributed according to the law of plane;

c) for curvature of rod there is taken approximate expression $\frac{1}{\rho} = y''$;

d) bent axis of rod is taken in the form of sinusoidal curve.

In basis of theoretical research in method of two calculated sections idealized diagram is assumed $\sigma - \varepsilon$ in the form of two slanted, straight lines, with help of which calculation is made of linear hardening of material in plastic stage.

Let us consider critical state of eccentrically compressed rod H-shaped section in the presence of unilateral yield on concave side. Investigated rod has hinged support on both ends and is loaded by compressing forces N, applied with eccentricity $m_0$ (Fig. 3).

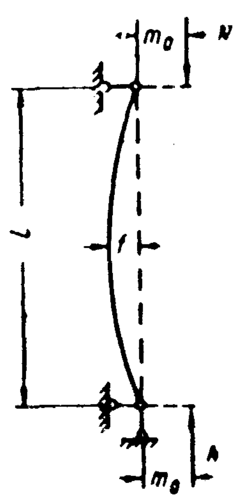

Fig. 3. Diagram of loading of rod.

For determination of critical compressing force of rod we use generalized Euler formula [2]:

$$N_{\text{кр}} = \frac{\pi^2 E J_2}{l^2}, \quad [\text{кр} = \text{crit}] \qquad (1)$$

where $J_2$ - moment of inertia of second calculated section.

Investigation of critical state of considered rod with application of formula (1) is conducted on the basis of analysis of repulse character, by which here is understood ability of rod to resist infinitesimal deflections from obtained states of equilibrium.

If magnitude of repulse of rod is greater than that of compressing forces acting on rod, then there is no loss of strength, if, however, magnitude of repulse becomes equal to external load, there will be buckling.

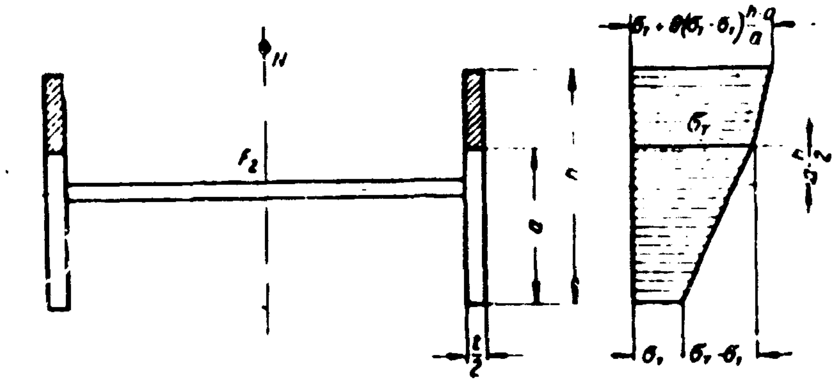

Fig. 4. Diagram of stresses in section.

That state of equilibrium is critical at which there is possible infinitesimal increase of deformation without increase of external load. Investigation of repulse is made by method of theory of strength of first kind.

Repulse of rod is characterised by second calculated sections obtained as a result of multiplication of basic area of actual section by relative tangent modulus $\theta$, which is equal to ratio of tangent modulus $E_k$, taken from diagram $\sigma - \varepsilon$, to elastic modulus E.

For determination of critical value of compressing force by formula (1) it is necessary to establish moment of inertia of second calculated section $J_2$ of considered rod in critical state of equilibrium. Definition of this moment of inertia constitutes the usual geometric problem.

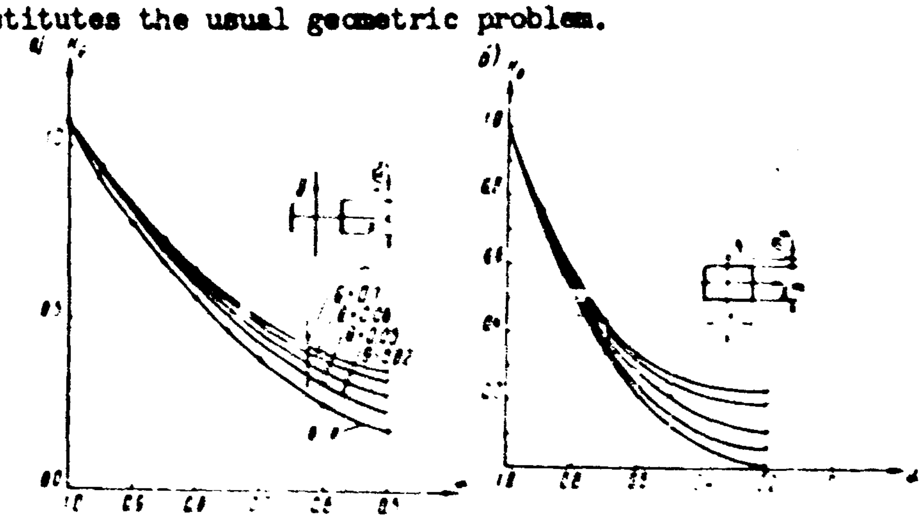

Fig. 5. Graphs of coefficient $k_1$ for rods a) of H-shaped section; b) of rectangular section.

For H-shaped section, depicted in Fig. 4, moment of inertia of second calculated section has the form

$$J_2 = \frac{th^3}{12} k_2, \tag{2}$$

where

$$k_2 = 4\alpha^3 + 4\theta(1 - \alpha^3) - 3\frac{a_1^2}{a_2} + 3\gamma. \tag{3}$$

Here

$$a_1 = \alpha^2(1 - \theta) + \theta + \gamma; \tag{4}$$

$$a_2 = \alpha(1 - \theta) + \theta + \gamma; \tag{5}$$

$$\gamma = \frac{F_1}{th}. \tag{6}$$

In order to simplify practical calculation of moment of inertia $J_2$, in Fig. 5, there are given auxiliary graphs for determination of coefficient $k_2$ depending upon relative depth of elastic core $\alpha$ at different values of magnitude of linear hardening ( $\theta$ = 0.02; 0.05; 0.08, and 0.1).

In Fig. 5, a such graphs are given for H-shaped section, and in Fig. 5, b - for rectangular section.

Thus, assigning magnitude of $\alpha$ we can determine moment of inertia of second calculated section, and by formula (1) we can establish magnitude of critical force.

For complete solution of problem of strength of eccentrically compressed rod it is necessary to find expression for deflection in critical state $f_{kp}$ and for eccentricity $m_0$, with which it is necessary to apply compressing force N, so that considered state of equilibrium is critical.

For that we write condition of equilibrium of external and internal forces and moments for section of rod of average length, diagram of stresses of which in the presence of unilateral yield is depicted in Fig. 4. We write moments relative to edge with least compression stress

$$N [illegible] F_1 [illegible] \left[ [illegible] F_1 [illegible] \frac{[illegible]}{2a} \right]. \tag{7}$$

$$M = \sigma_1 \frac{th^2}{2} + \sigma_1 F_2 \frac{h}{2} - (\sigma_T - \sigma_1)\left[\frac{ta^2}{6} + F_2 \frac{h\left(a - \frac{h}{2}\right)}{2a} - \theta t \frac{(h - a)^2 (a + 2h)}{6a}\right]. \quad (8)$$

Curvature of axis of rod on the basis of Bernoulli's hypothesis may be expressed through deformations on the average section:

$$\frac{1}{\rho} = -\frac{\sigma_T - \sigma_1}{Ea}. \quad (9)$$

Bent axis of rod loaded according to Fig. 3 we take as described by half-wave of sinusoid

$$y = f \sin \frac{\pi x}{l}. \quad (10)$$

Differentiating equation (10) twice, we obtain curvature of bent axis of rod, which for average section will be equal to

$$\frac{1}{\rho} = -\frac{\pi^2 f}{l^2}. \quad (11)$$

Equating right sides of (9) and (11), we obtain

$$\frac{\sigma_T - \sigma_1}{a} = \frac{\pi^2 E f}{l^2}. \quad (12)$$

Solving equations (7) and (12) jointly, we find expression for deflection in middle of length of rod

$$f = \frac{(\sigma_T - \sigma_N)(1 + \gamma)}{DC}. \quad (13)$$

where

$$D = \frac{\pi^2 E h}{2 l^2}; \quad (14)$$

$$C = \alpha^2 + 2\gamma\left(\alpha - \frac{1}{2}\right) - \theta(1 - \alpha)^2. \quad (15)$$

Placing values of (12) and (13) in (8), we obtain following expression for bending moment M:

$$M = th(\sigma_T - \sigma_N)(1 + \gamma)A, \quad (16)$$

where

$$A = \frac{B(1 - \theta) + \theta}{6\frac{C}{h}}; \quad (17)$$

(18)

Here $B = 3\alpha^2 - 2\alpha^3$.

Moment of external forces about center of gravity of average section is equal to

$$M_{н} = N(m_0 + f) = N\left[m_0 + \frac{(\sigma_т - \sigma_N)(1+\gamma)}{DC}\right]. \tag{19}$$

Solving equation (19) with respect to $m_0$, we obtain expression for eccentricity $m_0$, corresponding to given state of rod:

$$m_0 = (\sigma_т - \sigma_N)\left(\frac{A}{\sigma_N} - \frac{1+\gamma}{DC}\right). \tag{20}$$

Formulas obtained by us for determination of $N_{кр}$, $f$ and $m_0$ are just during unilateral yield on the average section of rod upon achievement by it of critical state.

During determination of limit of applicability of formulas of unilateral yield, as upper limit there is taken appearance of outer yield on the average section of rod ($\alpha = 1$), and as lower limit - state of strain at which yield appears and on stretched edge. Values of $\alpha$ corresponding to lower limit is determined from condition

$$\sigma_т - \sigma_1 \leqslant 2\sigma_т. \tag{21}$$

With respect to (7) this inequality may be written in the following form:

$$\frac{\sigma_N}{\sigma_т} \geqslant 1 - p, \tag{22}$$

where p is determined by the formula

$$p = \frac{\alpha^2 + \gamma(2\alpha - 1) - \theta(1-\alpha)^2}{\alpha(1+\gamma)}. \tag{23}$$

During fullfillment of inequality (22), in section of rod there will be unilateral yield; if it is not satisfied - bilateral yield.

Thus, the obtained adjoint equations (1), (13), and (20) allow us to completely solve probllem of strength of eccentrically compressed rods during unilateral yield on concave side.

Actually, knowing length of rod l and assigning certain depth of elastic core a or relative depth $\alpha$ there can be found magnitude of critical force $N_{кр}$, magnitude of deflection $f_{кр}$ and then by formula (20) eccentricity $m_0$, with which it is necessary to apply force $N_{кр}$ so that critical state actually sets is at selected value of $\sigma_{\kappa p}$.

This scheme of calculation allows us rather simply to construct graph of $\sigma_{\kappa p}(\lambda, m_0)$, with help of which there can be found $\sigma_{\kappa p}$ for any rod H-shaped section with given flexibility $\lambda$ and eccentricity $m_0$.

It is possible to show that criterion of strength of rods according to Euler (1) applied in this article is equivalent usually to applied analytic criterion of buckling

$$\frac{d\sigma}{df}=0, \tag{24}$$

which can also be written in the form [3]

$$\frac{dM}{d\alpha}=\frac{dM_{\text{в}}}{d\alpha}. \tag{25}$$

We take derivatives with respect to $\alpha$ from expressions of external and internal moments [equations (19) and (16)]. Placing them in equation (25) and solving it with respect to $N_{\kappa p}$, we find

$$N_{\kappa p}=\frac{\pi^2 E}{l^2}\left\{\frac{th^3}{12}\left[4\alpha^3+4\theta(1-\alpha^3)-3\frac{\alpha_1^2}{\alpha_2}+3\gamma\right]\right\}. \tag{26}$$

During the analysis of formula (26), we notice that expression in brackets constitutes moment of inertia of second calculated section (2).

Thus, we obtained expression $N_{\kappa p}$ (26), which completely coincides with generalized Euler formula (1). For rods of rectangular section formulas for determination of $N_{\kappa p}$, $f$ and $m_0$ can be obtained from corresponding formulas (1), (12), and (20) for rods of H-shaped section, assuming

$$\gamma=\frac{F_2}{th}=0.$$

In this article we limited ourselves to consideration of critical state of eccentrically compressed rods of two forms of cross section (H-shaped and rectangular). However, the above-mentioned method of approximation may be used for investigation of strength of rods with any form of section usually applied in metallic structures (I-beam, tee and other sections).

## 3. Test of Rods From Aluminum Alloy AV-T1 for Eccentric Compression

Experimental investigations for eccentric compression were conducted on rods of H-shaped and rectangular sections. Section of H-shaped profile was selected from "Catalog of Pressed Profiles" [4] and is close in form to steel I-beam of building assortment, but differs somewhat by large thickness of flanges and walls (Fig. 6).

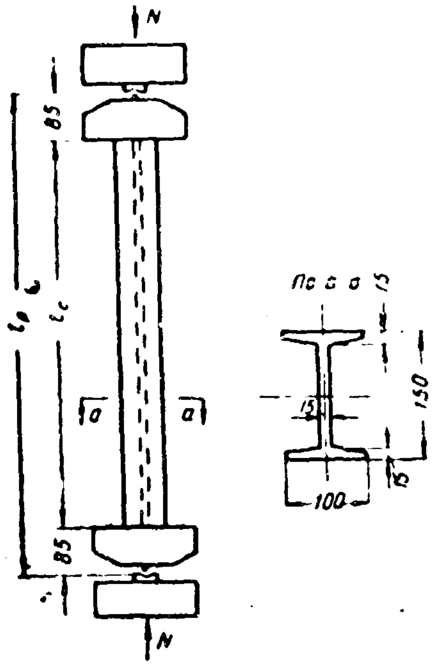

Fig. 6. Diagram of test of rods of H-shaped section.

Investigated H-shaped profile was prepared by method of hot extrusion from alloy AV-T1. Tests were conducted on rods with flexibility λ = 40 to 70 with bend in plane of least rigidity. In accordance with shown flexibility there were determined calculated lengths of rods, which differed from actual lengths in magnitude of height of supports (Fig. 6). Actual dimensions of all rods are given in Table 2.

During preparation of test samples, attention was given to quality of machining of butt ends, on which greatly depends accuracy of centering of rods. Machining of butt ends was done on boring machine by end milling cutter with maintainence of mutual parallelism of butts and perpendicularity of butt faces to longitudinal axis of rod.

Table 2. Results of Tests of Rods of H-Shaped Section for Eccentric Compression

| (a) Стержни | (b) Относительный эксцентриситет $m$ | (c) Длина стержня, в см | | (d) Гибкость λ | (e) Экспериментальные данные | | (f) Теоретическое напряжение | (g) Ошибка в % |
|---|---|---|---|---|---|---|---|---|
| | | $l_c$ | $l_p$ | | $N_{кр}$ (h) в кг | (i) $\sigma_{кр}$ в кг/см² | $\sigma^{т}_{кр}$ (i) в кг/см² | |
| (i) H1 | 0,2 | 70,1 | 87,1 | 40 | 104 470 | 2325 | 2360 | 1,5 |
| H2 | 0,2 | 91,9 | 108,9 | 50 | 90 060 | 2000 | 2140 | 7,0 |
| H3 | 0,5 | 91,9 | 108,9 | 50 | 77 010 | 1710 | 1770 | 3,5 |
| H4 | 0,2 | 113,7 | 130,7 | 60 | 68 810 | 1530 | 1600 | 4,6 |
| H5 | 0,5 | 113,7 | 130,7 | 60 | 60 270 | 1340 | 1440 | 7,5 |
| H6 | 0,2 | 135,4 | 152,4 | 70 | 51 530 | 1145 | 1160 | 1,3 |

KEY: (a) Rods; (b) Relative eccentricity in m; (c) Length of rod in cm; (d) Flexibility; (e) Experimental data; (f) Theoretical stress; (g) Error in %; (h) In kg; (i) In kg/cm$^2$

As a result of check it was found that test samples did not have initial curvature.

In Fig. 6 there is shown diagram according to which tests were conducted on rods of H-shaped section. Support of ends of rods during test was carried out with help of knife hinges, located in such a way that plane of bend of rods coincided with plane of their least rigidity. In direction perpendicular to knife hinge rods had rigid support.

Tests were conducted on hydraulic 500-ton press. Plates of press, having large height (230 mm) were preliminarily wedged, in order to exclude possibility of their rotation. On these plates there were fastened additional supports (Fig. 7), which ensured hinged support of rod on both ends. Each support consists of two steel plates, on one of which is fastered a "knife," and on other - "saddle" of hardened steel. During bend of rods under load, their ends, together with bearing discs, can turn freely about longitudinal axis of knife hinge by angle up to 16°.

Tests of rods for eccentric compression were conducted with eccentricities equal to m = 0.2 and m = 0.5, where m - relative eccentricity equal to $m = \frac{m_0}{\rho}$.

Here $m_0$ - absolute eccentricity;

$\rho = \frac{W}{F}$ - core distance.

Eccentricities of compressing force were set in plane of least rigidity of samples, with respect to an axis passing through center of gravity of section of sample. Magnitude and sign of eccentricity on both ends of rod were taken as identical. Six rods of H-shaped section were tested for eccentric compression.

Initial centering of rods before test was done by reference lines drawn on samples and supports. Control of initial centering was carried out with help of tensometers with base of 20 mm. Tensometers were established in pairs on edges of flanges in three sections through length of rod: in middle of calculated length and on ends - at distance of 70 mm from butt sections.

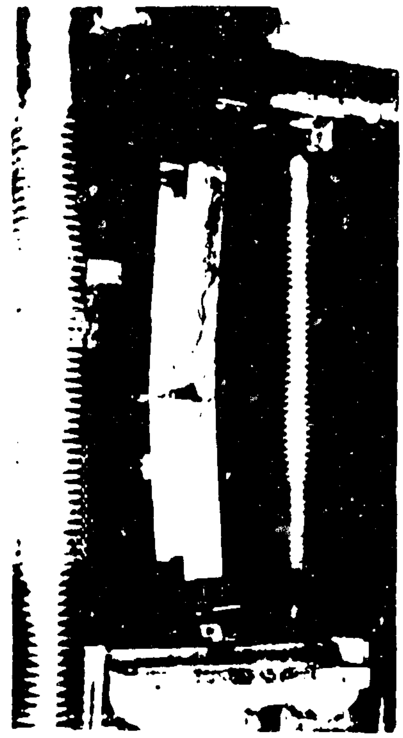

Fig. 7. Rod of H-shaped section during test; flexibility $\lambda$ = 70.

Fig. 8. Rod of H-shaped section at moment of buckling flexibility $\lambda$ = 50.

During centering ends of rods moved insignificantly on planes of supports so long as relationship of deformations by readings of tensometers did not differ from that given by less than 5 %. In process of tests of rods tensometers measured deformations through length of samples. In those places of H-shaped profile where installation of tensometers evoked difficulty there were glued wire detectors with base of 25 mm (Fig. 8).

Deflections in plane of least rigidity of samples were measured in the center section (through height of rod) by two deflectometers of N. N. Maksimov system. Deflectometers were mounted on special stands, not connected to press. Measurement of deflections with help of two deflectometers connected to both flanges of rod allowed detection of torsion of sample. Readings on instruments were taken at intervals of loading (3-5 t), decreasing with approach to critical state. Readings of tensometers and deflectometers were taken up to moment of buckling of rod.

As critical was taken that load at which deformations of rod increased intensely without increase of load and with its subsequent drop. Load on rod was determined by 125-ton scale of manometer of press.

General view of rods fixed on press is shown in photographs made in process of test and after buckling (Figs. 7 and 8).

Results of tests of rods of H-shaped section for eccentric compression are given in Table 2.

Experimental investigations for eccentric compression, besides those of rods of H-shaped section, were conducted also on rods of rectangular section from the same alloy, AV-T1.

The entire lot of samples of rectangular section consisted of six series (two samples each in every series), differing from each other by magnitude of flexibility in interval $\lambda = 58$ to 114. Eccentricity of compressing force was set in plane of least rigidity of rod, and for all samples was equal to $m = 1$. Geometric dimensions of rods are given in Table 3.

Table 3. Results of Tests of Rods of Rectangular Section for Eccentric Compression

| (a) Стержни | (b) Геометрические размеры сечения в см | | (c) Площадь $F$ в $см^2$ | (d) Длина стержня в см | | (e) Гибкость $\lambda$ | (f) Экспериментальные данные | | (g) Теоретическое напряжение $\sigma^T_{кр}$ в $кг/см^2$ (k) | (h) Ошибка в % |
|---|---|---|---|---|---|---|---|---|---|---|
| | $b$ | $h$ | | $l_c$ | $l_p$ | | $N_{кр}$ в кг (j) | $\sigma_{кр}$ в $кг/см^2$ (k) | | |
| (i) П1 | 3 | 1,56 | 4,68 | 26 | 26 | 57,75 | 4600 | 983 | 1020 | 3,8 |
| П2 | 3 | 1,56 | 4,68 | 20 | 26 | 57,75 | 4480 | 957 | 1020 | 6,6 |
| П3 | 3 | 1,45 | 4,35 | 31 | 31 | 74,1 | 3730 | 857 | 790 | −7,8 |
| П4 | 3 | 1,45 | 4,35 | 25 | 31 | 74,1 | 3450 | 793 | 790 | −0,4 |
| П5 | 3 | 1,45 | 4,35 | 36 | 36 | 86,6 | 2650 | 609 | 650 | 6,7 |
| П6 | 3 | 1,45 | 4,35 | 30 | 36 | 86,6 | 2640 | 607 | 650 | 7,1 |
| П7 | 3 | 1,55 | 4,65 | 43 | 43 | 96,1 | 2430 | 523 | 555 | 6,1 |
| П8 | 3 | 1,55 | 4,66 | 37 | 43 | 96,1 | 2490 | 535 | 555 | 3,7 |
| П9 | 2,99 | 1,39 | 4,158 | 41 | 41 | 102,[illegible] | 2000 | 481 | 507 | 5,4 |
| П10 | 2,99 | 1,39 | 4,158 | 35 | 41 | 102,2 | 2000 | 481 | 507 | 5,4 |
| П11 | 2,98 | 1,4 | 4,172 | 46 | 46 | 113,9 | 1800 | 431 | 440 | 2,1 |
| П12 | 2,98 | 1,4 | 4,172 | 40 | 46 | 113,9 | 1800 | 431 | 440 | 2,1 |

KEY: (a) Rods; (b) Geometric dimensions of section in cm; (c) Area F in $cm^2$; (d) Length of rod in cm; (e) Flexibility; (f) Experimental data; (g) Theoretical stress; (h) Error in %; (i) P1, 2, etc; (j) In kg; (k) In $kg/cm^2$.

Set-up and method of tests of rods of rectangular and H-shaped sections are approximately identical. Tests of rods were made on 50-ton press of the "Losenhausen" with mechanical drive, allowing us to sufficiently accurately determine magnitude of critical load. Critical state was fixed by lowering of lever of forcemeter of press.

During test of rectangular rods for eccentric compression, fiber deformations were measured by lever tensometers, and deflections were measured by indicators.



Fig. 9. Rod of rectangular section during test; flexibility $\lambda = 86.6$.

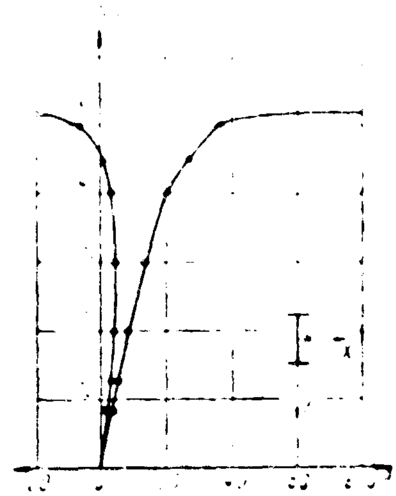

Fig. 10. Graph of fiber deformations for rod H6.

General view of rod in press at moment of test is shown in Fig. 9. Results of tests of rods of rectangular section for eccentric compression are given in Table 3.

Analysis of results of tests of rods of H-shaped and rectangular sections shows that experimental data agree well with the theoretical. Thus, for all rods tested difference between theoretical and experimental critical loads does not exceed 7.8 %.

Good coincidence of experimental data with that calculated indicates acceptability of assumptions made on basis of theoretical investigations, and also gives us reason to consider conditions of work of tested rods sufficiently close to theoretical (hinged nature of supports and absence of bending moment in plane of the highest rigidity of rods).

On the basis of results of tests there were constructed graphs of deformations measured by tensometers and detectors on convex and concave fibers of center section of eccentrically compressed rods. In Fig. 10 there is presented an example of graph of fiber deformations in relation to load for rods of H-shaped section H6. In Fig. 11 there is a graph of fiber deformations for rods of rectangular section P1. From these graphs it is clear that with increase of load on rod buildup of compressive strains on convex side of bent rod gradually ceased, and development starts of deformations of opposite sign. On concave side of rod loaded by eccentric force especially intense increase of compressing deformations starts with replacement of sign of deformations on convex side. In Fig. 12 and 13 as an example there are given graphs of deflections, constructed for rods of H-shaped (H6) and rectangular sections (P1).

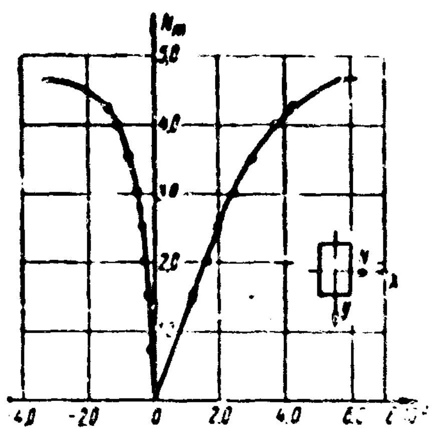


Fig. 11. Graph of fiber deformations for rod P1.

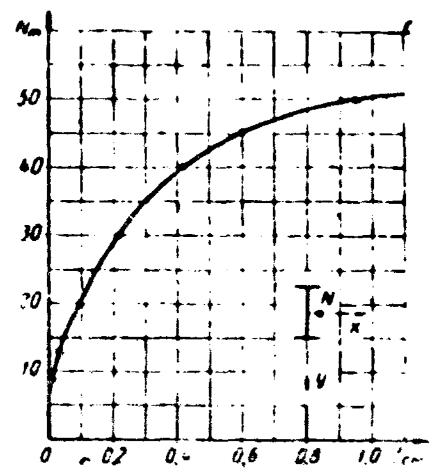


Fig. 12. Graph of deflection of rod H6 in the center section.

Comparison of coefficients $\varphi_{ecc}$ for rods of rectangular section from alloy AV-T1 is shown in Fig. 14. On this figure by solid line is shown curve calculated by formulas (1) and (24) of approximation method; dashed line is curve determined according to TU SN 113-60. Circles of this graph indicate experimental magnitudes of $\varphi_{ecc}$ obtained at TsNIISK during test of eccentrically compressed rods of rectangular section.

Data presented in Fig. 14 show that results determined by formulas of approximation method in overwhelming majority of cases agree well with experimental data.

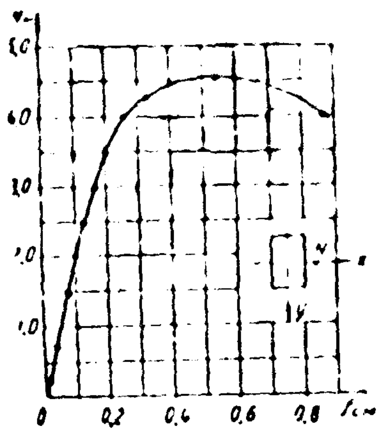

Fig. 13. Graph of deflection of rod P1 in the center section.

In this work there was performed experimental check above-offered approximation method for determination of critical forces on eccentrically compressed rods from aluminum alloy AV-T1 only. However, shown method can be extended to other aluminum alloys. For that it is necessary to know experimental diagrams $\sigma-\varepsilon$ of investigated alloys, and on the basis of their analysis to establish parameters of idealized diagrams with linear hardening utilized in calculation.

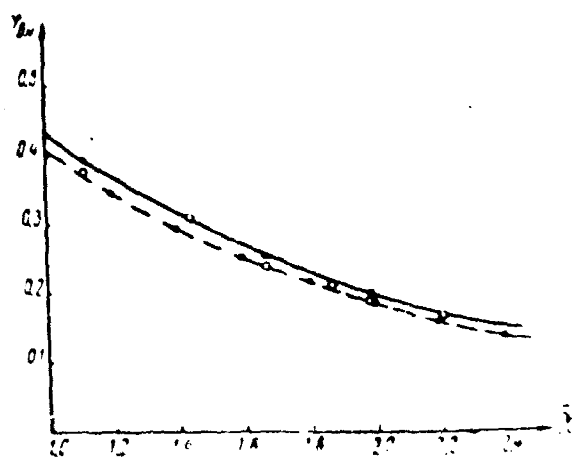

Fig. 14. Comparison of coefficients for rods of rectangular section from alloy AV-T1.

## 4. Conclusions

On the basis of conducted investigation there can be made the following conclusions:

1) offered approximation method of calculation founded on acceptance of idealized diagram $\sigma-\varepsilon$ with linear hardening allowed us to obtain convenient calculating formulas for determination of critical state of eccentrically compressed rods from aluminum alloys in elastic-plastic stage;

2) theoretical results determined with help of method of approximation agree well with experimental data obtained during test of rods of different flexibility ( $\lambda$ = 40 to 114) and with different form of cross section (H-shaped and rectangular section).

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# COLD RIVETING OF BRIDGE AND OTHER BUILDING STRUCTURES FROM ALUMINUM ALLOYS

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For bridge, crane, and other building parts such alloys as duralumin D1-T and D16-T, avial AV-T1, and aluminum-magnesium alloys AMg6 and AMg61 can find preferred use.

Alloys AMg6 and AMg61 belong to those not hardened thermally and construction from them is expediently done by welding.

By the Scientific Research Institute [NII] of bridges for a number of years there was conducted work on study of technology of cold riveting of structures from aluminum alloys with rivets of large diameters (16-24mm). Present article illuminates results of these works. More detailed data on questions concerning different forms of joints of combined rivets and high-strength bolts, and also welding, can be found in work of a body of authors of NII of bridges [2].

## 1. Manufacture of Rivets by Cold Forging

Selection of rivet material for building structures was dictated by thermal and ductile properties of different alloys. Alloys D1, D16, V95, D18, and V65 were checked for rivets. First three have higher strength, but significantly lower ductility than alloys D18 and V65. Furthermore, material of this first group of alloys is well suited to forging only in freshly quenched state, whereas after natural aging it becomes brittle, and during formation of rivet heads, cracks form on the latter. However, freshly quenched state for these alloys is kept for only 1-2 hours after quenching, upon the expiration of which for return of ductility there is required new heat treatment - the so-called recovery. Therefore, application for rivets of alloys D1, D16, and V95 requires very clear coordination of operations of heat treatment and the actual riveting, which may cause certain difficulties during manufacture of structures from aluminum alloys.

Alloys D18 and V65 are free from these deficiencies. They have high ductility in any thermal state, including that following natural aging. Therefore, applying these alloys, it is possible to completely avoid operations for heat treatment of rivets at factory-producer of structures if he is supplied with rod for rivets in state after quenching and aging. Normative data on basic mechanical properties and conditions of heat treatment of alloys D18 and V65 are given in Table 1.

Table 1. Mechanical Properties and Conditions of Heat Treatment of Rivet Alloys D18 and V65

| Характеристика (b) / Сплавы (a) | Предел прочности в кг/мм² (c) | Предел текучести в кг/мм² (d) | Относительное удлинение в % (e) | Сопротивление срезу в кг/мм² (f) | Температура закалки в град. (g) | Продолжительность естественного старения в сутках (h) |
|---|---|---|---|---|---|---|
| D18-T | 30 | 17 | 24 | 19 | 495—500 | 4 |
| V65-T | 40 | -- | 20 | 25 | 515—520 | 10 |

KEY: (a) Alloys; (b) Characteristic; (c) Ultimate strength in kg/mm$^2$; (d) Yield point in kg/mm$^2$; (e) Specific elongation in %; (f) Resistance to shear in kg/mm$^2$; (g) Temperature of quenching in degrees; (h) Duration of natural aging in days.

Investigation of rivet joints was made on rods from alloys D18 and V65, having diameters of 20 and 24 mm.

With the help of special die on 100-ton press there was checked forming of backing heads of rivets. As basic types of heads there were taken semicircular (All-Union Government Standard 1187-41) and flat-conical, somewhat decreased as compared to All-Union Government Standard 1193-41 (Fig. 1).

Experience of manufacture of rivets showed that cold forging of rivets with flat-conical head requires significantly less effort of press than rivets with semi-circular head.

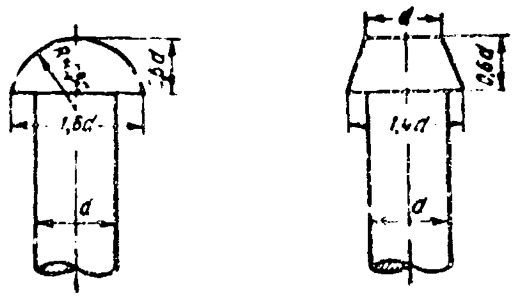


Fig. 1. Rivets with semi-circular and flat-conical heads.

On the basis of analysis of conducted experiments and also of data of foreign investigations [3] there may be recommended following formula for determination of force necessary for forming of rivet head:

$$Q = K \sigma_b d^2, \qquad (1)$$

where Q - force forming head;

- ultimate strength of upset material;

d - diameter of shank of rivet;

K - coefficient depending on form of head.

For semicircular head K = 8.6, for flat-conical K = 5.7.

During formation of backing head, rod is upset and completely fills hole of die. For extrusion of rivet from die considerable efforts are necessary; for their decrease it is useful to give certain conicity to hole of die, as was done during mass manufacture of rivets from alloy D18-T for construction from alloy D1-T.

## 2. Cold Riveting of Elements

Riveting was done in special attachment of bracket type of 100-ton press and under factory conditions by pneumatic clamp with 80-ton force. Fagots were riveted from sheets with thickness of 10-20 mm. Thickness of fagots was taken from 20-90 mm, which for rivets with diameter of 20 mm embraces all thicknesses encountered in building structures.

Rivets from alloys D18 and V65 were placed in fagots upon the expiration respectively of 4 and 10 days of natural aging after quenching. Let us note that if rivets from these alloys are upset in freshly quenched state, plastic flow during riveting will disturb somewhat normal course of process of natural aging and will decrease as our experiment showed, shear strength of rivets by approximately 15 %.

In Table 2 there are given mean values of efforts necessary for cold riveting of fagots.

Table 2. Magnitude of Necessary Efforts for Driving Rivets

| Марка сплава заклепок | Диаметр заклепок в мм | Усилия в т для образования замыкающей головки | |
|---|---|---|---|
| | | при полукруглой головке | при плоско-конической головке |
| D18-T | 20<br>24 | 78<br>88 | 57<br>71 |
| V65-T | 20<br>24 | Трещины в головке<br>То же | 61<br>Трещины в головке |

KEY: (a) Grade of rivet alloy; (b) Diameter of rivet in mm; (c) Efforts in m for formation of locking head; (d) with semicircular head; (e) with flat-conical head; (f) Cracks in head; (g) The same.

From table it is clear that rivets from alloy D18-T for both diameters were formed without cracks; in rivets from alloy V65-T there were formed flat=conical heads without cracks on rod with diameter of 20 mm.

Efforts necessary for forming of locking head and upsetting of shank, just as for backing heads, can be determined by formula (1). Coefficients K have to be decreased here, since method of upsetting in riveted fagot are easier than in die made of high-strength steel, and, consequently, efforts will be relatively smaller. For semicircular locking heads K may be taken equal to 6.7, for flat-conical --5.

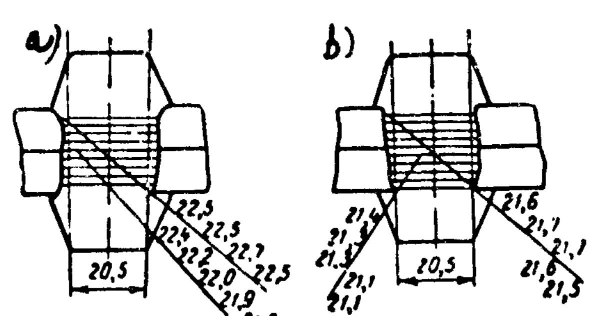


Fig. 2. Filling of fagots by rivets from alloys D18-T (a) and V65-T (b).

In Fig. 2 there is shown filling of hole in fagot by rivet, where it is clear that during cold upsetting of rivets from aluminum alloys (in distinction from hot riveting with steel rivets) holes are completely filled and are even bulged by rivets. This bulging is most noticeable for locking head, decreasing towards backing. Good filling was also obtained in fagots with thickness reaching 4.5 diameters of rivet.

Everything said above pertains to riveting by clamp - machine process. Meanwhile, under conditions of assembling of metallic structures on building site riveting is usually done by pneumatic hammer.

For detection of possibility of assembly by cold riveting tests were conducted on upsetting by press of rivets with heads of decreased dimensions, shown in Fig. 3. Aim of these investigations was determination of heads most useful for forming with pneumatic hammer.

For upsetting of rivets with diameter of 20 mm from alloy D18-T with types of heads shown in Fig. 3 there is required approximately identical effort - near 30 t.

The most useful for assembling use are rivets with decreased semicircular head, since with flat and conical heads it is difficult to attain good centering of rivet shank.

Then in institute, and also in factory during manufacture of parts hand riveting with pneumatic hammers KM-34 and Ke-32 was tested with pneumatic and jack-screw supports.

Experiment of factory riveting showed difficulty with forming during hand riveting of flat-conical or usual semicircular head.

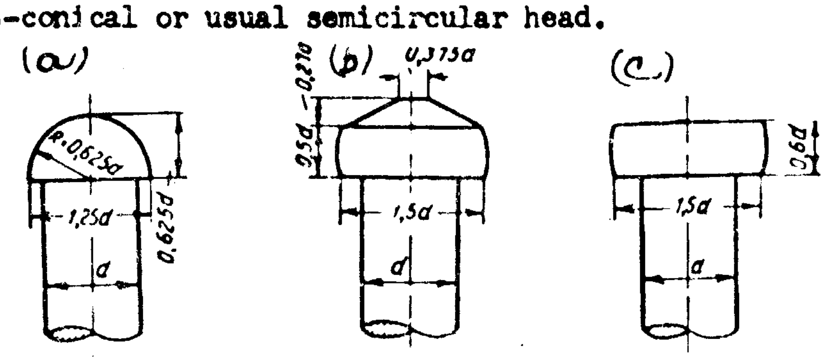


Fig. 3. Rivets with small-size heads a) decreased semicircular; b) conical; c) flat.

Significant simplification of hand riveting was realized by change to decreased semicircular head. In this case forming of head took from 30 to 60 sec. Heads were formed fully satisfactorily. From results of experiments of NII bridges, and also factory manufacture of structures there were determined length of blanks for rivets and length of rivets themselves, depending upon thickness of riveted fagots, diameter of rivet, and type of backing and locking heads.

Length of blank of shank for rivet with flat-conical backing and the same locking head before riveting by clamp, and also length of rod of unset rivet can be determined by the formulas

$$l_{blank} = 1.18\ H + 2.46\ d; \tag{2}$$

$$l_{rivet} = 1.1\ H + 1.2\ d, \tag{3}$$

where H - thickness of riveted fagot;

d - design diameter of rivet.

With flat-conical backing and small semicircular locking heads before riveting by hammer

$$l_{blank} = 1.15\ H + 2.13\ d; \tag{4}$$

$$l_{rivet} = 1.07\ H + 0.87\ d. \tag{5}$$

On the basis of experimental work of NII of bridges on technology of cold riveting there were composed "Technical specs for manufacture of riveted span structures of railroad bridges from aluminum alloys," which can also find application during manufacture of other building parts, for instance, cranes, crane jibs and girders, rafter girders, etc.

According to these technical specs there was prepared in a factory of Ministry of Transportation Construction a riveted structure from alloy D1-T with rivets from alloy D18-T. Experience of manufacture of the structure showed labor-consumption of such operations as cutting sheet and profile, drilling, and mainly assembly of aluminum structures decreases as compared with steel structures. Machine riveting with cold aluminum rivets has lower labor-consumption, as compared with riveting of steel structures by hot steel rivets, since it does not require use of heater. Manual cold riveting is more labor-consuming than hot in steel structures.

## 3. Strength of Riveted Joints From Aluminum Alloys

For assignment of calculating characteristics of rivet joints tests were conducted for shear and crumpling of samples from alloys D16-T and D1-T with rivets from alloys D18-T and V65-T.

A type of sample of double-shear rivet joint is shown in Fig. 4. Besides double-shear samples with one rivet in half joint there were also tested single-shear butt joints and joints with two and three rivets in half joint. Tested also were rivet joints with diameter of rivets of 24 mm. Rivets from alloys D18 and V65 with help of machine riveting were set in samples after quenching and full natural aging (respectively after 4 and 10 days). Tests were made on 100-ton rupture-test machine.

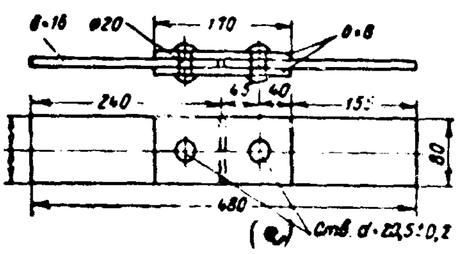

Fig. 4. Sample for static tests.
KEY: (a) Shank, d = 20.5 ± 0.2.

Critical shear stress were determined as quotient from division of shearing force by calculated area of shear. Ultimate bearing strength was taken as quotient from division of load $P_{cr}$ by conditional area of crumpling, equal to product of thickness of joint by design diameter of rivet. For $P_{cr}$ there was taken load provoking first plastic flows at joint. Its magnitude for various samples varied from 0.83 $P_{sh}$ to $P_{sh}$.

Through tests on large quantity of samples there was determined ratio of shearing forces to ultimate strength of rivet material. Results of tests are given in Table 3.

Table 3. Results of Tests of Rivets for Shear

| Сплавы заклепок | Экспериментальное значение $k_{sh} = \frac{\tau_b}{\sigma_b}$ | Нормативное значение предела прочности в кг/мм² | Предельное сопротивление срезу в кг/мм² |
|---|---|---|---|
| D18-T | 0,63—0,7 | 30 | 19—21 |
| V65-T | 0,56—0,6 | 40 | 22,5—24 |
| D1-T | 0,63 | 38 | 24 |
| V95-T | 0,5 | 50 | 25 |
| D1-M | 0,7 | 21 | 15 |
| V95-M | 0,75 | 26 | 19 |

KEY: (a) Alloys of rivets; (b) Experimental value; (c) Normative value of ultimate strength in kg/mm²; (d) Ultimate shear strength in kg/mm².

The least experimental data was obtained on crumpling. Here it is possible to take ratios $\frac{\sigma_{sh}}{\sigma_b}$ equal to 2 for rivets from alloy D18-T and 1.8 for rivets from alloy V65-T. For comparison, in Table 3 there are given analogous data on shear for rivets from other alloys investigated by us.

From comparison it is clear that high-strength alloy V95 is of little use for rivets. In hardened state its strength little exceeds strength of alloys V65-T and D1-T, and in annealed state is lower than strength of alloy D18-T. Therefore, considering that alloy V95 has the worst corrosion properties as compared to duralumin, one should not recommend it as material for rivets. Alloy D1-T does not have advantages in shear resistance, as compared to alloy V65-T. At the same time, its application has significant technological deficiency, including the fact that rivets from it have to be set in construction only in freshly quenched state, i.e., no more than 2 hours after quenching.

Thus, the most suitable material for rivets in bridge and other building parts from aluminum alloys are alloys D18-T and V65-T.

For comparison of strength of joints riveted by clamp and pneumatic hammer, in factory with help of these two forms of riveting there were prepared special samples from alloy D1-T with rivets from D18-T, results of tests of which are given in Table 4.

From the table it is clear that method of riveting did not influence shear strength of rivet joints.

Let us note that by technical specs of designing of metallic structures of certain countries (for instance, France) it is prescribed to assign different allowed stresses on rivets set by clamp or pneumatic hammer. Our experience shows that such separation in aluminum structures is not evoked by necessity, and that calculated loads on rivets with riveting by clamp or pneumatic hammer can be taken as identical.

Table 4. Mechanical Properties of Rivets in Respect to Method of Their Setting

| Form of riveting and type of locking head | Average shear stress in $kg/mm^2$ |
|---|---|
| Riveting by clamp. Locking head, flat-conical | 22.6 |
| Riveting by hammer. Locking head, decreased semicircular | 22 |

Table 5. Influence of Form of Head on Load-Bearing Ability of Rivet

| Type of locking head | Average shear stress in $kg/mm^2$ |
|---|---|
| Semicircular | 21.3 |
| Flat-conical | 22.1 |
| Small semicircular | 21.6 |
| Countersunk | 21.7 |
| Without head | 21.2 |

From given experiment one may see also that strength of joint was not influenced by type of locking head. For more precise determination of this condition there were conducted additional tests on samples of joints riveted by clamp from alloy D1-T with rivets from alloy D18-T having different types of locking heads (Table 5).

Shear stresses were found approximately identical for joints with different types of rivet heads. The same strength was shown by joints with rivets without locking head, in which small end (5-9 mm) of rivet shank was pressed by effort of clamp into riveted fagot.

Results of experiment show that shear strength of rivet joints does not depend on type of head and should be taken into account for all types of heads as identical. Therefore, there is no need in structures from aluminum alloys to lower allowed efforts, for instance on rivets with countersunk heads, as is done in steel structures.

For ascertaining of possibility of riveting of connective uncalculated seams by non-heat treated rivets there were conducted comparative tests of strength of joints from sheets of alloy D16-T with rivets from alloy V65, results which are given in Table 6.

Table 6. Influence of Heat Treatment on Load-Bearing Ability of Rivet

| Состояние заклепок | Предел прочности заклепочного материала $\sigma_b$ в кг/мм² | Среднее срезывающее напряжение $\tau_b$ в кг/мм² | $\frac{\tau_b}{\sigma_b}$ |
|---|---|---|---|
| Закаленные и естественно состаренные | 35,9 | 22,3 | 0,62 |
| Термически обработанные (в состоянии поставки) | 32,7 | 19,1 | 0,58 |

KEY: (a) State of rivets, (b) Ultimate strength of rivet material $\sigma_b$ in kg/mm$^2$, (c) Average shear stress $\sigma_b$ in kg mm$^2$, (d) Quenched and naturally aged, (e) Heat treated (in delivery state).

Tests showed that strength of joints on non-heat treated rivets was 17 % less than strength of joints with quenched and aged rivets. Therefore, application of non-heat treated rivets for uncalculated connecting seams may be considered permissible. For such seams it is possible to apply also alloy D1-M, results of tests of which were given earlier (Table 3).

For investigation of uniformity of work of rivets during cold riveting, samples were tested with resistance detectors. Samples had three rivets each in half joint. Results of tests showed that diagram of distribution of stresses through length of half joint constitutes almost a straight line. This indicates that each rivet transmits from joint to cover plate an identical effort, i.e., rivets work equally.

Of great value in riveting of aluminum alloys is question of selection of pitch of rivets, since small pitch sheet, as experiment showed, can lead to rupture of sheet during riveting owing to significant bulging of hole. Experimental investigations of the institute showed that for joints of sheets with thickness of 8 mm and more minimum distance from center of rivet to margin of sheet may be taken equal to 2.5 $d_{rivet}$.

Besides purely riveted structures from aluminum alloys in building practice, riveted-welded structures can find application, i.e., structures with welded elements and riveted assembly joints. Inasmuch as these will be structures from nonheat-treated aluminum-magnesium alloys, to avoid intercrystallite corrosion rivets in them also have to be of similar alloy.

In NII of bridges there were conducted technological and strength investigations of joints with rivets of 20 mm diameter from alloy AMg6 with ultimate strength of 37.6 kg/mm$^2$, yield point of 17.6 kg/mm$^2$, specific elongation of 20.5 %.

Technological tests of rivets showed that good flat-conical head will be formed for rivet from alloy AMg6 where effort of press is 45-50 t.

Shear tests of rivets showed average shear strength $\tau_b$ = 23.6 kg/mm$^2$. Ratio $\frac{\tau_b}{\sigma_b}$ = 0.63, i.e., close to other aluminum alloys already investigated by us.

In conclusion let us note that complex of works conducted by Institute of Bridges for the study of technology of cold riveting and strength of riveted joints started by laboratory tests and continued under factory conditions during manufacture of riveted structures, shows that at this time all data for assimilating of aluminum alloys in the most diverse riveted building parts is available.

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# NODAL JOINTS OF TUBULAR ALUMINUM TRUSSES

I. V. Levitanskiy, Engineer

## 1. Application of Tubing in Aluminum Structures

Practical application of aluminum tubular structures is still extremely limited owing to small volume of application of aluminum alloys in structures, and owing to wide possibilities of obtaining of closed profiles of other form. However, it is possible to give a number of examples of use of tubular sections in designs and actual structures [1].

High-strength aluminum tubing has all advantages of a thin-walled metallic ring, but has and specific peculiarities (as compared to steel tubing):

a) high local and overall strength of tubular rod has especially important value for material with low elastic modulus;

b) cylindrical tubing, as compared to other closed profiles, is the most universal, has been adapted, and may be prepared with thinner wall;

c) extruded tubes are cheaper than pressed, closed profiles and not much more expensive than open profiles; but drawn and rolled (thin-walled) tubing is considerably more expensive.

Thus, important advantages of high-strength aluminum tubes, as compared to other profiles, give us all bases for their use in lattice building parts.

Just as those of steel, aluminum tubing is most expediently applied in welded structures. According to practice, the most pracitable field of application of aluminum tubes in the near future should be considered tubular structures of light and medium type, i.e., with application of extruded or rolled tubes with diameter to 150-250 mm.* Structures of heavy type with application of large dimension profiles, including welded tubes, obviously, will be applied in the future, taking into account the experience in light structures.

To the number of insufficiently developed questions retarding application of tubular structures pertain constructional-technological solutions of nodal joints.

Let us consider the frequently encountered in light structures (of trusses) adjoining of strut to boom at a certain angle recommended is $\alpha \geq 30°$). Joining can be both by direct and by transition elements.

d Direct Joining of Tubular Strut to Tubular Boom.

Joining is distinguished by structural simplicity and minimum expenditure of metal and, is frequently applied in steel tubular structures.

Joining has a number of deficiencies:

a) ends of struts are processed by milling or boring, and removal of campfer is done manually; these operations strongly appreciate construction;

b) technology of welding requires keeping of very small gaps - from 0.5 to 1.5 mm, which are 2 times less than gaps allowed for steel; such tolerances require heightened accuracy of manufacture;

c) the welded seam cannot be considered butt, since it is impossible to ensure backing or penetration of root of seam. Furthermore, on separate sections wall of strut narrows significantly (Fig. 1, b and c), and on certain sections welding is hampered (Fig. 1, c).

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*All-Union Government Standard 1947-56 on tubes from aluminum and aluminum alloys.

All these circumstances for aluminum alloys still have greater value than for steel and can significantly worsen quality of joining, since fillet weld is weaker than butt weld and welding tool is of little use for welding in almost inaccessible places.

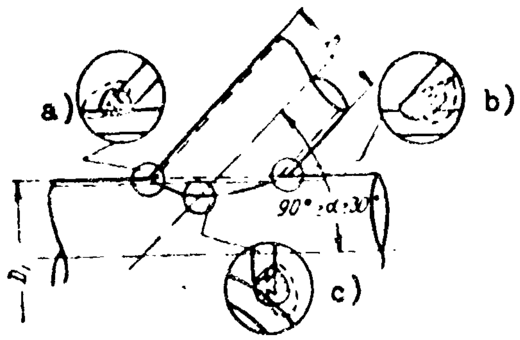


Fig. 1. Joining of strut of tubular truss to boom

Deficiencies of quality of seams are somewhat compensated by increase of their length. By English standards calculated length of joining of tubular strut and boom (Table 1) depends on relationship of diameters $D_2$ and $D_1$ and on angle of inclination of strut and changes within limits (with respect to perimeter of strut), shown in Table 1.

d) tubular boom under struts is deformed, where this deformation may be extremely nonuniform and evoke overstrain on separate sections of joint. Necessary thickening of wall of boom contradicts basic requirement - thinness of walls of tubular rod. Local thickenings and strengthening significantly complicate considered light structures;

e) along with different rigidity of boom, within limits of connecting seam, joining is characteristically by sharp transitions of section and areas of concentration of stresses. Combination of sections of rigid joint (and consequently, heightened stresses) with areas of concentration can lead to local rupture of material. Shown peculiarities can be altered with change of ratios of diameters and angle of inclination of strut and boom; some of deficiencies are thereby smoothed away, and some - are strengthened.

The very same can be said about varieties of this joint - about joinings of tubular strut to plane and longitudinal fashion to boom. For these joints technology of manufacture is simplified.

Table 1. Calculated Length of Seam of Joining Tubular Strut to Boom

| Отношение $D_2 : D_1$ (a) | Отношение расчетной длины шва к периметру раскоса при $\alpha$ = 30 : 60° (b) |
|---|---|
| 0,4 | 1,555 – 1,088 |
| 0,7 | 1,586 1,126 |
| 1 | 1,678 1,24 |

KEY: (a) Ratio $D_2$:$D_1$; (b) Ratio of calculated length of seam to perimeter of strut at $\alpha$ = 30 to 60°.

Joining of Tubular Strut to an Incised Gusset.

Such a joint is technologically simpler than the preceding; required clearances all much easier to maintain, welds are full value fillets and can have necessary length. For these reasons nodes on gussets are applied rather widely and frequently serve as basis for assembly joints.

But joints on gussets lead to over-expenditure of material and evoke nonuniform work of sections of rods within limits of node.

In work [2] it is shown that one incised gusset gives coefficient of concentration of stresses K = 2.26 at $H : D_2 \geqslant 1$, where H - depth of incision of gusset in strut. It is obvious that there are no bases to expect for aluminum alloys a smaller concentration of stresses.

On boom gusset is fastened on upper generating line, i.e., actual deformed part of tubing, and also creates areas of concentration in boom.

Thus, consideration of node joints applied in light tubular structures shows both their imperfection and impracticability in general, and also specific peculiarities of aluminum structures as compared to steel.

For steel tubular structures at present there are no definite conditions on calculation of nodal joints. Thus, in English and German norms* it is suggested that one consider direct, transverse joints of tubing with tubing welded by fillet weld, and only with special proofs (test of joints $D_2 : D_1 > 1/3$, and others) can weld be considered butt. Length of seam here is taken according to

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*Appendix 1 (1953) to English norms BS-449 (1948); DIN-4115, light steel and tubular parts in above-ground construction.

above-indicated relationships.

During calculation of beam systems, there are considered only longitudinal efforts with equal distribution through connecting seams and support sections of beams. In many cases this prerequisite can significantly differ from real work of nodal joints.

Of decisive value is strength of welded seams in direct joinings of closed tubular sections.

Above-indicated constructional-technological deficiencies allow us to pose question of development of certain new types of joints and of study of real work of tubular joints in reference to aluminum structures of light type.

One of means of development of new joints is application of plastic deformation of tubular sections. This means is possible because majority of weldable aluminum alloys recommended for application in building parts are quite ductile ($\varepsilon > 15$ %), and it is important because it does not lead to building of structures.

During development of nodal joints with plastically deformed sections of tubular beams, it is necessary to fulfill the following conditions (in preservation and increase of strength of joints):

a) deformation must not evoke appearance of cracks;

b) one should avoid plastic flow in direction of principal work of material;

c) transition of sections should be smooth in avoidance of significant local bend;

d) deformation should be executed in cold state, which is the most acceptable for enterprises manufacturing building parts;

e) deformation should simplify technology of manufacture and welding of structures.

## 2. Plastic Deformation of Tubular Sections

Let us consider flattening by flat dies of section of aluminum tubing (Fig. 2). In first stage (before straightening of wall under dies) there are true dependencies for concentrated forces, and plastic flow increases faster under dies. But after straightening of these sections, further build-up of plastic flow will go into lateral B sections.

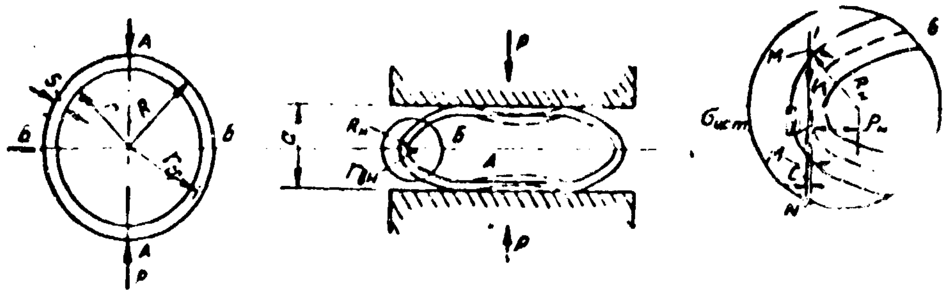


Fig. 2. Diagram of deformation of annulus. сп = mean; н = ext; вн = int; ист = true; н = neut.

In A sections under dies in first stage following geometric relationships will take place:

$$\rho_{neut} = R - \frac{S}{2} = r + \frac{S}{2} \text{ (since } r:S > 5) \quad (1)$$

$$\varepsilon_{ext.\ int.} = \pm\frac{R - \rho_{neut}}{\rho_{neut}} = \pm\frac{\frac{S}{2}}{R - \frac{S}{2}} = \pm\frac{S}{2R - S}. \quad (2)$$

Here $\rho_{neut}$ - radius of neutral surface; at $r : S > 5$ it is equal with sufficient accuracy, to mean radius;

$\varepsilon_{ext.\ int.}$ - specific elongation of external and internal fibers of wall ring;

R, r, S - parameters of annular section.

From given dependence it is clear that for material with $\varepsilon_{ult}$ = 0.15 to 0.18 relationship $r : S \geq 6$ to 7 is necessary so that under die deformations are not disruptive (Table 2).

Actually, shown region excludes only thick-walled tubes for which plastic forming is inexpedient.

In B sections following relationships will take place:

$$\rho_{neut} = R_{ext.} - \frac{S}{2} + C;$$

$$C = \frac{N}{2\sigma_{true}} = \frac{N(1 - \psi)}{2\sigma_b} \quad \text{(see [6]).} \quad (3)$$

**Table 2. Data of Tests of Tubular Samples for Plane Flattening**

| (a) Сплав | (b) Труба 2R/S в см | (c) $R_{кр}$ в см | (d) $a:2R_н$ | $a:S$ | $C:S$ в % | (e) $\varepsilon_{теор}$ в % по измеренному $R_{кр}$ | (f) $\varepsilon_{серт}$ в % | (g) Технология изготовления трубы |
|---|---|---|---|---|---|---|---|---|
| AMg | 6,6/0,3 | 0,39 | 0,94 | 2,43 | 13,9 | 34 | 16,3–17,5 | Rolled |
| | 8/0,35 | 0,45 | 1,01 | 2,69 | 13,9 | 33,4 | 18,7–20 | . |
| AMg5-V | 7/0,25 | 0,5 | 1,63 | 6,52 | 4,6 | 25,3 | 15 | . |
| | 11/0,25 | 0,5 | 1,35 | 5,4 | 6,4 | 25,6 | 13,7–21,2 | . |
| | 10,5/0,4 | 0,8 | 1,41 | 5,65 | 5,1 | 25,1 | 18,7–21,5 | . |
| | 11,4/0,7 | 1,15 | 1,4 | 4,57 | 6,8 | 21 | 19–26 | Extruded |
| AMg6 | 8/0,4 | 0,65 | 1,46 | 4,72 | 5,6 | 32,3 | 12,5–22,5 | Rolled |
| | 9/0,8 | 1,5 | 1,51 | 5,55 | 6,6 | 20,2 | 16,9–24 | Extruded |
| | 11/0,3 | 0,55 | 1,41 | 5,17 | 4,5 | 30,2 | 20–22 | Rolled |
| | 11/0,6 | 1,2 | 1,35 | 5,4 | 9,5 | 20,8 | 23–28 | Extruded |
| AV-T1 | 8/0,4 | 0,85 | 2,64 | 8,6 | 3,9 | 22,5 | 11–15 | Rolled |
| | 11/0,6 | 1,5 | 2,24 | 11,2 | 4,8 | 16,4 | 16–21 | Extruded |
| | 9,5/1,25 | 2,4 | 1,42 | 5,46 | 6,9 | 14 | 12–14 | . |

Note: One sample of AV-T1 with dimension 95 x 12.5 mm broke under die.
KEY: (a) Alloy; (b) Tubing 2 R S in cm, (c) $R_{ext\ crit}$ in cm; (d) a : 2 $R_{ext}$; (e) ε theor. in %, according to measured; (f) ε certified in %; (g) Method of manufacture of tubing.

where C – displacement of neutral axis under influence of moment and normal force (in this case – compressing), since in limiting stage $\sigma_{necking} = \sigma_{true} = \sigma_b \frac{F_0}{F_{die}} = \frac{\sigma_b}{1-\psi}$ (Fig. 2);

$\sigma_{true}$ – true stress in material given degree of deformation, $\sigma_{true} = f_1(\ )$ or $\sigma_{true} = f_2(\psi)$;

$R_{ext}$ – radius of external surface of tube on lateral B sections between dies.

Let us find plastic flow of external fibers of B section of ring (tube)

$$\varepsilon_{ext} = \varepsilon_{plast\ def\ (ext)} + \varepsilon_{init\ ext}, \qquad (4)$$

where $\varepsilon_{init}$ – initial deformation of outer fibers of wall during manufacture of tubing, here $\varepsilon_{init} = 0$.

$$\varepsilon_{plast\ def\ (ext)} = \varepsilon_{ext} - \varepsilon_{init\ def\ (ext)} = \frac{R_{ext} - \rho_{neut}}{\rho_{neut}} - \frac{S}{2R - S} = \frac{RS - 2CR - R_{ext}S}{(2R - S)(R_{ext} - \frac{S}{2} + C)}. \qquad (5)$$

During derivation of formulas it was assumed that thickness of wall does not change in process of plastic flow.

Thus, by given formulas, knowing specific elongation of given material during simple extension, there can be found limiting radii of curvature of external layer of wall of tube in B zone, and by these radii - and degree of plane flattening of tube with given external diameter and thickness of wall. Moreover, in first approximation it is possible to consider C = 0. In this case calculating formulas are considerably simplified:

$$\text{plast def (ext)} = +\left[\frac{S}{2R_{ext} - S} - \frac{S}{2R - S}\right] = +\frac{2S(R - R_{ext})}{(2R_{ext} - S)(2R - S)} \qquad (6)$$

With sufficiently plastic material and thin wall there can be obtained considerable deformation of cold flattening without causing rupture of material.

In this work during carrying out of experimental investigations there was carried out plane flattening in cold state of a large quantity of samples of tubes from various weldable aluminum alloys (with help of flat dies) for the purpose of clarification of conformity of actual results to the above - mentioned dependencies, and also determination of change of mechanical properties of material in deformed zones

On these samples at moment of appearance of cracks there were measured degree of plane flattening and limiting radii of curvature.

Types of samples and certain results of tests are given in Table 2. Test samples are shown in Fig. 3.

On the basis of consideration of results of tests there can be made following conclusions.

1) Preliminary conclusion is confirmed concerning small magnitude of displacement of neutral layer C, composed of 4 to 9 % of thickness of wall; an exception is alloy AMg, where we were unable to correctly fix $N_{limit}$, since formation of cracks did not occur.

2) Comparison of magnitudes of $\epsilon_{cert}$ and $\epsilon_{meas}$ shows small divergences, which are explained by following factors:

a) heterogeneity of metal is great, giving us wide scattering of mechanical properties;

b) measurement of radius of curvature $R_{ext}$ was insufficiently accurate (radii were measured by template);

c) actually, thickness of wall in critical place does not remain constant, but is changed, where on the side of stretched fibers it decreases, and on the compressed side it is increased; introduction into calculating formula of decreased thickness $\delta$ will give us lowering of $\epsilon_{meas}$, which will lead to better convergence of results the less is $R_{ext}$:

d) much influence on degree of deformation is rendered by character of treatment of tubing during manufacture - extrusion or rolling. Since measured deformation is directed across axis of tube, for extruded tubes it should be less, and for rolling - greater than certified relative deformation, measured along axis of pipe. Introduction of such correction improves convergence of results.



Fig. 3. Plane-flattened samples

3) Comparison of critical radius of curvature with degree of flattening of pipe - $a_{crit} : 2 R_{ext}$ - shows that deformation of wall of investigated section does not follow the arc of a circle, but a curve of parabolic type, having at its vertex $\frac{1}{R_{ext}}$; for all alloys from AMg5V to AV-T1 ratio $a_{crit} : 2 R_{ext}$ constitutes from 1.35 to 2. If one were to give section of wall between B section and die the

contour of arc of circle with $R = R_{ext\ crit}$, then $a = 2R > \frac{a_{crit}}{1.35 \text{ to } 2}$, i.e., there can be obtained significantly greater flattening without increase of degree of deformation. (In all cases a - distance between dies, $a_{crit}$ - the same at moment of appearance of crack: see Table 2). After straightening of section under die, its bend is possible inside cavity of tube; for obtaining of flat wall in separate cases it is necessary to apply limiting inserts.

On the whole coincidence of calculated and certified data can be considered satisfactory, which allows us to recommend this method for assignment and control of flattening of metallic tubing.

Simultaneously with destruction of samples during plane flattening, part of analogous samples was deformed 10 % less (coefficient 1.1 is characteristic for similar operations) and metal from different plastically deformed zones was subjected to standard mechanical tests with determination of yield points and strength, specific elongation, and reduction of area (Table 3).

Table 3. Results of Mechanical Tests of Metal of Plane-Flattened Samples: of Certificate; Type a - From Straightened Section Under Die, Type b - From Section of the Greatest Deformation, in % of Certificate Data

| (a) Сплавы и сечения трубы | | (b) Сертификатные данные | | | | (c) Предел прочности $\sigma_b$ | | (d) Предел текучести $\sigma_{0,2}$ | | (e) Относительное удлинение $\delta$ | | (f) Относительное сужение $\psi$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\sigma_b$ | $\sigma_{0,2}$ | $\delta$ | $\psi$ | (g) типы | | | | | | | |
| | | (h) в кг/мм² | | (i) в % | | а | б | а | б | а | б | а | б |
| AMg | 66×3 | 15.2 | 11.9 | 16.9 | 58.6 | 89 | 89 | 94 | 104 | 113 | 92 | 103 | 96 |
| | 80×3.5 | 17.1 | 12.9 | 19.3 | 48.6 | 106 | 105 | 103 | 109 | 90 | 91 | 108 | 112 |
| AMg5-V | 70×2.5 | 31.8 | 20.8 | 15 | 27.1 | 104 | 102 | 101 | 102 | 96 | 97 | 105 | 104 |
| | 110×2.5 | 30.8 | 18.8 | 15.8 | 29.3 | 102 | 101 | 106 | 109 | 95 | 84 | 99 | 95 |
| | 105×4 | 31 | 18.2 | 20.9 | 32.7 | 108 | 102 | 113 | 113 | 86 | 90 | 83 | [illegible] |
| | 114×7 | 29.3 | 17.2 | 26.9 | 41.8 | 101 | [illegible] | 114 | 110 | 89 | 87 | 98 | 92 |
| AMg6 | 80×4 | 35.6 | 19 | 18.1 | 14.7 | 103 | 102 | 108 | 111 | 83 | 77 | 110 | 100 |
| | 110×3 | 35.2 | 17.2 | 19.1 | 25.4 | 102 | 95 | 93 | 92 | 91 | . | 83 | — |
| | 110×6 | 34.6 | 17.2 | 26.1 | 23.3 | 102 | 102 | 121 | 125 | 83 | 64 | 88 | 60 |
| AV-T1 | 80×4 | 33 | 30 | 12.5 | 41.2 | 98 | 103 | 93 | 102 | [illegible] | 76 | 97 | 86 |
| | 110×6 | 28.[illegible] | 24.4 | 20.6 | 42 | [illegible] | 116 | 107 | 123 | 88 | 79 | 84 | 88 |

Note. All tests were conducted on samples with $l$ = 75 mm, section of 10 mm X S; each result was obtained as average of 2-6 results.

KEY: (a) Alloys and section of tubing; (b) Certificate data; (c) Ultimate strength $\sigma_b$, (d) Yield point $\sigma_{0.2}$; (e) Specific elongation; (f) Reduction of area; (g) Types; (h) In kg/mm$^2$; (i) In.

Results of these investigations allow us to affirm that on the whole static tests showed preservation of mechanical properties in direction of generating line, as compared to certificate data. Thus is confirmed the premise that with significant (15 % and more) plastic flows in one direction in the other direction the metal in great measure preserves its elastic properties.

Basically, scattering of characteristics does not exceed 12-15 %, which for aluminum alloys is the usual phenomenon.

In detailed consideration it is possible to note increase of yield point $\sigma_{0.2}$ and lowering specific elongation $\epsilon$. In this case these changes can not be considered dangerous, since they are insignificant at ultimate degrees of plastic flow. It is possible that these changes might show up better during the study of vibration strength of analogous joint.

Thus, one may assume that deformation of increase of curvature of wall of tubing from different aluminum alloys is quite possible within significant limits with preservation of mechanical properties in axial direction.

With specific elongation $\epsilon$ = 15 to 18 % straightening of wall of pipe is possible at R : S > 6 to 7, i.e., besides thick-walled tubes), as is flattening to magnitude of (5-10) S.

On the basis of above-stated considerations for further investigations there were selected types of plastic flow of sections of tubes (Fig. 4).

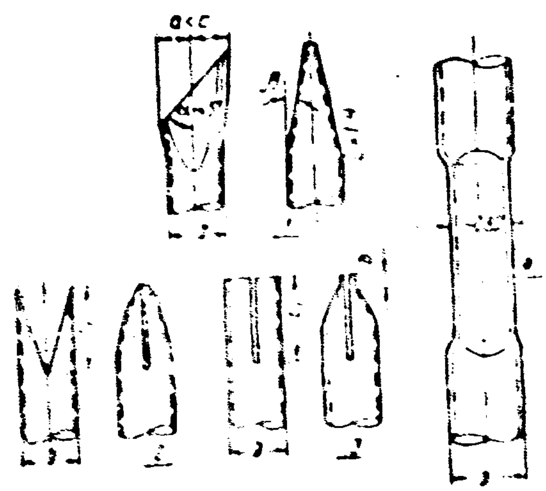


Fig. 4. Different forms of shaping of sections of tubular rods.

type 4-1 - diagonal flattening of end of strut for direct joining to boom;

types 4-2 and 4-3 - flattening of slotted ends of struts to gusset;

type 4-4 - flattening "to square" of section of boom at place of joining of struts.

All these types of shaping can be carried out on the simplest dies and saws. Introduction of these operations instead milling should be considered a technological simplification. Simultaneously in nodes with application of types of rods 4-1, 4-3, and 4-4 there are significantly improved welding conditions.

On large quantity of tubes from alloys AMg, AMg5-V AMg6, and AV-Tl (Table 2) with the help simplest devices (development of improved devices did not enter into our problem there were carried out all types of shaping shown in Fig. 4.

In joints of types 4-1, 4-3, and 4-4 basic directions of plastic flow and force influences in beam are mutually perpendicular.

In sample of type 4-2 plastic flow coincides with direction of application of power, but does not attain critical values (constituting to 6% instead of 12-15%).

All types of samples used ensure hermetic sealing of internal cavity of pipes without additional expenditure of material and transition of sections is carried out quite smoothly, which is also obligatory condition. However, no comparative investigations of form were made, and therefore one should expect that for different diameters and thicknesses of wall there can be found the best dependence both for those used and for other types of shaping by flattening.

Type of molding with plane flattening of end of tubing was not investigated further in view of evident unfavorable form of transition of section.

Characteristic dimensions in each of the types of samples were designated according to the following considerations:

type 4-1 $\alpha = 45°$ in connection with further investigation nodes with angle of joining of struts is 45°. After flat cut and removal of chamber, no additional trimming of joint is required:

types 4-2 and 4-3 - length of cut $l_1$ is assigned because equal strength of welded fillet seam depends on thickness of wall (height of seam) and can constitute (1.5-2) D of pipe work. In work [2] it is indicated that with depth of incision of one gusset $l_1$ ~ D distribution of stresses does not depend on these magnitudes. With certain caution (since in work [2] there are given experiments with undeformed tubing and in this case one may assume that specificity of results will not depend on diameter of tube and length of incision, but thickness of wall can have the most important value. In samples 4-2 cut was made flat, but with bend of ends of cut to gusset (both in these samples and also in samples 4-3) application is necessary of limiting inserts, giving prescribed form with respect to elastic resistance;

type 4-4 - in deformed section there is formed a square with rounded edges. Length of section is designated as necessary for joining of struts (in our case 250 mm). With ratios $\epsilon$ = 15 to 18 %, D : S ≥ 14, and safety factory of deformation 1.1 there may be found site for welding of struts with width of 0.57 D, and with respect to neighboring sections of transition to rounded surface - with width 0.7-0.8 D.

Following stage of investigation was experimental determination of strength characteristics of beam samples, including types of molding shown in Fig. 4.

## 3. Determination of Strength Characteristics of Tubular Beam Samples

All beam samples were designated for tests for axial static loads. In reality, as was shown by subsequent works of the author [3], in beams of tubular aluminum systems there can exist significant bending moments, but study of their influence on beam samples did not enter into our assignment.

Welded samples (Table 4) were prepared from alloy AMg6 applicable to struts of a tubular girder. Diameter of tubing was 80 X 4 mm ($F_0$ = 9.65 $cm^2$; $\sigma_b$ = 3,580 $kg/cm^2$, $\sigma_s$ = 1,860 $kg/cm^2$).

M1 - simple incision of gusset $\delta$ = 8 mm in tube; M2 - M4 - incision with forming of end of tube into types 4-2 and 4-3 (distinction between samples M2 and M3 - in width, completely flattened section - 20 and 55 mm). In gusset there was made a cut of 20 mm, so as not to weaken support section of tubing;

M5 - shaping as per type 4-1 and welding to slanting flange. For these sample testing scheme does not correspond completely to work in real structures, since rigid flange replaces compliant boom. However, to realize actual conditions turned out to be difficult.

In samples M1-M4 length of incision was determined by calculation of equal strength of longitudinal fillet weld (see section 2) and constitutes 155 mm.



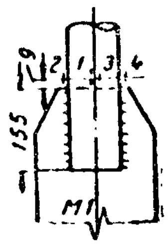
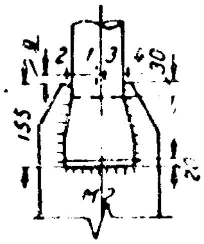
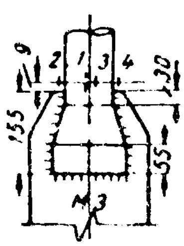
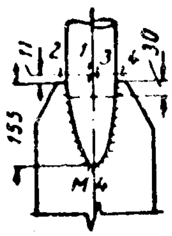
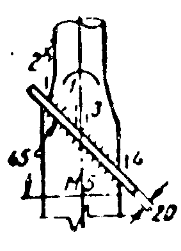
Fig. 5. Jig and attachment for assembly of beam and nodal samples.

In samples M2-M3 transverse fillet welds give us a reserve of strength (subsequently [3] it was clarified that these seams can also be included in calculation, decreasing thereby dimensions of gusset).

Samples had length from 1,000 to 1,260 mm and were assembled and welded on special jig (Fig. 5). Welding was done manually with tungsten electrode in stream of argon. Filler material was AMg6 wire with diameter 3 mm. In all three were prepared two bilateral samples, which allowed us to obtain four results. On gussets there were made centering holes with diameter of 50 mm, through which with help of rollers and coupling rods samples were secured in clamps of PU-200 press.

Samples were tensile tested, since for such joints of all static loads the most dangerous is stretching. Certain samples (Table 4) were strain-measured in elastic stage with help of strain gauges with base of 10 mm at characteristic points of support sections. Load was applied by steps of 6, 9, and 11 tons, where yield point of material was 17.9 tons and ultimate strength was 35.2 tons.

Table 4. Data of Tests of Welded Tubular Samples for Axial Extension

| (a) Эскиз образца и наклейки датчиков | (b) Точки измерений | (c) Коэффициенты неравномерности деформаций при напряжениях в кг/см² | | | (d) $\frac{\sigma_т \text{ образца}}{\sigma_т \text{ материала}}$ | (e) Снижение прочности $1 - \frac{\sigma_b \text{ образца}}{\sigma_b \text{ материала}}$ в % |
|---|---|---|---|---|---|---|
| | | $\sigma$, 622 | $\sigma$, 932 | $\sigma$, 1140 | | |
|  | 2,4<br>1,3 | 1,85<br>0,82 | 1,84<br>0,825 | 1,82<br>0,855 | 0,95 | 32 |
|  | 2,4<br>1,3 | 1,48<br>0,65 | 1,47<br>0,66 | 1,46<br>0,665 | 0,93 | 33,5 |
|  | 2,4<br>1,3 | 1,85<br>0,46 | 1,99<br>0,48 | 2,57*<br>0,475 | 0,89 | 33 |
|  | 2,4<br>1,3 | 1,5<br>0,61 | 1,47<br>0,62 | 1,39<br>0,68 | 0,99 | 31 |
|  | 4**<br>1,3 | 0,82<br>1,13 | 0,795<br>1,07 | 0,8<br>1,09 | 0,895 | 24 |

KEY: (a) Sketch of sample and gluing of detectors; (b) Points of measurements; (c) Variation factors of deformations due to stresses in kg/cm$^2$; (d)$\sigma_T$ Sample/$\sigma_T$ material; (e)Lowering of strength sample $\sigma_b$ /$\sigma_b$ material in %.

* Deformations significantly higher than yield point.

** Detector No. 2 did not work.

Readings were recorded on chart through recording device of press. After rupture of one of the ends of each sample, to remaining end there was joined a special clamp [3] and sample was ruptured finally.

Consideration of data in Table 4 allows us to note the following.

1) Smaller coefficients of concentration were shown by samples M2 and M4 (k = 1.4 to 1.5), larger by M3 (k = 2.5). In sample M1 there was noted concentration k = 1.85. In sample M5, at point 2, we were unable to measure deformation. Coefficients of concentration are somewhat conditional, since measurements were made at distance of 9-11 mm from butt of gusset, but for sample M1 coefficient 1.85 is near to coefficient 2.26 for analogous sample of plastic [2]. Actually coefficients of concentration characterize also irregularity of application of force.

2) Elastic loads for tested joints were lowered insignificantly - from 1 to 11 %. Loss of strength with respect to basic material much greater: for samples M1 - M4, 3 - 33 %, for samples M5-24 %. Samples of types M1 and M4 from tubing with diameter of 50 X 4 mm (alloy AMg6), tested at TsNIISK [Central Scientific Research Institute of Structural Parts] in 1960 [4], showed the same lowering of strength (41.4 and 39% respectively). It is necessary to note that in these samples of gussets did not have notch, but slot in pipe butt of gusset was not welded (with welding by semiautomatic machine, samples of type M1 showed lowering of strength of approximately 16%, which requires additional check).

3) Sections of beginning of rupture of samples completely corresponded to concentrators of stresses of elastic stage of work.

Samples M1-M4 ruptured from butt of gusset across support section, samples M5-from point 2 partially through seam, partially across section. Rupture of all samples (besides first speciman of types M1 and M3) was accompanied by large deformations; samples shown in parentheses were fractured brittle even under light loads, since during installation of detectors there were erroneously sawn seams

Fig. 6. Ruptured welded samples.

at beginning of gussets, and thereby a sharp cut was formed. Certain types of ruptured samples are shown in Fig. 6.

Of the considered welded samples all tested types of joints have lowered strength. But this is explained by various causes. Sample M5, with quality butt weld, indisputably could show higher strength. Difficulties in welding of closed sections without auxiliary welding of root of seam, inherent to aluminum alloys, showed up during tests of nodes with direct joining of tubular struts to boom (including nodes with joints of M5 type [3]), where strength of joint constituted 50-55% (on lowering of strength a greater influence was rendered by considerable bending moments). For this reason joint of type M5 may be considered an improvement over simple joint (see Fig. 1) and can be recommended for further study and application.

Samples M1-M4 gave us lowering of strength due to organic deficiency - nonuniform work of material in critical section in the presence on sections of overload of areas of concentration of stresses. As was shown in section 2, results obtained can be considered characteristic and independent of diameter of tubing and depth of incision (at H >D).

Of the considered samples the most nonuniform transmission of force for joint is M3, but this type of joint may be recommended for assembly joints (assembly bolts on a wide, flattened part), and it should not be ignored.

Joint M1 occupies intermediate position, but still requires hermetic sealing of internal cavity. Therefore, joint M2-M4, showing best results, should be considered improvement over usual joint through gusset, all the more so since gusset may be decreased by introduction into calculation of transverse fillet weld, whereby cavity of tubing is closed without additional expenditure of material.

Expressed considerations do not speak, of course, in favor of joints on gussets; such joints for light tubular structures should be considered impractical. They have been used so long only because of relative simplicity of technological operations and good quality of welded seam.

In spite of significant lowering of strength for tested samples M1-M5 from alloy AMg6, ratio of yield point to ultimate strength does not exceed 0.7, for which there are no bases for lowering of calculated resistances [5]:

<u>Samples flattened to square in middle</u> (see Fig. 4) in quantity of 5 pieces were prepared with following of typical dimensions: AD1 - 110 X 5 (1); AMg5-V- - 110 X 2.5 (2) 105 X 4 (3), 114 X 7 (4); AMg6 - 110 X 6 (5). They were tested for axial compression. Purpose of test was to clarify load-bearing ability of such rods and possibility of their application as elements of boom in tubular trusses. Compression for such samples is the most damaging load and can therefore well characterize work of beam. Length of samples was 600 mm; length of flattened section was 250 mm.

Data of tests allows us to make following conclusions:

1) breaking loads are 8-55 % lower than strength of basic material, where the

lowest results were for samples with thin wall; No. 2 - 55 %, No. 3 - 37 %;

2) rupture of all samples was caused by local buckling of wall on transition portion of sections. Certain samples are shown in Fig. 7.

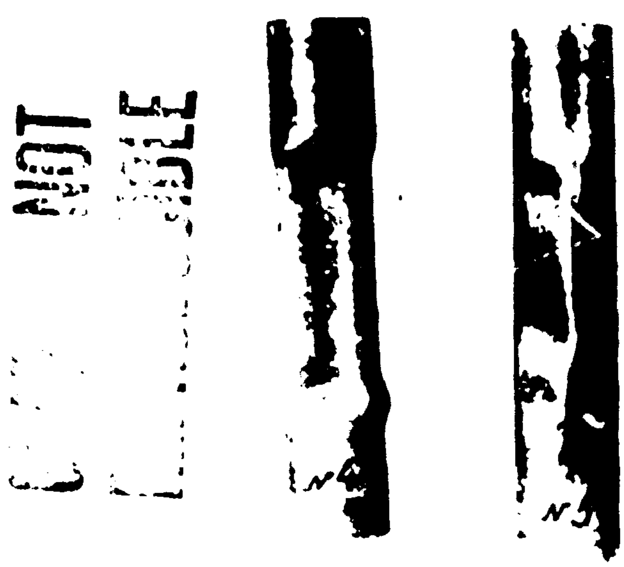


Fig. 7. Ruptured samples of tubular beams with center flattened "to square."

Deficiency of investigation is low number of tested samples. Samples of this type are equivalent in strength to above-considered connections of tubular struts, they improve technological efficiency forming, assembly, and welding, and can be fully recommended for application in real structures. Research should be continued for improvement of form of transition of section and calculation of influence of wall thickness. It is possible that with small wall thicknesses such type of forming will become impractical, which would confirm results of tests of sample No. 2.

In conclusion one should note that main problem of question posed here is increase of strength of joints in nodes of tubular, light welded trusses from aluminum alloys. Basic causes of lowering of strength are low quality of seam, overstrain in direct joints, and irregularity of work of material in gusset joints.

For light structures it is impractical to complicate joints with flanges, paired gussets, diaphragms, and others. Best means is working out of strength of direct joints with regard for technological efficiency of manufacture and economy of material. One of such attempts is this investigation.

The offered joints for tubes from aluminum alloys, not lowering strength of applied types of nodal joints, improve technological efficiency and conditions of welding without over-expenditure of material.

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# ON VIBRATION STRENGTH OF RIVETED JOINTS FROM DURALUMIN AND ALUMINUM-MAGNESIUM ALLOY AMg61

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Long experience in exploitation of metallic railroad bridges showed that one of the most important characteristics of joints of elements of steel span structures is their vibration strength. Therefore, studying possibility of application in bridges of aluminum alloys, it is necessary to thoroughly check their strength.

In this article there are given data on strength of duralumin - thermally hardened aluminum alloys, the most useful for riveted span structures, and non-thermally - hardened aluminum-magnesium alloy, which may be used in welded and riveted-welded span structures.

As far as we know, both in native and also in foreign literature there is no information about strength of aluminum joints with rivets of large diameter (16-24 mm). Available data concern the basic strength of small samples from different aluminum alloys. Those works were conducted in VIAM [All-Union Scientific Research Institute of Aviation Materials] [1], LISI [Leningrad "Order of the Red Banner of Labor" Construction Engineering Institute][2], and Moscow Aviation Technology Institute [MATI] [3], [4]. The latter extensive investigations were [illegible] a group of colleagues [illegible] leadership of professor S. V. Serensen [illegible] fatigue strength [illegible] aluminum alloys V95 and D16 depending upon method of their production and manufacture of parts. Large place is given to method of setting up of tests and methods of treatment of their results on the basis of contemporary statistical concepts.

From foreign investigations of interest are experiments of Graf [5], Howell and Miller [6]. In work of Hunter and Friche [7] there are investigated causes of formation, development, and interaction of fatigue cracks in aluminum alloys. Metallographic observations of the authors showed that fatigue cracks start to form in very early stage of loading, and fatigue limit depends basically on factors connected with appearance of cracks, but not with their growth. The phenomenon was noted of time stabilization of fatigue cracks with sharp lowering of limiting stresses of the cycle. Temporary stopping of growth of small cracks was observed also after achievement by them of certain, definite dimensions.

In article by Smith [8] there is offered method of determination of fatigue limit of structures from aluminum alloys by given values of coefficients of concentration and conditions of loading, which are applicable to aircraft building.

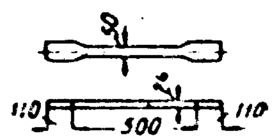
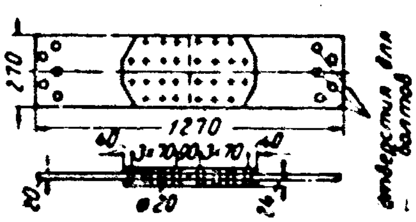
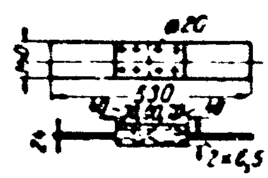
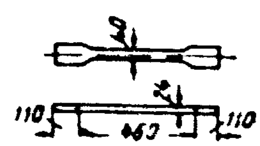
Results presented in present this article of fatigue tests of riveted joints from duralumin D1-T and aluminum-magnesium alloy AMg61 with rivets from alloys D18-T and V65-T are continuation and development of investigations of strength of aluminum alloys started by NII [Scientific Research Institute] of bridges in 1958 [9].

Method of tests contains no essential distinctions from that created through long experience for testing of strength of steel samples and joints encountered in steel span structures of bridges.

Magnitude of fatigue limit of aluminum alloys is taken for determination on significantly larger base than for steel, on order of (20-500) $10^6$ cycles. Certain data [2] attest to smaller extent to point of fracture of fatigue curves of aluminum alloys, compiled on a base of (4-5) $10^6$ cycles.

In described experiments ultimate fatigue limit of aluminum alloys was

Table 1. Characteristics of Samples

| № серий | Наименование серий | Вид образца | Статические характеристики материала: предел текучести в кг/мм² | предел прочности в кг/мм² | относительное удлинение в % |
|---|---|---|---|---|---|
| 55 | Эталонные образцы из целого металла, сплав Д1-Т |  | 27,8 | 44,8 | 19,5 |
| 56 | Клепаные соединения из сплава Д1-Т с заклепками из сплава Д18-Т |  | 27,8 | 44,8 | 19,5 |
| 60 | Эталонные образцы из целого металла, сплав АМг61 |  | 21,6 | 40,8 | 13,2 |
| 61 | Клепаные соединения из сплава АМг61 с заклепками из сплава В65-Т |  | [illegible]1,6 | 40,8 | 13,2 |

KEY: (a) No. of series; (b) Designation of series; (c) Form of sample; (d) Static characteristics of material; (e) Yield point in kg/mm²; (f) Ultimate strength in kg/mm²; (g) Specific elongation in %; (h) Standard samples from whole metal, alloy D1-T; (i) Riveted joints from alloy D1-T with rivets from alloy D18-T; (j) Standard samples from whole metal, alloy AMg61; (k) Riveted joints from alloy AMg61 with rivets from V65-T; (l) Holes for bolts.

In each series seven samples were tested with variable load.

Standard samples of series No. 55 were cut from extruded tees, standard samples of series No. 60 - from pressed strip. Both series of samples were tested on press-pulsator PDM-PU-100 with frequency of pulsation of 324 cycle per minute with characteristic of cycle $\rho = 0.25$. More precise definition of effective stresses was produced by electrical resistance detectors on sample of series

No. 55-5. Increase of stresses during dynamic work of sample constituted 10% on oscilliograph. Therefore, in final values of fatigue limits for standard samples of series No. 55 and 60 we considered dynamic coefficient of increase of stresses equal to 1.1. Dynamic character of application of load renders influence and on magnitude of characteristic of cycle. This magnitude was set according to loads of scale of dynamometer of press.

For considered samples characteristic of cycle, calculated according to dynamic stresses, constituted 0.073 instead of that designated in the beginning of 0.25.

In Fig. 1 there are presented straight-line regressions of standard samples of series No. 55 and 60 in comparison with earlier-obtained results for samples from alloy D16-T without concentration and with concentration of stresses [9]. On the same graph there are plotted straight-line regressions of samples from low-alloy steel of grade 15KhSND with concentration and without concentration of stresses. From comparison of them with analogous straight lines for alloy D16-T it is possible to see that duralumin is less sensitive to concentration of stresses, especially in region of small quantity of cycles. Standard samples from alloys D1-T and AMg61 showed low coefficients of correlation - respectively - 0.564 and 0.[illegible] with large scattering of experimental points. Fatigue limits calculated with probability of 19/1 for samples on base of 2 X $10^6$ cycles without calculation of dynamic coefficient constitute:

for alloy D1-T . . . . . . . . . . . . . . . . . . . . 13.06 $\pm$ 2 X 0.39 kg/mm$^2$;

for alloy AMg61 . . . . . . . . . . . . . . . . . . . 10.6 $\pm$ 2 X 0.34 kg/mm$^2$.

Rupture of standard samples occured in working part or in place of transition from working part to clamp. Fatigue cracks started from ribs of sample or from small defects in the form of scratches, dents, and burrs on its surface. Zone of development of fatigue cracks, as a rule, is great and in relief differs from zone of final rupture. This distinction is more clearly expressed on samples of series No. 60.

Of greatest interest are tests of samples of series No. 56, copying full-size joint of vertical wall of element of planned and built structure (see Table 1). Joints were made under factory conditions; rivets of 20 mm diameter from alloy D16-T were set by clamp in cold state.

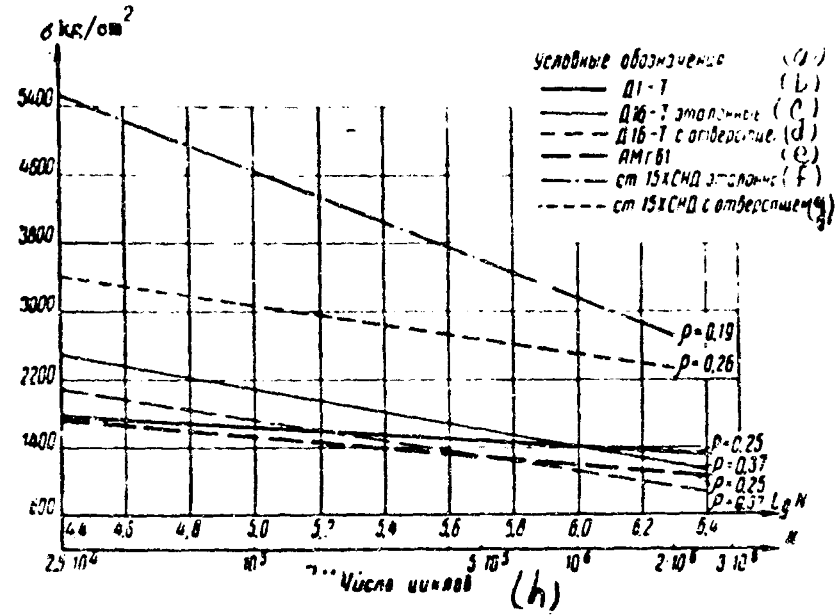


Fig. 1. Comparison of strength of samples from light alloys and of steel 15KhSND
KEY: (a) Special designations; (b) D1-T; (c) D16-T standard; (d) D16-T with hole; (e) AMg61; (f) Steel 15KhSND standard; (g) Steel 15KhSND with hole; (h) Number of cycles.

For installation in press of samples changes were prepared for it joined on high-strength bolts with preliminary tension. Samples were tested at characteristic of cycle of 0.026 on press-pulsator TsDM-PU-200 with frequency of application of load of 244 cycles per minute. General view of sample with clamps in press-pulsator is presented in Fig. 2. For these samples we obtained coefficient of correlation equal to 0.787. Fatigue limit on base of 2 X $10^6$ cycles was equal to 6.70 ± 2 X X 0.21 kg/mm$^2$ without regard for dynamic coefficient. Magnitude of the latter by readings of oscillograph on detectors of sample of series No. 56-7 constituted 1.31. Characteristic of cycle of stresses in process of work of joint under vibration load was changed from given $\rho = 0.026$ to $\rho = 0.071$.

Results of tests of samples of series No. 56 are depicted on graph (Fig. 3), where there are presented experimental points and straight-line regressions in comparison with results obtained for rivet joints from alloys D1-T, D16-T, and

AMg61. Of highest strength are riveted joints from alloy D16-T, very lowest - joints from alloy AMg61. It is necessary to note that comparison here is very approximate, inasmuch as results presented on figure pertain to samples having various dimensions and to those tested during somewhat varied characteristics of cycle (from 0.026 to 0.18) on various pulsators. Only joints and sizes of rivets set in cold state are identical. Of seven samples of series No. 56 six ruptured on first row of rivet holes. Fatigue cracks as a rule, start from edges of one or both holes and develop along them forming through thickness of sheet.

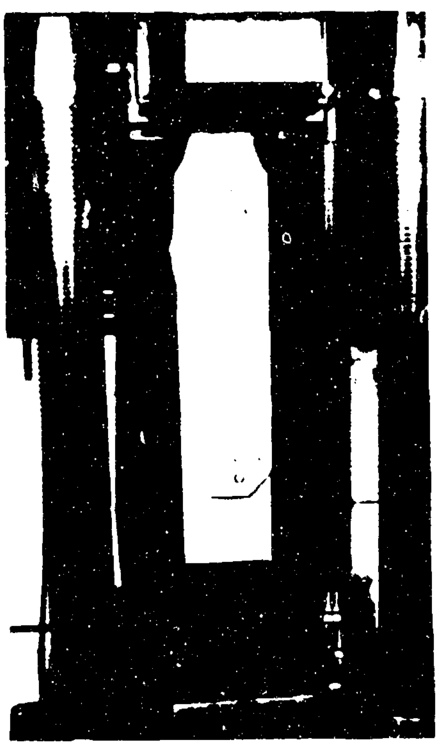


Fig. 2. General view of sample of riveted joint of series No. 56 in press-pulsator.

Shortly before rupture on sheet of three samples of this series (Nos. 2, 5, and 6) there was noted slight mobility of cover plates on one side. After cutting of these cover plates, along transverse rows failures of rivets were revealed in one cut: 10 in first three rows from one end of one cover plate of sample of series No. 56-2; 6 in two rows from both ends of one cover plate of sample of series No. 56,5, and 6 in two rows from one end of cover plate of sample of series No. 56-6, sustaining 2 X $10^6$ cycles of loadings without failure of sheet. Last of shown samples with remaining intact rivets was torn by static load. Rivets here showed high shear stresses, not yielding to normative ( $\tau_{av}$ = 20.8 kg/mm$^2$). One of half-sheets of sample of series No. 56-6 was also torn by static load and showed, in comparison with initial characteristics of material, lowered mechanical properties. This is explained by the fact that in its cross section on place of contact of sheet with end of cover plate there was a fatigue crack, not revealed upon completion of fatigue tests. Consequently, in this sample fatigue limit of sheet coincided approximately with fatigue limit of rivets.

In Fig. 4a, there is presented break of one of rivets of sample of series No. 56-2 magnified twice. From remaining parts of six ruptured rivets of this sample we prepared round Gagarin samples. Tests of them showed significant work hardening of material of rivets. Increase of yield point of rivets of first row constituted approximately 50%; of second row - 40% in comparison with yield point of still unworked factory rivets.

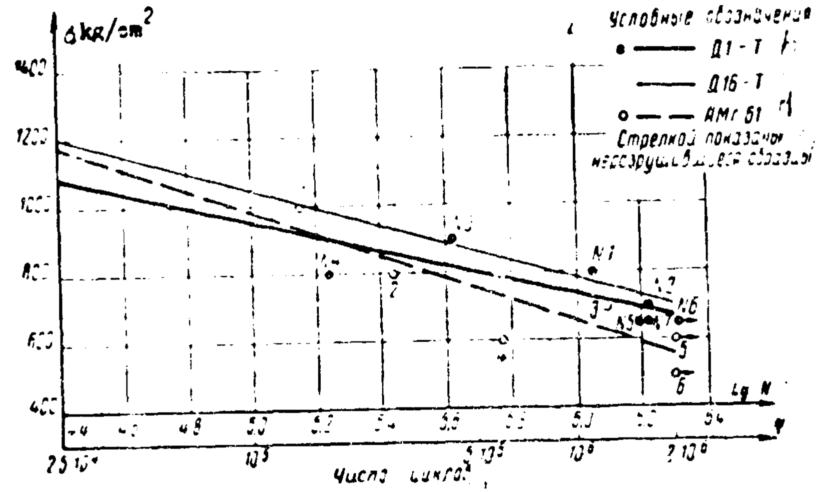


Fig. 3. Strength of rivet joints from duralumin D1-T and D16-T with rivets from alloy D18-T and joints from aluminum-magnesium alloy AMg61 with rivets from alloy V65-T
KEY: (a) Special designations; (b) D1-T; (c) D16-T; (d) AMg61; (e) Arrows indicate unruptured samples; (f) Numbers of cycles.

In 1958 experiments [9] an attempt was made to estimate shear strength of rivets from alloy D18-T and to compare it subsequently with strength of analogous rivets from alloy V65-T. This problem is more difficult and indefinite than that for check of strength of samples from whole metal, since strength of rivets depends on greater number of factors than strength of sheets. Along with factors determining strength of the latter, of influence here is shrinkage of fagot, degree of filling of hole and its bulging, possibility of failure of joint outside rivets. Blanks for samples were made of low-alloy steel. This circumstance also affected magnitude of fatigue limit of rivets, but, obviously, produced a reserve of strength. Inasmuch as rivet from alloy V65-T was supposed to have been tested in the same blanks, the comparative data on two series of rivet material were fully comparable.

Under these conditions samples with rivets from alloy D16-T upon shear fracture of rivets showed, with respect to dynamic coefficient, average fatigue limit of 6.7 kg/mm$^2$ with characteristic of cycle $\rho = 0.13$.

For rivets of sample of series No. 56-2 loaded with respect to dynamics up to $P_{max} = 33 \times 1.31 = 43.3$ t, shear stresses constitute

$$\tau_{av} = \frac{P_{max}}{2n F_3} = \frac{43,300}{2 \times 14 \times 3.14} = 492 \text{ kg/cm}^2,$$

where $F_3$ - area of cut of rivet;

n - number of rivets in half of cover plate.



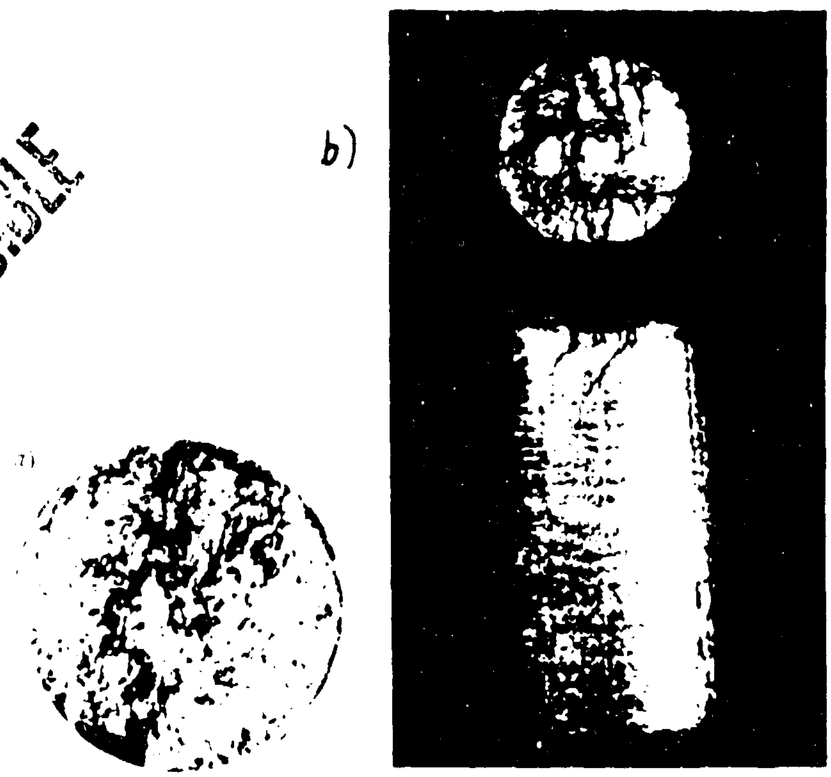



Fig. 4. Fatigue fracture of rivet
a) sample of series No. 56-2; b) from alloy D16-T.

If we consider irregularity of distribution of efforts end to end and more rigid conditions of tests, as compared to those at which fatigue limit of rivets was determined, then it becomes evident that first rows of rivets worked under stresses close to fatigue limit, which was cause of their failure. Certain role could be played here by unfavorable coarse-grained structure of material of rivet

(Fig. 4a). which, apparently, was result of inaccurately consistent conditions of their heat treatment.

However, fractures of rivets noted here in samples of series No. 56 in form differ from fatigue fractures obtained earlier in rivets from alloy D18-T, one of which is shown in photography of Fig. 4b. Here longitudinal fatigue cracks are quite conspicuous spreading deeply into body of rivet. In rivets of samples of series No. 56 such cracks were not observed. It is possible that shown distinction is connected with difference in material of sheets of rivet joint.

Rivet joints of series No. 61 from alloy AMg61 were tested by varied load with characteristic of cycle of $\rho = 0.13$ on pulsator PDM-Pu-100 at frequency of 324 cycles per minute. In spite of the fact that all of them were supposed to fail on sheet, and reserve on cover plates constituted nearly 10%, three of the seven samples tested in this series failed on cover plates. Fatigue cracks started here from edges of rivet holes in internal cover plate, and in one of samples they were transferred from cover plates to rivet heads, on one of which edge broke away, and on a second a noticeable rent was formed, as is shown in Fig. 5. Transition of fatigue cracks from cover plates to rivet heads indicates monolithic nature of joint obtainable in process of cold riveting. It is necessary to note that in other tested samples of riveted joints from aluminum alloys such failures were not observed.

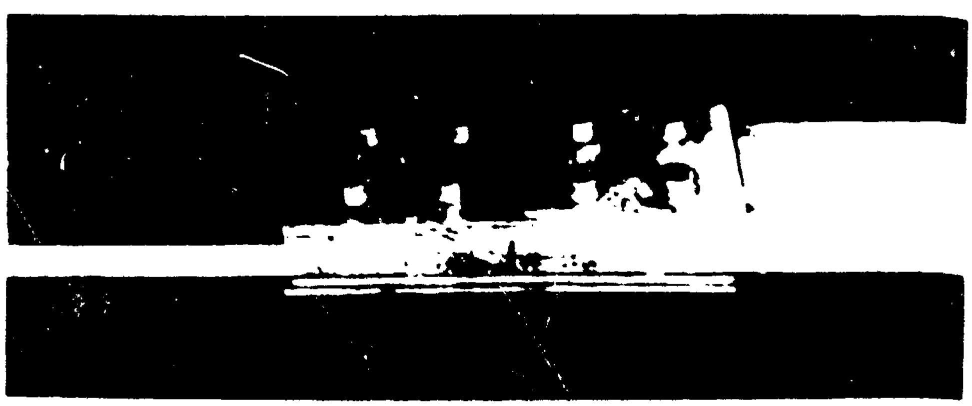


Fig. 5. Fatigue crack in sample of riveted joint of series No. 61.

Cover plates opposite those ruptured of above-indicated samples were torn by static load and showed sharp lowering of ductile properties of material of cover plates in process of vibration. Thus, as compared to initial state, lowering of specific elongation constituted 70–80%.

During static load tests in cover plates surviving after vibration small zones of fatigue were also revealed, not revealed upon completion of vibration tests.

Owing to deficiency of material, samples fractured on cover plates were repaired by means of setting of new cover plates with thickness of 12 mm from alloy D16-T of known higher strength, thanks to which destruction of these samples on cover plates was completely excluded. Durability of these samples by sheet was determined as sum of cycles before rupture of cover plates and before rupture of sheet.

Average magnitude of dynamic coefficient for samples of this series constitutes 1.2. Characteristic of cycle during vibration varies from 0.13 to 0.036.

Coefficient of correlation of samples destroyed by sheet, - 0.886. Fatigue limit on base of $2 \times 10^6$ cycles without dynamic coefficient is equal to $5.5 \pm 2 \times 0.31$ kg/mm$^2$.

Rupture of considered samples occured on first row of rivet holes, here ruptures of rivets from alloy V65-T were not observed.

Fatigue tests conducted in 1960 of rivets from alloy V65-T by method described above for rivets from alloy D18-T show higher results. Thus, tentatively determined fatigue limit of rivets from alloy V65-T, taking into account dynamic coefficient exceeds [illegible] kg/mm$^2$ with large scattering of experimental points. Fracture of rivets in form is similar to fracture presented in Fig. 4a. Fatigue cracks on lateral surface of body of rivets, as this is depicted in Fig. 4b, in rivets from alloy V65-T were not observed.

[illegible] the basis of obtained experimental data in work of NII of bridges there are offered norms of coefficients $\gamma$ of lowering of stresses during variable load for riveted span structures of railroad bridges from aluminum alloys. In our country such norms have so far not been developed. A broad calculation of sign-alternation of load in structures from aluminum alloys in most cases is generally not made. In norms of the United States, England, and France there are rather scanty indications about calculation of strength for structures experiencing significant quantity of cycles of load changes [11].

In basis of norms of NII of bridges there is given a method of B. N. Duchinskiy, Cand. of Tech. Sciences, recommended by him for calculations of strength of welded joints of steel span structures of railroad bridges [12], [13]. Coefficient $\gamma$ is determined by this method as function of magnitude not only of characteristic of cycle $\rho$, but also of $\beta$ - effective coefficient of concentration of stresses and of $\zeta$ - coefficient of conditions of change of load. In general form the formula of B. N. Duchinskiy for calculation of coefficients $\gamma$ for allowed stresses has the form

$$\gamma = \frac{1}{(A_1\beta + B_1) - (A_1\beta - B_1)\rho} \leq 1, \qquad (1)$$

where

$$A_1 = \frac{[\sigma]\, n_{-1}}{2\sigma_{-1}\,\zeta}; \quad B_1 = \frac{[\sigma]\, n_{-1}}{2\sigma_b};$$

$[\sigma]$ - basic allowed stress in strength calculation;

$\sigma_{-1}$ - fatigue limit during symmetric cycle;

$n_{-1}$ - safety factor for strength;

$\sigma_b$ - ultimate strength.

Following values of coefficients $\gamma$ were obtained of lowering of stresses during variable load for riveted joints of railroad span structures:

From alloy D1-T $\quad \gamma = \dfrac{1}{1.3 - 1\rho};$ (2)

from alloy AMg61 $\quad \gamma = \dfrac{1}{2.1 - 1.6\rho}.$ (3)

Earlier there were calculated magnitudes of $\gamma$ for riveted joints from alloy D16-T:

$$\gamma \quad \frac{1}{2,7 \quad 2,2\rho}; \tag{4}$$

they can be analogously obtained for rivets from aluminum alloys. Among the investigated alloys the highest values of coefficients $\gamma$, close to those which are taken for low-alloy steels, belong to duralumin D1-T.

As a result of fatigue tests of joints from duralumin on rivets from alloy D18-T and joints from aluminum-magnesium alloy AMg61 on rivets from V65-T, we can make following conclusions.

1. Duralumin D1-T, quenched and naturally aged, possesses higher strength than duralumin D16-T of heightened strength. For pressed profile from D1-T ratio of fatigue limit during symmetric cycle of stresses to ultimate strength constitutes $\frac{\sigma_{-1}}{\sigma_b} = 0.17$, as compared to $\psi = 0.11$, obtained for rolled plated sheets of D16-T.

Fatigue limit of samples without concentration of stresses from alloy D1-T on base of 2 X $10^6$ cycles with characteristic of cycle of 0.073 constitutes 14.36 $kg/mm^2$, taking dynamics into account.

2. Fatigue limit of samples of riveted joint of structure made from alloy D1-T, during rupture of sheet, taking dynamics into account, constitutes 8.77 $kg/mm^2$ on base of 2 X $10^6$ cycles with characteristic of cycle 0.071, or over 65% of strength of basic material. Vibration strength of such a joint is determined by strength of basic material. Vibration strength of such a joint is determined by strength of rivets from alloy D18-T.

3. Aluminum-magnesium alloy AMg61 in vibration strength is near to duralumin D16-T. Thus, fatigue limit of samples without concentration of stresses from pressed strip of AMg61 on base of 2 X $10^6$ cycles with characteristic of cycle of 0.073 constitutes 11.65 $kg/mm^2$, taking dynamic coefficient into account. For

that alloy

$$\psi = \frac{\sigma_{-1}}{\sigma_b} = 0{,}16.$$

4. Fatigue limit of samples of riveted joints from alloy AMg61 with cold-set rivets with diameter of 20 mm from alloy V65-T upon rupture of sheet, taking dynamics into account, constitutes 6.6 kg/mm$^2$ on base of 2 X 10$^6$ cycles with characteristic of cycle of 0.036, or nearly 57% of strength of basic material.

Under these conditions vibration strength of cover plates with thickness of 6 mm, cut from wall of pressed girder, turned out to be lowered by 10%.

5. In process of fatigue fracture development is observed of several fatigue cracks in the most stresses sections of sample. Fracture occurs through the shortest distances between separate cracks in weakened sections, and it is most frequently disposed in more than one plane. Separate fatigue cracks outside fracture can not appear.

6. On the basis of experimentally fixed fatigue limits of samples, in this work there were calculated coefficients of lowering of allowed stresses for structures elements working under sign-alternating and varying loads of riveted span of railroad bridges from different aluminum alloys. Obtained data allow us to determine $\gamma$ also for other forms of structures experiencing vibration.

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## INVESTIGATION OF WORK OF COMPOUND I-BEAMS FROM ALUMINUM ALLOYS

Yu. S. Mkrchants, Engineer

In this article results are given of investigation of real work of compound riveted beams from alloy D16-T and welded beam from alloy AMg6 of I-profile with thicknesses of webs on order of $(\frac{1}{185}-\frac{1}{90})h$ under static load.

Included in the work are data on investigation of local stability of webs, distribution of stresses in elements of beams, local and overall deformations, and also ultimate strength of shown structures.

### 1. Introduction

During designing of certain forms of building parts and building from aluminum alloys it can happen that in a number of them application of solid, compound beams will be the most efficient.

However, necessity of guarantee of local stability of webs, provoking either thickening of them, or introduction of additional elements (stiffeners) even in these forms of parts and buildings significantly lowers effectiveness of use of metal in solid beams, which is especially strongly manifested in riveted beams from high-strength alloys, and also those welded, where there is divergence between required thicknesses of webs, determined from conditions of strength and that required for stability.

One of methods increasing effectiveness of use of material in solid beams is calculation of their work after buckling by web, inasmuch as this state still does not signify total exhausting of load-bearing ability of the whole beam.

At present concerning this question there is a number of experimental and theoretical works. Such, for instance, are works by professor H. Wagner [6], who in 1929 first published his own investigations of strain state of beam with uniaxial field of stresses in web by: A. Yu. Romanshevskiy [3], who investigated beam with thin web; by V. M. Striguno [4], who inspected beam with webs of average thicknesses; by M. L. Nisnevich, who offered calculation of thin-webbed beams during action of evenly distributed load; by Rockey and Jenkins [8], [9], and also by Moore [7], who conducted a number of experimental-theoretical investigations of behavior of beams from different alloys during different schemes of loadings; and other works.

However, majority of them concerned chiefly aviation structures, form and condition exploitation of which essentially differ from building structures.

Thus, in these investigations there frequently were considered small thicknesses, which allowed the authors to introduce into calculation a number of facilitating assumptions, justice of which with increase of thickness of considered elements, as this is observed in building structures, could be disturbed.

Therefore, for use of above-indicated reserve of efficiency of beams intended for application in construction it is necessary to carry out a number of experimental and theoretical investigations, having purpose of obtaining additional information, definitizing real character of work of beams from aluminum alloys.

For solution of this problem this work was conducted, which included carrying out of experimental investigations and comparison of their results with theoretical conclusions for the following questions:

1) deformability of basic elements, and also beams on the whole;

2) influence of different components of strain state of webs on their stability;

3) strain state of basic elements of beams;

4) ultimate strength and more precise definition of work of beams after buckling by webs;

5) composition of proposals definitizing recommendations given in SN 113-60 [Building Norms] in part of calculation of compound beams.

## 2. Basic Assumptions of Calculation of Thin-Webbed Beams After Buckling by Webs

Theoretical calculations of thin-webbed beams were conducted by approximation method accepted in aircraft building with use of basic calculating assumptions and formulas presented in works [2-5] and in certain others.

In derivation of formulas following assumptions were made:

1) flanges of girders are parallel and absolutely resistant to bend;

2) uprights are vertical;

3) web has finite thickness $\delta$;

4) bracing of uprights to flanges is hinged;

5) in beams with webs of thickness on order of $\frac{1}{185}h$ and thinner (where h - rated height of webs) bending moment is born completely by flanges of beams, but shear force - by web; with thickness of webs on order of $\frac{1}{100}h$ given assumption is also kept, but with the difference that web before buckling besides severing force, can bear, partially, the bending moment; in derivation of calculating formulas the last circumstance was considered because determination of critical shear stresses ($\tau_{cr}$), entering in these formulas, was made with regard for influence both of normal and also of shear forces. In other respects method of calculation remained without changes;

6) shear stresses in web of each panel are constant;

7) before buckling by web, stresses $\sigma_y = 0$.

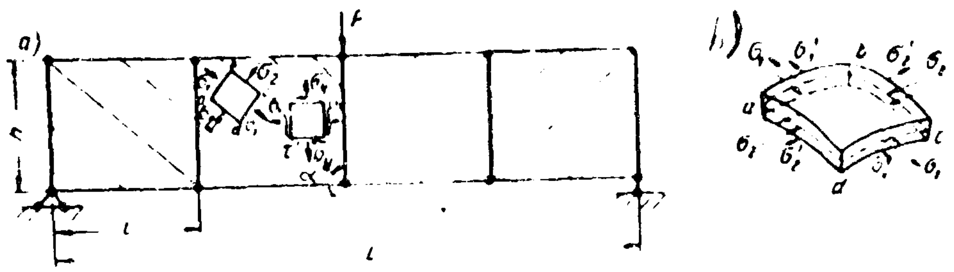


Fig. 1. Diagram of beam and stresses in web after buckling.
a) Diagram of beam and principal stresses in web; b) Diagram of basic and secondary stresses acting on element of web abcd.

In example of thin-webbed beam, for which all above-made assumptions hold true except second half of assumption [5], in part of absorbtion by web of bending moment, we understand work of beam after buckling of web.

Owing to this assumption, web of beam will be loaded only by shift with evenly-distributed shear stresses through height of beam $\tau$ to which, as it is known, correspond main stretching and compressing stresses $\sigma_1$ and $\sigma_2$ (Fig. 1).

With magnitude of shear force less than critical these stresses will be equal among themselves in absolute value, i.e., $\sigma_1 = |\sigma_2| = \tau$, and with magnitude higher than critical, when wet of beam has already buckled, on the basis of experimental investigations [4] it is possible to allow that stresses $\sigma_2$ remain constant and equal to critical stresses $\sigma_{cr}$ and stresses $\sigma_1$ will continue to grow and will be directed along generators of waves.

In this stage of work of beam shear force is born basically by extension of web, when flange and stiffener are loaded additionally by horizontal and vertical components of linear efforts of this extension.

Thus, after buckling of web, work of beam assumes new character, reminiscent of work of trussed girder, where role of uprights begins to be played by stiffener of beam, and stretched struts - forming diagonal folds of wall.

Practically, calculation of beam after buckling of web i.e., during load $P > P_{cr}$ (where P - main load applied to beam, and $P_{cr}$ - that magnitude of this load at which web buckles in one of panels of beam), it is possible to reduce to consideration and calculation of two states of system.

In the first state, satisfying conditions of equilibrium, in all elements of beam under influence of external force P with help of usual methods of calculation of bent elements there are determined internal forces (in webs - course of linear shear forces $q=\frac{P}{h}$, and in flanges and uprights - longitudinal forces N).

In second state, which is self-balanced, since external force P in first state is already balanced, there are determined those additional efforts which appear in elements of beam from action of force ($P - P_{cr}$), after buckling of web.

Totaling these two states, we obtain the sought for, total strain of whole system.

Considering that investigated beams had web with thickness on order of $\left(\frac{1}{100}-\frac{1}{185}\right)h$, i.e., belonged to class of webs "of average thicknesses,"* then during determination of stresses in webs, it was necessary to consider main compressing stresses $\sigma_2$, since shear force in such beams is absorbed partially by shear and partially by extension of web. This condition makes problem statically indeterminable. Then for its solution, owing to insufficiency of some equations of statics additional equation is introduced expressing dependence between main stresses $\sigma_1$, and $\sigma_2$, which was obtained by experimental means in work [4].

On the basis of assumptions made, and also establishment of dependence between $\sigma_1$ and $\sigma_2$, we obtain, as a result of solution of equations of statics, following basic formulas for determination of deflections of beams.**

1. Tensile stresses are assumed evenly distributed through sections of web perpendicular to axes of waves:

$$\sigma_1 = (2\tau - \tau_{cr})\frac{1}{\sin 2\alpha}.$$

*By classification accepted in work [4].

** Derivation of formulas is given in work [5].

2. Compressive stresses are assumed evenly distributed through sections of web parallel to axes of waves:

$$\sigma_2 = \sigma_{cr} = \frac{\tau_{cr}}{\sin 2\alpha}. \tag{2}$$

3. Shifts of $f_k$ point of beam k in the direction of action of force $P_k$ applied to beam which is loaded by one concentrated force (Fig. 1) or whole force system:

$$f_k = \sum \frac{\sigma_1 \sigma_1' \delta F}{E} + \sum \int \frac{NN' ds}{EF_i} + \sum \int \frac{MM' ds}{EJ}, \tag{3}$$

where $\sigma_1'$, N' and M' - stress in web, effort in rod, and bending moment in section of beam caused by unit force $P_k = 1$;

S and $F_i$ - length and area of cross section of elements of contour of beam flanges and uprights);

$\alpha$ - angle of inclination of waves of web to horizontal axis of beam;

E - modulus of longitudinal elasticity of material.

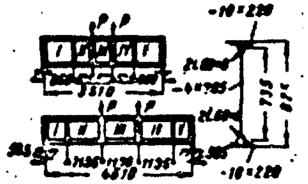
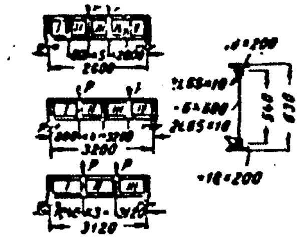
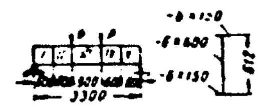
In formula (3) summation spreads to entire region enveloped by power factors from $P_k = 1$.

Besides formulas (1) and (2), serving for determination of basic stresses in webs, there is still another series of formulas by which stresses and in other elements of beams are determined and also secondary stresses $\sigma_1'$ and $\sigma_2'$, appearing in webs owing to bend of them in two planes during wave formation. These formulas and also their derivation are given in works [2], [3], [4], and certain others.

## 3. Testing of Structures

Objects of tests. For carrying out of these investigations for the purpose of comparison of work of beams with different thicknesses of webs and types of joints (riveted and welded) there were prepared the following three series of test beams, diagrams of which are given in Table 1.

Table 1. Geometric Characteristics of Tested Beams

| (a) № серий | (b) Марки испытываемых балок | (c) Схемы и поперечные сечения балок* | (d) Количество балок шт. | (e) Материал балок (марки сплавов) | (f) Моменты инерции в см⁴ | | (g) Моменты сопротивления в см³ | | (h) Площадь каждого из поясов $F_п$ в см² | (i) Площадь стоек $F_{ст}$ в см² | (j) Отношение расчетной высоты стенки балки к толщине h/δ | (k) Отношение расчетной высоты стенки балки к длине панели h/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $J_{бр}$ | $J_{нт}$ | $W_{бр}$ | $W_{нт}$ | | | | |
| I | BK-1 |  | 1 | D16-T | 143 050 | 121 330 | 3 480 | 2 950 | 42 | 20** 40 | 184 | 0,55*** 1,25 1,15 |
| | BK-2 and BK-3 | | 2 | D16-T | 143 050 | 121 330 | 3 480 | 2 950 | 42 | 20 40 | 184 | 1,25 0,65 0,63 |
| II | BK-4 |  | 1 | D16-T | 79 594 | 57 400 | 2 560 | 1 820 | 43 | 20 | 90 | 0,97 |
| | BK-5 and BK-6 | | 2 | D16-T | 79 594 | 57 400 | 2 560 | 1 820 | 43 | 20 | 90 | 0,68 |
| | BK-7 and BK-8 | | 2 | D16-T | 79 594 | 57 400 | 2 560 | 1 820 | 43 | 20 | 90 | 0,52 |
| III | BS-1 |  | 1 | Amg6 | 27 261 | — | 895 | — | 9 | 8 | 100 | 1 1 0,67 |

KEY: (a) No. of series; (b) Grades of tested beams; (c) Diagrams and cross sections of beams*; (d) Quantity of beams; (e) Material of beams (grades of alloys); (f) Moments of inerita in cm$^4$; (g) Moments of resistance in cm$^3$; (h) Area of each flange $F_p$ in cm$^2$; (i) Areas of uprights $F_{up}$ in cm$^2$; (j) Ratio of rated height of web of beam to thickness h/δ ; (k) Ratio of rated height of web of beam to length of panel h/l.

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*On these diagrams figures I-V designate No. of panels of samples.

**First figure pertains to unloaded uprights, second - to loaded.

***First figure pertains to first panel, second - to second, etc.

I series - riveted beams of grades BK-1, 2, and 3 with relatively thin webs, thickness $\delta = 4\text{mm}\ (\frac{1}{185}\ h)$.

II series - riveted beams of grades BK-4-BK-8 with thicker webs, thickness $\delta = 6\ \text{mm}\ (\frac{1}{90}\ h)$.

III series - welded beam of grade BS-1 having thickness of web $\delta = 6\ \text{mm}\ (\frac{1}{100}\ h)$.

All test samples were planned according to "Technical specs of designing of building structures from aluminum alloys" (for experimental designing, second edition, 1958), and then they were recalculated and checked according to recommendation of SN 113-60 [Building Standards].

Series of samples (BK-2 and BK-3; BK-5 and BK-6, and also BK-7 and BK-8) were made absoultely identical in structure.

All riveted samples were planned from alloy D16-T and prepared in factory conditions.

Joints of all elements of riveted beams were made with rivets with diameter of 14 and 19 mm set in cold state on clamp. In beams BK-7 and BK-8 rivet with diameter of 19 mm were installed non-hardened from material D18p in state of delivery, in remaining beams all rivets were installed hardened - in state D18-T.

Thorough inspection of all riveted beams after manufacture showed that initial distortions of their webs constituted very insignificant magnitude (less than $0.3\delta$), which allowed us to consider such webs in separate panels of beams as flat plates without initial damage.

Welded beam (BS-1) was planned from alloy AMg6 and prepared in welding room of laboratory of metal construction TsNIISK [Central Scientific Research Institute of Structural Parts]. Manufacture of beam was carried out in special jig by means of electric arc welding in atmosphere of argon on automatic machine ARK-1 and, partially, manually. After manufacture of beam its web obtained significant distortions, which later were considered during treatment and analysis of results of tests.

All basic characteristics of tested samples are given in Table 1.

Material of samples. As it was shown above, for test beams two grades of alloys were used: D16-T - for riveted beams and AMg6 - for welded.

Application for test samples of two grades of alloys with very different mechanical characteristics allowed us to conduct investigation of stability of webs of beams and also their behavior both in region of elastic and also non-elastic deformations with approximately identical geometric characteristics of sections.

For obtaining of a number of mechanical characteristics of applied materials special special investigations were conducted of their mechanical properties under extension and compression - for sheets and pressed profiles.

Determination of mechanical properties of material during extension was made on standard flat samples by usual method of tests in accordance with specs of All-Union Government Standard 1497-42.

Determination of the same mechanical characteristics of material during compression was made with help of special attachment, intended for test of thin sheets under compression. This attachment, consisting of two guide elements, between which was located test sample, assured its stability during entire test. General view of attachment together with test sample and tensometers fastened to it is shown in Fig. 2.* Results of tests of these samples for extention and compression are given in Table 2.

Installation for Tests of Beams. All test beams were tested on special installations, general view of which is shown in Figs. 3 and 4. In Fig. 3 there is presented installation intended for tests of beams of I series. On this installation load on beam was created by two 150-ton hydraulic jacks located on upper flange of beam. Load applied at two points equidistant from both ends of beam. In connection with this center panel was under action of pure bend, but end - combination of bend and shear.

*Described devices and method and analysis of results of tests are given in work by the author "Investigation of mechanical properties of certain aluminum alloys under extension and compression," included in this collection.

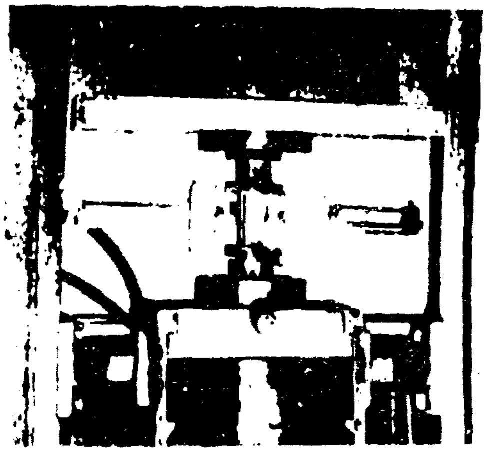

Fig. 2. General view of installation for compression of samples from thin sheets.

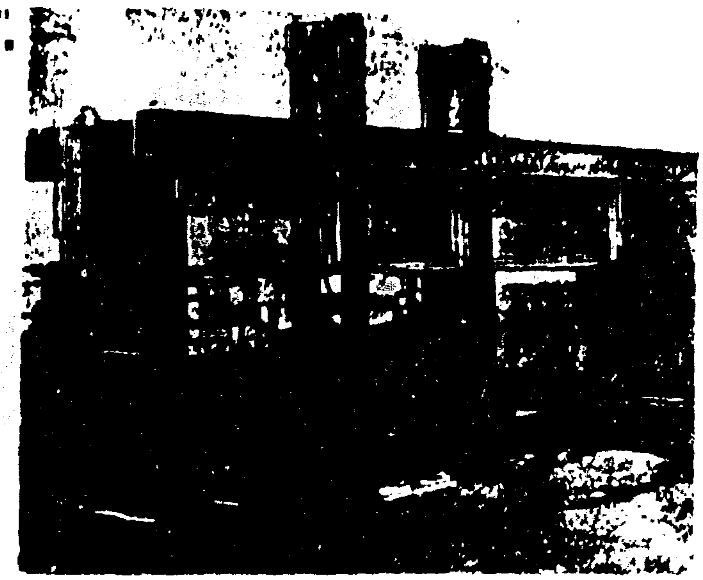

Fig. 3. General view of installation for test of beams of I series.

Table 2. Mechanical Characteristics of Material of Test Beams

| Grades of alloys | Form of material | Form of tests | Ultimate strength $\sigma_b$ in kg/mm² | Conditional yield point $\sigma_{0.2}$ in kg/mm² | Limit of proportionality $\sigma_p$* in kg/mm² | Modulus of longitudinal elasticity E in kg/mm² | Specific elongation $\delta$ in % |
|---|---|---|---|---|---|---|---|
| D16-T | Sheet $\delta = 4$ mm | Extension | 46.3 | 35.9 | 31.4 | 7200 | 16.3 |
| | | Compression | — | 34.4 | 28.7 | 7200 | — |
| | Sheet $\delta = 6$ mm | Extension | 48.7 | 35 | 30.8 | 7300 | 16.2 |
| | | Compression | — | 33.5 | 28.3 | 7430 | — |
| | Sheet $\delta = 10$ mm | Extension | 43.3 | 32.9 | 28.5 | 7250 | 15.8 |
| | | Compression | — | 32 | 26.8 | 7300 | — |
| | Angle 65 X 65 X 65 X 10 mm | Extension | 54.5 | 42 | 40.5 | 7200 | 11 |
| AMg6 | Sheet $\delta = 6$ mm | Extension | 37.6 | 17.7 | 16 | 7200 | 21.9 |
| | | Compression | — | 18 | 16.3 | 7140 | — |

*Limit of proportionality of material was determined according to All-Union Government Standard 1497-42.

For assurance of overall stability of test beams compressed flange, of the latter was braced on both sides by horizontal ties, consisting of struts and diagonal rods, fastened on the one side to compressed flange of test beam and on the other - to steel channel welded to upper branches of step columns (Fig. 3).

For assurance of free vertical shifts of test beams all common joints of ties were weakened as far as possible, and fastening of ties to steel channel was carried out by means of bolts passed through holes elongated in vertical direction in wall of channel. With help of other bolts, screwed into flange of channel and resting on elements of horizontal ties, it was possible with increase of deflections of test beam to displace simultaneously the horizontal ties.



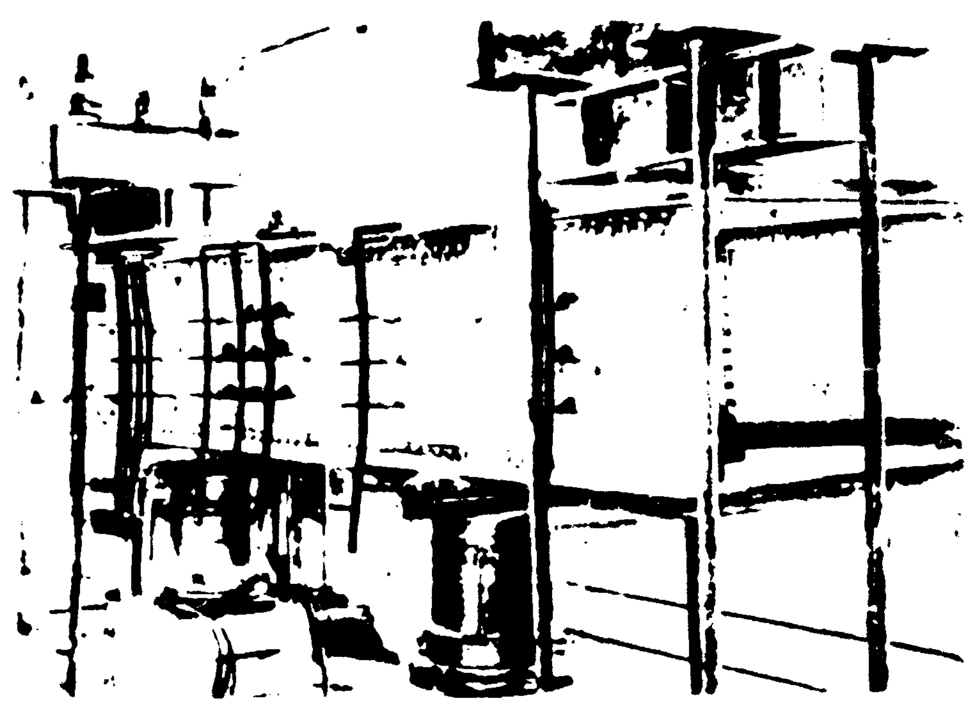

Fig. 4. General view of installation for test of beams of II and III series.

Beams of II and III series were tested on another installation, shown in Fig. 4, where load, just as for beams of I series, was applied at two points equidistant from both ends of beam by means of two 150-ton jacks standing on floor and transmitting pressure to beam through stationary rollers.

On ends beams rested in collars consisting of flexible belts fastened by means of anchor bolts in slots supporting floor.

Support of test beams was carried out with help of free roller on one support and stationary roller on the other. Overall stability of test beam was ensured by horizontal and vertical ties located between test and additional beams, of which the latter was disposed next to that tested on special stands. Horizontal ties were disposed on level of compressed flange, but vertical - on center and support sections of beams.

So that ties did not constrain vertical shifts of test beams and were not included in work second additional beam, measures were taken analogous to those for beams of I series (weakening, as far as possible, of all bolt joints of ties, provision for shift of additional beam in vertical direction in process of test, and so forth).

Pressure in jacks was created by two pump stations with hand drive, while magnitude of load on test beams was determined by indications of two manometers at 400 atm, fixed for each jack separately.

<u>Organization and carrying out of tests</u>. Below there are enumerated measurements conducted during test of beams.

1. Measurements of initial curvature of webs were made for all beams before start of tests, for which steel tapes were used with lengths of 500-1000 mm. A set of feeler gauges was used for measurement of small, initial distortions of webs, metallic rods with attached indicators were used for measurement of large distortions observed in welded beam.

2. Measurements of lateral deflections of webs in each of panels of beams were taken for determination of loads provoking local buckling of webs and also for more precise definition of character of wave formation rendering influence on strain state of webs. For this purpose indicators were applied with value of division of 0.01 mm, which were established normal to surface of web in three sections of each panel of beam where appearance was expected of the greatest lateral deformations of web.

Through height of panel in each section were established three indicators each. All instruments were held by special clamps fastened to beam relative to middle plane of its web. General view of location of instruments on test beams is shown in Fig. 4. Furthermore, for measurement of magnitudes of diagonal folds on certain end panels indicators were established close to each other in the direction passing through center of panel and perpendicular to these folds.

3. Measurements of vertical deflections of beams were made for judgement on deformability of beams. For this purpose there were applied deflectometers of N. N. Maksimov with value of division of 0.1 mm, which were established in three sections of beams: in the middle of span and in places of application of load.

Instruments were mounted outside beam, and threads from them were fastened to small screws threaded into flange of beam in the middle its width.

Vertical shifts of supports of beams, caused by pressing down backings, and also for other reasons, were measured by indicators set up two on each support.

4. Measurements of relative deformations were taken for the purpose of judgement about distribution and magnitude of deformations and stresses in elements of beam. For this purpose there were used wire electrical detectors with base of 25 mm and automatic strain guage prepared in MEI laboratory of TsNIISK.

On webs of beams, within limits of central panels affected by pure bend, detectors were glued on middle sections of panels and were directed along horizontal axis of beams.

For the purpose of check of uniformity of distribution of normal stresses through length of center panels, in two beams (BK-6 and BS-1) detectors were glued in two sections: in the middle of panel and somewhat nearer to stiffener.

In end panels of beams detectors were disposed in the most stressed sections of each panel in the form of clusters of three detectors, which allowed us to determine magnitude of shear stresses in given section.

For control of operation of electrical detectors and also recording of probable deviations in indications of electronic strain guage, at certain points of beams there were set up in parallel with electrical detectors mechanical tensometers with base of 20 mm, and on separate plates, independent of test structures, additionally there were glued control active detectors.

5. Measurements of magnitudes of shifts between elements of flanges of beams and their walls were taken for clarification of influence of these factors on work of beams. To this end, on base of indicator with value of division of 0.01 mm a special instrument was prepared.

Shift of above-indicated elements was measured according to relative shifts of two phonograph needles, one of which was pressed in web near flange corner, and other - in vertical shelf of the flange corner itself.

On one of needles the shift gauge rested with stationary part having a cut in the form of a "dovetail," and other part, which is mobile, leaned on other needle through special plate without cuts, which ensured higher accuracy in measurements (owing to possible inaccuracy of location of two needles). Inasmuch as instrument was "portable," i.e., after taking of reading it was removed from test structure, three such readings were taken and their average was recorded.

Test measurements made by given instrument before test of beams revealed that its indication were of sufficient stability.

6. Measurements of magnitudes of deflections of flanges from plane of beams were taken for realization of control of preservation by beams of overall stability. These measurements were made with help of N. N. Maksimov deflectometers fixed on stands outside beams. Threads from deflectometers were fastened to screws threaded into edges of both flanges of beams in 3-4 sections (two support and one center, or two center at places of application of load).

Load of each beam during test was applied in several stages.

On the first of them beams were loaded to those amounts provoking buckling of web in either one of panels. At subsequent stages load on beam rose to magnitudes exceeding load of first stage by approximately 2 times - for beams of II and III series (having relatively high values of critical loads in local stability of webs) and by 4-5 times - for beams of I series, for which values of critical loads were not very great.

At last stage beams were loaded up to failure.

After each stage of load beams were unloaded and permanent sets were measured.

Before beginning of test of each beam installation was "broken in" by means of test loading of beams with load equal approximately to half of that calculated at which operation of instruments was checked, as were ties and other units.

In all tests load was applied in separate steps - bigger at beginning of test (on order of 5t) and somewhat smaller in subsequent loads (1 or 2 tons).

After application to test beam of new step of load or unloading readings from all instruments were not taken at once, but after a small interval of time, on the order of 5 minutes.

For more exact determination of loads provoking local buckling of webs in separate panels of beams, readings on indicators and electrical detectors fixed on webs of beams for this purpose were taken after smaller steps of loading than readings on other instruments.

After each load there was conducted a thorough inspection of entire test set-up, especially of ties and test beams, after which appropriate notations and sketches were made in journal of tests, and necessary adjustment of installation was made.

## 4. Results of Tests

Lateral deflections of webs. The most characteristic peculiarity of work of all webs is that on them from the very beginning of load gradual increase is immediately observed of lateral deflections, which significantly complicates clear determination of loads provoking local buckling of webs.

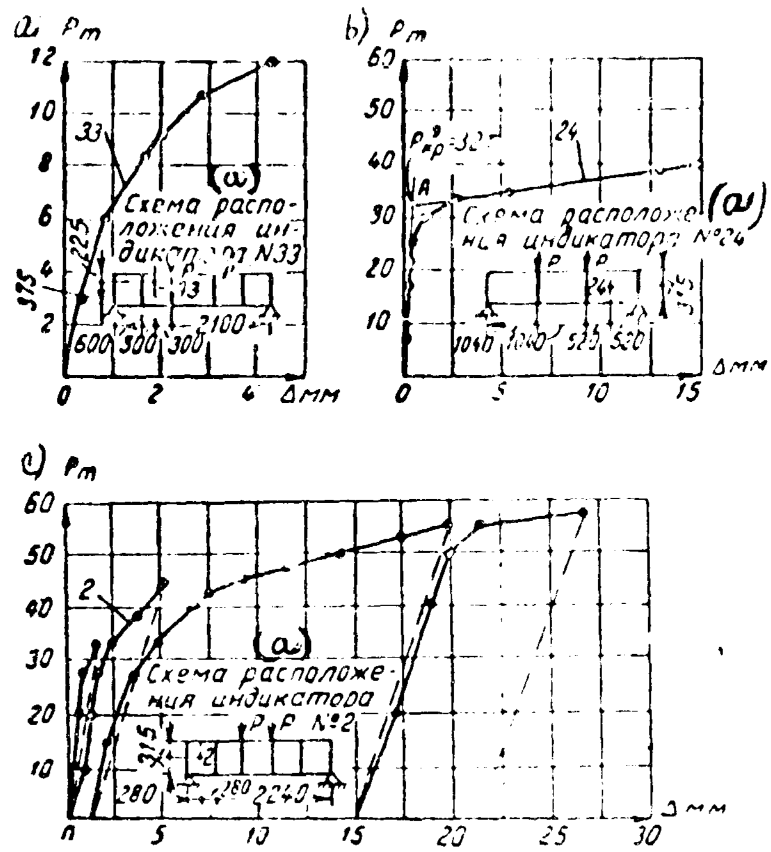

Fig. 5. Graphs of the greatest lateral deformations of webs of beams
a) BS-1; b) BK-8; c) BK-4.
KEY: (a) Diagram of location of indicator.

However, majority of graphs expressing dependence of lateral deflections of webs on load have clearly expressed fractures, indicating on transition of given web under certain load to qualitatively new state. Subsequently, load corresponding to this state of beam was taken as critical ($P^{э}_{cr}$) by condition of local stability of web.

In Fig. 5 there are presented the most characteristic examples of such graphs, where the first of them (Fig. 5a) is typical dependence, little promoting determination of critical loads, whereas second graph (Fig. 5b) is characteristic for curves on which during determination of loads there is clearly expressed fracture, allowing us more clearly to determine loads provoking buckling of webs.

Comparing work of webs of beams under different loads, it is possible to note that under loads higher than critical in webs of end panels of beams there started to form folds, disposed in all test beams basically in the direction of diagonals, independent of dimension of panels (see Fig. 13).

In center panels, located on diagram of loading under action of pure bend, formation of folds under these loads was not noted.

Upon unloading of beams, folds of web disappeared without a trace when load on beam was such that stress in webs did not exceed limit of proportionality of material; otherwise in webs of beams permanent sets were observed, which were greater, the higher the load (Fig. 5c).

During loading of beams by critical load $P^{T}_{cr}$ equal in magnitude to theoretical load provoking buckling of web in one of panels of beam, permanent sets in webs during subsequent unloading were not observed in general. With increase of load to calculated $P^{T}_{p}$ constituting for beams of I series $(2.7-3)P^{T}_{cr}$, and for II series - $1.4P^{T}_{cr}$, permanent sets of webs upon subsequent unloading either were not observed in general, or did not exceed magnitude equal on the average to $(0.3-0.5)\ \delta$ where $P^{T}_{p}$ - theoretical magnitude of load at which values of given stresses in web attain magnitudes of calculated resistance of material, and $\delta$ - thickness of web.

With loads higher than critical in webs of separate panels of beams there starts to form not one, but several folds, different in magnitude. Here the greatest depth and width belonged to center folds, whereas small sections of webs adjacent to periphery of panels practically remained flat.

Comparison of the greatest lateral deflections of webs of beams in panels with identical dimensions, under action of shear forces of identical magnitude and different normal efforts shows that influence of latter on growth and magnitude of lateral deformations of walls is very insignificant (Fig. 6).

Comparison of magnitudes of lateral deflections of webs at critical $(P^{T}_{cr})$ and calculated $(P^{T}_{p})$ loads, measured in places of the greatest deflections of webs, shows that these magnitudes in all sections of test samples under their respective critical and calculated loads were small and did not exceed magnitudes equal to $0.5\delta$ for critical loads and $1.2\delta$ for those calculated which with respect to least of dimensions of panels constituted respectively 0.002b and 0.01b.

Graphic dependencies of the greatest lateral deflections of webs were constructed for all panels of test samples.

And the most characteristic of these graphs i.e., those which were constructed for webs with least initial distortions, and for which graph in connection with this had the most clear break of curve, were used for determination of critical loads for each of such panels.

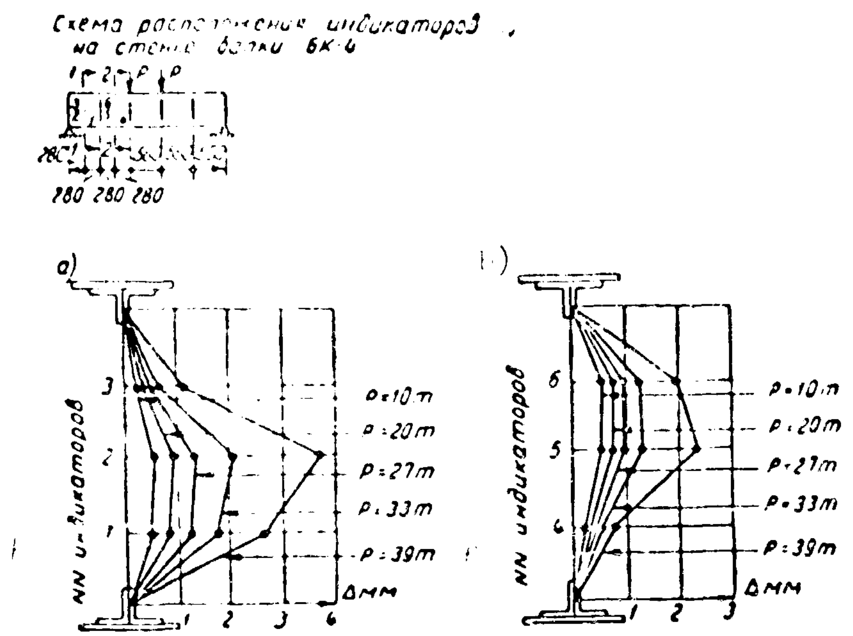

Fig. 6. Lateral deformations of web of beam BK-4
a) in section 1-1; b) in section 2-2.
KEY: (a) Diagram of location of indicators on web of beam BK-4; (b) [NN] of indicators.

Here there was used "method of tangents," consisting fact that on graphs expressing dependence of lateral deflections of web on load, where curve in place of fracture was split in two directions, to each of them there were constructed tangents, and then point of intersection of the latter (point A Fig. 5b) determined load provoking buckling of web in this panel.

For more exact determination of critical loads, besides those shown graphs there were also used graphic dependencies between load on beam and relative deformations of web, measured by electrical detectors glued on both sides of webs in places of the greatest lateral deflections across generators of folds (Fig. 7).

Final values of critical loads were defined as average magnitudes obtained after appropriate treatment of curves of both types. Experimental magnitudes of critical loads for webs of beams in separate panels comparison of them with calculated magnitudes determined according to TU [Tech. Specs] [10] turned out to be on the average 1.3 times higher than those calculated for beams of I series, and 1.2 times higher - for beams of II series, which may explain rather high pinching of webs in elements of circuit.

In welded be· experimental magnitudes of critical loads for separate panels turned out to be somewhat less than calculated. But, inasmuch as web in these panels had large initial distortions, to compare results obtained for them with results for beams having web with insignificant distortions would be incorrect. Therefore, such comparison was not made.

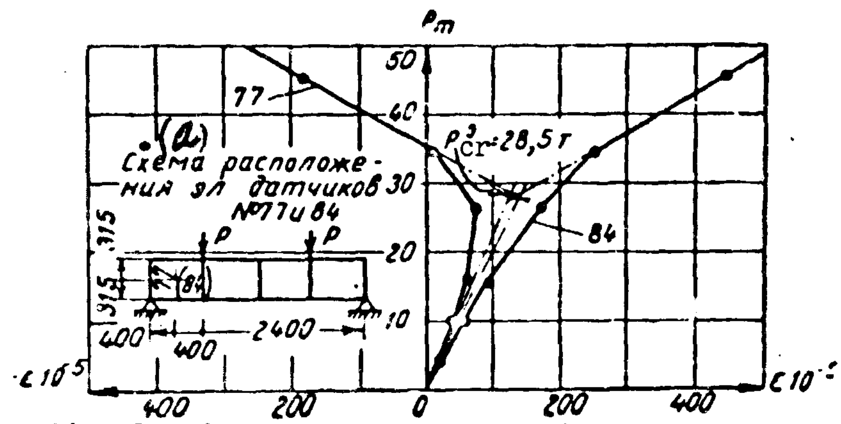


Fig. 7. Graphs of operation of electrical detectors No. 77 and 84, located in places of the greatest lateral deformations of web of beam BK-5, perpendicularly to forming folds.
KEY: (a) Diagram of location of electrical detectors No. 77 and 84.

Vertical deflections of beams. In Fig. 8 there are presented graphic dependencies between loads on test samples and their vertical deflections, measured in sections under loads.

Comparison of dependencies of the greatest lateral deflections of web and vertical deflections of one and the same sample shows that beginning of buckling of webs does not render essential influence on vertical deflections of samples.

This is clear, at least from the fact that, as observed from the very beginning of load of samples, approximately linear dependence between load and vertical deflections of samples was kept also during loads exceeding the critical for webs of samples in separate panels, in spite of the fact that after buckling of web growth of vertical deflections of samples is somewhat accelerated.

Comparison between measured magnitudes of vertical deflections of test samples and those calculated by formula (3) shows that agreement between them for all samples was fully satisfactory up to loads not exceeding (6-7) $P_{cr}$ - for samples of I series and (1.4-1.7) $P_{cr}$ - for samples of II series (Fig 8). Under larger loads, when in walls there appeared stresses exceeding limit of proportionality of material, and between flange and wall - large shifts, there was observed accelerated growth of vertical deflections, which on graphs was marked by appearance of sections of curves with nonlinear dependence.

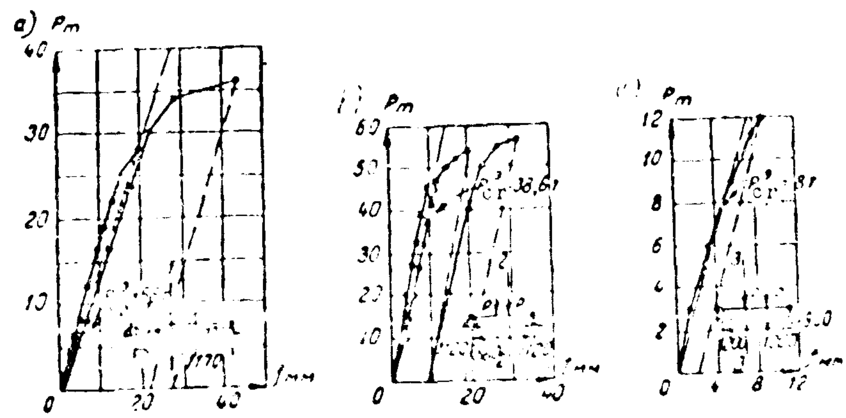

Fig. 8. Graphs of vertical deflections of beams, measured in places of application of load
Special designations: ——— experimental curve; ——— · ———theoretical, by formula (3); ———··———the same, by usual formulas of resistance of materials; ---- unloading
a) in section 1-1 of beam BK-2 (I series); b) in section 2-2 of beam BK-4 (II series); c) in section 3-3 of beam BO-1 (III series)

On rectilinear section of graphs the biggest divergence of measured magnitudes of vertical deflections from those calculated (to smaller side) for certain samples attained 17%, which it is possible to explain mainly as influence of high rigidity of nodes of test beams in places of joining of flanges and uprights.

Comparison of vertical deflections of samples with stresses in beam shows that, in spite of appearance in webs of beams of stresses equal to or even somewhat above limit of proportionality of material, caused by wave formation of web in early stages of loads, linear character of curve expressing dependence of vertical deflections on load was almost not disturbed. This is explained, first, by the fact that shown stresses spread in very small region, mainly in center of panel, with or across center fold, and, secondly, they are concentrated not through entire section of web, but nearer to its surface, and only gradually do they penetrate entire section with increase of load on sample.

Measurements of vertical deflections of test samples upon full removal of load after each stage showed that permanent vertical sets were practically absent during loading of beam by load equal to $P^{\text{т}}_{cr}$ and they had very insignificant magnitudes (on order of 0.1–0.3 mm) during loading of beams by calculated loads ($P^{\text{т}}_{p}$).

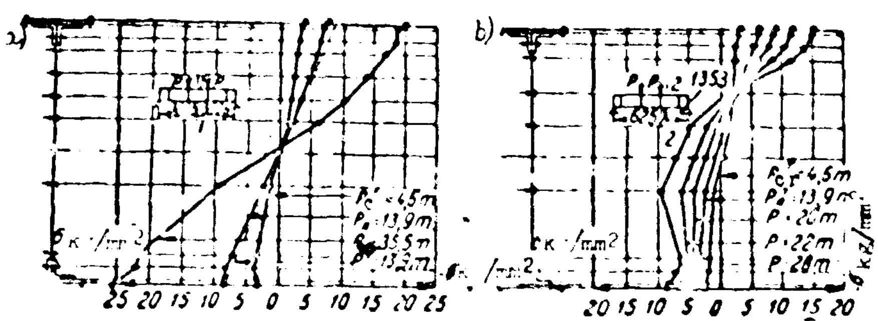


Fig. 9. Distribution of normal stresses in cross sections of test beams
a) in section 1-1 of beam BK-2; b) in section 2-2 of beam BK-3.

During large loads and subsequent unloading of beams magnitudes of permanent sets gradually rose. Magnitudes of vertical deflections of test beams, respectively for I, II, and III series, constituted on the average, under critical loads

$$(P^{\text{т}}_{cr}) - \frac{1}{1830} L, \quad \frac{1}{540} L \text{ and } \frac{1}{680} L.$$

and under calculated loads

( ... and ... )

Strain state of beams. In Fig. 9, 10, 11 there are given graphs showing distribution of stresses in different sections of test samples.

From Fig. 9 it is clear that distribution of normal stresses in places of joining of web with flange corners, and also of flange corners with flange sheets, is even, and the more so, the greater the load on test sample. The phenomenon is most strongly expressed in sections of samples nearer to supports, where there are observed large mutual displacements of riveted elements, provoking disturbance of inseparability of deformations and leading, thereby, to nonuniform distribution of normal stresses in given section of sample.

In connection with this, stresses in webs of test samples were somewhat higher than calculated. Thus, during critical loads, normal stresses in webs of test samples exceeded those calculated on the average by 5%.

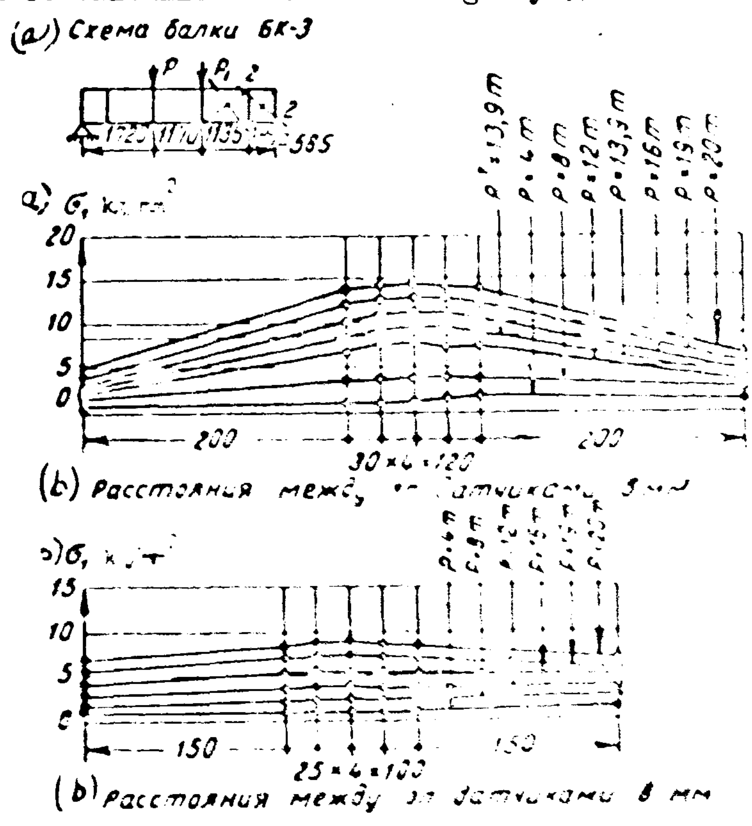


Fig. 10. Distribution of main tensile stresses in sections of web of beam BK-3, perpendicular to forming folds
a) in section 1-1; b) in section 2-2.
KEY: (a) Diagram of beam BK-3; (b) Distances between electrical detectors in mm.

Dur   loads higher than critical irregularity in distribution of normal stresses is still more strengthened. Part of web is disengaged from operation, neutral axis shifts nearer to com   ssed flange, which owing to forming in web of field of diagonal tension is somewhat overloaded, while stretched flange is unloaded for this reason.

Thus, on this stage of work in beam there occurs redistribution of internal efforts, and it starts to work already according to now diagram as truss-beam with "flexible struts," role of which is played by diagonal folds formed on wall. Then total strain state of web will be composed of main tensile stress $\sigma_1$, directed along fold, main compressing stress $\sigma_2$, directed perpendicularly to fold, and of two local bending stresses $\sigma_1'$ and $\sigma_2'$, appearing as a result of distortion of web in two planes (Fig. 1).

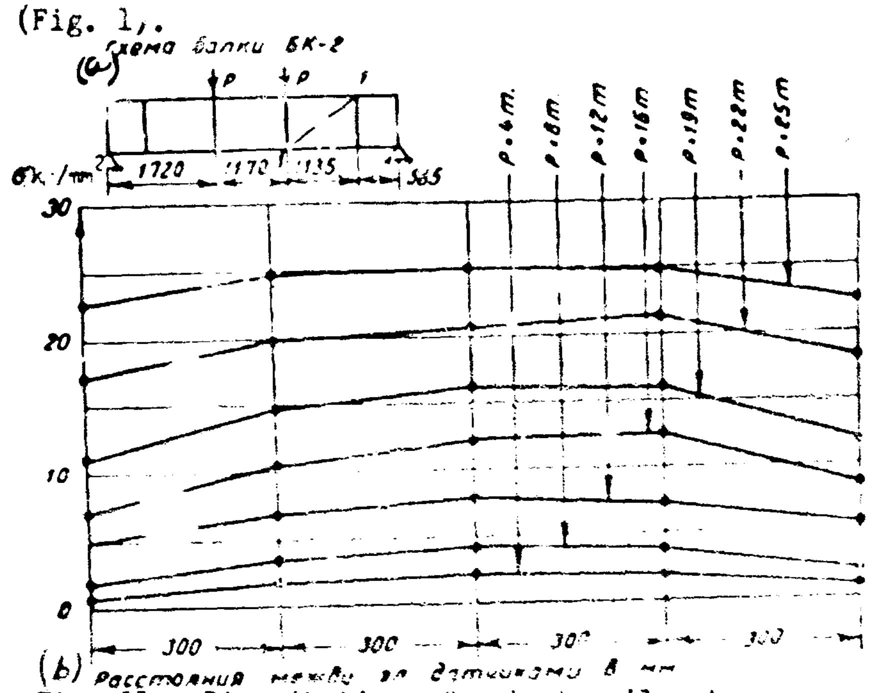


Fig. 11. Distribution of main tensile stresses (in direction 1-1) along diagonal fold of web of beam BK-2.
KEY: (a) Diagram of beam BK-2; (b) Distances between electrical detectors in mm.

Let us consider character of distribution of these stresses, inasmuch as during subsequent loads of beam they are developed most intensely, and therby in significant measure determine work of structure.

In Fig. 10a, b, there are presented graphs of distribution of main tensile stresses $\sigma_1$ by sections of webs of test samples perpendicular to direction of folds and passing through center of panels.

As can be seen from these graphs, distribution of stresses $\sigma_1$ in shown direction has very nonuniform character. Here the greatest magnitude of stress $\sigma_1$ is reached in center folds of webs. Comparison of experimental magnitudes of $\sigma_1$ with those calculated, determined by formula (1), shows that in center part of folds experimental magnitudes of stresses were 1.1-1.2 times more than those calculated.

This divergence may be explained by the fact that calculating formulas were derived for case of flanges absolutely rigid under bend, whereas in reality of flanges possessed certain elasticity under bend. In connection with this, in panels with shorter length, where linear rigidity of flanges turns out to be higher, irregularity in distribution of stresses $\sigma_1$ decreases somewhat (Fig. 10b).

Irregularity in distribution of stresses $\sigma_1$ is observed also along the actual wave (Fig. 11), inasmuch as in this direction of fold in plane perpendicular to plane of web there also is formed a half-wave. Thus, owing to formation of folds in web, the latter is bent in two planes, which generates in it secondary bending stresses $\sigma_1'$ and $\sigma_1''$, from which first are directed across generators of waves, and second - with them. Presence of these stresses leads to fact that of all elements of thin-webbed beam just in folds of web are there first of all attained calculated stresses which determined calculated load.

Comparison of maximum magnitudes of main tensile stresses with work of other elements of beam, and also the structure on the whole, shows that passage of outer fibers of wall beyond the limits of proportionality of material very insignigicantly shows up on vertical deflections of whole beam. This is possible to explain by the fact that passage of material of web beyond the limits of proportionality occurs in very small region.

However, in spite of very limited region of propagation of these stresses, they should not be disregarded, especially in webs of low-ductile material, inasmuch as disregard of them can lead to formation in webs of cracks.

Comparison of calculated and measured magnitudes of shear stresses in webs of beams shows that these magnitudes agreed quite well among themselves. Divergence between them on the average did not exceed 7%.

Load-bearing ability of beams. Tests made of compound beams from aluminum alloys once again confirmed the well-known assumption that buckling of web of beam still does not signify exhaustion of its load-bearing ability, and characterizes only transition of given structure into new state, at which it starts to work according to another diagram.

Comparison of graphs of stresses in different elements of test samples and lateral deformations of web shows that in beams of considered series buckling of web in outer panels occurred during comparatively small stresses.

During loads corresponding to this state in center panels having different ratios of geometric dimensions for different samples, magnitude of normal stresses in outer fibers of flanges constituted from 5 to 12 $kg/mm^2$, and shear stress in outer panels of webs - 1.5-9 $kg/mm^2$.

At this stage of work of beams their vertical deflections were small and elastic.

Calculated load $(P_p^T)$, at which given stresses in webs attained magnitude of calculated resistance of material, was on the average 2.7-3 times higher than critical $(P_{cr}^T)$ determined in accordance with recommendations of TU [10], for beams of I series 1.4 times higher than for beams of II series.

At this stage of work, i.e., during loads $P^T$, maximum stresses in outer fibers of flanges in center panels constituted 8-15 $kg/mm^2$, and permanent sets of beams - 0.1-0.3 mm.

Further increase of load led to still larger growth of total and local deformations and stresses in elements of beams.

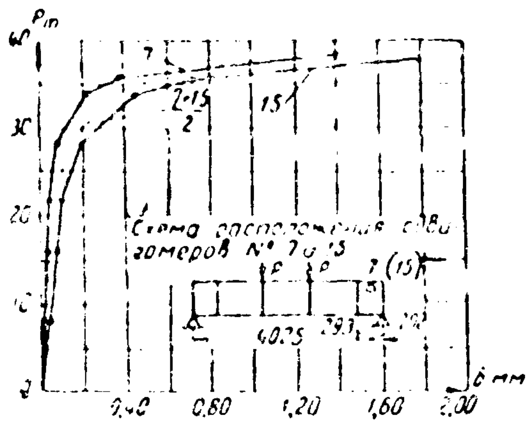

Fig. 12. Graph of shifts of web of beam BK-3 relative to flange corners of compressed flange. Shift gauge No. 15 was located on opposite side of beam.
KEY: (a) Diagram of location of shift gauges, No. 7 and 15.

Thus, during loads equal approximately to (6-7) $P_{..}$ and (1.4-1.7) $P_{..}$ respectively for beams of I and II series, form of graphs of vertical deflections of beams started to take on nonlinear character (Fig. 8). With these loads vertical deflections of beams I and II series constituted respectively magnitudes on order of $\left(\frac{1}{160}-\frac{1}{140}\right) L$ and $\left(\frac{1}{185}-\frac{1}{240}\right) L$, and main tensile stresses and stresses in outer fibers of flanges of center panels constituted respectively on the average 32 and 18 kg/mm$^2$ - for beams of I series, and 34 and 14 kg/mm$^2$ - for beams of II series.

With these same loads there were observed also relatively large magnitudes of shifts between web and elements of flange of beam, as this may be see from Fig. 12.

Total exhaustion of load-bearing ability of test samples occured as a result of failure of web in center stretched diagonal - for samples of I and II series (Fig. 13), and local bucklings by compressed flange - for sample of II series (Fig. 14).

Failure of riveted beams started in the beginning in the corner of the most stressed panel between two rivets, where there was observed the greatest bend of sheet of web in two planes, provoking appearance of cracks here, but then this rupture was developed further to neighboring rivets located along flange and stiffeners of beams.

Fig. 13. General view of beam BK-2, ruptured during test.

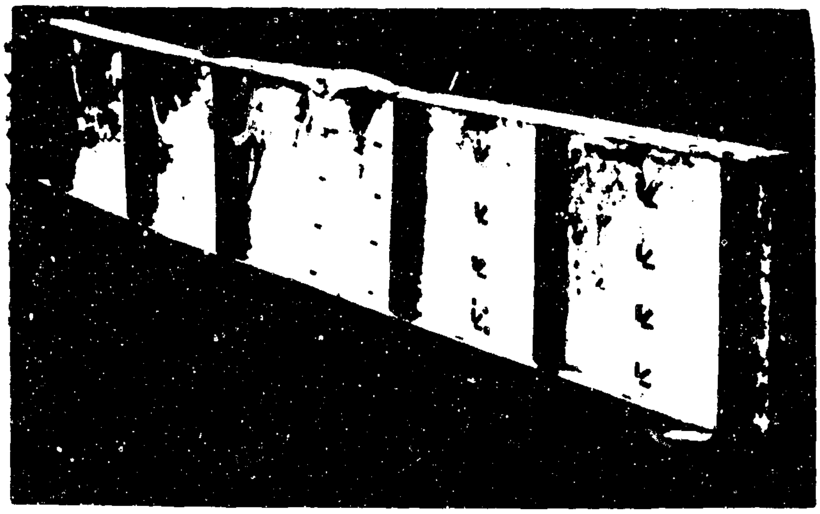

Fig. 14. General view of beam BS-1, ruptured during test.

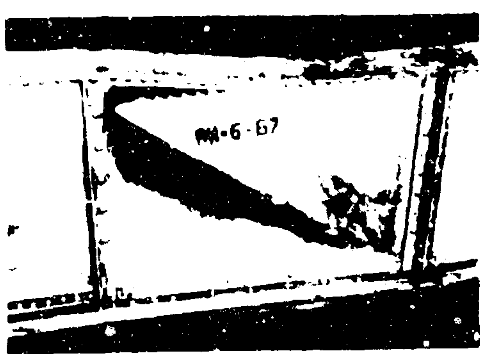

Fig. 15. General view of ruptured web of riveted beam BK-2.

Failure of web in riveted beams occurred in the form of tear of sheet, or appearance of cracks between nearby rivets in direction perpendicular to forming folds (Fig. 15).

For test samples from BK-1 to BK-8 and BS-1 limiting breaking loads ($P_{lim}$) constituted magnitude equal respectively to 45; 35.5; 38; 56; 59; 57; 48; 43.5, and 12.8 t, which with respect to critical loads ($P^T_{cr}$) constituted following ratios: (7.8–8.3) – for beams of I series; (1.7–2.1) – for beams of II and III series.

## 5. General Remarks on Conducted Tests

As a result of conducted tests, it is possible to note that all instruments and nodes of test installations, and also test beams themselves basically worked fully satisfactorily.

Tests revealed in test beams a number of structural deficiencies, of which the most important was too close disposition of rivets to one another on angles of panels, and also to edge of sheet of web. In these sheets there was observed large concentration of stresses, evoking here destruction of web in the form of tear of sheet or appearance of cracks between nearby rivets in direction perpendicular to forming folds.

Furthermore, conducted tests confirmed necessity of further study of questions of local stability of flanges, overall stability of beams, and also of long-term tests of beams with buckling webs.

## 6. Conclusions

On the basis of conducted investigations following basic conclusions can be made.

1. Webs of all beams had initial distortions, attaining small magnitude in riveted beams, on order of 0.8-1.8 mm (0.2-0.3 $\delta$) and significant magnitude in welded - on order of 2-8 mm (0.3-1.[illegible] $\delta$).

These distortions, usually predetermining direction of buckling of webs and lowering critical loads for them, however, had no essential influence on general behavior of webs and ultimate strength of beams.

2. Angle of inclination of diagonal folds forming after buckling of web in outer panels of beams loaded by combination of bend and shift with sufficient accuracy for practical calculations may be taken equal to angle of inclination of main diagonal of considered panel.

3. In riveted beams elements of circuit created for webs rather high pinching, for which experimental magnitudes of critical loads exceeded the calculated determined by SN 113-60, on the average by 20-30%.

4. Calculated magnitudes of vertical deflections of test beams rather closely corresponded to those measured, somewhat exceeding them. The biggest

divergences within limits of 17% were observed for riveted beams, which is explained by influence of great rigidity of nodes connecting flange and upright in test beams.

Furthermore, measured magnitudes of vertical deflections of beams were in good agreement with calculated magnitudes, determined also by usual formulas of resistance of materials, but taking into account influence on deflection of shear force.

5. Magnitudes of vertical deflections of beams in claculated loads ($P_p^r$) constituted on the average $\left(\frac{1}{250}-\frac{1}{685}\right)L$.

6. Beginning of buckling of webs does not evoke sharp increase of vertical deflections of beams.

7. Measured magnitudes of normal and shear stresses and also law of their change through height of beam were close to those calculated which confirmed correctness of premises assumed in basis of calculation of beams with webs of different thicknesses.

The biggest deviations between measured and calculated magnitudes on the average constituted 7% for shear stresses and 9% for normal.

8. It is possible to consider fully acceptable the assumption taken in calculations about uniformity of distribution of shear stresses through height of wall, inasmuch as divergence between the biggest and least measured magnitudes of shear stresses in the same section of beam was small.

9. Main tensile stresses $\sigma_1$, effective in outer panels of beams along diagonal folds, are distributed both along and across them very nonuniformly, attaining the biggest magnitude in centers of panels. Here with decrease of thickness of webs and increase of bend rigidity of flanges this irregularity in distribution of stresses decreases.

10. Beams planned according to "Technical specs of designing of structures from aluminum alloys" (SN 113-60) under loads within limits of critical ($P_{cr}^r$).

i.e., the calculated as determined by TU [10], showed fully satisfactory agreement of results of tests with results obtained on the basis of TU's. Furthermore, there was revealed a real possibility of exploitation of beams during loads ($P^{T}_{K}$) exceeding critical ($P^{T}_{cr}$) by approximately 1.4-3 and more than once in relation to thickness of web, since with decrease of thickness of webs unaccounted reserves of efficiency of beams increase still more. This circumstance gives basis for subsequent introduction of a number of appropriate recommendations to TU, and makes us consider it necessary to continue these investigations for more precise definition of a number of little studied questions on work of beams after buckling of web.

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ASSORTMENT OF GENERAL-USAGE PROFILES FROM ALUMINUM ALLOYS

A. G. Immerman Cand of Tech. Sciences

Although contemporary technology of manufacture of profiles from aluminum alloys by method of hot pressing or bending is comparatively simple and allows us to obtain profiles of practically any configuration with large variety of dimensions, it is necessary to have assortment or catalog of certain general-usage structural profiles. This is dictated by both economic considerations and also by considerations of accelaration of production, easing of designing, and assurance of proper quality.

Necessity in assortment of general-usage profiles which will be combined with special ones, practicable for given concrete structure is confirmed by experience of application of light alloys in adjacent branches of industry (in aircraft and shipbuilding), by analysis of existing structures, and by foreign practice. In a number of countries - England, France, FRG, Japan - along with company catalogs* there are state standards on building profiles from aluminum alloys.** In raised structures together with special profiles there are also

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*Cegedur, Companis générale du duralumine et du cuivre, Paris (catalog of profiles); Reynolds Aluminium (catalog of profiles), and others.

**BS-1161-1951, Aluminium and Aluminium alloy Section; DIN 1771 (angles), 9712 (I-beams), 9713 (channels), 9714 (tees); NF H65-162-1950, French standards.

used the "classical," form of which was predetermined by development of steel structures.

Our present standards and catalog of former Ministry of Aviation Industry [7] do not satisfy need of builders, since profiles included in them have small dimensions and do not correspond to requirements of TU SN [Tech. Specs and Building Standards] 113-60 [8]. At disposal of builders have to be profiles of two categories, first, profiles designed for architectural finishing, transoms, stained glass panels, and also wall and roof barriers; secondly, profiles load-bearing structures.

In this article there is given data on planning of assortment of general-usage profiles for load-bearing structures, developed in Scientific Research Institute on Construction of Ministry of Construction of RSFSR. It was composed on the basis of presented method including main concepts of general theory of assortment of metallic profiles [1—5], and it contains equal-sided and unequal-sided angles with beads and without beads, I-beams and ordinary channels with flanges, strengthening beads, bead tees, tubings and certain other profiles. All of them can be prepared from aluminum alloys recommended in TU SN 113-60.

## 1. Basic Concepts of Method of Development of Assortment

In development of profiles included in assortment and of the assortment itself on the whole there were taken into account general requirements;

a) technology of pressing with respect to overall dimensions of section, thicknesses of walls, radii of curvature, and linkages, of length, and so forth;

b) technology of manufacture of structures in respect to simple and convenient carrying out of nodal and butt joints of elements, laying of welded seam, distribution of rivets and bolts, etc.;

c) economy, strength, and stability in accordance with assignment of profile. Last requirements are interconnected and are satisfied by means of rational distribution of material in section, application of bead thickenings of flanges of profiles working under compression, differentiated by assignment of relative thickness ( $\delta$/b) walls of profiles, acceptance of variable coefficient grading of assortment.

Dimensions of profile from the point of view of technology of its manufacture are limited, on the one hand, by power of press determining diameter of container, ingot, and diameter of dimensional circle(circle drawn around section of profile); and on the other hand, by power of drawing machine for straightening of profile after pressing. Power of contemporary presses reaches 12,000-14,000 t [9, 10], corresponding dimensional circle has diameter of 58-62 cm, however, the more widely used presses have power to 5,000 t [6]. TU SN 113-60 establish in connection with this a dimensional circle with diameter of 32 cm, allowing for separate cases a circle with diameter of 58 cm. Dimensional circle of profiles of assortment does not exceed this last magnitude. Power of drawing machines limits not overall dimensions, but area of cross section of profile. The most widely used machines are those allowing us to straighten profiles with area up to 50 $cm^2$, although straightening is possible of profiles and with larger area. In practice contemporary equipment allows us to prepare profiles with area of section from 0.1-0.3 to 200-300 $cm^2$ [6]. In assortment the biggest area of section is 200 $cm^2$.

Minimum thickness of wall of profile depends on its overall dimension. With diameter of dimensional circle of 60 mm, least thickness constitutes 2-2.5 mm, with circle of 320 mm, 6-8 mm. Because of condition of resistance to corrosion, TU's of designing allow least thickness of profiles for load-bearing elements inside building and for elements protruding outside 1.5 mm, and for structures exposed to open air 3 mm.

In profiles of assortment minimum thickness of wall was designated, taking these new requirements into account.

Length of profile is determined by TU SN 113-60 according to dimensions of billet and size of drawing machines; volume of finished article must not exceed 80% of volume of billet, which with dimensional circle of 32 cm has diameter of 34.5 cm and length of 145 cm. In practice length of semifinished product must not exceed 10-12 m, greater lengths are established by agreement with manufacturer. Length of articles not subjected to heat treatment may be somewhat increased.

Radii of curvature are fixed according to indications of appendix Kh of TU SN 113-60.

In planned profiles this radius (Fig. 1) is taken equal two thicknesses of flanges, which in all cases satisfies formulas shown in TU. This is somewhat larger than that taken in foreign assortments, but according to investigations, increase of radius of curvature improves resistance of profile to torsion. Radius of curvature of flanges and bead is fixed at 1.5 mm with thickness of wall to 10 mm, and 2 mm with thickness of more than 10 mm.

Allowances for dimensions of sides, for thicknesses, and radii of curvature, and also for different deflections and distortions of form are regulated by existing technical specs, depending upon type of alloy. However, in accordance with recommendations of technologists for building profiles, allowances for dimensions are taken somewhat larger.

During establishment of configuration of profiles it was considered that for normal course of process of pressing, when there is uniform discharge of metal through die and for elimination of waste one should avoid:

a) thin walls on big cross sections;

b) hollow sections with very narrow slot (slit);

c) sections with walls, thicknesses of which strongly differ among themselves.

From the point of view of technology of manufacture of structures it is necessary that form of profiles ensure possibility of good and convenient realization of joining of elements of structure. Profiles must have dimensions

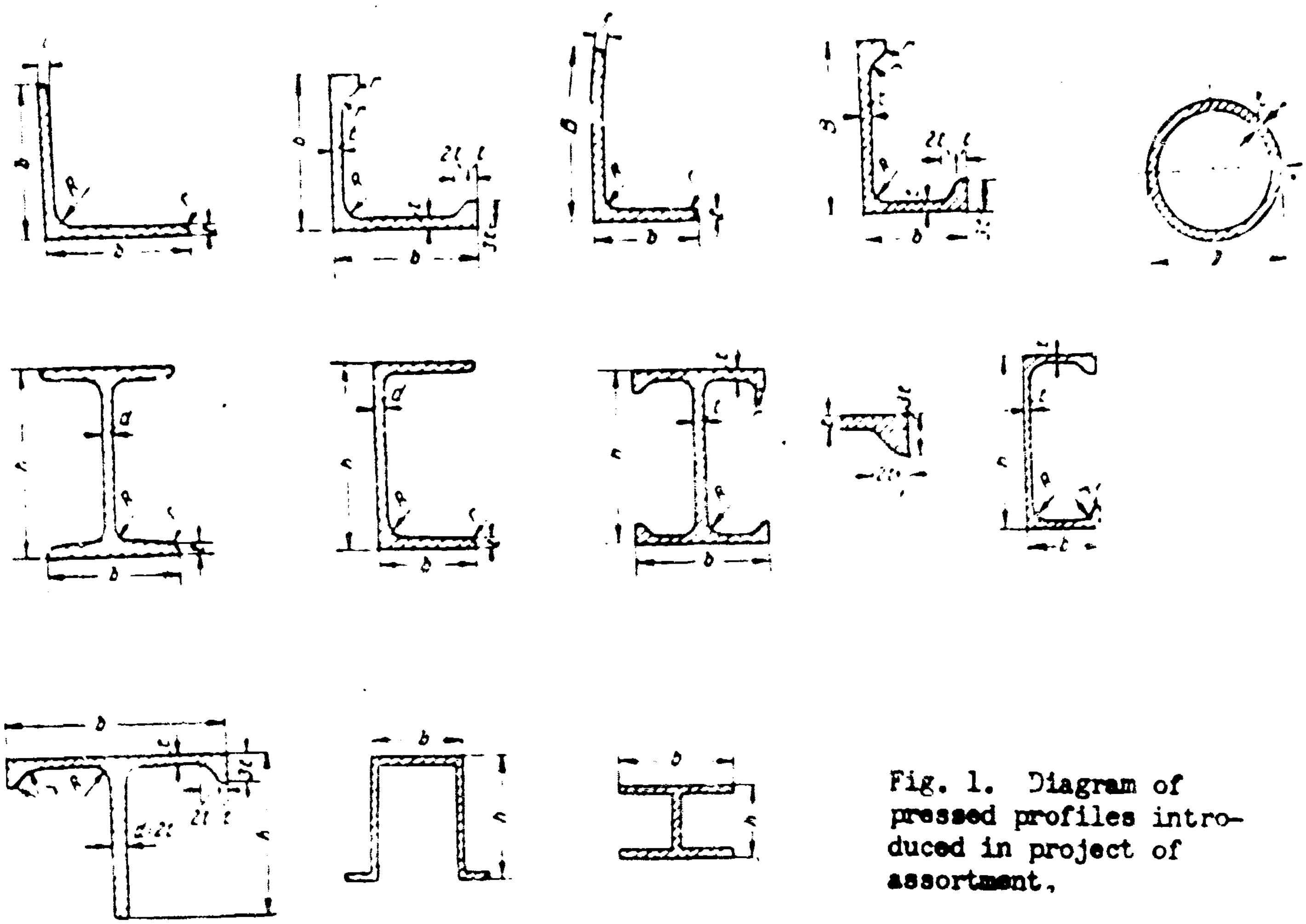

Fig. 1. Diagram of pressed profiles introduced in project of assortment.

allowing us to position rivets in riveted joints. Inasmuch as technology of pressing allows this, flanges of profiles were planned with parallel surfaces; this simplifies joining of elements and riveting.

Distances between parallel walls of one profile were taken from condition of possibility of realization of starting of electrodes or riveting machine. Edges of profiles have to be by convenient for laying of longitudinal fillet welds.

Requirements of economy, strength, and stability are formulated in accordance with forces under which profile is intended to work.

## 2. Assignment of Dimensions of Profiles

Economy of profiles working under compression, in particular corners and tees, is higher, the greater the value of specific radius of gyration

$$i_{sp} \quad \frac{i}{\sqrt{F}}. \qquad (1)$$

where F - area of section;

i - radius of gyration of section.

Maximum magnitudes of $i_{sp}$ are attained at least values of thickness of flanges (walls). Thickness of flange or, more exactly, ratio between it and width of flange $b/\delta$ is determined by local stability. Limiting values of $b/\delta$ are given in TU; they depend on type of alloy, structural shaping of feather of corner or edges of wall, and change with change of overall flexibility of element. For usual corner, for instance from alloy D16-T, with flexibility $\lambda$ = 19, b/t = 8.5; and for corner from alloy AMg6-M - with flexibility $\lambda$ = 104, b/t = 16.5 (here b - width of flange from back edge to feather).

Corresponding values of specific radius of gyration with respect to an axis parallel to wall, $i_{xssp}$ constitute 0.64 and 0.9; difference is significant - 40%.

Owing to low elastic modulus of alloys of aluminum, assurance of stability should be given serious attention. Together with that, high cost of alloys requires creation of especially economic profiles. Acceptance of least limiting value of $b/\delta$ according to the most unprofitable case would contradict this requirement. Relative thickness of walls of profiles working under compression should be designated differentially. During development of assortment, this was done with help of nomographs composed for selection of section of compressed elements.

According to technical specs of designing of building structures from aluminum alloys SN 113-60, during selection of sections of compressed rods, there have to be observed requirements of overall and local stability. Section will be selected rationally, if it has not unnecessary reserve with respect either to overall or local stability, i.e., when load-bearing ability will be used completely. Fulfillment of this condition during selection of sections by separate attempts is quite labor-consuming. Application of special monographs* allows us, using

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*Method of construction of nomographs was offered by Yu. B. Shul'kin, engineer.

given calculated length of rod and effort, to find without difficulties efficient section of given configuration.

Area of compressed section

$$F = \frac{N}{\sigma}, \tag{2}$$

where $\sigma = mR\varphi$

N - calculated effort;

m - coefficient of conditions of work;

$\varphi$ - coefficient of longitudinal bend;

R - calculated resistance.

Area of section may be expressed through basic dimension of profile b, its thickness and form factor k:

$$F = kb\delta. \tag{3}$$

For one simple equal-side corner without beads $k = 2 - 0.142\frac{\delta}{b}$; for one corner with beads of trapezoidal form $k = 2 + 7.86\frac{\delta}{b}$; for other profiles k can also be determined as function of ratio of thickness to width of characteristic side of section.

We shall designate

$$\frac{b}{\delta} = n,\ \frac{i}{b} = c \text{ and } \frac{l}{i} = \lambda. \tag{4}$$

Here $l$ - calculated length of element;

i - calculated radius of gyration of section.

Let us note that magnitude of c, practically, does not depend on dimension of section, and for each configuration of section it can be taken as constant.

Proceeding from formulas (2) and (3), it is possible to write

$$F = \frac{kl^2}{nc^2\lambda^2}$$

and

$$\frac{N}{\sigma} = \frac{kl^2}{nc^2\lambda^2}.$$

Hence

$$\frac{\sqrt{N}}{l} = \frac{1}{c\lambda}\sqrt{\frac{\sigma k}{n}}. \tag{5}$$

With given form of section of quantities $\sigma$ $\lambda$, and $n$ and are interconnected: each value of $\sigma$ with known m and R corresponds to certain $\varphi$ and, this means $\lambda$, and the latter in turn, according to TU, corresponds to certain value of n. Thus, formula (5) establishes mutual conformity between $\frac{\sqrt{N}}{l}$ and any of quantities $\sigma$, $\lambda$, and n.

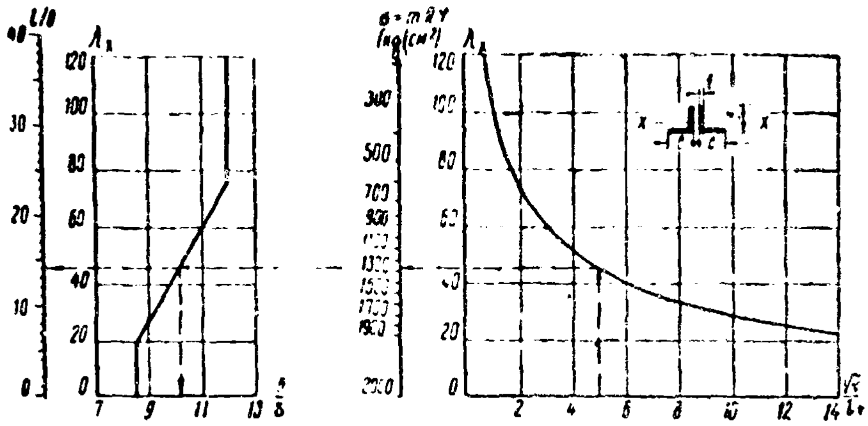

Fig. 2. Nomograph for selection of sections of compressed rods from alloy D16-T

Depicting graphically dependence of n on $\lambda$ or the same on $\frac{l}{b} = c\,\lambda$, and magnitudes of $\frac{\sqrt{N}}{l}$ on $\lambda$ and $\sigma$, we can obtain nomograph for selection of sections satisfying simultaneously requirements of overall and local stability.

Such nomographs were composed for selection of sections from pair of simple equal-sided corners (without beads) and corners with beads adjacent to flanges in reference to profiles from all alloys recommended in TU SN 113-60. In Fig. 2 there is shown one of them - for two simple angles from alloy D16-T. Use of it quite simple: by known force from calculated load N (in tons) and calculated length of rod l (in m) there is determined ratio $\frac{\sqrt{N}}{l}$; on right graph by this ratio we find flexibility $\lambda$ and here on center scale we find magnitude of $\sigma = mR\varphi$. On left graph on axis of abscissas we obtain corresponding value of $n = \frac{b}{\delta}$, and on axis of ordinates - ratio $\frac{l}{b}$; and since length l is known, be found $\frac{l}{b}$ we calculate dimension b, and then by this dimension and magnitude of n - thickness $\delta$ . Thus, there are obtained all dimensions of profile forming section. By these dimensions from assortment we choose the nearest largest profile.

Nomographs were composed for T-shaped sections from two angles when coefficient of conditions of work m = 0.8. With help of special conversion factors they may be used for other sections and profiles with other values of m, only if limiting overhang of flanges, determining local stability, have the same dependence on flexibility that exists for shown angles.

Method of assignment of thicknesses will be shown in example of equal-sided angles without beads.

Analysis showed that the biggest practically possible value of magnitude of $\frac{\sqrt{N}}{l}$ (where N - calculated force and l - calculated length) in heavy structures constitutes nearly 6. This value, depending upon type of alloy, on nomographs corresponds to flexibility from 22 to 40 or ratio l/b from 7 to 12; least value corresponds to alloy AMg-M, the biggest to D16-T (of the latter one can be convinced from Fig. 2; nomograph for alloy AMg-M is not shown there. Minimum value of magnitude of $\frac{\sqrt{N}}{l}$ in calculations may be very small, but by requirements of TU flexibility of compressed elements must not be more than 120, ratio l/b here is equal to 38. It is possible to consider that in usual structures calculated length of compressed elements made from angles within limits lies 1,000 to 4,000 mm; then minimum width of flange of angle in assortment will constitute 1,000: 38 = 26 mm, maximum width is found quite significant, but for constructional considerations it can be limited to 250 mm. Within these limits width of flanges and its gradation is expediently taken from conditions of community the same as in standard on steel angles, i.e., in twentieth row of preferable numbers (see All-Union Government Standard 8032 - 56).

For determination of magnitude of $n = b/\delta$ corresponding to certain dimension of b, we consult graph of dependence of n on $\lambda$ (Fig. 3), built according to TU (this graph corresponds to left graph of nomograph for selection of sections). We note limiting lines: on the left - for alloy D16-T within limits of flexibilities from 40 to 120, and on the right - line for alloy AD33-T1 within limits of flexibilities from 22 to 69, and further, line for alloy AMg-M to point corresponding to flexibility 120 (Fig. 3). We break noted limiting lines (sui generis) into several separate sections, and we find values corresponding to these sections 1/b, n, $b_{min}$ and $b_{max}$; these values are given in Table 1.

By this table we established conformity between dimensions of b and values of n; result is given in Table 2.

For establishment of thicknesses δ we must divide width b into values of n corresponding to, lying within limits shown in Table 2.

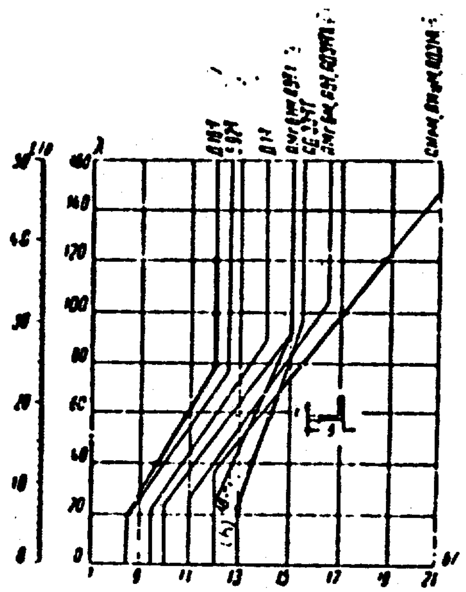

Fig. 3. Relationships between geometric dimensions and flexibility of bars of angular section.
KEY: (a) D16-T; (b) V92-T; (c) D1-T; (d) AMg61-M, AV-T1; (e) AD33-T1; (f) AMg6-M, AV-T, AD31-T1; (g) AMg-M, AMts-M, Ad31-T; (h) AV [illegible].

In practice least width of δ angle in assortment is taken not as 26, but 45 mm, inasmuch as small angles, generally encountered quite rarely, are in All-Union Government Standard 8110-56. Thicknesses are designated in accordance with Table 2 and in such a manner that difference between adjacent values of them are not exceeded by magnitude of allowances.

Thanks to application of described method, in assortment there can always be found economic profile applicable to any of alloys recommended by TU, but this does not mean that any profile is suitable for any alloy - during selection, there have to be observed requirements of TU.

Table 1. Limiting Values of n, $b_{min}$, and $b_{max}$

| | l/b | 38–31 | 31–25 | 25–19 | 19–12 | 12–7 |
|---|---|---|---|---|---|---|
| Левая граничная линия | n | 12 | 12 | 11 | 9,8 | — |
| | $b_{мин}$ | 26 | 32 | 40 | 53 | — |
| | $b_{макс}$ | 129 | 160 | 210 | 250 | - |
| Правая граничная линия | n | 17 | 15,5 | 14 | 13,5 | 13 |
| | $b_{мин}$ | 26 | 32 | 40 | 53 | 83 |
| | $b_{макс}$ | 129 | 160 | 210 | 250 | 250 |

KEY: (a) Left limiting line; (b) Right limiting line.

Table 2. Value of Ratio of n, Depending Upon Width b

| b | 26–32 | 32–40 | 40–53 | 53–83 | 83–129 | 129–160 | 160–210 | 210 и более |
|---|---|---|---|---|---|---|---|---|
| n | 17–12 | 17–12 | 17–11 | 17–9,8 | 17–9,8 | 15,5–9,8 | 14–9,8 | 13,5–9,8 |

KEY; (a) and more

Assortment of other corner profiles and tees was composed analogously. Form and dimensions of beads (trapezoidal form) in angles with beads are taken on the basis of data of investigations of local stability of these profiles. This form is rather simple constructively and is convenient for laying of welded seam. Dimensions of flanges in unequal-sided angles are taken in accordance with recommendations of TU, establishing ratio of sides as 3 : 2 for obtaining of identical moment of inertia about both axes during designing of compound sections.

With respect to geometry of stretched elements no special requirements are presented, and they are usually executed from the same profiles which are useful for work under compression.

Economy of profiles working basically under bend, those of I-beam and channel type, is higher, the greater the specific moment of resistance

$$W_{sp} = \frac{W}{F\sqrt{F}} \qquad (6)$$

($W$ – the biggest moment of resistance of section).

Maximum value of specific moment of resistance, as it is known, is attained during equal distribution of material between wall of profile and flanges. In this case

$$W = F^{3/2}\sqrt{\frac{n}{18}},\tag{7}$$

where $n = \frac{h}{\delta}$;

h - height of wall;

$\delta$ - its thickness.

Other things being equal, the most profitable, consequently, is that profile for which owing to condition of stability, there may be allowed minimum thickness of wall. Under allowances of TU for I-beams and channels working under bend, $\frac{h}{\delta} \approx 45$ maximum $W_{sp} = 1.5$.

Change of ratio of amount of material in wall to total amount from 0.5 to 0.4 lowers economy of profile by approximately 1%, while decrease to 0.3 lowers it by 5% [1].

Coefficient of gradation of assortment, i.e., ratio of area of section of subsequent profile in assortment to area of preceding, should be variable. Least value - on order of 1.05 - should correspond the most commonly used profiles. This ensures the most economic selection of sections of elements of structures without unnecessary reserves.

## 3. General Data on Assortment

In Fig. 1 there are presented diagrams of basic profiles of assortment on the whole.

In assortment of equal-sided angles without beads there are 55 profiles, in assortment of equal-sided angles with beads - 48; least dimension of b of these angles is 45 mm, the biggest - 250 mm. Of unequal-sided angles without beads there are also 48, and unequal-sided angles with beads - 42. Least dimension of side b is 45 mm, the biggest - 200 mm. Specific radius of gyration with respect to an axis parallel to wall of equal-sided angles without bead is 0.7-0.9, of equal-side angles with beads it varies from 0.78 to 0.98. Thus, effectiveness of angles with beads if 10% higher than effectiveness of simple angles. The latter in compressed elements should be applied only i special cases, when this is necessary for constructional considerations; basically they are applied in stretched rods.

Coefficient of gradation in assortments on angles for the most commonly used profiles is 1.03-1.05; for less commonly used big profiles it is 1.06-1.1.

Tees are used in compressed rods and for formation of compound sections capable of working under compression and bend. Dimensions are selected in such a manner that section has identical rigidity relative to both axes. Height h of smallest profile is 70 mm; of the biggest - 210 mm; width b of smallest profile is 100 mm; of the biggest - 300 mm. Specific radius of gyration of sections is 0.8-0.9, coefficient of gradation is 1.1-1.2. Number of profiles in assortment of tees is 15.

Assortment of simple I-beams and channels (without bead-strengthened flanges) contains two groups of profiles: one is intended for work both under bend and compression (profiles No. 8, 10, 12, 14, and all others with index "b"), the other - only for work under bend (from No. 16 on with index "a"). For the first ratio $h_p/\delta$ ($h_p$ - inside height of wall between flanges, $\delta$ thickness of wall) is taken equal to 25, and for the second - 45. Such delimitation allows us to select more efficiently when we need section of beams, which is very important, owing to low elastic modulus of alloys and impossibility of complete use of calculated resistances to bend in simple spans. Calculated overhand of flanges $b_p/\delta$ in these I-beams and channels is taken equal to 7.5, distribution of material between flanges and wall is approximately identical, which is the most profitable.

Specific moment of resistance of profiles intended for work under bend constitutes 1.5. In Fig. 4a, b there are given graphs of dependence of W' on F for profiles of different assortments of I-beams and channels; from these graphs one can be convinced that developed profiles with index "a" are the most economical - their curve lies significantly higher than others.

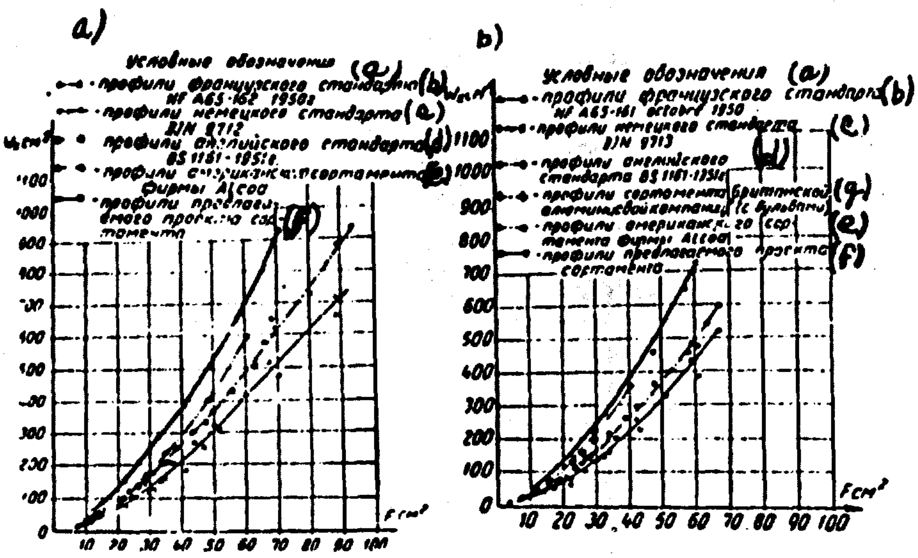

Fig. 4. Comparison of characteristics of rolled profiles of different assortment.
a) I-beams; b) channels.
KEY: (a) Special designations; (b) Profiles of French standard; (c) Profiles of German standard; (d) Profiles of English standard; (e) Profiles of American assortment of Alcoa firm; (f) Profiles of preferred project of assortment; (g) Profiles of assortment of British Aluminum Company (with bulbs).

Coefficient of gradation of these profiles is 1.05—1.1. I-beams and channels with flanges and strengthening bulbs are designed for use basically in compressed and is compressed-bent elements; specific moment of resistance of them in plane of the highest rigidity if less than for simple I-beams or channels, but during work in plane of least ridigity, they have best indices. Coefficients of gradation of them is 1.15-1.22. Number of profiles in assortment of I-beams is 23, of I-beams with flanges and strengthening beads - 13, of channels - 24, channels with flanges and strengthening beads - 14. Least height h of all channels - 80 mm, of I-beams - 100 mm, the greatest height of these profiles is 400 mm.

Assortment of tubing is partially covered by assortment of All-Union Government Standard 1947-56, but in accordance with TU it contains profiles with thinner walls which makes it more favorable. Least external diameter of tubing D - 32 mm, the biggest - 250 mm. Number of profiles in assortment of tubing - 136.

Besides those shown, in assortment there is included a number of profiles ("hat", wide-flange I-beam, and others), manufacture of which has already been mastered by factories and which were applied in structures. These profiles are characterized by profitable location of material by section and thus, as angle with beads and as tees, meet specifications of aluminum structures.

With accumulation of design and building experience. It is considered expedient in the future to supplement assortment with new successful profiles for use in newly designed structures.

For all profiles there have been calculated corresponding geometric characteristics.

## 4. Brief Conclusions

Project of assortment of general-usage profiles for building structures was composed on the basis of specially developed method, including main concepts of general theory of assortment of metallic profiles.

Indices of a number of planned profiles from the point of view of their economy is higher than foreign ones.

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DESIGNING OF CERTAIN TYPES OF ROOF AND WALL PANELS WITH APPLICATION OF BENT PROFILES

K. D. Fink, Engineer

## 1. Introduction

As it is known, question of sharp lowering of weigh of newly raised structures has great value, since weight of transported building materials for seven-year-plan construction attains impressive dimensions.

Application in construction of industrial buildings of large panel plates for coverings from aluminum alloys with light heating allows us to sharply lower weight of structures.

Experimental designing bureau of ASiA [Academy of Construction and Architecture] of USSR jointly with laboratory of metallic structures of TsNIISK [Central Scientific Research Institute of Structural Parts] is developing certain forms of lightened coverings for industrial buildings from cold-stamped corrugated aluminum sheets.

Lower there is given description of four such large-panel plates.

## 2. Construction and Designing of Roof Plates From Aluminum Alloys

Designing of plates of coverings was done on the basis of "Technical specs of designing of structures from aluminum alloys" SN 113-60, approved by Gosstroy of USSR, in 1960.

During designing of plates there were considered following loads:

1) gravity of structure (coefficient of overload 1.1) with weight of heater for heated plates (coefficient of overload 1.2);

2) snow load according to SN 69-59 for region III for snow cover (100 kg/$m^2$); coefficient of overload 1.4.

Rated dimensions of plate 6 X 1.5 m.

Plate is designed as a beam on two supports. During calculation for deformations, ultimate deflection of plate is taken equal to 1/125 of span.

Plates are not calculated for application in places of drop of heights, where additional snow pockets are formed.

Heated plates are intended for calculated temperatures: external minus 35 and internal plus 18°. Relative humidity of internal air in location is not limited.

Plates have been developed for use as coverings of single-span industrial buildings without skylights with unified spans and external water outlet. They are laid upon upper flanges of steel girders having incline of 1/12, with smaller incline forming steps among themselves, which ensures free drain of water, allowing us simultaneously to provide reliable watertight joint between plates without application of Rubsroid sheet.

Plates are being developed both for cold and for heated industrial buildings.

As heater there are taken mineralized mats in synthetic binder of brand S-100, constituting piece flexible articles, obtained by means of impregnation of fibers in process of their formation by solution of synthetic resins, with subsequent packing of panels and heat treatment for polymerization of binder.

Production of these mats up to now was retarded exclusively owing to acute shortage of phenol resins. At present the output of mats has increased. Cost price of mineralized mats has been lowered drastically and continues to be lowered. Volumetric weight of mat - 100 kg/m$^3$ with coefficient of thermal conductivity in dry state at a temperature + 30° -0.04 kilocalorie/m hour deg. Mechanical strength of mats is low, therefore, they are applied with facing from asbestos-cement sheets with thickness of 6 mm.

For the purpose of prevention of formation of condensate on internal surface of upper aluminum sheet of heated plates, space above thermal insulation layer is ventilated, or which in face parts of plate there are provided appropriate air holes.

Linkage of plates among themselves is carried out by fold of edges of upper sheet. Along one side edge of sheet is bent downwards, and along other three sides - upwards.

Thanks to such form of sheet, slots between plates are covered by upper sheet of plate lying above it on incline; slots along short sides (across drain) are covered with overlay strips.

Packing of joint between plates is attained by laying a strip in them of poroizol (spongy mixture of rubber and asphalt). Aluminum elements of plate are connected among themselves with the help of resistance (point) electric welding.

Two types of roof plates have been planned: flat type 1 and corrugated type 2. For each of these plates there is foreseen cold and heated (types 1-t and 2-t) use.

Plate of type 1 (Fig. 1) constitutes sheet with thickness of 1 mm with ribs welded to it from bent box-like profiles of rectangular outline, which approximates plate to the most profitable - symmetrical - section.

Experiment of TsNIISK for testing of aluminum plates of analogous construction showed that longitudinal ribs will work together only in the presence between them of appropriate transverse elements, distributing load between ribs more evenly on plate, in view of low rigidity of plate in transverse direction.

Therefore, on bottom of plates there are provided angular stiffeners.

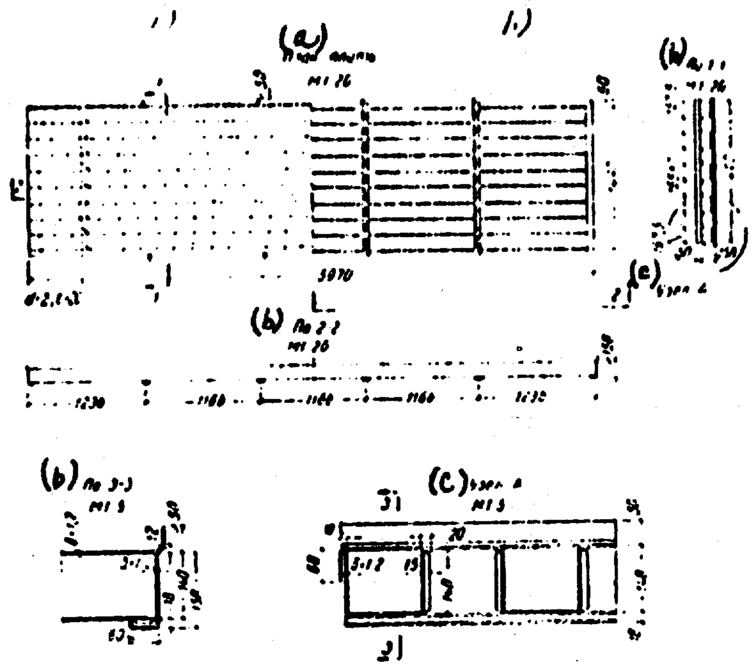


Fig. 1. Cold plate: a) top view; b) bottom view
KEY: (a) Plan; (b) Section; (c) Assembly.

Plate of type 1-t (Fig. 2) differs from preceding only by presence of heater in the form of layer of mineralized mats with thickness of 50 mm of glued sheet of asbestos material with thickness of 6 mm, fastened to plate from below with the help of self-cutting screws.

Plate of type 2 differs from plate of type 1 by the fact that sheet it is corrugated. Corrugations are closed, which simplifies face framing of plate and also creates best conditions for drainage of water.

There are only two longitudinal ribs. In other respects structure of plate of type 2 is analogous to structure of plate of type 1.

Plate of type 2-t (Fig. 3) differs from plate of type 2 by presence of heater. Construction and fastening of heater are executed just as in plate of type 1-t.

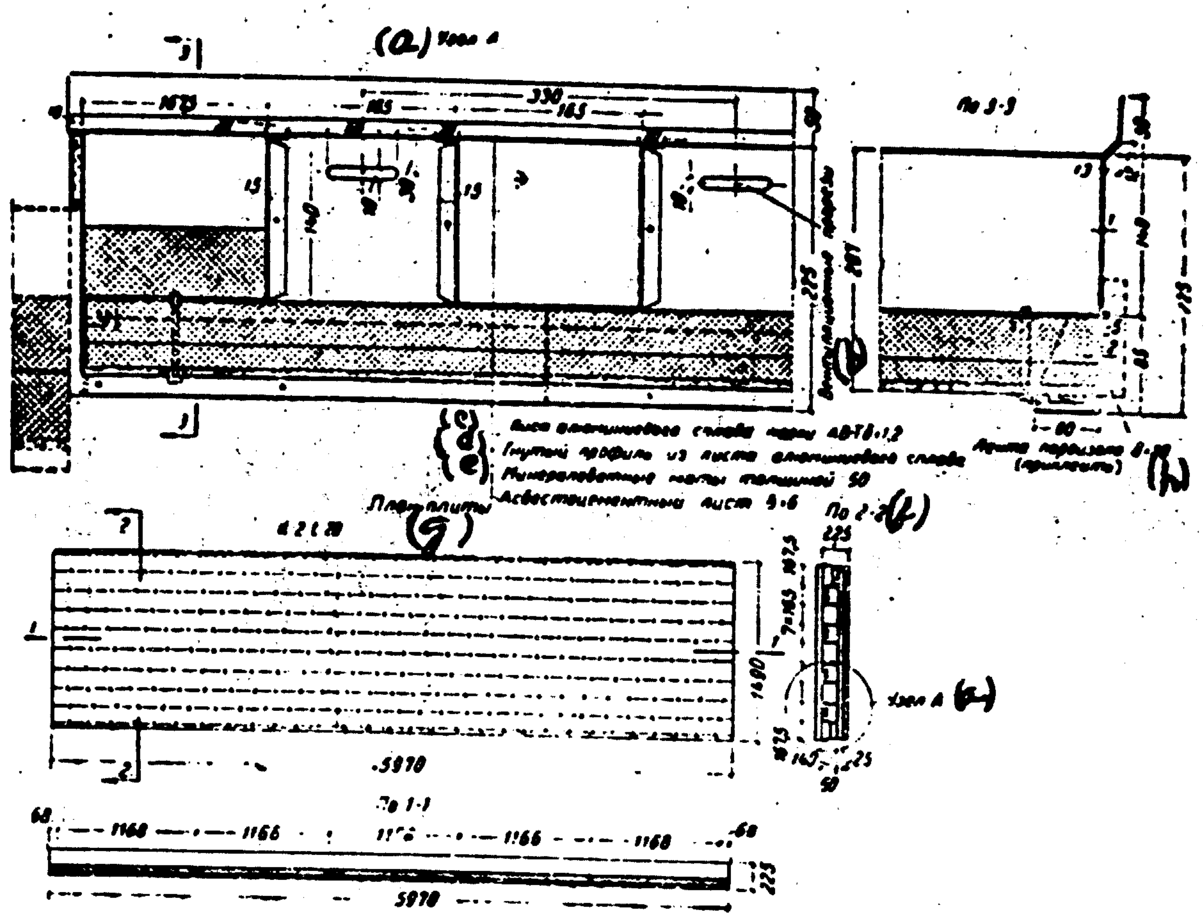


Fig. 2. Heated roof plate.
KEY: (a) Assembly; (b) Ventilation slots; (c) sheet of aluminum alloy of grade AV-T, $\delta = 1.2$; (d) Bent profile from sheet of aluminum alloy; (e) Mineralized mats with thickness of 60 mm; (f) Asbestos-cement sheet, $\delta = 6$; (g) Plan of plate; (h) Poroizol strip, $\delta = 20$ (glued).

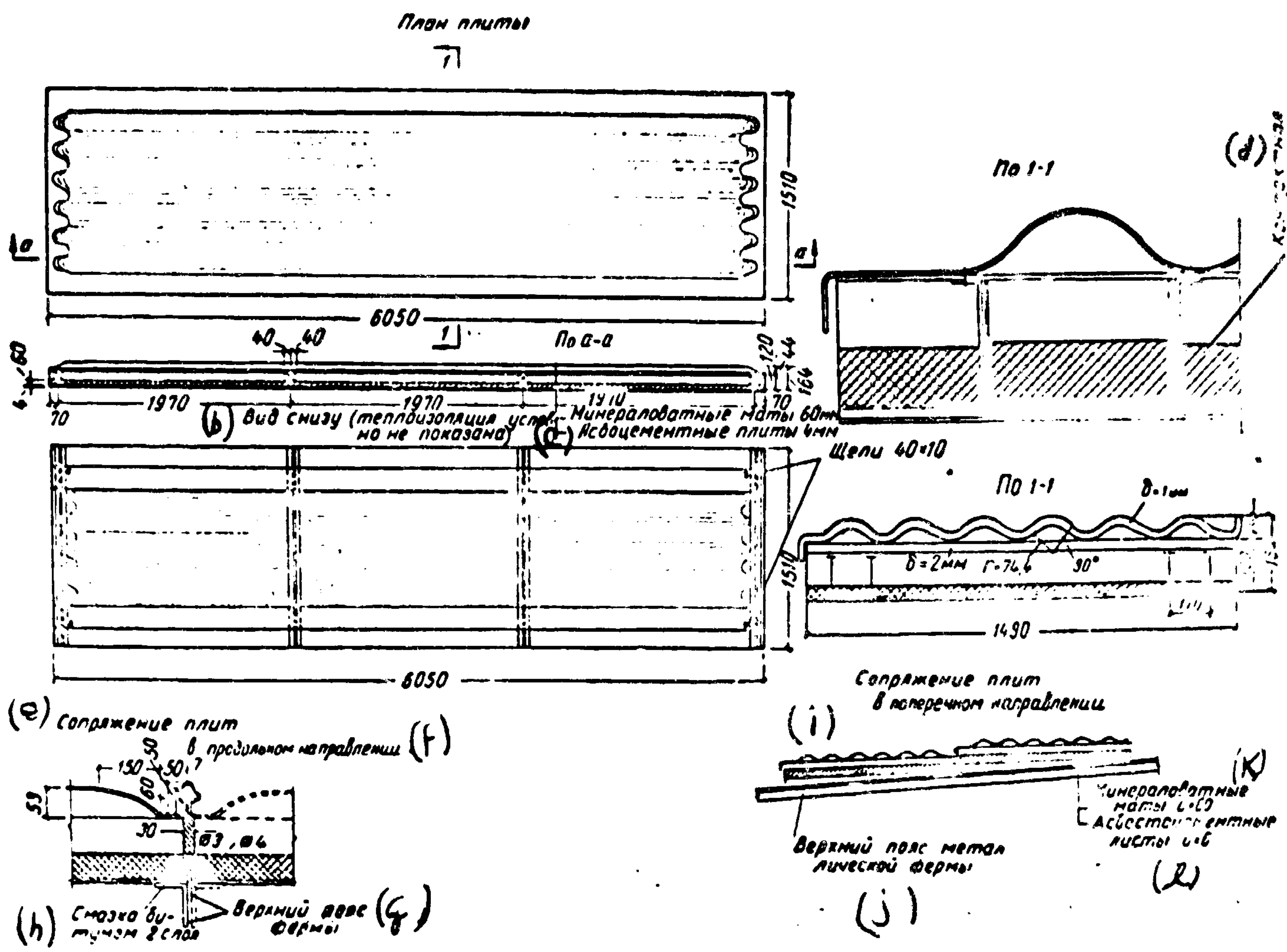



Fig. 3. Heated roof plate (structure and diagram of stacking).
KEY: (a) Plan of plate; (b) Bottom view (thermal insulation is not shown); (c) Mineralized mats 60 mm, Asbestos-cement sheets 4 mm; (d) Resistance welding; (e) Linkage of plates; (f) In longitudinal direction; (g) Upper flange of girder; (h) Smeared with bitumen, 2 layers; (i) Linkage of plates in transverse direction; (j) Upper flange of metal girder; (k) Mineralized mats, $\delta = 60$; (l) Asbestos-cement sheets, $\delta = 6$; (m) Slots.

## 3. Preparation of Experimental Plates

In view of novelty of construction it was resolved to prepare several experimental plates for carrying out of their testing and determination of technological effectiveness of their manufacture.

In accordance with material available in laboratory there was developed experimental cold plate with length of 5 m, analogous to plate T-1. Plate was prepared at Sokolvskiy factory of metal construction.

For assembling and welding of plate there was specially prepared a steel jig, a level platform of girders and a number of racks fastened by cleats to lugs on platform, clamping to it the assembled plate with ribs and fixing their correct mutual position.

On jig a plate was laid with sheet downwards and ribs upward. For topping of heat on jig under the plate there was laid an aluminum sheet with thickness of 10 mm.

In process of manufacture of plates there were introduced certain correctives.

In connection with the fact that the factory does not have at present a machine for resistance welding, it was necessary to use manual argon arc welding with intermittent seams.

According to plan, bent profiles (longitudinal ribs) were welded to sheet by points with diameter of 5 mm every 15 mm.

Actually the factory executed welding with intermittent seams having length of 15-25 mm with spacing to 80-90 mm

Welding was done with tungsten electrodes with diameter of 2 mm. Filler was grade AK.

Current density was 60-75 a. Voltage, 34 v.

Cutting of aluminum sheets was produced on guillotine.

Bending of sheets was produced on edge-bending machine.

Since length of bent elements constituted 5 m, which exceeded length of working part of machine, bending of them was executed in two passes.

Replacement of spot welding by hand electric arc necessitated recomputation of plate, modification of bent profiles, and also change of their height.

For convenience of welding with intermittent seams fewer ribs had to be used, which in turn necessitated thickening of upper sheet of plate.

During welding, plate was insufficiently tightly clamped in jig, as a result of which there were obtained significant thermal deformations of plates, which we later managed to partially remove.

In places of joining of grooves to plate welds penetrated poorly; initial form of bent profiles should have been kept, and modified according to requirement of factory.

During test it was found that in respect to strength plates sustained significantly larger load than in respect to deformations.

Thickness of sheets was 1-1.5 mm, too thin for welding with intermittent seams, inasmuch as burns occured in separate places, and surface of sheet after welding became strongly hilly.

Distance between seams of 80-90 mm evidently was an essential cause of premature destruction of plates.

In general, such structures must be welded only by resistance point or seam welding, since this form of welding is more productive and gives best quality.

## 4. Technico-Economic Indices

For appraisal of merits and deficiencies of the structure we shall compare technico-economic indices of four types of heated coverings (see table):

1) covering from aluminum plates of type 1-t;

2) covering from aluminum plates of type 2-t;

3) covering from ribbed plates, KAP-16, from cellular concrete, developed by Giprotis [State Institute for Standard and Experimental Design and Planning and Technical Research];

4) covering from plates, KPKN-5, from porous-clay-filled-concrete, also developed by Giprotis.

From table of comparison of technico-economic indices for 1m$^2$ of covering there can be made following conclusions:

Whereas, considered four types of covering have almost identical load-bearing ability, they sharply differ in weight: weights of coverings with aluminum plates constitute 32 and 25 kg/m$^2$; coverings with plates KPKN and KAP—215 and 225 kg/m$^2$.

Plates of type 1-t and type 2-t are completed sections of covering. Plates KPKN and KAP are only elements of covering, on which it is still necessary to lay Ruberoid sheet on bituminous mastic, which considerably complicates production of works and is not possible in any weather.

During determination of tentative cost, there was used method of calculation of cost of construction at the design stage developed by NIIZS, [Scientific Research Institute of (Z?) Construction], NIIZhB, [Scientific Research Institute of Concrete and Reinforced Concrete], Glavstroyproektom [Central Administration of Designing Organizations of State Committee on Structural Matters], and Giprotis.

Cost was determined for I-beam.

Comparison of technico-economic indices for 1 $m^2$ of covering.

In view of absence of official norms on aluminum building structures, for determination of cost of processing of them we took cost of sheet steel of structures after subtracting cost of material and multiplied by coefficient k = 1.88. This sum was added to cost of aluminum sheets.

Coefficient

$$k = A\left(B + C\,\frac{\gamma_{steel}}{\gamma_{alum}}\right),$$

where A = 1.2 - coefficient for cost of assembling of heat insulation;

B = 0.7 - coefficient for cost of processing of steel constructions, not depending on their weight (welding, layout, drilling of holes, etc.);

C = 0.3 - coefficient for cost of processing steel structures, depending on their weight (edging, transport, etc);

$\gamma_{alum}$ - weight of aluminum;

$\gamma_{steel}$ - weight of steel.

Substituting these magnitudes, we obtain k - 1.88.

Waste of materials was taken according to "Temporary Specifications" State Committee on Structural Matters.

Comparison of Technico-Economic Indices for 1 $m^2$ of Covering

| Designation of indices | Unit of measurement | Types of coverings | | | |
|---|---|---|---|---|---|
| | | 1-t | 2-t | KPKN-5 | KAP-16 |
| Load on covering: | | | | | |
| calculated | $kg/m^2$ | 175 | 170 | 370 | 395 |
| useful | $kg/m^2$ | 140 | 140 | 155 | 170 |
| Weight: | | | | | |
| covering with heater and | | 32 | 25 | 215 | 225 |
| Ruberoid sheet of plate | $kg/m^2$ | 32 | 25 | | 195 |
| Cost: | | | | | |
| as of 1961 | rubles | 16 | 10.4 | 10.3 | 9.8 |
| of manufacture | rubles | 13.5 | | 5.1 | 5. |
| Expenditures on labor: | | | | | |
| on manufacutre | man-hours | 1.2 | | 1.8 | 1.8 |
| on building site | man-hours | 1.4 | | 2.2 | 1.6 |
| Expenditure of materials: | | | | | |
| aluminum alloys | kg | 9.85 | 5.73 | — | — |
| mineralized mats | $m^3$ | 0.08 | 0.06 | — | — |
| asbestos-cement sheets | $m^2$ | 1 | 1 | — | — |
| steel | kg | — | — | 3.8 | 6 |
| cement | kg | — | — | 59 | 58 |
| foamy cement | $m^3$ | — | — | 0.117 | 0.157 |

Notes: 1. Information on coverings from plates KPKN-5 and KAP-16 are taken from data given in joint work of Giprotis and TsNIISK (series 7-87).

2. Overhead expenses and planning accumulations for construction were calculated with coefficient of 1.196 (average for RSFSR).

Labor expenditures on stacking of heater were determined from ENiR [Unit Norms and Prices].

## 5. General Conclusions

Heated plate of type 1-t is more expensive than other considered structures; cost of plate of type 2-t already at current price on aluminum is commensurable with them.

Application of light plates from aluminum alloys ensures lightening and, consequently, reduction of costs of remaining load-bearing structures, which also should be taken into account during selection of type of coverings.

Advantage of aluminum plates still further be increased, if we consider that Ruberoid sheets require constant repair and periodic alteration, while corrosion of aluminum under the given conditions will be practically absent. Plate of type 2-t, as compared to plate of type 1-t, is significantly less metal- and labor-consuming.

It is necessary to prepare this plate for carrying out of tests its load-bearing ability and deformability, for determination of its thermotechnical properties, and fire-resistance, and, at last, for determination of technology of manufacture.

Taking results of investigations into account, it will be possible to adjust given design resolution and to develop plate for different snow loads.

DESIGNING AND MANUFACTURE OF BUILDING STRUCTURES AND ARTICLES FROM ALUMINUM ALLOYS

V. N. Spriov, Engineer

A number of engineers since 1957 have studied the questions of designing and manufacture of aluminum structures and articles for construction. Works are conducted basically in field of enclosing structures (wall panels, roofs, windows, stained glass panels). Whole complex of works, starting with designing and ending with manufacture and finishing of test samples, is being conducted in close contact with technologists.



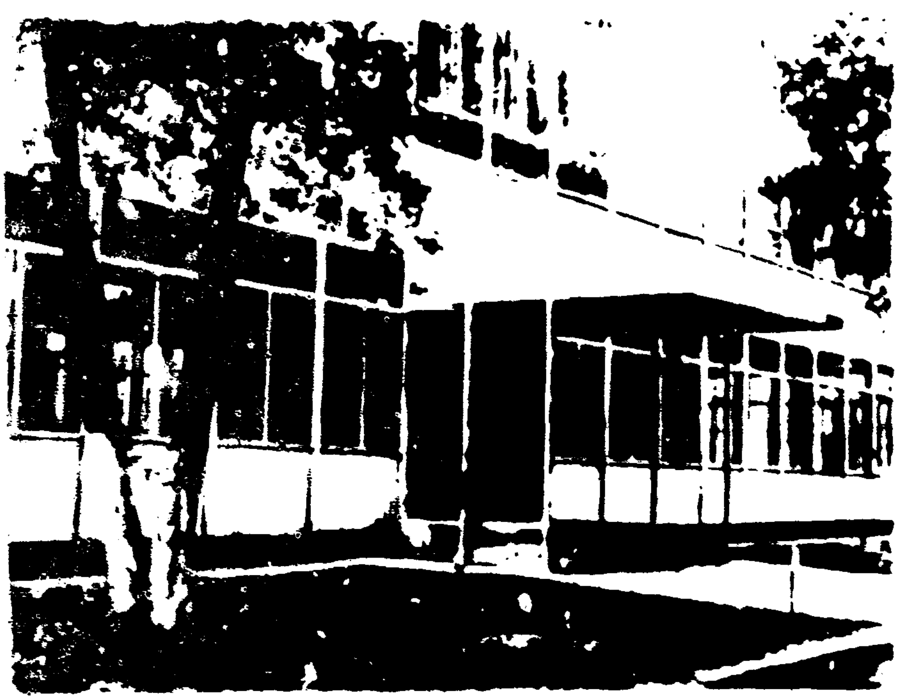


Fig. 1. Part of experimental building.

Structures and article from aluminum alloys developed by us in this period have been applied in a number of dwelling, public, and industrial buildings part from which has been in use since 1958. In 1960 on territory of one of Moscow factories there was built an experimental building (Fig. 1), where aluminum was very widely used both in enclosing structures and also in finishing of interior.

This article is devoted to experience of designing and manufacture of wall panels, windows, and doors, partitions and stained glass panels, roofs and suspension ceilings.

## 1. Wall Panels

First experiment of application of aluminum in wall panels was construction in 1958 of an industrial building with area of 6 X 12, height of 30 m, with heightened liberation of heat. Rejection of usual framework brick wall allowed us to use for hanging of panels a frame built in plant, which lowered several time the weight of walls and sharply reduced building time.

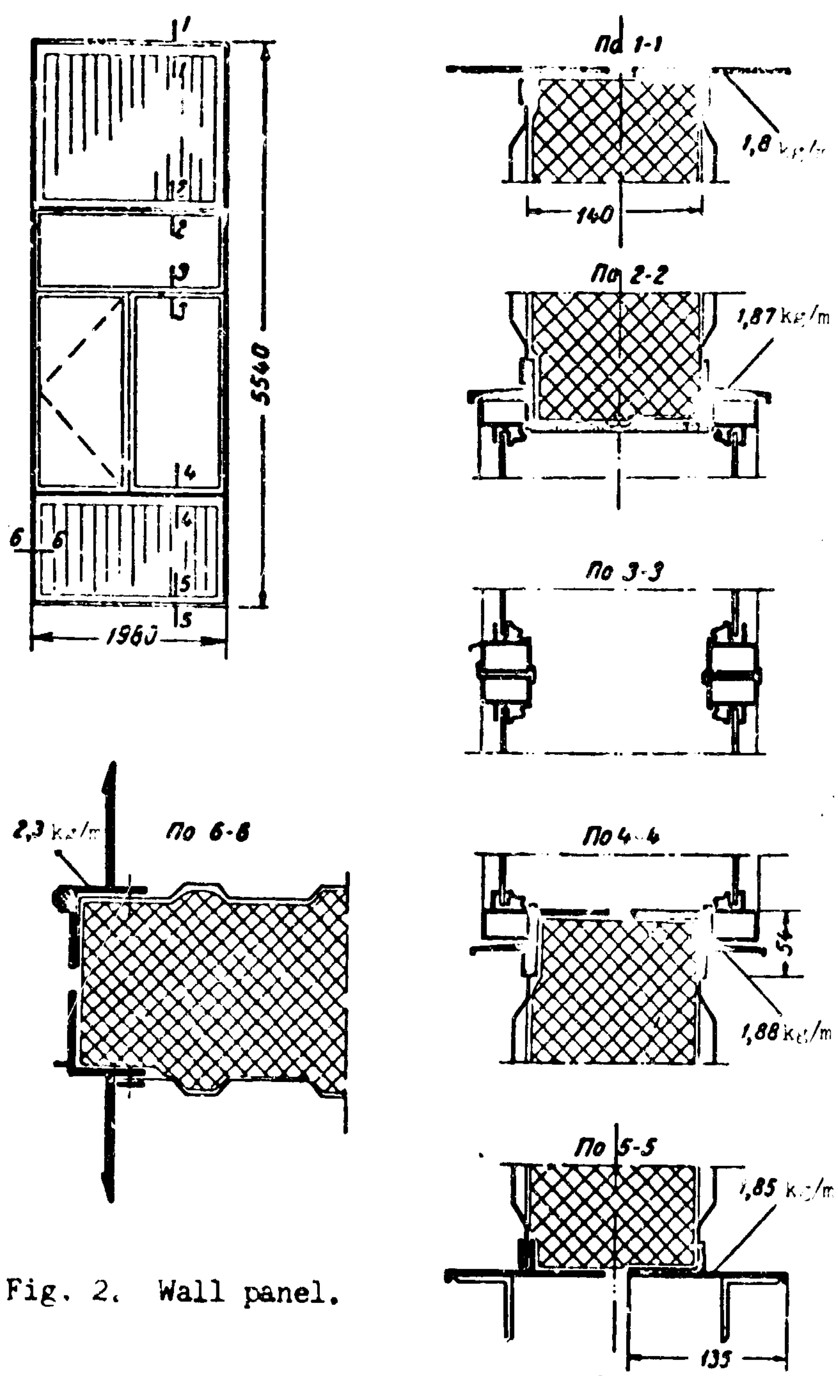
Panel consists of a light steel frame on which there are secured corrugated aluminum sheets with 2-3 layers of bituminized building paper pressed between them. Fastening of sheathing to frame was done with oxidized steel woodscrews through wooden spacers. Woodscrews were supplied with washers. After installatio heads of woodscrews were painted with aluminum powder. Joint of panels, both horizontal and vertical, were resolved by simple overlap of corrugated sheets. Dimensions of ordinary panel were 6 X 4 m, weight of aluminum about 100 kilograms.

Assembly of panels was done on building site without jigs and templates. Panels were assembled upon readiness.

Corrugated sheets from alloy AMg-P were obtained on single stand bending mill with transverse formation of wave. Thickness of sheet is 0.6 and 0.8 mm, length in working direction up to 2500 mm, width is not limited by conditions of rolling. Height of wave 19 mm, length 75 mm.

In 1958-1959 there were planned, prepared, and applied all-aluminum panels intended for public buildings. Panels were made one story in height with horizontal joint at level of window sill (for convenience of assembling and work safety). Typical dimensions of two - 5.5 X 2 mm, and 4.6 X 2 mm; thickness of panel (without ribs) - 140 mm.

Panel (Fig. 2) consists of two shells, between which there is pressed heat insulation. Internal and external shell are almost identical, and each of them consists of binding, blind parts (under and over window inserts), and sashes.

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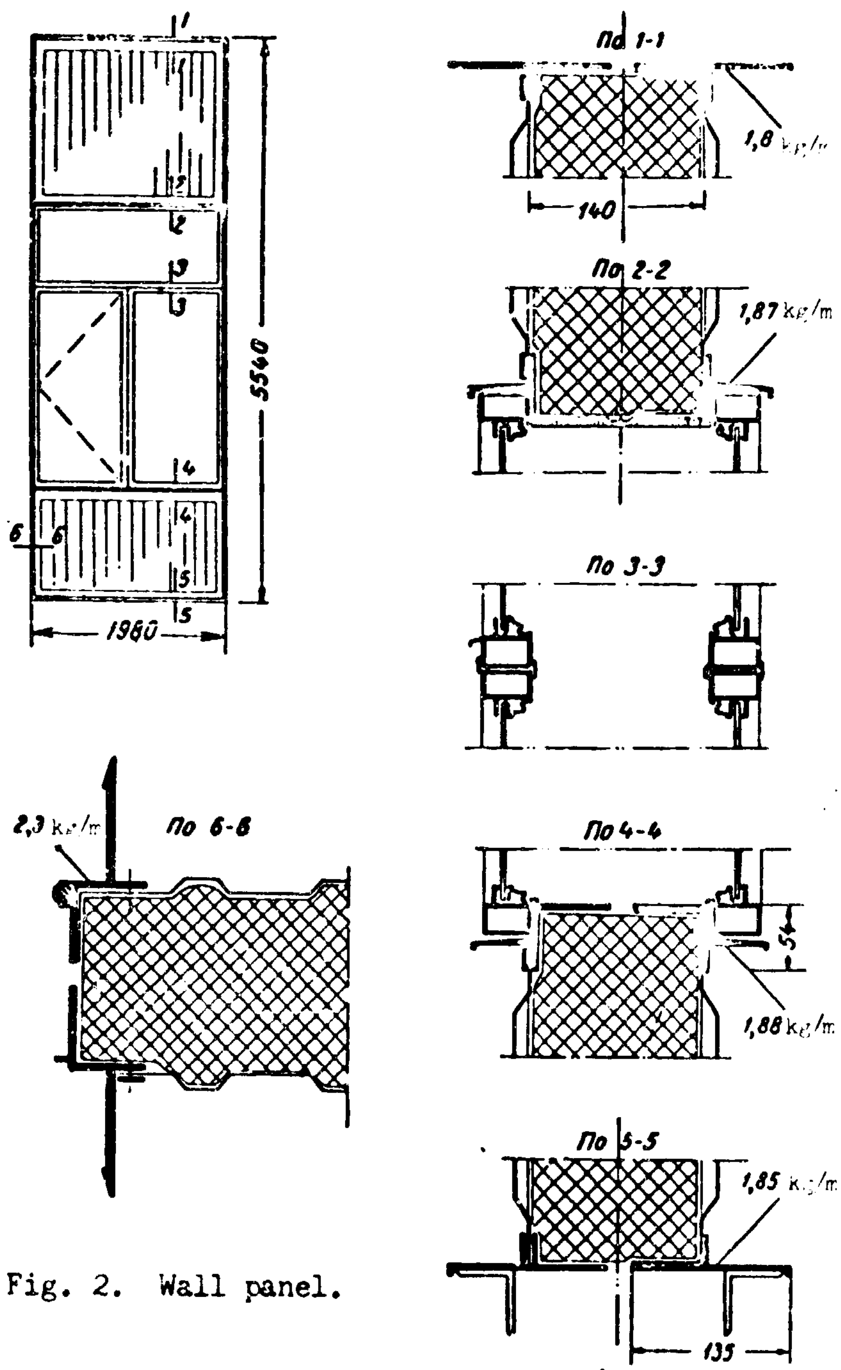


Fig. 2. Wall panel.

Shells are interconnected by steel laths fixed on screws. With small section of laths compared with warmed shell, danger of cooling of the latter before loss on it of condensate was practically absent, but for additional decrease of total heat loss, steel connecting laths were installed through spacers of several layers of pergamyn. Frameworks of panels and sashes - welded, blind parts of panels from stamped sheet were riveted by aluminum rivets. Hermetic sealing of joints of panels was done with sponge rubber, where in horizontal joints pressing of rubber occurred under weight of panels, but in vertical - by means of horizontal shift during assembling and joining of neighboring panels of aluminum laths. Joints of panels were additionally protected by special pressed profiled-latch, fixed without screws or bolts. Channels formed by ribs of panels and latches were used for installation of hidden electric wiring. Latches with length of 10 m were placed simultaneously on two floors.

All profiles both of bindings of panels and also sashes were pressed from alloy AV-T with copper content of not more than 0.1%. Inasmuch as joining of bindings and sashes was produced by welding, and baths anodizing of these elements in assembled form were unavailable, they remained without additional protection against corrosion. Only latches covering joint of panels were anodized. Blind part of panel was made from stamped sheet from alloy AMts-M. Maximum dimensions of sheet were 1650 X 2000 X 1.2 mm. After stamping, conducted on hydraulic press in lead-zinc die, sheets were anodized. Heating was produced by Mipor, placed in packs of polyamide film. Mipor was chosen from economic considerations, in spite of the fact that this caused additional technical difficulties during manufacture of panels and entailed certain loading of frameworks.

For packing of joints of panels there was applied porous rubber of varied thickness, and in windows, furthermore, profiled rubber (see description of windows); all steel reinforcing parts were cadmium-plated or galvanized.

Expenditures of aluminum on panels by elements are given in Table 1. Total weight of panels of first and second floors respectively, were 300 and 330 kg, i.e., about 30 kg/m$^2$.

During manufacture of elements of panels there were planned two technological lines:

1) manufacture of shells;

2) manufacture of sashes.

Table 1. Expenditure of Aluminum on Wall Panels in kg

| № | (a) Элемент | (b) Панель первого этажа (d) на 1 м² | (e) на панель | (c) Панель второго этажа (d) на 1 м² | (e) на панель |
|---|---|---|---|---|---|
| 1 | Обвязки (f) | 7,73 | 85 | 7,79 | 71,7 |
| 2 | Штампованные листы (g) | 1,04 | 22,4 | 0,97 | 8,96 |
| | Итого: (h) | 8,77 | 107,4 | 8,76 | 80,66 |
| 3 | Переплеты (i) | 6,07* | 34 | 6,28* | 44 |
| 4 | Петли (j) | — | 0,24 | — | 0,36 |
| | Всего (k) | 12,86 | 141,64 | 13,6 | 125 |

*Per 1 m$^2$ opening.

KEY: (a) Element; (b) Panel of first floor; (c) Panel of second floor; (d) per 1 m$^2$; (e) per panel; (f) Bindings; (g) Stamped sheets; (h) Altogether; (i) Sashes; (j) Hinges; (k) In all.

1. Profiles of frameworks, proceeding into workshop, were cut on band saw and (in separate cases) were straightened. Then profiles went to milling machines for milling of ends (grooves and cuts), where framework were planned in such a way that only short (less than 2 m) horizontal elements were milled, while long vertical (5.5 and 4.6 m) went to assembly immediately after cutting.

Assembly of frameworks was produced by welding in special jigs, ensuring accuracy of dimensions and preventing deformation after welding. Jigs constituted of frame welded from steel channels, on which there were clamp-holders. For convenience of welding and cleaning of seams holders were somewhat removed from angles of frameworks. Jigs were made to turn about longitudinal axis, so that it was possible to put all seams in horizontal or slightly slanted position. Welding was done manually with the help of serial apparatuses for argon arc welding; filler - AK wire. In those places where seams could hamper further work or affect appearance they were cleaned.

In the same jigs was made installation in framework of stamped sheets of blind parts of panels. Sheets were fastened by aluminum rivets through spreaders from aluminum strip. Holes were drilled by pneumatic drills in packet, rivets were set manually. Finished shells went to assembly.

2. In workshop hollow profiles of sash were straightened manually with the help the simplest devices and were cut on disk saw fixed at an angle of 45°, which excluded additional operation for cutting of ends. Welding was done in jigs turning around longitudinal axis (construction of them was analogous to construction of jigs for welding of frameworks of panels). Here, welding of sashes was conducted just as for frameworks. Frameworks were welded to hinges in the same jigs. After cleaning of seams, sashes were mechanically polished. Sashes were affixed to shells with glass in place (method of fastening glass is considered further in part concerning window frames).

Assembly was produced in two stages:

1) hanging on shells of sashes;

2) joining of shells to panel with simultaneous packing of heater (Fig. 3).



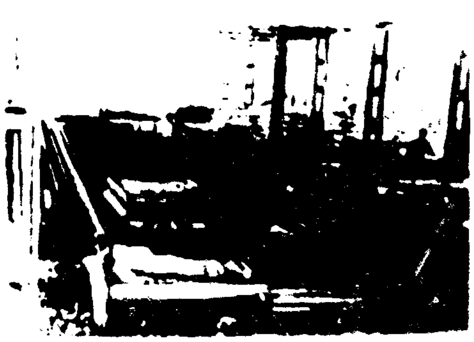

Fig. 3. Section of assembly of wall panels.

Both operations were produced on one bench by team under leadership of a fitter of 6-7th class. Sashes were affixed directly to frameworks of panels, which allowed us to leave out boxes, and they were fastened with bolts. After hanging of sashes one shell was laid on bench face downward, on sheets of blind parts there were placed packets with Mipor, which were compressed by second shell. It is necessary to note that application of Mipor required in view of its hygroscopicity, special protection (packing in packet of polyamide film). Possibility of its shrinkage in process of exploitation necessitated structural design in which thickness of packet was increased over that designed by 20-25%, so as to press packet to design thickness during assembly. Pressing prevented danger of shrinkage and improved thermotechnical qualities of insulation, since in Mipor, which was applied in the form of meal, during pressing voids were closed. Unfortunately, economic considerations do not allow us for the present to use effective plate heaters of type PKhV-1 or PKhV-2, which would allow us lighten and simplify construction. After pressing of Mipor with the help of clamps to design thickness, frameworks were connected by steel laths fixed, as was said earlier, through spacer of several layers of pergamyn. Simultaneously, there were installed hooks for hanging of panels. Last operation was gluing of rubber for packing of joints, after which panel was ready for assembling (Figs. 4 and 5).

Low weight of panels (not more than 330 kg) allowed us to make assembly without cranes, with the help of block fixed on roof of building, and a hand winch. Time of assembling of panel, including laying it on earth before lifting and trussing, 12-15 minutes (Fig. 6). Installed panels were interconnected by screws (panels joined in height, directly through frameworks, panels of one row - through aluminum laths), then joint of panels on two floors was closed by latch (Fig. 7).



Fig. 4. Gluing of porous rubber for packing of joint.

Fig. 5. Control of accuracy of assembly of panel.

Fig. 6. Assembling of panel.

First experiment in USSR in application of aluminum panels for public building showed rationality of use of similar structures in our climatic conditions. Aluminum panels completely eliminated wet processes of stopping of joint, calking, etc. Panels are convenient for transportation and assembling, but setting their production in motion will bring labor-consumingness of manufacture to minimum. Panels do not need paint and have very attractive appearance.

Experiment showed that in similar constructions development of such details as joints of panels, elements of fastening to frame, sashes, etc., should be very thorough. Special attention should be given to elimination of [cold bridge] and thickness of window locks. Work absence of special mastics and elastic linings for hermetic sealing of joints and locking.

Now there is being conducted work on improvement of construction of panels.

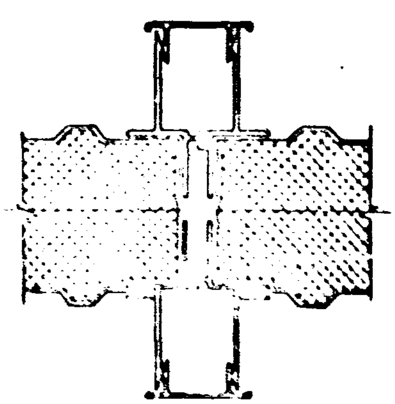

Fig. 7. Joint of wall panels.

## 2. Windows and Door

Work on aluminum windows and doors has provided for creation of structures both for public and for habitable buildings. Basic problem should be considered not creation of some one type of window or door, but output of series of profiles, allowing us during use of units developed for given series a certain freedom of operation. For a number of reasons aluminum profiles have found wide use in windows of public buildings (see Table 2). Thus, series of profiles for public buildings of 1957 issue was applied for development of a number of types of windows, in particular by Planning Institute (Promstal'konstruktsiya) (one of examples of use of them - window in new building of NII [Scientific Research Institute] - 200); series of profiles of 1959 is applied in aluminum panels of experimental building and with insignificant supplements - in window blocks developed by Giprovuz [State All-Union Institute for the Planning of Higher Educational Institutions with Scientific Research and Investigation Depts.] for student body of institute named after Gubkin, Mosproekt [Office of Designing of Civilian-Dwelling and Collunal Construction of Mosgorispolkom] for patent library building, and others.

In Fig. 8 there are shown typical profiles of series enumerated in Table 2. Characteristic for all types of windows (with the exception of sashes of industrial buildings) is application of hollow profiles of different outlines. Basic merits of such profiles, as compared to profiles of open section, are the following: smaller expenditure of metal; fastening nodes both by welding and by inserts with help of screws and rivets; greater architectural expressiveness.

Fastening of glass is varied: in windows for public buildings (1957 and 1959) there were applied aluminum latches of different profiles and hermetic sealing by rubber, in windows for habitable buildings (1958 and 1959) and industrial buildings (1959) - steel springs and mastic; in hinged window with double glass (1960) the double glass sheet is pressed between frames of sash, hermetic sealing is with mastic; in hinged window with single glass (1960) the glass is inserted in groove of profile [illegible] h, hermetic sealing is with mastic and rubber.

Structure of windows in the same series of profiles may be different, for instance, profiles for public buildings (1959) were applied in panels where sashes were affixed directly to bracing of panels, and in brick walls where there were inserted window blocks.

Table 2. Characteristic of Windows From Aluminum Alloys

| № | Region of application | Year of issue | Expenditure of aluminum per 1 $m^2$ opening in kg | Quantity of profiles | Type of opening | Glass | Recommended dimension of fold in $m^2$ |
|---|---|---|---|---|---|---|---|
| 1 | Public buildings | 1957 | 12,5 | 12 | Unfolding | Two glasses | Up to 2 |
| 2 | Habitable buildings | 1958 | 8 | 11 | The same | The same | • 1 |
| 3 | Public buildings | 1959 | 6,1* | 6* | The same | The same | • 2 |
| 4 | Habitable buildings | 1959 | 5,92 | 11 | The same | The same | • 1 |
| 5 | Public and habitable buildings | 1960 | 3,2 | 1 | Turning on horizontal axis | Double glass sheet | • 2 |
| 6 | The same | 1960 | 2,7 | 3 | The same | One glass | • 2 |
| 7 | Industrial buildings** | 1959 | 2,2 | 4 | Blind | The same | 1,65 |
| | | | 3,86 | 6 | Upper suspension | The same | 1,65 |

Note: Windows placed in table above line were installed in a number of buildings; then below were prepared in samples. In column "quantity of profiles" are included hinge profiles.

*Only weight of sashes is considered, since windows of this type are applied in aluminum panels and do not have frames. In case of manufacture of blocks expenditure of aluminum will be increased roughly to [illegible] kg, and quantity of profiles - P-9.

**Joint work with Proyektstal'konstruktsiya.

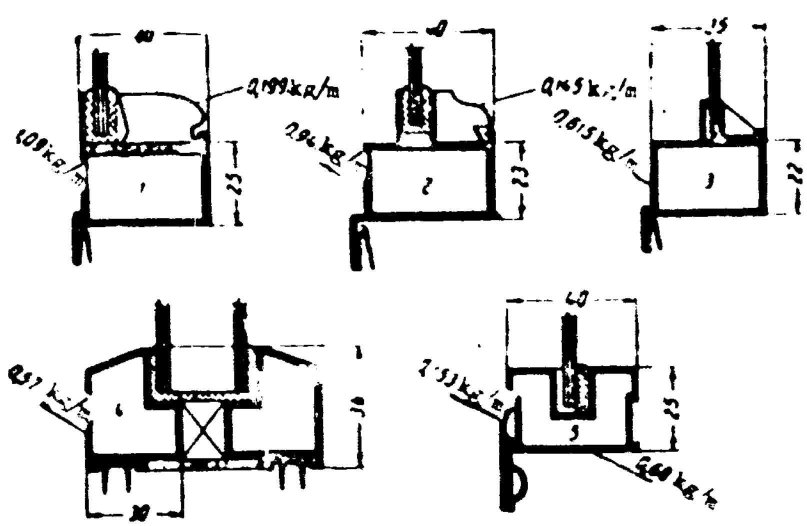


Fig. 8. Typical profiles of windows of habitable and public buildings, fastening and hermetic sealing of glass, rubber profiles, packing of locking. 1) series of profiles of public buildings (1957); 2) the same, (1959); 3) series of profiles for habitable buildings (1958); 4) series of profiles for habitable and public buildings with double glass sheet (1960); 5) series of profiles for habitable and public buildings with single glass (1960).

All profiles for windows were pressed from alloy AV. In separate cases, when profiles were connected on inserts, they were anodized. Material of frame - basically wood. Attempt of application of box made from porous-clay-filled concrete (windows for habitable buildings 1958, Fig. 9) one should recognize as a failure for a number of causes: joining in one article of details with sharply different technology, degree of industrial efficiency and accuracy of manufacture, significant increase of weight and impossibility of fitting during hanging of sashes. At present search for design of box is pressing problem facing designers planning windows.


Fig. 9. Window for habitable buildings (1958).

To date our industry cannot offer sufficiently strong, low-heat-conducting, and cheap material. Attempt to use asbestos cement for boxes is enticing. Work in this direction has been started.

Technology of manufacture of sashes has already been described in section "Wall panels." To this one should add only that during manufacture of sashes connected on inserts all machining of profiles (cutting, milling, drilling of holes) is produced beforehand, then profiles are anodized, and only after that is assembly carried out.

Anodizing of sashes welded by argon arc welding manually is undesirable, since through anodizing the welded seam, as a rule, sharply differs in color. Application of machines for butt seam welding will allow us to produce anodizing of sashes after assembly, seam is then seen as a clear line with width near 1-1.5 mm, which does not worsen appearance. Application of such machines is generally desirable, since besides acceleration of the actual welding, they strongly simplify cleaning of seam.

In 1959 there were developed and in 1960 prepared glazed doors from aluminum alloys intended for public buildings. Doors of swinging type can be applied both inside buildings and also as entrances. Framework of door consists of hollow profiles on inserts and screws. In lower part of door - blind insert from aluminum stamped sheet glued on plywood, in upper - glass. Fastening of glass - on aluminum spreaders with steel springs or screws. Opening is framed by special pressed profiled-jams. Packing of seal - by ш - shaped rubber. Profiles from alloy AV-T, fastening - cadmium-plated steel.

Profiles proceeding to workshop after straightening on stretching machines were cut on disk saw, and in separate cases they were subjected to final straightening manually. Then milling was done of grooves and selections, and holes were drilled. After inspection of assembly of frameworks, profiles went to anodizing. Anodized also was plate-handle (alloy AMg), where in distinction from profiles it was subjected to preliminary polishing.

Application different alloys and methods of treatment gave noticeable effect, since profiles from alloy AV-T after anodizing took on dull pearl-gray hue, but plate from alloy AMg was a brilliant "metallic" color with slightly yellowish tint. Stamped sheet of blind insert anodized a black color. After anodizing there was produced final assembly and hanging of doors.

Three-year experience of work on windows and doors showed that at present basic problem is absence of fully acceptable material for flames and also of window and door hardware developed in reference to aluminum profiles. The problem is very urgent of obtaining of long-lasting packing for sealing.

## 3. Partitions and Stained Glass Panels

For partitions and stained glass panels there was developed general series of profiles and structural assemblies. Full set of profiles, including doors which are installed in partitions, contains 8 designations. Basic load-bearing profiles, hollow with box-like sections, are pressed from alloy AV-T. All joints of load bearing profiles among themselves are carried out on bushings. Frame is assembled from separate elements on site. Panel variation was rejected, since it possesses following deficiencies:

1) required large expenditure of metal;

2) evokes necessity of camouflage of joints between panels;

3) hampers filling to structures of building;

4) requires large volume of design works;

5) complicates transportation, especially over distant distances.

Series may be recommended for stained glass panels and partitions with height to 4.5 m. Spacing of uprights is designated depending upon loads.

Expenditure of aluminum can vary within rather wide limits and depends, mainly, on dimension of panels. In Table 3 there are given data on three structures actually built.

Table 3. Characteristic of Stained Glass Panels and Partitions from Aluminum

| No. | Structure | Type of building in which structure was used | Expenditure of aluminum per 1 $m^2$ opening in kg | Height in m | Spacing of uprights in m |
|---|---|---|---|---|---|
| 1 | Stained glass | Cafe | 2.65 | 3.25 | 2 |
| 2 | Partition | Experimental aluminum building* | 4.2 | 4.5 | 1.2 |
| 3 | Partition | Design bureau | 2.93 | 4 | 2 |

*See Fig. 10.

System of installation of filling of frame was with the help of spreaders secured on steel springs or on screws allows us to use materials of different thickness: with intermediate horizontal imposts, to 18 mm; with filling to entire height of partition to 40 mm.

Model design for partition that of intermediate impost and filling of frame in lower part by opaque material (wood-chip plate, plywood with micro-plywood pasted on both sides, or stamped aluminum sheet, or other material), and in upper - glass (Fig. 11).

Machining before anodizing includes following operations: straightening and cutting of profiles, milling of them in places of joining of neighboring elements, drilling and threading of holes for fastening of bushings and springs. Then profiles are anodized, obtaining dull pearl-gray color, on them there are installed bushings, springs, and, at last, finished elements are packed for transport. Assembling, depending upon treatment of ends of imposts, is conducted according to one of two variants.

1. In case where imposts have cuts on ends for bushings, a sleeper is first laid and fastened to underlying structure. On bushings screwed to foundation beam there are put uprights, upper ends of which are fastened to crosspiece or to ceiling with the aid of T-form bushings, not preventing vertical shifts of ends of uprights. Such construction gives us possibility of compensation of inaccuracies in rather wide limits. After alignment and final fastening of uprights, on bushings fastened to stands there are laid horizontal imposts. There are fastened elements of cornice concealing joints of uprights to ceiling. Filler panels are installed and are secured. With suspension ceiling uprights pass through it, and need for cornice is eliminated.



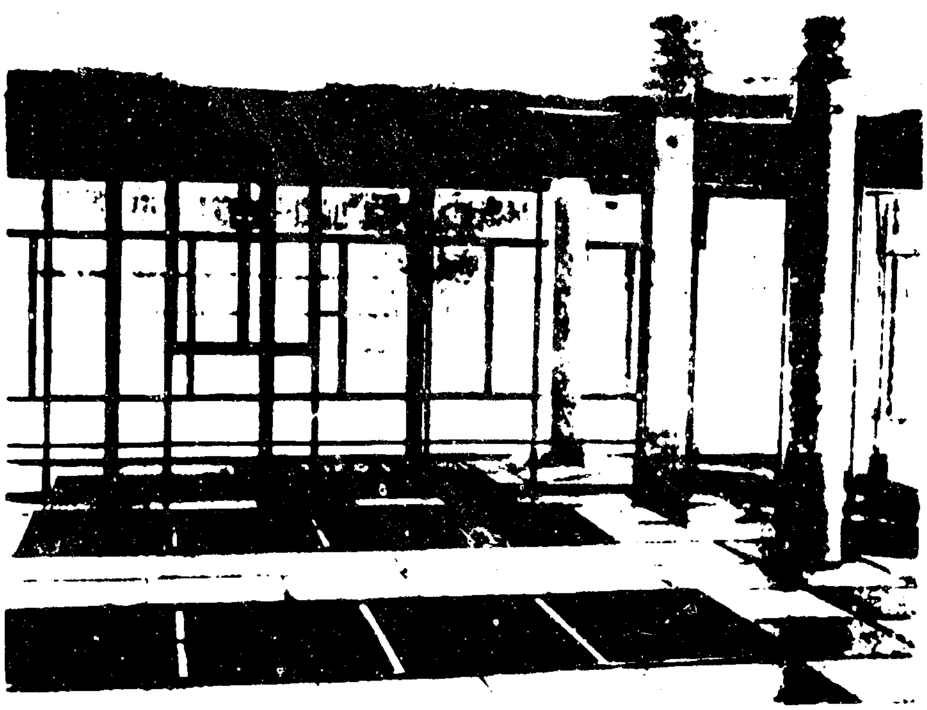

Fig. 10. Aluminum partitions and suspension ceiling of experimental building.

2. If imposts do not have cuts, there changes somewhat order of installation of them and uprights. After installation of first uprights, imposts on one end are placed on bushings and by one or the other method are retained in this position while following upright is positioned, put on bushing of foundation beam, where bushings of upright are simultaneously put into profile of impost. After that upright is aligned and secured, and operation is repeated from the start.

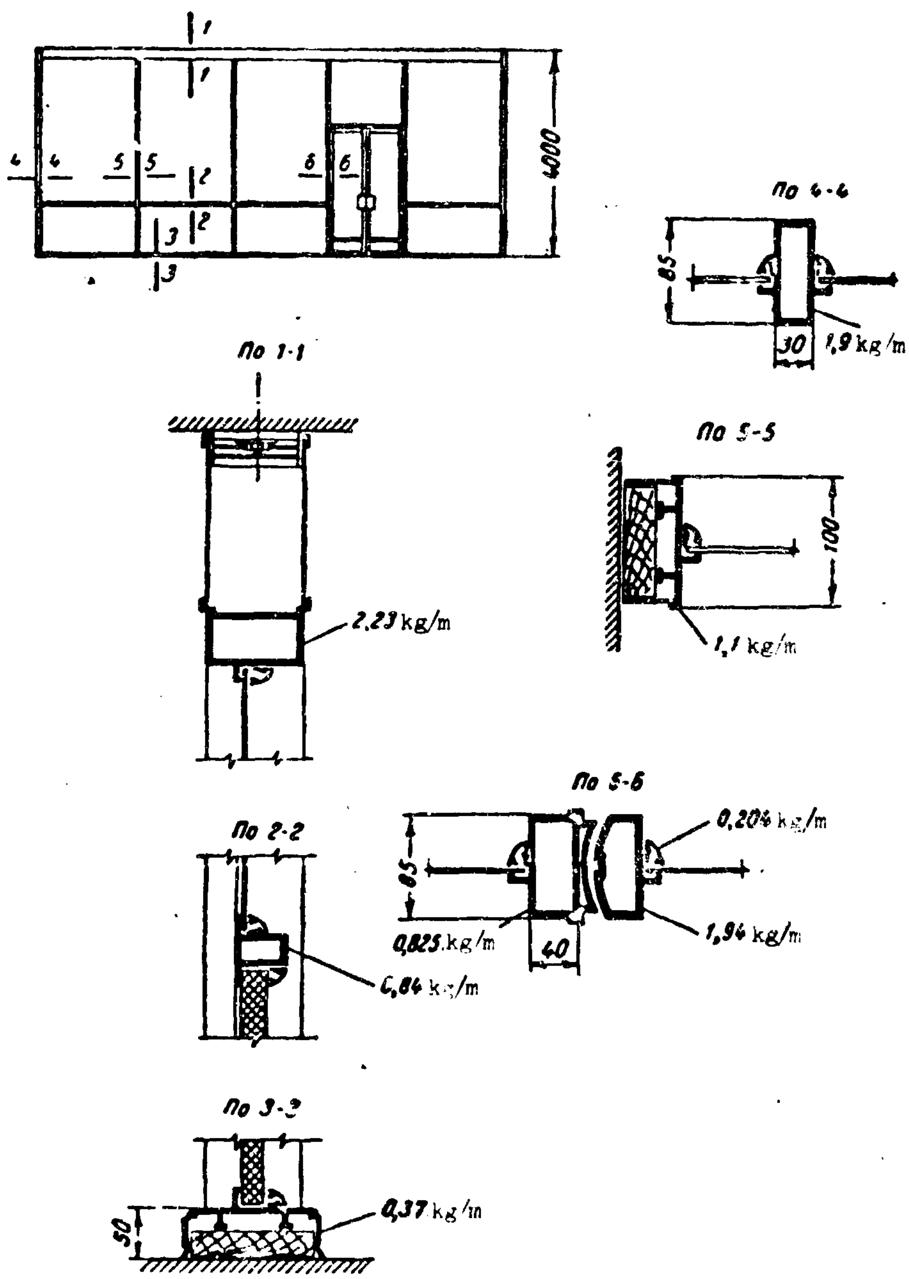


Fig. 11. Aluminum partitions; general view and joints.

This second method, very inconvenient during building of projects of large size, with small dimensions of structure turns out to be simpler, since necessity of very exact cutting of ends of imposts is eliminated.

And in any case assembling is simple, is done quite rapidly, and allows us to conduct fitting of elements to finished structures of building without any difficulties.

## 4. Roofs

Our experience of construction in this field is limited to construction in 1958 of roofs on one industrial and two habitable buildings. For roofs there were used corrugated sheets from alloy AMg-P. Wave length was 75 mm, height 19 mm, thickness of sheet, 0.8 mm. Roof of industrial building - panel with structure analogous to that of wall panels described above. Only distinction was in increase of overlap of corrugated sheets and strengthening of heat insulation.

Roofs of habitable buildings from corrugated sheets with dimension of 2.5 X 1.2 m were installed on wooden lathing. All joints were made by simple overlap. Fastening to lathing was done on steel galvanized wood screws with washers.

Work on development of more perfect structures of roof continues.

## 5. Suspended Ceilings

Decorative suspension ceilings, developed by us and first applied in an experimental building, consist of structural lattice, suspended on special rods from structures of building and filler. Part of cells has blind filling of corrugated aluminum sheet with thickness of 0.5 mm, and part is used for mounting of flourescent lamps located above level of ceiling (Fig. 10). Use of similar ceilings allows us to conceal all plumbing and electrical communications, gives surface of ceiling free from repairs, allows us to apply lamps hidden behind ceiling of the simplest design. Not in last place is the architectural expressiveness of structure.

Structural lattice is made from profiles of tee section (alloy AV-T), able with span between rods of 2 m to sustain assembly loads - weight of worker with tools. With such location of rods and installation of current flooring use is possible of straight-through suspension ceiling. Structure of rods gives us possibility to regulate height of suspension of frame and thereby to align horizontal position of ceiling.

Filling from aluminum corrugated sheets was laid in cells of ceiling and was clamped to flanges tees by wooden cleats and steel springs.

All visible elements of ceiling: tees of structural grids, corrugated sheets of filler and shading of lamps (from strips of alloy AMg-P with thickness of 1 mm) were anodized. Design of ceiling because of alternating of blind cells and lamps of various orientation with respect to light of corrugated sheets and light play of hues, owing to anodizing of various alloys, is very effective and at the same time clean and uncluttered.

Several remarks about corrosion. According to visual observations, corrugated sheets from alloy AMg-P (facing of panels of industrial building) after two years of exploitation in aggressive industrial atmosphere are in good state. Sheets darkened somewhat, but there are practically no noticeable defects (there are separate pits with diameter of 1-1.5 mm).

Profiles from alloy AV-T behaved well under extremely severe conditions of exploitation: in spite of atmosphere containing vapor of nitric and hydrochloric acid, alkali, and chlorine of high concentration with heightened humidity, profiles of frameworks of panels and sashes not having anodized covering, had only surface damage in the form of small spots with diameter up to 1-1.5 mm.

Comparatively low resistance of alloys AMts was unexpected. It is recommended by all native and foreign sources as the most corrosion resistant. Anodized sheets from alloy AMts have damage in the form of spots with diameter up to 2-3 mm, located quite thickly. It is necessary, however, to note that iron content in sheets is at upper limit.

This speaks for necessity of more thorough investigation of standard alloys and development of new corrosion resistant alloys.

Using experience accumulated in process of application of a number of aluminum structures, we are continuing work on improvement roofs, wall panels, stained glass panels, windows, doors, partitions, and suspension ceilings. Basic problems which we place before ourselves during development of new variants of structures are such:

1) Wall panels - simplification of processing and lowering of expenditure of aluminum. Detecting of new heat insulation materials and structures allowing elimination of double metallic shell.

2) Roofs - development of roof panels (cold and warm), possibility of realization girderless designs. Determination of parameters of corrugated sheets of large dimension.

3) Stained glass panels, windows, doors - further increase of reliability of locking, simplification of construction for the purpose of giving it higher technological effectiveness. Development of technology of protective-decorative coverings of ready-made elements.

4) Partitions - creation of systems of assembling and dissembling partitions for public and industrial buildings in panel, loose, and intermediate variants.

5) Suspension ceilings - design of straight-through suspension ceilings with heightened degree of hermetic sealing for industrial and public buildings. Questions of application of enlarge elements.

Since for a number of years the carrying out of experimental and research works in field of aluminum structures meets with significant organizational difficulties, we consider it timely to pose question about creation of a specialized experimental designing-technological bureau for designing, manufacture and tests of building structures from aluminum alloys. Bureau should have its own industrial-experimental base and be disposed at one of aluminum-rolling factories which significantly would simplify obtaining of semifinished products and in best manner would solve question of utilization of waste.

Simultaneously it would be useful to organize issue of a series of pamphlets in which native and foreign experience of designing and manufacture of separate forms of aluminum constructions would be illuminated.

The need has definitely arisen for organization of special factories (or workshops) for serial output of aluminum structures. At present building structures from aluminum are prepared almost exclusively in machine-building factories not suited for these purposes and using unique equipment, which sharply increases cost of structures.

# EXPERIENCE OF DESIGNING OF STRUCTURES FROM ALUMINUM ALLOYS

G. D. Popov, Engineer

In our country aluminum alloys have started gradually to find application in building structures. Already at present it is possible to name a number of structures where, in spite of high cost, application of light alloys turns out to be economically profitable, even in comparison of building cost only, not counting convenience of subsequent exploitation.

In 1960 by an institute of Proekstal'konstruktsiya [State Planning Institute for the Planning, Research, and Testing of Steel Structures and Bridges] there was carried out a number of projects in which there were applied aluminum alloys, and there was obtained certain experience, a brief account of which is given in this article.

As a material, light alloys have their peculiarities, predetermining the unique forms of structures. Low elastic modulus, and, consequently, also the worst work under longitudinal bend, unavoidable leads to application of more well-developed sections in which walls turn out to be thinner than in steel structures. Such decrease of thickness of elements from light alloys quite possibly for exploitational reasons is a significant consequence of their better corrosion resistance than steel.

Somewhat poor local strength of light alloys with thin-walled profiles leads to necessity of application of special forms of section. The most favorable quality belongs to annular section in which local strength of walls is ensured where their thickness is 1/100 - 1/140 of diameter, which allows us to have good development of element with minimum area of section.

In that case when there are applied sections of other type, local strength may be ensured either by bordering with beads or by means of corrugating surface and putting diaphragms in elements.

Of alloys available at present which can be applied in construction, the most acceptable turns out to be alloy AV-T1.

With good corrosional resistance, this alloy also possesses sufficiently high mechanical properties, but in cost it is one of the cheapest alloys.

Alloy AMg6 (the most acceptable of magnesium group of alloys) is approximately 20% more costly than alloy AV-T1, and at the same time has mechanical characteristics 25% lower. It is true that during welding alloy AMg6 loses in all 10-15% of its strength, while loss of strength of alloy AV-T1 during welding reaches 40%, but owing to greater relative strength of alloy AV-T1, final strength of both alloys after welding turns out to be quite close, with smaller value for the latter.

Furthermore, in majority of structures welding evokes only local weakening in region of laying of seams, which lowers strength approximately the same as weakening by rivet holes. In this case it turns out to be possible to use almost completely the high mechanical properties of alloy AV-T1.

Alloy D16-T has very high strength, but it is absolutely not useful for welding, and in it corrosion develops rather quickly. Therefore, alloy D16-T to data has found little application in completed projects.

Light alloys can be very profitably used in roof coverings in exchange for heavy roof from reinforced concrete plates. On the one hand, cost of heated shields from light alloys is even cheaper than cost of reinforced concrete plates, heater, protective layer, and roof sheet. On the other hand, low weight of roof significantly decreases total load on load-bearing structures and allows us to decrease expenditure of steel in the latter.

Application of light roof for building of hangar in the city of Alma Ata allowed us to lighten load-bearing structures by 25%, which on two hangars constituted saving of steel of 460 tons.

In this case use of light alloys was especially efficient, since structure was intended for region with eight-point seismicity. Therefore, decrease of weight of structure here in significant degree was reflected not only in rafter girders, but also in strength of columns and joints.

During designing of roof panels there were considered different types, in the beginning with installation of wooden lathing, until a type of panel was found which could be considered first rate in satisfying both conditions of factory manufacture and also conditions of exploitation. In all likelihood, this type of panel can subsequently be given certain changes, but at present, while there is yet no sufficient experience in designing and manufacture, this structure seems the most successful (Fig. 1).

Roof is formed of separate self-supporting panels with dimension of 1.5 X 12 m. Width of panels, set at the beginning at 3 m, has been reduced to 1.5 m because spot welding was done at Chelyabinsk factory im. Ordzhonikidze, which does not have equipment with large clamping device.

Panel consists of two layers of corrugated aluminum with thickness of 0.8 mm. In upper sheet waves are located across panel (along slope of roof), and in lower - with panel. Each layer is joined by spot welding with transverse frame and lathing set at each 1 m across direction of waves. For convenience of welding all elements of frame and lathing are made from z-shaped profile with height of 40 mm.

Two halves of panel are connected by bolts set in protruding flange of transverse frames. For heat insulation of one half of shield from other, between them there is laid a solid layer of pergamyn, while under heads and nuts of bolts there are placed washers from the same material. In lower half of panel the space between corrugated flooring and pergamyn is packed with slag wool.

With 6-meter span panels can have below two beams of box-like section, which together with lower flooring form structure of sufficient strength. Corrugated flooring can work freely in compressed zone of structure, since local strength of wave is significantly higher than strength of flat sheet, and 1 m spacing of cross pieces ensures total strength of entire wave.

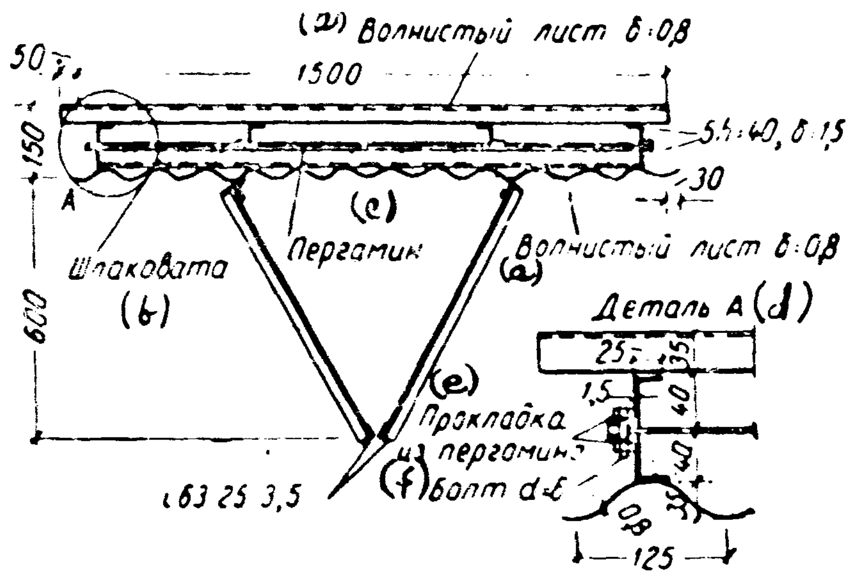


Fig. 1. Roof panel with strut.
KEY: (a) Corrugated; (b) Slag wool; (c) Pergamyn; (d) Detail A; (e) Packing of pergamyn, (f) Bolt.

With 12-meter span panels are strengthened by stiffeners consisting of two planes set at an angle, so that in cross section together with flooring there is formed a trihedral structure. Such form was selected because panels distributed on roof can occupy slanted position, and in this case supporting girder must possess appropriate lateral strength. Triangular form of supporting structure allows it to accept torsion, in consequence of which panels can also work under asymmetrical loading.

Each plane of girder is formed from two flange angles joined by angular lattice roof welded to them. Lower flanges of two slanted girders are connected in angles by bolts with help of angle clips, forming common flange of cross section. Upper flanges are fastened to panel also with help of angle clips, welded to lower corrugated sheet.

In all panel is made of 201 kg of alloy AV-T1, which constitutes expenditure of 11.2 kg/m$^2$. Load from panel together with heater is about 17 kg/m$^2$.

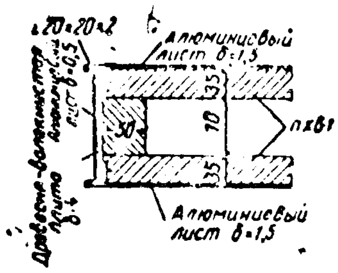


Fig. 2. Three-ply roof panel.
KEY: (a) Wood-fiber plate; (b) Aluminum sheet.

With spans to 6 m there is possible also another form of heated panels, which may be applied both for covering of roof and also for wall panels (Fig. 2). Construction of such panel, developed by an institute of Proektstal'konstruktsiya jointly with TsNIISK [Central Scientific Research Institute of Structural Parts], consists of three layers. External and internal surfaces are made from flat sheets of aluminum alloy AMg6 of 1.5 mm thickness. Inside is laid a layer of foam plastic PKhV-1.

For the purpose of imparting high rigidity to panels their thickness is made equal to 14 cm. For decrease of expenditure of foam plastic filling is made from three layers. Outer layers are solid with thickness of 3.5 cm, and inner are bars with 7 X 5 cm section layed each 60 cm.

Panels are bordered by frame of channel section composed of two angles - 20 X 20 X 2 mm and wood-fibrous plate δ = 4 mm glued on the outside by aluminum sheet with thickness of 0.5 mm. Thus, wood-fibrous plate is pressed between angles and aluminum sheet by which break of seal is created.

Angles are riveted to sheets of panel and to vertical walls by rivets having d = 3 mm with spacing of 150 mm.

Aluminum sheets are glued to foam plastic heater or to wood-fibrous plates by cold-hardening glue consisting of epoxy resin ED-6 with addition of polyester resin MGF-9, still residue, and cement of brand M400.

Foam-plastic layers are glued together phenol-formaldehyde resin B with contact Petrova and wood meal.

Joining of panels with each other in direction across drain is done in "lap fashions" and with drain - by standing groove.

Space between shields is zapolnyaetsya elastic plasticm (foamed break).

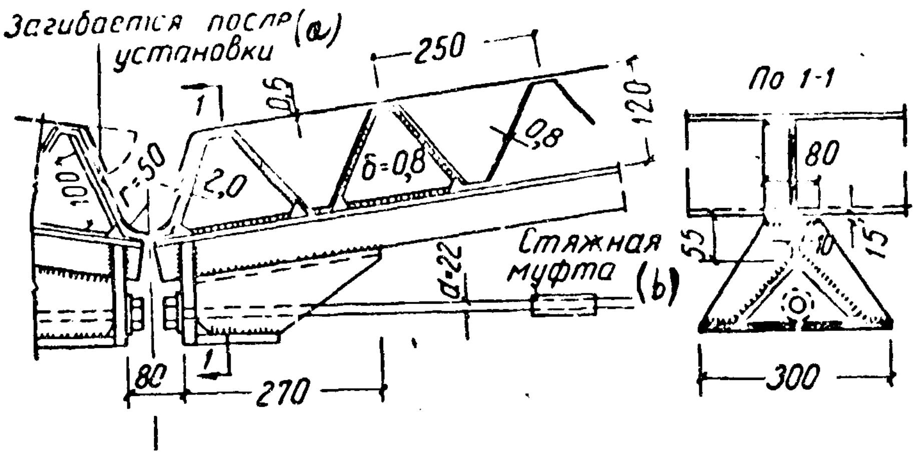


Fig. 3. Roof panel with preliminary stress.
KEY: (a) Bent after installation; (b) Buckle.

Expenditure of aluminum alloy in panels of this construction constitutes near 10.5 kg/m$^2$, and expenditure of foam plastic - near 6.5 kg/m$^2$.

Analogous structures are planned also for wall panels, but for them thickness of aluminum sheets is taken equal to 1 mm. In these panels expenditure of aluminum constitutes 7.2 kg/m$^2$.

In case of application of panels in remote area, where all materials must be transported, light weight of three-ply panels creates significant advantages. Thus, for instance, in conditions of construction for Mirnyy settlement in Yakutiya cost of three-ply panels with delivery to site is considerably cheaper than cost of porous-clay-filled concrete panels.

Roof panel of three-ply construction, prepared in plastics laboratory of TsNIISK, was test under load of 200 kg/m$^2$, exceeding that calculated (with coefficient of overload) by 50%. No signs of damage of panel were noted. Sag in the middle of span under testing load was found equal to 22 mm, which constitutes 1/270 of span.

Aluminum alloys can also be quite effectively applied in cold roofs where owing to industrial conditions there cannot be made reinforced concrete roof, for instance in hot workshops. The roof made usually applied in such conditions from steel sheets should have thickness of not less than 3 mm, but also with this thickness 35-40 kg/m². From aluminum alloy, owing to its significantly higher corrosion resistance, roof may be made considerably thinner, so that expenditure of alloys per 1 m² panel will constitute near 8.5 kilogram. Panels of such construction were developed by an institute of Proyekstal'konstruktsiya for covering above hot workshops (See Fig. 3).

Panels having 12 X 3 m dimension were designed to be self-supporting. Layer of panels is formed from two sheets of alloy AV-T1. Upper sheet of thickness of 0.6 mm is flat, and lower, having thickness of 0.8 mm, is bent with folds of trapezoidal outline. Upper layer is put on ridges of lower and is connected with them by spot welding. To lower ridges of upper layer, also by spot welding and before welding to it of upper layer, there are welded two ribs of tee profile, to which on ends there are welded support struts. For best transmission of transverse forces and imparting of strength, to walls of first folds between flange of tee ribs and walls of folds there are welded two diaphragms on each end of rib. To support struts there are fastened tie-rods from round steel, supplied with nuts on ends. With help of these nuts to ties there is given preliminary tension of 3 tons on each tie. Since ties are fastened on supports with eccentricity with respect to panel, from their tension panel obtains required bend upwards, as a result of which upper layer obtains preliminary extension, acting along panel. This effort allows flat sheet to work as strained diaphragm and to sustain bend from concentrated forces well.

With uniform load panel works as tied arch. At the same time upper, prestressed layer together with tee ribs forms rigid structure united by walls of folds playing role of struts. This allows panel to take nonuniform load also. Simultaneously, rigidity of folds ensures reliable work of panel in transverse direction.

Panels are connected among themselves across slope in "lap fashion," for which upper sheets protrude beyond the limits of folds by 80 mm. Along slope between faces of panels there are established trays from sheets with thickness of 2 mm. After installation of panels upper sheets of layer are bent over edges of tray.

On one panel there is expended 306 kg of alloy AV-T1 and 100 kg of round steel St. 3, or on 1 $m^2$ area of panel of alloy AV-T1, 8.5 kg/$m^2$ and of steel - 3 kg/$m^2$.

If we compare this expenditure with expenditure of steel on steel roof, we find, after subtracting expenditure of steel in aluminum panels, it turns out to be in 4 times less, i.e., application here of light alloys turns out to be more effective than in other structures.

Presence of lower folded sheet, however, requires corresponding expenditure of light alloys, but, besides creation of necessary rigidity of whole structure, it also guards upper sheet from action from beneath of harmful precipitation and, therefore, must promote more prolonged operation of structure.

Under existing relationships of prices of steel and light alloys, application of latter in load-bearing structures may be profitable only with very large spans, where decrease of weight of structures can give us considerable reduction of calculated efforts, and consequently also lightening of structure.

By an institute of Proyektstal'konstruktsiya there was developed a design covering with span of 90 m, where as load-bearing structures there are used jointless arches (see Fig. 4). Application of jointless system in this case ensues from special properties of light alloys. Decreased elastic modulus requires for efficient operation of structure all possible decrease of flexibility. In jointless arches free length in plane of arch is 30% less than for two-joint. In steel structures application of jointless arches is restrained by

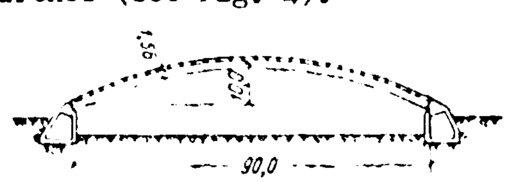


Fig. 4. Diagram of large-span structure.

danger of nonuniform settling of supports. In arches from light alloys, owing to decrease of elastic modulus by 3 times, nonuniform settling of identical magnitude will evoke three times smaller stresses, which is significantly less dangerous. Influences of temperature changes, in spite of twice larger coefficient of linear expansion of light alloys, as compared to steel, is also less feared, since with three times lower modulus these stresses, as a result, will be one and a half times less than in analogous steel structures.

If one were to consider the considerably better operation of jointless arches under nonuniform loading, and also great simplicity of manufacture of structure having identical section through entire length and absence of support parts, one may assume that in this case application of light alloys would allow us to adopt significantly more efficient form of structure.

Section of arches is taken as solid-walled with three faces (Fig. 5). All faces have identical width of 1.8 m. Height of arch is equal to 1.56 m, which constitutes 1/57 of span, with rise equal to 1/9 l.

Thickness of sheets from which web plates of arches are formed is equal to 2.5 mm. For imparting local strength to web plates to sheets there is attached folded profile with width of side of fold of 84 mm, which constitutes 35 thicknesses of sheet and completely ensures local strength of sheets.

Strength of entire folded surface is ensured by setting of diaphragms inside arch at each 1.5 m. These diaphragms are made from sheets with thickness of 2.5 mm, bent in the form z-shaped profile, and spot welded to ribs of folds which on internal side have width of 10 mm. To place of assembling sheets are delivered in disassembled form, and there from them there is made a hollow trihedral section. In the same place these are connected joints of diaphragms at angles with help of corner cover plates, to which web plates of disphragams are attracted by bolts. Among themselves the panels are also connected by bolts.

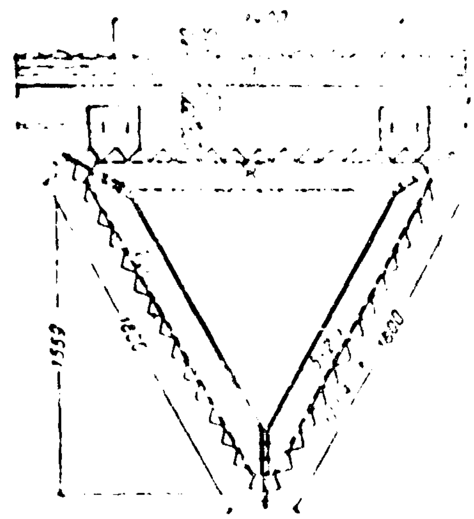

Fig. 5. Cross section of large-span structure.

Assembly joints of arches are made with bolts. Owing to small thickness of sheets, web plates are overlapped, for which bolts connecting panels of section of arch are loosened on one end so that inside this section there may be fed end of other element, after which connecting bolts are again tightened.

Joint bolts are made from heat treated steel St. 5 and work on friction developed between tightened surfaces.

Bolts and washer under them, for elimination of electrolytic interaction of steel with aluminum, are covered by layer of cadmium.

Assembling of arches is to be executed as a unit, lifting each arch with two cranes having load capacity of 5 t each, which with weight of arch of 7.1 t and its rigid profile can easily be carried out.

Roof panel consists of heated sheets of structure analogous to the above-described. Since triangular form of section of arch allows it to work well under torsion, a hinged-cantilever scheme of panel has been adopted. On each of the upper ribs of arch there rest sheets of panel having span of flight 1.4 m and two cantilevers of 1.35 m each. On ends of sheets there rest sheet inserts with span of 4 m. Owing to reduction of spans of sheets, beams of each sheet are made in box-like profile with overall height of 150 mm. On center part of covering inserts are made in the form of sheets with lathing from aluminum tee profiles and with filling of glass blocks for illumination of building.

Expenditure of light alloys in arches constitutes 9.7 $kg/m^2$, in heated panels of covering 1[illegible].5 $kg/m^2$, and in framework of glass blocks 6 $kg/m^2$.

On the average, on the entire covering the expenditure of light alloys constitutes 16 $kg/m^2$.

In coverings of larger spans application of light alloys gives us up to 50% saving even without considering lightening of supporting structures (for instance, foundations).

Successful results are obtained from application of light alloys in bridge structures. Especially profitable is that structure in which an orthotropic plate is used.

Lower elastic modulus of light alloys in this case is contributory factor, since flat flooring of diaphgram type from light alloys works under more profitable conditions than steel.

Actually, from identical load with the same span the deflection of aluminum flooring is found 3 times greater, as a consequence of which in operation of flooring a more essential role is played by share of thrust part of work of diaphragm. Here bending stresses, again as a result of lower elastic modulus, are found less than in steel flooring.

All this allows us to have flooring with thickness of 4-6 mm (depending upon span i.e., approximately twice less than from steel sheets. Small thickness of sheets is possible owing to high corrosion resistance of aluminum alloy, which also allows us to lay asphaltic covering directly on sheet of flooring.

The noted peculiarities of light alloys are used during designing of a highway span structure where $\underline{l}$ = 42 m.

Orthotropic plate, consisting of separate sheets, is used as upper chord of trussed girders.

Panels have upper sheet with thickness of 6 mm, resting on longitudinal beams set each 300 mm (Fig. 6). Girders are made from pressed I-beam profile with height of 250 mm having webs of different area. Sheets have length of 7.1 m, equal to two panels of truss. In the middle at same level with longitudinal girders there is placed transverse girder. On edges sheets are terminated by channels which, being connected with the same channels of neighboring sheets, form an I-beam.

Section of this beam also includes upper sheet of flooring and joint cover plates connecting above and below the two neighboring sheets. For easing the work of transverse beams middle of them is supported by transverse ties.

On axes of main trusses I-beams are replaced by box-like profile, to which there are fastened gussets of vertical trusses. Lower chords just as struts and uprights are made of H-shaped section with bulbous bordering of edges of profile.

For decrease of expenditure of alloy these elements together with gussets are made from alloy D16-T, since they are connected on assembly only by high-strength bolts.

Upper sheets are designed from alloy AV-T1. Factory joints in them are welded, and assembly joints - on high-strength bolts.

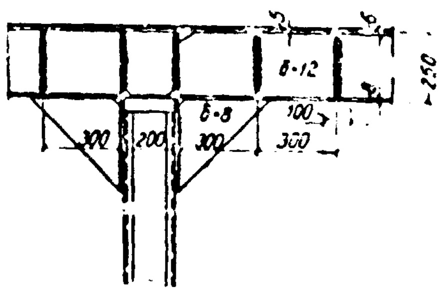


Fig. 6. Orthotropic plate of flooring of span part of highway bridge.

Weight of light alloys in span structure constitutes in all 28 t, or 77.5 kg/m$^2$ for bridge. For comparison it is possible to give figures of expenditure of materials in model highway span structure of the same span and for the same load N18. Weight of steel, including fittings of plate, in it constitutes 58.2 t, and volume of concrete in plate is 65 m$^3$.

Owing to present very high cost of aluminum alloys, application of light alloys for spans of average magnitude is found ineffective. However, with growth of distance of span the effectiveness of application of light alloys is all the more increased, and one may assume that with spans of 100-120 m span structures from light alloys will have identical cost with those of steel concrete.

Analogous structure is planned and for installation of lower part of suspension bridge across the Volga at Volgograd with center span of nearly 800 m. Here use of orthotropic plate was found especially profitable as a result of location of roadways on two stories, so that both chords essentially, consist of plates of span part.

In given structure expenditure of light alloys constitutes only about 40 kg/m$^2$.

At present there is still very little experience in manufacture of structures from aluminum alloys.

In all probability in factory manufacture of most expedience will be application of welding, especially point welding.

Assembly joints are most conveniently made with bolts, since with sections of closed or semi-enclosed form it is the most acceptable for structures from light alloys. Assembly riveting entails great difficulties.

The most convenient may be considered joining with high-strength bolts, working with use of frictional forces developed on compressed surfaces.

Although experiments with joining by high-strength bolts on aluminum structures showed the worst performance of bolts, in comparison with their performance in steel structures, in those experiments there was checked only work of pure friction. In reality, high-strength bolts after certain shift still have great reserve before failure of joint.

Magnitude of shift constitutes 1.5-2 mm on each joint. If for steel structures such magnitude can be of essential value with respect to elastic deformations, then in aluminum structures, where magnitude of elastic deformation constitutes 2-2.5 mm for each meter of length of element, complicance in joints will have relatively smaller value.

Thus, only in sign-alternating elements must there be ensured work of high-strength bolts only on friction. However, even in this case it almost always happens that force of one sign turns out to be significantly larger than the other. In this case work on pure friction must be ensured only for the smaller force. In the same cases, when both forces are found to be close, they, as a rule, have insignificant magnitude, and here there may be fully ensured reliable work of joint on friction with lowered value of friction coefficient 0.2-0.25.

In this article there are given only first results of very little experience of designing of structures from light alloys. Many questions had to be solved for the first time and, of course, it is impossible to consider that all described structures have been designed absolutely correctly. Very much should be obtained by industrial check.

In any case, along with introduction into practice of manufacture and construction of planned structures there should be conducted broad and systematic work on detection of optimum methods of their manufacture and assembling. Only comprehens- experience will allow us to obtain structures from light alloys which are indeed economical, having low labor-requirements of manufacture and being convenient for assembling.

The broader the work for the development of new form of structures, the faster they will occupy their proper place in construction and will give the corresponding economic effect.

DESIGNING OF FIRST HIGHWAY BRIDGE IN USSR WITH ALUMINUM SPAN STRUCTURE

Yu. S. L'vov, Engineer

## 1. Introduction

In 1960 in State Planning Institute of Giproavtotrans there was completed the designing of first span structure in the Union of permanent highway bridge from aluminum alloys with designed span of 32.4 m.* Considered aluminum span structure will be installed on a river bridge.

At present at the crossing there is a wooden beam bridge, instead of which there will be built a new bridge with total length of 78.5 m. Center span of new bridge is an aluminum span structure, on each side of which there are two 12-meter spans each covered by standard prefab reinforced concrete span structures.

New bridge is designed for passage of automobile load N-13 and caterpillar NG-60. Width of span part of bridge is 7 m; width of sidewalks 0.75 m each.

Because of length of span and local conditions of crossing aluminum span structure is planned with roadway on top. Span structure is to be riveted.

During designing, it was taken that span structure should satisfy following main requirements:

1) structure should have lowest weight possible, i.e., require minimum expenditure

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*In working out the design there participated engineers G. A. Vasil'yev, A. Yu. Reznik, and I. L. Markovich.

of aluminum alloys;

2) it should be easy to manufacture and transport;

3) volume of assembly riveting should be as low as possible.

Desire to obtain structure requiring least expenditures of material assumes during designing of aluminum structures especially high value in connection with high cost of aluminum alloys.

Requirement of simplicity of structure and convenience in manufacture ensues from novelty of structure, specific peculiarities of aluminum as a building material, and absence here of sufficient experience in manufacture of engineering structures from aluminum alloys.

Of paramount value during designing and building of aluminum structures is decrease of volume of assembly riveting. Rivets in aluminum structures, unlike those of steel are set, as a rule, in cold state. Here for upsetting of shank of rivet and formation of rivet head there are required considerable forces.

Under factory conditions in the presence of powerful riveting presses cold riveting of aluminum rivets may be carried out without special difficulties. Under field conditions, when riveting is done by pneumatic hammers, manually, setting of rivets of large diameters is considerably complicated.

Described span structure may be wholly built in factory and delivered to place of installation, ready for use.

Aluminum span structure is designed for normal exploitation on highway with rather intense traffic.

Together with this, being first span structure from aluminum alloys, it is an experimental object, which gives us possibility to check and to study number of questions pertaining to designing and building of aluminum bridge structures.

Program of experimental study of planned span structure includes observation and investigation, both in process of manufacture of structure and also during period of exploitation.

## 2. Selection of Grade of Alloy

Selection of alloy was based on following requirements and considerations:

1) alloy should possess high strength;

2) it should be easily processed and quite well resist corrosion under normal conditions of exploitation;

3) alloy should be well studied and checked in real structures;

4) Manufacture of articles from the chosen alloy should have been mastered by industry.

Above set requirements are best satisfied by alloys D1-T and D16-T, belonging to duralumin group.

Proceeding from main problem on hand - to obtain structure of least weight - preference was given to the stronger alloy D16-T.

Railing on aluminum and on reinforced concrete span structures of bridge are designed from weldable alloy AMg.

Of no less important value than selection of grade of alloy for riveted structure is question of selection of material for rivets.

For structures designed from duralumin the most expedient is application of rivets from alloys V65 or D18, also belonging to this group of alloys. Rivet alloy V65 differs by higher shear resistance and somewhat lower ductility, as compared to alloy D18. In magnitude of shear resistance alloy V65 is preferable. The experience of cold riveting of aluminum rivets shows that rivet with diameter of 20-24 mm from alloy D18 and V65 can be successfully set by both clamp and pneumatic hammer, however, forming of rivet head is more successfull with use of more ductile alloy D18.

When working with alloy V65, quality of rivet heads is lower.

It is necessary to emphasize that experiments in upsetting of heads from alloy V65 were conducted to extraordinarily limited extent with use of rods, the material of which did not satisfy technical requirements. This circumstance shows that sufficient data allowing us to objectively estimate advantage and deficiencies of considered rivet alloys are at present unavailable.

Considering somewhat higher ductility of alloy D18 and available experience of successful manufacture of structure with rivets from this alloy, it was resolved to settle on rivet alloy D18.

Before manufacture of span structure we planned to execute preparatory work on riveting. Purpose of this work is devising of technology of cold riveting by clamp and pneumatic hammers, check of quality of prepared tool and adopted equipment, and also increase of skill of those doing the riveting.

Experimental works will be conducted on rivets from both alloys - V65 and D18 with different forms of rivet head.

## 3. General Questions of Designing of Span Structure

For the adopted span of 32.4 m there were considered variants with open main trusses and with plate girders, variants with two, three, and four trusses in cross section with height of trusses 2.5; 3, and 4 m, which constitutes 1/13; 1/10.8, and 1/8.1 of calculated span.

Roadway part of bridge was considered in two basic variants: in the form of reinforced concrete plate, placed on main trusses, and in the form of purely aluminum structure, consisting of transverse and longitudinal beams and sheet flooring. Reinforced concrete plate in turn was considered in two variants: from usual "heavy" reinforced concrete $\gamma = 2.5$ t/m$^3$, and from "light" concrete $\gamma = 1.8$ t/m$^3$.

Comparison of data obtained in examining of diverse variants leads to following conclusions.

a) Type of structure of main trusses. With identical reinforced concrete plate of roadway part structure with solid main beams requires approximately 40% more metal than with open trusses. With aluminum roadway part difference in weight is somewhat less (35%).

Another deficiency of structure with three main plate beams is necessity of riveting in assembling.

For spans of more than 30 m advantage of open trusses over plate, from the point of view of economy of metal, will be still more significant.

Besides considered types, serious attention should be given span structures designed in form of plate thin-webbed space structures.

b) Number of trusses in cross section of bridge. Investigation showed that for considered span of 32.4 m and width of roadway of 7 m least weight of metal is obtained by structure with three main trusses. Practically the same weight is obtained and with four main trusses in cross section.

Structure with two main trusses, depending upon nature of support of plate of span part, requires 18-27% more metal. Furthermore, relization of structure with two main trusses inevitably is connected with assembly-riveting. Therefore, final selection should be made between variants with three and four main trusses.

Considering that structure with four trusses may be easily carried out in the form of two units on each two trusses and that transport of such units, thanks to small dimensions of them in cross section, can cause no difficulties one should recognize that the most efficient structure is that with four main trusses in cross section.

c) Efficient height of trusses. Designing showed that height of main trusses of 2.5 m with calculated span of 32.4 m is insufficient; with this height expenditure of metal is increased, and rigidity decreases as compared to trusses of greater height.

With theoretical height of trusses of 4 m, weight of metal is 8.8% less than with height of 3 m, and rigidity is correspondingly greater. Thus, of the three considered heights the most preferable is truss with height of 4 m, but with combined structure necessary rigidity of span structure is ensured with a height of 3 m.

Imparting to main trusses with roadway on top of excess height of 1 m, brings with it an essential increase of height of embankment and its appreciation. During designing of combined structure, height of main trusses with roadway on top is expediently taken equal to 1:11-1:12 of spar.

d) Deflections. Question of magnitude of deflection which it is possible to allow during designing of span structure from aluminum alloys has extraordinarily important value.

During assignment of rigid norms of deflection, use for bridge structures of high-strength aluminum alloys becomes impractical, since dimensions of sections in this case are determined not from condition of guarantee of strength, but from conditions of necessary rigidity of structures. By our norms elastic deflection of open metal span structure is fixed at 1/900 of magnitude of span. During designing of described span structure, it was recognized as possible to take deflection at 1/600 of span. In those structures where reinforced concrete plate is combined with main beams relative deflection varies from 1/560 to 1/776, i.e., accepted norm of deflection is completely satisfied. In noncombined structure the achievement of deflection of 1/600 is possible only through increase of sections, i.e., refusal to use strength of taken alloy.

Investigation shows that with good use of material of alloy D16 in combined structure deflection of 1/600 can be obtained where height of trusses is near 3 m. In noncombined structure the obtaining of such deflection is impossible; such structures may be applied only with increase of deflection to approximately 1/400.

e) Type of roadway part. Roadway part of bridge, as was already said, is considered in two variants: in the form of reinforced concrete plate laid on main beams, and in the form of aluminum structure consisting of longitudinal and transverse beams and sheet flooring. Road bed in both cases is a layer of asphalt concrete.

Weight of roadway part in first case constitutes 660 $kg/m^2$, and in second - only 170 $kg/m^2$.

Accordingly, calculated load from gravity changes by 1 running meter of main truss. Essential change of forces in variant with aluminum roadway part is attained, furthermore, thanks to releasing upper boom from work on bend. As a result of joint action of both factors, weight of main trusses with aluminum roadway part is approximately 25% less than with reinforced concrete plate. However, thanks to introduction of transverse and longitudinal beams and especially to solid sheet flooring, total expenditure of metal significantly increases. From the point of view of expenditure of metal structure with reinforced concrete plate of roadway part is significantly more expedient. Gross weight of such a span structure differs little from steel-concrete, since difference in weight is realized only owing to difference in weight of metal, specific cost of which in total weight of structure is insignificant. With installation of aluminum roadway part gross weight of span structure turns out to be almost 3 times less than with reinforced concrete plate, which gives us possibility to lighten supports of bridge considerably.

## 4. Description of Developed Structure

Basic data. Calculated span of main trusses - 32.4 m - is divided into 8 panels of 4.05 m each; theoretical height of trusses is 2.7 m; lattice - triangular without struts (Figs. 1 and 2).

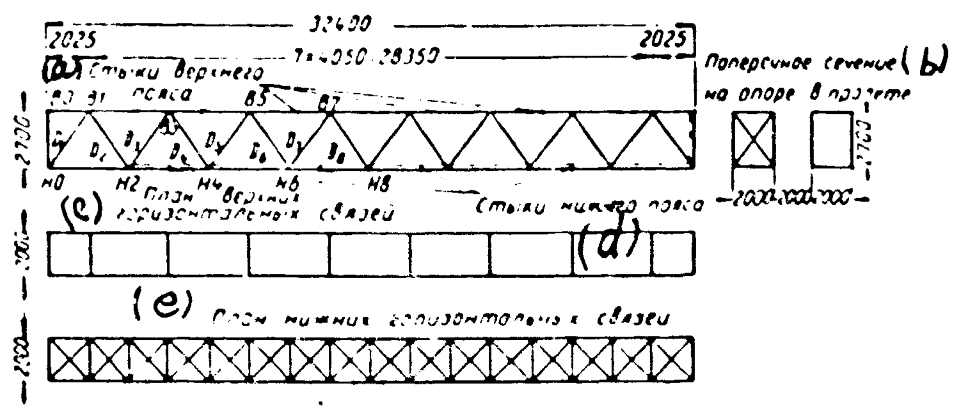


Fig. 1. Diagram of span structure
KEY: (a) Joint of upper boom; (b) Cross section on support in span; (c) Plan of upper horizontal ties; (d) Joints of lower boom; (e) Plan of lower horizontal ties.

In cross section of bridge there are 4 trusses located at distance 2 m axis to axis (Fig. 3); girders are united in pairs by longitudinal and support transverse ties and form two independent units of identical dimensions. Both units are connected between themselves by reinforced concrete plate of roadway part with thickness of 15 cm placed over main trusses and joined with upper boom with help of corner dogs. Road bed is a layer of asphalt concrete with plastic additions with thickness of 5 cm.

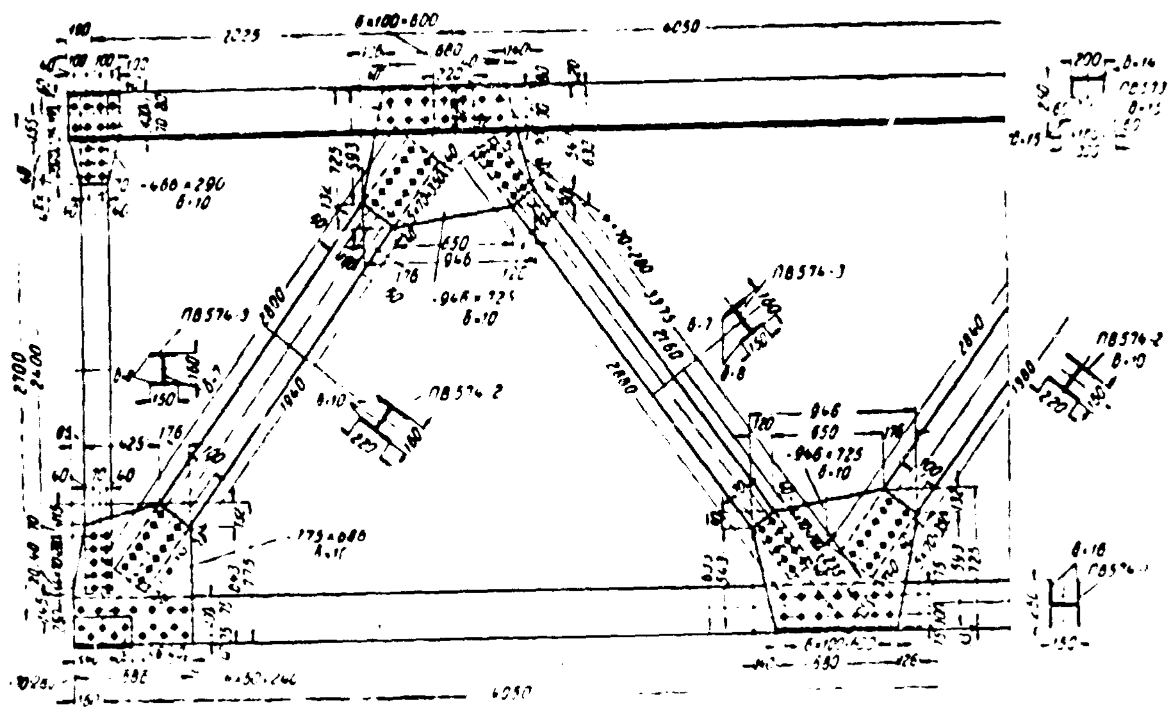

Fig. 2. Main truss (facade).

Support parts - steel of the same type as support parts of steel span structures of this span.

During designing of pressed profiles for described span structure, following principles were taken as basis:

1) Section of elements of trusses should be formed from one pressed profile, and not riveted from separate smaller profiles, or sheets. This condition was considered as one of the most important, since its fulfillment ensures maximum possible decrease of volume of riveting work.

2) Planned profiles have to be by universal, i.e., suitable for application during designing of other structures from aluminum alloys.

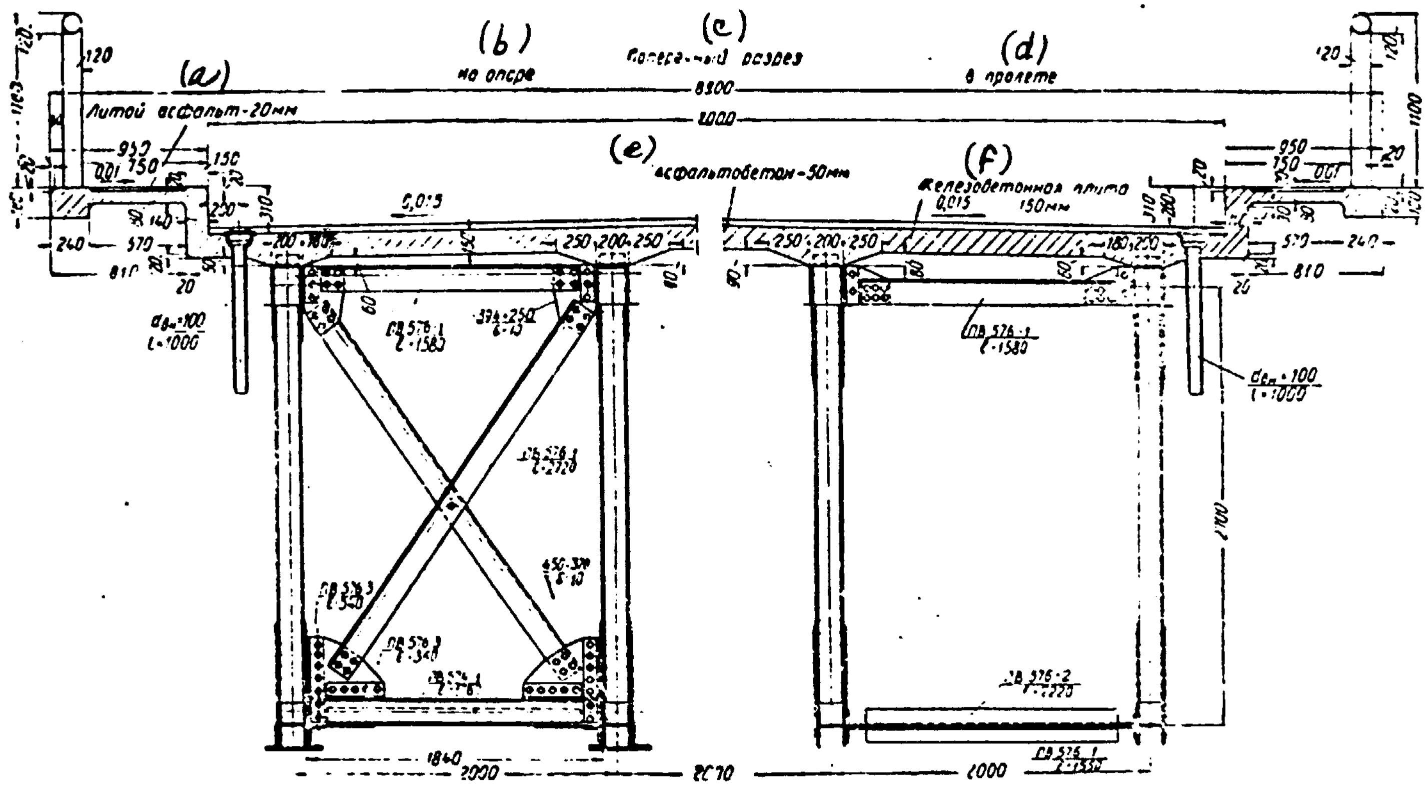


Fig. 3. Cross sections of span structure.
KEY: (a) Poured asphalt; (b) on support; (c) Cross section; (d) in span; (e) asphaltic concrete; (f) steel concrete plate.

3) Form and dimensions of profiles have to satisfy technological requirements of manufacture of pressed profiles, and also requirements of convenient and reliable riveting.

4) Number of separate profiles should be as far as possible decreased for the purpose of simplification and reduction of costs of all operations, both in manufacture of profiles themselves and also in manufacture of the span structure.

As a result of consideration and appraisal of diverse variants of profiles for span structure, there were taken following profiles, shown in Fig. 4:

1) for upper boom of trusses - one profile for entire length of span;

2) for lower boom also one profile;

3) for lattice - two profiles: one for all compressed struts, and the other for stretched struts and support columns working on local load.

Thus, main girders of span structures are planned from four profiles in all. Furthermore, there is planned four corner profile, from which one serves for dogs uniting reinforced concrete plate of roadway part with upper boom of trusses while three others are elements of connections.

Character of work of upper boom, as element of combined section, dictated its form, shown in Fig. 4. With such form of section upper horizontal sheet is disposed in zone of the biggest compressing stresses and simultaneously serves for fastening of dogs; lower horizontal webs give stability to vertical web plates and simultaneously can be used for support of sheathing of plate of roadway part, which is monolithic and is poured [concrete] on site.

Designing of profiles demanded coordination of them with factory-producer.

Joints and splices of trusses. Designing of sections of elements of trusses from homogenous profiles allowed us to limit riveting operation only to joints and splices of trusses.

Joints of trusses are formed by paired gussets with 10 mm thickness. On upper beam gussets are disposed inside profile, while on lower boom, conversely, on the

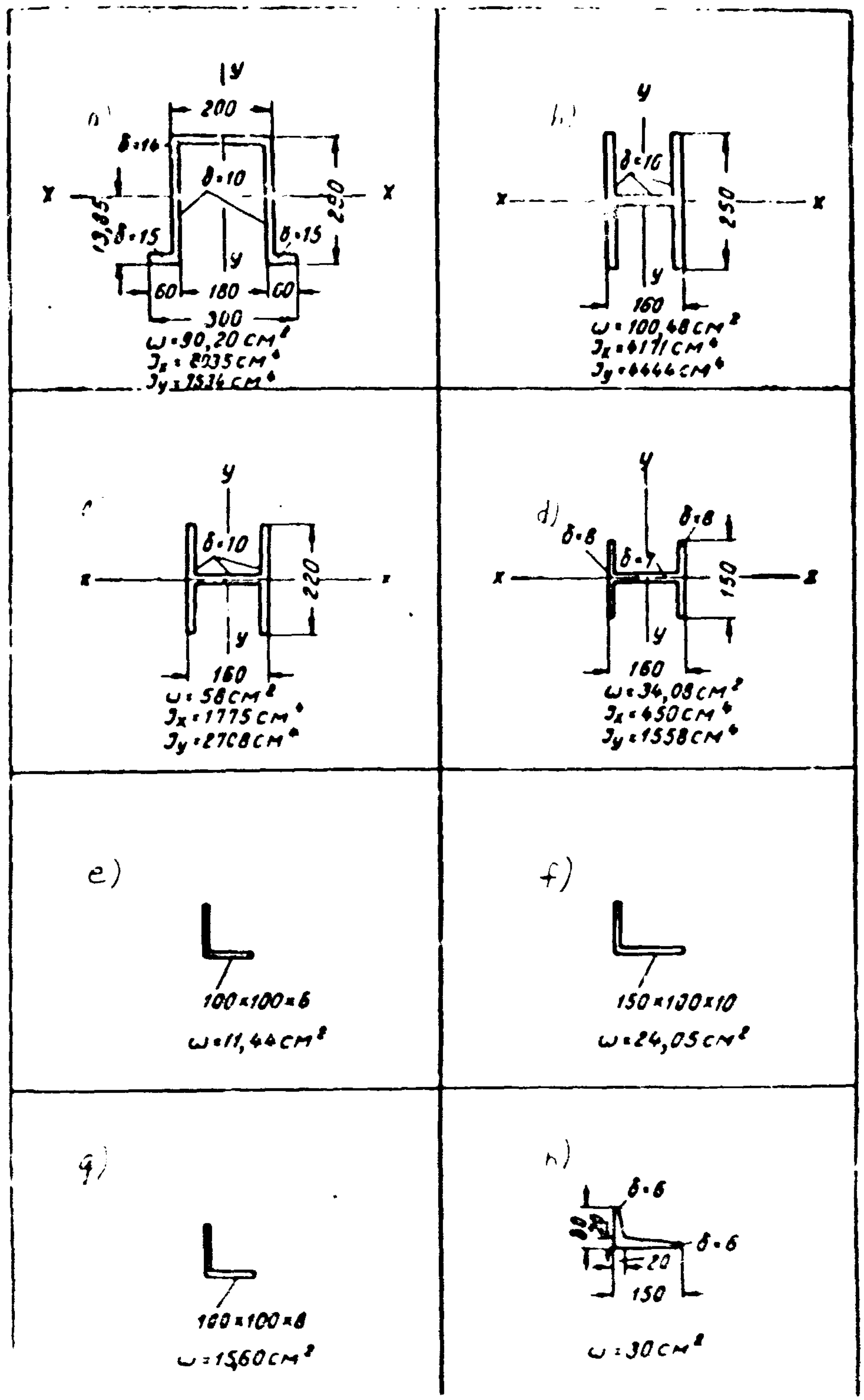

Fig. 4. Types of pressed profiles
a) upper boom; b) lower boom; c) compressed struts; d) stretched struts, support stands, and diaphragms; e) diagonals of ties; f) struts of ties; g) angles for fastening of ties; h) dogs.

outside of profile. Gussets are fastened to booms by rivets of 20 mm diameter.

All rivets in span structure are factory.

Splices of trusses are planned in two variants. In the first of them splices of both booms are disposed outside joints for the purpose of maximum simplification and easing of assembly and riveting of two-webbed sections of limited dimensions. Both in upper and also in lower boom there are to be four splices each; number of splices is determined from condition of length of profiles supplied by factory. Splices of both booms are covered by paired horizontal and vertical cover plates with thickness of 10 mm.

Second variant of splices differs from first by the fact that all splices are disposed in centers of joints; this allows us to somewhat decrease expenditure of metal on splice cover plates and also to decrease total volume of riveting. Location of splices in joints at the same time leads to complication of assembly and riveting of trusses. Final variant of splices was adopted after preliminary experimental riveting.

Unification of sections of booms and lattice of trusses allowed us to unify also the joint gussets of all average joints and to plan their identical form and dimensions.

Ties between trusses. Immutability of trusses forming units is ensured by horizontal ties in plane of lower boom of trusses, reinforced concrete plate of roadway part placed on upper booms, and also transverse ties located on ends of units on supports.

Lower longidudinal ties of cross system are formed from angles of two dimensions: struts - from angles 150 X 100 X 10 mm, and diagonals - from angles 100 X 100 X 8 mm. Panel of lower ties is equal to half of panel of trusses. Ties are fastened to booms through joint gussets from sheets of 8 mm thickness riveted to booms by paired angles 100 X 100 X 8 mm.

For assurance of immutability of blocks during transport and installation, in all joints of upper boom there are sturdy struts from angles 150 X 100 X 10 mm.

Unification of sections and its influence on weight of trusses. The broad unification of sections adopted, naturally, let to significant underutilization of material.

If, complying with effective forces, we design upper boom not from one, but from two elements, preserving without change the number of splices, then easing of weight of boom will constitute 625 kg. For lower boom introduction of one new profile gives economy in weight of 705 kilograms. At last, addition of two new profiles in struts could give economy in weight of 480 kilograms. Thus, the unification of sections adopted in the project demanded additional expenditure of 1810 kg of metal, which constitutes nearly 13% of possible lower weight of span structure.

In spite of considerable economy which may be attained by introduction of four new profiles such design was recognized as impractical, since it led to general complication of construction.

## 5. Protection of Span Structure From Corrosion

The bridge is disposed in region where there are no industrial enterprises; thus, the aluminum span structure will be in the most favorable atmospheric conditions. On this basis it was resolved not to resort to paint or any other means of protection of span structure. Application of structure without special measures of corrosion protection is mainly for experimental purposes and should give us additional material for objective appraisal of corrosion-resistance of structures prepared from alloy D16-T.

During designing it was considered that not all elements of structure are under identical conditions. Thus, for instance, upper boom of girders, on which there is laid on-site-poured reinforced concrete plate of roadway part, is with respect to corrosion in more dangerous conditions than other elements of structure not touching the concrete. The greatest danger of corrosion is experienced, apparently, by horizontal sheet of upper boom with dogs riveted to it.

Considering special conditions surrounding upper boom of girders, it was resolved to cover entire surface of horizontal sheet of boom and corner dogs with two layers of chrome-zinc paint. Special attention here should be allotted painting of heads of rivets and slots on perimeter of corner dogs touching boom.

The same paint is to be on internal surfaces of joints of lower boom, whence drainage of water is hampered. In that expanse between joints drainage of water from closed profile of lower boom is attained by providing in horizontal sheet of drain holes - two in each panel.

All remaining surface of girders remains without any paint.

To avoid appearance of bimetallic corrosion in places of support of span structure on steel support parts, upper plates of support parts are chromium plated.

### 6. Manufacture, Transport, and Installation of Span Structure

Manufacture of span structure is to be in one of their factories.

Thanks to comparative proximity of factory in which there will be prepared span structure from place of its installation, and also thanks to designing of span structure from two separate blocks, the possiblity arose of complete exclusion of assembly riveting, limiting work on crossing to installation of span structures on supports. Plane girders are joined in factory into blocks of two girders each by means of setting of cross longitudinal ties in plane of lower boom, transverse struts in plane of upper boom, and support transverse ties on ends of blocks. In factory to upper boom of girders there are riveted corner dogs.

Weight of thus prepared block of two trusses constitutes 7.7 t. Overall dimensions of unit are the following: length 32.76 m; width 2.16 m, height 3.02 m. Dimensions of units and their low weight allow us to transport them by motor transport from factory to place of river crossing. Distance between these points on roads outlined for transport constitutes 160 kilometers. Transport will be carried out on low semitrailers towed by motor venicle.

Loading of block on trailers in factory, unloading of them on building site, and mounting on supports are ensured by two truck cranes.

## 7. Peculiarities of Calculation of Structure

a) Technical specs of designing. Technical specs for designing of span structures of highway bridges from aluminum alloys do not yet exist. Therefore, during composition of design there were used "Technical Specs for Designing of Bridges from Aluminum Alloys (supplement and amendment to TUPM-56 [Technical Specs for Bridge Designing])," composed by MIIT [Moscow "Order of Lenin and Order of the Red Banner of Labor" Institute of Railroad Transportation Engineers] in 1958 in reference to railroad bridges, "Technical Specs for Designing of structures from Aluminum Alloys (project)," composed by TsNIISK [Central Scientific Research Institute of Structural Parts] in 1960, and also effective TU's [Tech. Specs] and rules for designing of steel bridges and structures.

Designing of span structure was done in respect to allowed stresses, which are taken as the following:

1) for alloy D16-T - basic allowed tensile stress

$$[\sigma_{ten}] = 1{,}700 \text{ kg/cm}^2;$$

allowed bearing stress

$$[\sigma_{bear}] = 1.8\,[\sigma_{ten}] = 1.8 \times 1{,}700 = 3{,}060 \text{ kg/cm}^2;$$

shear stress

$$[\sigma_{sh}] = 0.6\,[\sigma_{ten}] = 0.6 \times 1{,}700 = 1{,}020 \text{ kg/cm}^2;$$

2) for rivet alloys

| Alloy | $[\sigma_{bear}]$ kg/cm² | $[\sigma_{sh}]$ kg/cm² |
|---|---|---|
| D18-T | 2100 | 800 |
| V65-T | 2660 | 1000 |

b) <u>Work of united section of upper boom.</u> During calculation of upper boom of girders united with reinforced concrete plate of roadway part, there are considered peculiarities ensuing from combination of reinforced concrete with aluminum.

Thanks to lower modulus of longitudinal elasticity of aluminum, unification of it with reinforced concrete is significantly more effective than inification of reinforced concrete with steel. If in steel-concrete construction effect of unification of both materials is determined by ratio $\frac{E_{st}}{E_{st\ con}} = 8\text{-}10$, then in aluminum concrete construction degree participation of reinforced concrete plate in joint work is significantly larger and is determined by ratio

$$\frac{E_{al}}{E_{st\ con}} = 3$$

The significantly greater participation than in steel concrete construction of plate in joint work with boom stipulates larger values of given area of combined section and its moment of inertia, which allows us to designate more economic sections of boom.

Combined section is calculated for loads of two forms corresponding to two stages of its work.

Below in table there are given values of stresses appearing in combined section first and second stages of its work.

From this table it is clear that calculated stresses in aluminum upper boom are significantly lower than those taken, while compressing stresses in reinforced plate are utilized to approximately 50%. This table shows also that 76% of stresses in it arise from loads of first stage; in second stage boom works poorly, which is explained by large effect of unification with reinforced concrete plate.

## 8. Conclusions

Designing of described span structure allows us to make following conclusions:

Stresses in Combined Section of Upper Boom

| Calculated loads | Stresses in kg/cm$^2$ | | |
|---|---|---|---|
| | $\sigma_{al}^{upper}$ | $\sigma_{al}^{lower}$ | $\sigma_{con}$ |
| I stage - gravity of plate, girder, and sheathing | -1139 | -435 | Plate does not work |
| II stage - remaining part of constant load, temporary load N13, and group . . . . | -111.5 | -21.0 | -33.0 |
| Stresses: from eccentric fastening of struts . . . . . . . | +48 | -168.5 | +14.9 |
| from temperature . . . | -287.6 / +287.6 | +32.4 / -32.4 | +6.0 / -6.0 |
| from deflection of stresses . . . . . . . . . . | — | — | -28.5 |
| Total stresses . . . . . . | -1490.1<br>-915.7 | -550.1<br>-614.9 | -40.9<br>-52.9 |

1) For riveted aluminum structures the most suitable for purposes of economy of alloy metal is alloy D16-T, possessing high strength, satisfactory corrosion resistance, and ensuring good use of material with simultaneous satisfaction of requirements of rigidity.

2) Combination of reinforced concrete with aluminum alloy, thanks to low elastic modulus of aluminum, is more effective than combination with steel. Main merit of combined aluminum concrete structures is their high rigidity.

3) Installation on bridges of aluminum roadway part allows us to sharply decrease load from gravity and has therefore great meaning in reconstruction of old bridges not suited to passage of new heavy loads. During designing of new aluminum bridges, it is necessary to consider that installation of aluminum roadway part of usual type requires significant overexpenditure of metal. Rigidity of bridges with aluminum roadway part is lower than rigidity of bridges of combined construction.

4) Riveted span structures of bridges with open main trusses, starting from span of 30 m and more, are considerably more economical in expenditure of aluminum alloys than those with solid main beams.

5) It is necessary to significantly expand investigation of our available and newly created rivet alloys with an eye on their application for cold rivets of large diameters.

## PRESTRESS OF OPEN TRUSSES FROM ALUMINUM ALLOYS FOR INDUSTRIAL BUILDINGS

B. A. Speranskiy, Cand of Tech. Sciences, F. F. Tamplon, Engineer

In the article there are given certain results of work of authors pertaining to prestress of open trusses of industrial buildings from aluminum alloys with span up to 60 m.*

Investigation of steel structures showed that the most promising method of creation of prestress of open steel girders is installation of straining elements from high-strength steels. In structures of steel and aluminum girders have much in common [1]; therefore, authors of the article in the first place treated girders from aluminum alloys, also those reinforced by straining elements from high-strength steels.

Application of high-strength steels for straining elements is economically profitable.

Location of straining elements in respect to basic structure renders serious influence on distribution of forces, deformation, and technico-economic indices of metallic prestressed trusses. Depending upon this, it is possible to subdivide girder into three types:

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*Work was carried out in Scientific Research Institute for Industrial Buildings and Structures of ASiA [Academy of Construction and Architecture] USSR and in chair of building parts of Ural Polytechnic Institute in 1959-1960.

a) those with separate prestressed beams;

b) those with ties or struts placed within limits of dimension of basic structure;

c) those with ties or struts carried beyond the limits of basic structure (Fig. 1).

## 1. Trusses with Separate Prestressed Beams

Beams with the greatest stretching efforts from calculating load are precompressed (in flitched trusses - beams of lower boom and those tension struts nearest to supports). Cross sections precompressed beams consist of two parts: rigid - from usual profiles and flexible straining elements from high-strength steel (Fig. 1 a).

Amount of lowering of expenditure of materials and cost of separate precompressed beams are connected with ratio of strength characteristics and elastic moduli of applied materials and magnitude of calculated stresses.

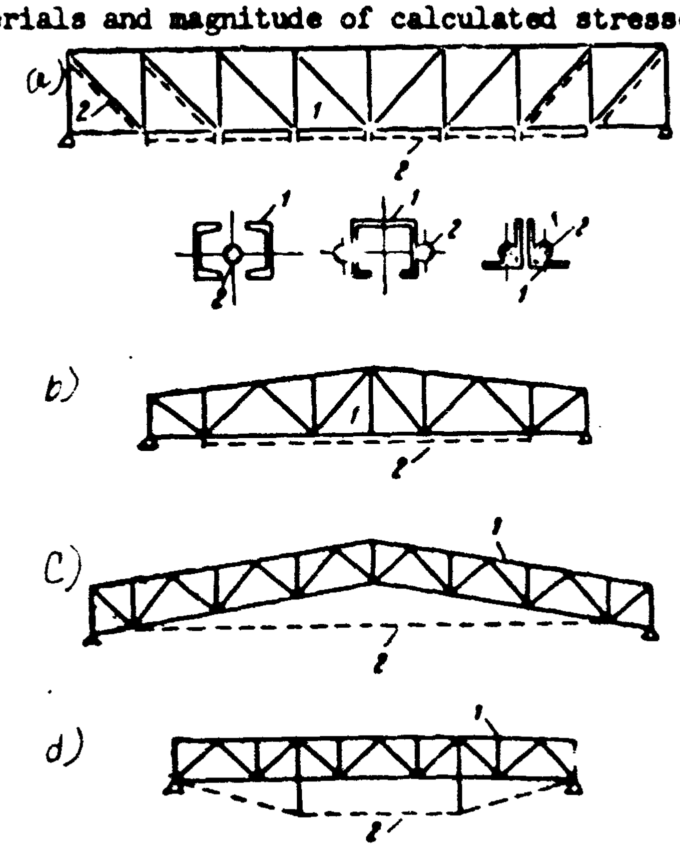


Fig. 1. Diagram of prestressed metallic trusses
a) truss with separate prestressed beams and cross sections of prestressed beams; b) truss with prestressed lower boom; c) truss with "tied arch;" d) strutted truss; 1) basic structure; 2) straining elements.

Merit of trusses with separate prestressed beams consists in the fact that all operations connected with prestressing, can be executed by factory-producer of structures.

Elastic modulus of aluminum alloys, three times lower than for steel, renders essential influence on distribution of stress between aluminum part of beam and steel straining element. This circumstance requires increase of ratio of calculated resistances of aluminum alloy and steel of prestressed beam.

It is possible to establish criterion of feasibility of preliminary stress of aluminum beam. For this purpose we shall use formulas offered by S. N. Klepikov [2] for steel beam. S. N. Klepikov, taking for limiting state on load-bearing ability simultaneous achievement of calculated resistances by straining fittings and by rigid part of beam during equality of their deformations, obtained following formulas for selection of section of precompressed beam (designations in formulas are modified to fit beams from aluminum alloys):

$$F_c = \frac{n' \varphi \beta a^2 R_a}{a(\beta R_c + n' \varphi R_a) - N}, \qquad (1)$$

$$F_a = a - \frac{F_c}{\beta}, \qquad (2)$$

$$a = \frac{N}{R_a(1 + n' \varphi)}. \qquad (3)$$

Here N - calculated stress in beam in t;

Fc, Ec, Rc - respectively - area of cross section in $cm^2$, elastic modulus, and calculated resistance of steel straining element in $t/m^2$;

Fa, Ea, Ra - the same qualities for rigid strained part of beam from aluminum alloy;

$a$ - area given to aluminum of whole beam in $cm^2$;

$\beta = \frac{Ea}{Ec}$ - ratio of elastic moduli of aluminum alloy and steel;

$\varphi$ - coefficient of longitudinal bend of aluminum part of beam;

n' = 1.1; n" = 0.9 - coefficients of overloading and underloading of straining steel fittings.

From formula (2) it follows that precompression of rod is possible only when

$Fa > 0$,

i.e., when $$a - \frac{F_c}{\beta} > 0. \qquad (4)$$

We shall introduce designation for ratio of calculated resistances of steel and aluminum alloy k, make necessary substitutions and algebraic transformations in formula (4), and shall obtain condition of possiblity of precompression of aluminum beams:

$$k_{min} > \frac{N}{\alpha\beta R_a} = \frac{1 + n'' \varphi}{\beta}.$$

Table 1. Minimum Values of $k = \frac{Rc}{Ra}$

| $\varphi$ \ $\beta$ | (a) Жесткая часть стержня | | | | | |
|---|---|---|---|---|---|---|
| | (b) из стали | | | (c) из алюминиевого сплава | | |
| | 1,24 | 1,06 | 1 | 0,41 | 0,35 | 0,33 |
| 1 | 1,52 | 1,8 | 1,89 | 4,6 | 5,4 | 5,66 |
| 0,75 | 1,35 | 1,59 | 1,67 | 4,07 | 4,75 | 5 |
| 0,5 | 1,27 | 1,38 | 1,45 | 3,5 | 4,15 | 4,34 |
| 0,25 | 0,98 | 1,15 | 1,2 | 2,95 | 3,42 | 3,62 |

KEY: (a) Rigid part of beam; (b) of steel; (c) of aluminum alloy.

Taking values of elastic modulus for steel cables $E = 1.7 \times 10^3$ t/cm$^2$, for rolled beams from high-strength steel $E = 2 \times 10^3$ t/cm$^2$, and for beams from low-carbon steel $E = 2.1 \times 10^3$ t/cm$^2$, we obtain for beams from aluminum alloys with steel fittings values of K equal to 0.41, 0.35, 0.33.

In Table 1 there are given minimum values of ratio of calculated resistances of fittings and rigid structure of beans of steel and aluminum alloys as function of coefficient of longidinal bend $\varphi$ and ratios of elastic moduli $\beta$. Experience of designing shows us that for obtaining of perceptible economic effect it is necessary to choose of ratio of calculated resistances k at least 2-3 units higher than minimum values from Table 1. If, however, magnitude of k is selected close to minimum, large share of calculated stress will be absorbed by fittings, and aluminum part of beam becomes unnecessary. For instance, when ratio of calculated resistances k = 4.17, ratio of elastic moduli 0.41 and coefficient of longitudinal bend $\varphi$ 0.75, in beam from alloy D16-T 96% calculated stress is transmitted to fittings from high-strength cable. If, however, we increase flexibility of beam in such a manner that coefficient of longitudinal bend drops to $\varphi = 0.5$, then to steel cable there will go 71% of calculated stress, while area of cross section of aluminum part of beam turns out to be less than area of steel cable, which in practice is also unrealizable.

Analyzing data of Table 1 with respect to remarks made, it is possible to conclude that for beams from alloy D16-T acceptable values of magnitude of k have to be no less than 5-8. This condition necessitates application of steel fittings with calculated resistance of not less than 14-19 t/cm$^2$, which, for instance, requires tensile strength of wire of steel cables of 26-36 t/cm$^2$. In reality native industry puts out steel cables useful for prestressed structures with tensile strength of wire not higher than 19-20 t/cm$^2$, and production of high-strength hot-rolled round steel beams still just beginning. Therefore, prestress of separate beams from aluminum alloy D16-T at present is practically unrealizable. Shown limitation drops for beams from less strong alloys, for instance, from alloy AMg6 with calculated resistance of 1,350 kg/cm$^2$, since in this case it is possible to obtain steel fittings with strength 5-8 times more than for aluminum alloy. Here it is possible to realize lowering of weight of beam by 25% and lowering of weight of whole truss by 8-10%. However, practical application of such precompressed beam is also inapplicable owing to development of excessively large deformations. Specific elongation of aluminum reinforced by steel of beams increases to 0.3-0.5% and more, then, as for precompressed steel beams, this magnitude does not exceed 0.1-0.15%. Shown increase of deformations is impermissible, because prestress of separate beams should be executed by factory-producer, and therefore, the possibility of control of deformations in process of assembling of constructions is excluded.

Everything said regarding separate precompressed beams pertains also to trusses with prestressed ties on lower boom, as per Fig. 1b, since lower boom with prestressed tie differs from separate precompressed beam by only variable magnitude of stress.

As can be seen from that presented, not all schemes of prestressed trusses developed for steel structures are applicable in structures from aluminum alloys. Thus, it is impossible to recommend for application trusses with separate precompressed beams and ties within limits of dimension of truss. For obtaining of large effect, obviously, one should dispose straining elements with respect to rigid part of structure in such a manner that prestress creates state of strain of reverse sign in all or in majority of beams of truss. Such prestress not only will allow us to regulate effort in beams of truss and in large measure will promote lowering of expenditure of materials and cost of construction, but also will give us possibility of regulating deformation in process of raising of structure. All these requirements are satisfied by trusses with straining elements carried beyond the limits of dimensions of basic structure: trusses with "tied arch" and strutted trusses (Fig. 1c and d).

## 2. Trusses of "Tied Arch" Type

There were studied trusses with span of 30, 36, and 45 m with spacing of 6 and 12 m under full calculated load of 250 kg/m (dead rated load of 100 kg/m$^2$ with with coefficient of overload 1.1 and rated snow load of 100 kg/m$^2$ with coefficient of overload 1.4). Diagrams of trusses are shown in Fig. 2. Outline of all prestressed trusses is taken as two sloping surfaces with parallel contour of booms. Lattice triangular with additional struts for decrease of flexibility of upper boom and struts. Length of panel of basic lattice figured on upper boom is 3 m. Height of truss between axes of boom is 1/12-1/12.5 of span, i.e., the same as for analogous steel trusses with "tied prestressed arch." Pitch of booms is 1/7-1/8.

Cross sections of trusses with span of 30 and 36 m are single-webbed, mainly from two angles with beads disposed in a tee. Upper boom of truss with span of 36 m

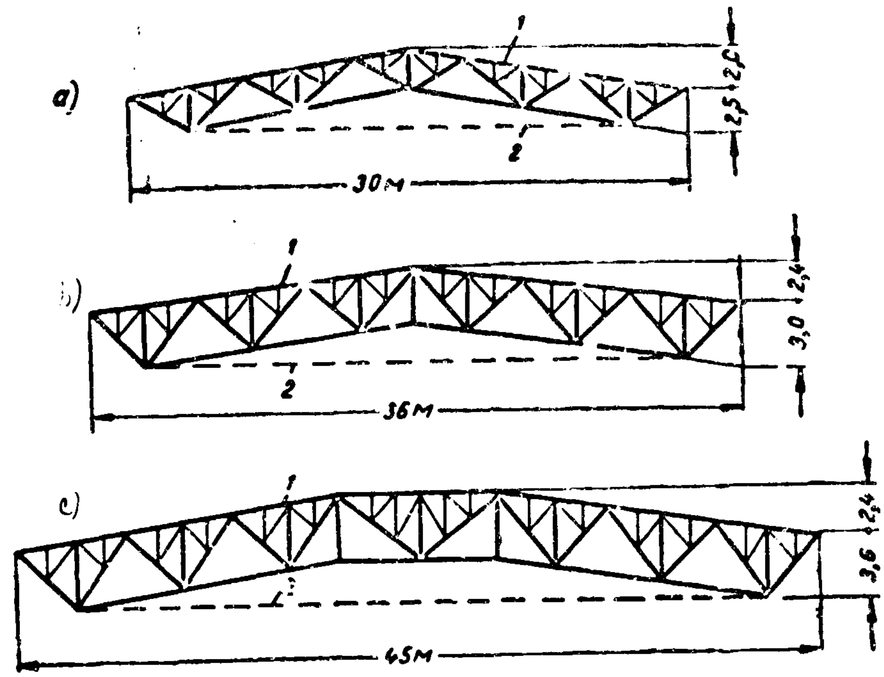


Fig. 2. Diagrams of prestressed roof trusses from aluminum alloys
a) span of 30 m; b) span of 36 m; c) span of 45 m;
1) basic structure from aluminum alloy; 2) straining elements from high-strength steel cable.

is planned in two variants - from angles and from tee profile with beads; lower boom - also in two variants - from angles and from special box-like profile. Cross sections of beams of 45-meter span are taken as double-webbed from two beaded angles with flanges turned to opposite sides. Material of basic structure of trusses of all considered spans - alloy AMg6; furthermore, there are considered trusses with span of 45 m from stronger alloy D16-T.

Tying of trusses is done with steel cable of factory manufacture with rigid core with tensile strength of wire of 17-19 t/cm$^2$. Ties are terminated by anchor devices of sleeve type, constituting cylindrical sleeve of steel St 3 with conical cavity on which is wound end of cable, untwisted to separate wires and degreased. Cavity of heated sleeve is filled with melted babbit. Before installation on site, cables are drawn for not less than one hour by force exceeding that calculated by 20%.

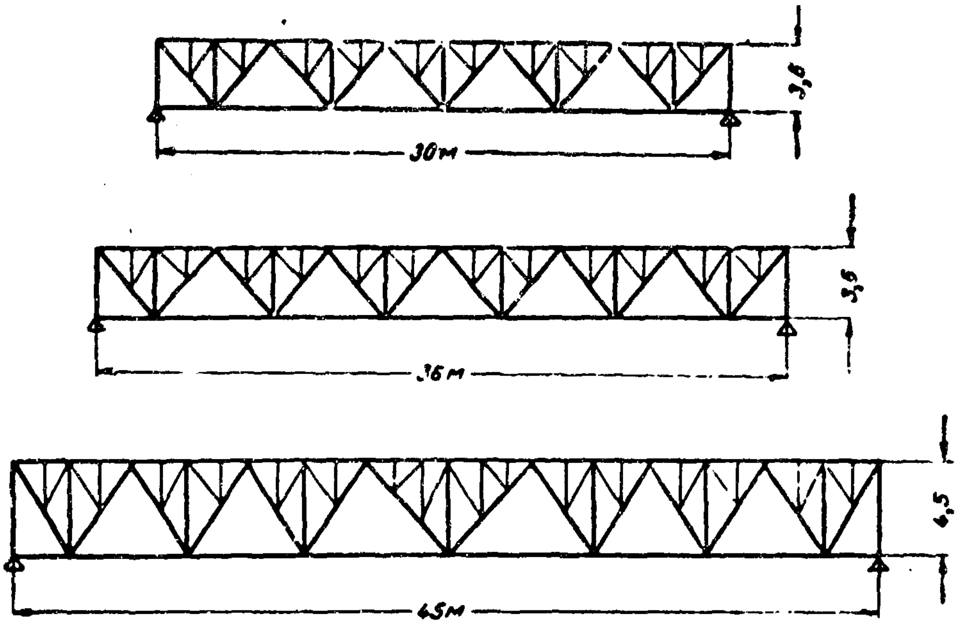


Fig. 3. Diagrams of roof trusses from aluminum alloys without stress.

Tension of cables on trusses is produced by different equipment. Selection of tension equipment depends on required tensile stress. The most suited are hydraulic pulling devices (rods with junction boxes NIIPS [Scientific Research Institute on Industrial Construction] or sleeves) or pushing jacks. Detailed description of methods and equipment for prestressing of metallic structures is given in work of one of authors of article [3].

After pulling of ties in lower boom of arched trusses there can appear compressing forces, therefore, during designing there was provided fastening with joints of lower booms of trusses at each 6 m in lateral plane.

In order to estimate effect of prestress we determined expenditure of materials, weight and deflection of trusses with "tied arch" and of trusses with parallel booms without prestress, as per Fig. 3. To this end there was performed full static and constructional calculation of prestressed trusses and there were made drawings to scale of technical project, on the basis of which there was determined requirement of aluminum alloy and steel cable. During calculation of weight of trusses there was considered structural coefficient of 1.1 for welded single-webbed

Table 2. Expenditure of Materials and Weight of Prestressed Roof Trusses From Aluminum Alloys

| Пролет фермы в м (a) | Шаг ферм в м (b) | Сплав (c) | Соединения (d) | Расход материалов в кг (e) | | Общий вес в кг (h) |
|---|---|---|---|---|---|---|
| | | | | алюминиевый сплав (f) | стальной канат (g) | |
| 30 | 6 | AMg6 | Сварка (i) | 850 | 92 | 942 |
| 30 | 12 | AMg6 | Сварка | 1410 | 152 | 1562 |
| 36 | | AMg6 | Сварка | 1153 | 121 | 1274 |
| 36 | 12 | AMg6 | Сварка | 2090 | 275 | 2365 |
| 45 | 12 | AMg6 | Сварка | 3480 | 440 | 3920 |
| 45 | 12 | D16-T | Заклепки (j) | 2200 | 440 | 2640 |

KEY: (a) Span of trusses in m; (b) Spacing of trusses in m; (c) Alloy; (d) Joints; (e) Expenditure of materials in kg; (f) aluminum alloy; (g) steel cable; (h) Total weight in kg; (i) Welding; (j) Rivets.

trusses, 1.15 for riveted single-webbed, and 1.2 for riveted double-webbed trusses.

Trusses without prestress were designed from the same alloys, for identical loads, and with identical types of cross sections as truss with prestress. Detailed data on trusses without prestresses are given in article of one of authors published in this collection [4]. From this article there are taken data on weight of trusses obtained as a result of development of working drawings.

Information about expenditure of metal and weight of prestressed trusses is given in Table 2. In Fig. 4 there is depicted graphically the influence of prestress on weight of trusses from alloy AMg6.

Analysis of given data allowed us to establish the following.

Prestressed trusses with "tied arch," as compared to trusses with parallel booms without prestress, reduce expenditure of aluminum alloys by 15-24% and are lighter in weight by 5-15%.

Economic effect of prestress is increased with increase of calculated stresses, or the very same occurs with increase of spans and spacing of trusses. Thus, prestress of truss with span of 30 m with spacing of 6 m gives us possibility to save only 15% of aluminum alloy AMg6 and to lower total weight of girder by 5%. Increase of load and stresses by 2 times with preservation of the same 30-meter span is accompanied by growth of economy of aluminum alloy to 20% and lowering of total weight to 12%.

With transition from truss with span of 30 m to 45-meter truss calculated for identical load effect of prestress is increased: requirement in aluminum alloy is reduced to 24% and weight of truss is eased by 15%.

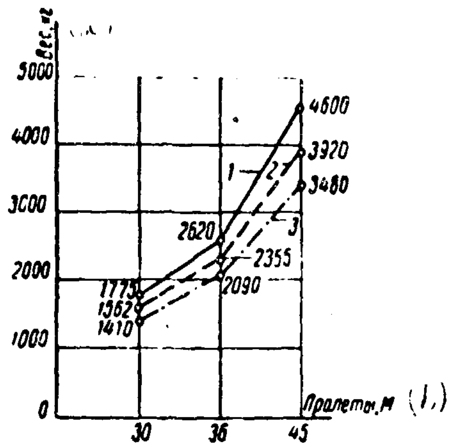


Fig. 4. Weight of roof trusses from aluminum alloy AMg6 (spacing of trusses is 12 m) 1) truss without prestress; 2) prestressed truss; 3) weight of aluminum alloy in prestressed form.
KEY: (a) Weight in kg; (b) Spans in m.

It is necessary to note that lowering of cost of prestressed aluminum trusses occurs more intensely than lowering of weight. This is explained by replacement of part of aluminum alloy by cheaper and stronger steel cable.

In trusses with span over 36 m application is justified of high-strength aluminum alloys of type D16-T. Thus, prestressed truss with span of 45 m from alloy D16-T is 22% lighter and requires 36% less aluminum alloy than such a truss from alloy AMg6.

In Fig. 5 there are depicted loading diagrams - deflections of average joint of prestressed truss with "tied arch" having span of 45 m. Fig. 5a, pertains to truss from alloy AMg6. Fig. 5b, characterizes build-up of deflection of truss from alloy D16-T. Diagrams reflect following sequence of prestress and loading of trusses. Tie is directly included in work of a truss, then there is applied constant load, after that there is produced tension of tie and net (snow) load is applied. Tensile stress of tie of truss from alloy AMg6 is taken at 50 t, and for truss from alloy D16-T — 45 and 30 t.

Diagrams (Fig. 5) explain how by tension of tie it is possible to regulate deformation of truss. Thus, if one were to change tensile stress of tie from

30 to 45 t, deflection of truss from alloy D16-T decreases from 1/180 to 1/280 of span (readings of deflection are from initial position of truss before loading and tension). These diagrams also show that height of basic structure of truss with "tied arch" equal to 1/12.5 of span derived from steel prestressed trusses satisfies requirements of rigidity of trusses from alloy AMg6 (deflection from normative snow load was found at 1/440 of span, but it is insufficient for trusses from twice - stronger alloy D16-T. It is obvious that height of prestressed trusses from alloy D16-T should be designated at not less than 1/11 - 1/10 of span.

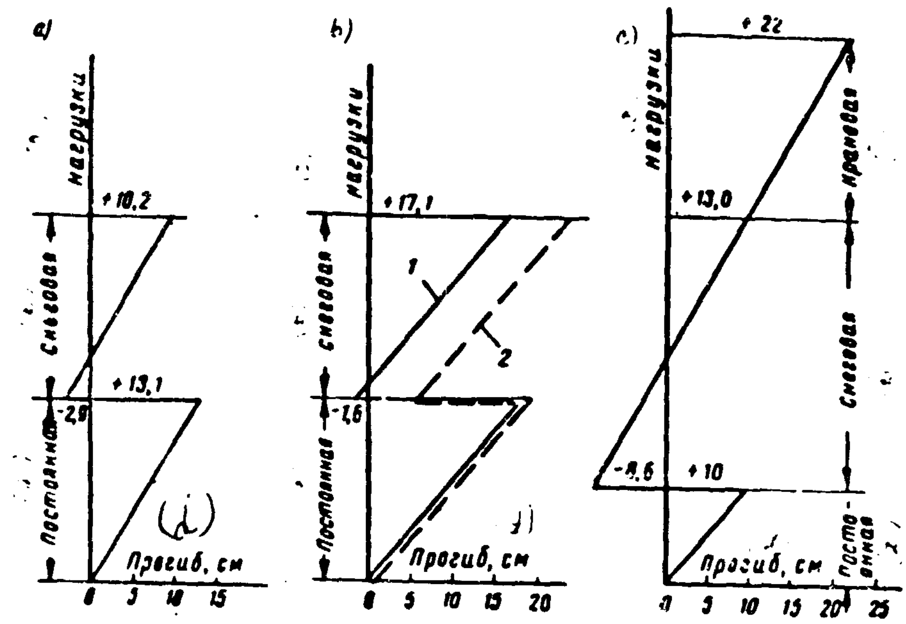


Fig. 5. Deflections of average joint of prestressed trusses from aluminum alloys
a) truss with span of 45 m from alloy AMg6, tensile stress of tie 50 t; b) truss with span of 45 m from alloy D16-T (1 - tensile stress of tie 45 t; 2) tensile stress of tie 30 t); c) truss - crossbar of prestressed combined frame with span of 60 m.
KEY: (a) Dead; (b) Snow; (c) Load; (d) Deflection in cm; (e) Crane.

Trusses with "tied arch" are static indeterminable systems. In such systems with variations of temperature there appear additional stresses. Coefficient of linear expansion of aluminum alloys is 2 times more than for steel. Therefore, it is necessary to detect magnitude of temperature stresses in trusses from aluminum alloys with ties of steel, which is necessary to determine whether these stresses must be considered during designing of trusses. Calculation of trusses with "tied arch" with span of 30 m with temperature drop of 50° revealed change of calculated stress in tie of + 6.5%. Small change of stresses under the influence of thermal effects is explained by the fact that the elastic modulus of aluminum alloys, three times less than for steel, compensates influence of twice-larger (than for steel) coefficient of linear expansion.

### 3. Transverse Frame of Combined Structure For Industrial Building With Upper-Suspension Cranes

Transverse frame of building with span of 60 m consists of reinforced concrete columns and roof truss-crossbar (Fig. 6). Linkage of truss with columns is hinged. Transverse frames are located with spacing of 24 m. Frames bear load from weight of covering, snow, and from multiple-seated upper-suspension cranes with load capacity of 15 t. Net loads at first are transmitted to intermediate transverse trusses of covering with span of 12 m, then to longitudinal five-span truss (5 X 24 m) and, at last, to main truss-crossbars of frame.

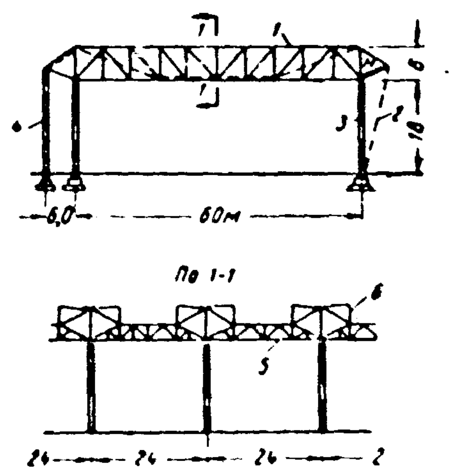


Fig. 6. Diagram of combined prestressed frame with span of 60 m
1) truss-crossbar from alloy D16-T; 2) steel cable; 3) reinforced concrete column; 4) suspension web plate; 5) longitudinal truss; 6) connecting piece.

Enclosing structures of coverings are from two-layered aluminum panels with 1.5 X 6 m dimensions heated by foam plastic. Such panels are 24 times lighter than covering with reinforced concrete panels, foamy cement heater, and Ruberoid sheet, which very favorably affects lowering of weight of supporting roof of large-span structures. It is necessary to note that sharp lowering of weight of enclosing structures is attained with comparatively small appreciating of the enclosure. Construction of panels is slated for factory manufacture .*

*For detailed description of large-span building with aluminum prestressed superstructures see work of authors [6].

Main girder-crossbar of frame is made from heat treated aluminum alloy D16-T with basic calculated strength of 2650 kg/cm$^2$. Height of truss was varied from 6 to 7.2 m and from considerations of assurance of sufficient rigidity it was taken at 7.2 m. Lattice of truss is diagonal with descending struts. Length of panel was also varied from 4 to 6 m, and 6 m was selected for the purpose of decrease of quantity of joints on assembly. Excessive height of truss necessitates transport of it from factory-producer to place of assembling in separate lengths, therefore, a great volume of nodal joints is transferred from factory to assembly site. This circumstance impelled us to adopt least labor-consuming assembly joints on pre-stressed high-strength bolts from heat treated alloyed steel 40 Kh.

Cross section of booms and support struts are designed from box-like pressed profiles with one partially open side. Basic dimensions of profiles are 400 X 400 mm, thickness of web plates from 5 to 12 mm. In box-like profile material is efficiently distributed through cross section, which promotes increase of strength of compressed rods. Furthermore, box-like section of beams permits convenient fastening of gussets, while presence of open side allows us to start high-strength bolts in place. For assurance of local strength web plates of box-like profile are reinforced from within by longitudinal shelves with height of 30 mm. Cross sections of less-loaded beams of lattice are composed of two channels with walls turned to oppostie sides.

Prestress of frames is created by two steel cables with diameter of 55 mm from wire with tensile strength of 190 kg/mm$^2$.

Cables are passed along center part of lower boom of truss, then are led off obliquely upwards to terminal joints of upper boom of truss, and after this they are bent around outside of crossbar and column and are secured behind base of columns or through suspension web behind a special foundation (Fig. 6). Cables rise together with truss, but are strained after assembling of metallic structures and plates of covering. Tension of cables is produced by sleeves, pulled downward by hydraulic jacks in places of fastening cables to columns simultaneously from both ends. Tensile stress of both cables for truss with height of 7.2 m by means of test attempts was selected at 80 t (for truss with height of 6 m optimum tensile stress turned out to be 100 t). In parallel with designing of frame with aluminum crossbar there was developed a design of analogous combined frame with steel crossbar of steel 15KhSND under load from covering with reinforced concrete large-panel flooring heated by foamy cement and with Ruberoid roof. In this case tensile stress of cables had to be 350 t.

Tension of cables very significantly affects magnitude of calculated stresses in beams of truss-crossbar. Stresses decrease: in upper boom by 23-35%, in struts and uprights by 35-50%. Calculated stresses in lower boom are balanced and become 2-4 times less than stresses in lower boom of truss without prestress. So significant a decrease of stresses in lower boom is explained by double pinch effect of it during tension of cable, first, from bending of entire truss upwards by tie, secondly, from compressing forces transmitted through M elements to support assemblies of truss. Thanks to these M beams (Fig. 6) terminal panels of upper boom are relieved of additional compressing stresses appearing in trusses with prestressed tie within limits of dimension of basic structure.

Offered scheme of prestress allows us to regulate not only stress, but deformation also. In Fig. 5c there is shown diagram of deflection of average joint of truss in process of tensing and loading. From diagram it follows that deflection from dead load is equal to 10 cm. Pretension of cables eliminates this deflection and bends truss upwards by 8.6 cm. After application of full time of load, deflection of truss downwards, reckoning from initial position, reaches 22 cm, of which 9 cm constitutes deflection from crane load. Changing force and sequence of tension of cables, it is possible to artificially regulate deformation of truss-crossbar.

Peculiarity of considered transverse frame of buildings is application of reinforced concrete, combined columns. This became possible owing to sharp lowering of weight of structures of covering and thanks to hinged linkage of crossbar with columns.

In Table 3 there are given data on weight of normal and prestressed truss-crossbars from aluminum alloy D16-T and from low-alloy steel 15KhSND. In Table 4 there is analogous data on frame as a whole.

Data on expenditure of materials was obtained on the basis of experimental designing.

From Table 3 it is clear that prestress allowed us to reduce expenditure of aluminum alloy on truss by 32% and gave us lowering of its overall weight of 23%. Aluminum prestressed truss turned out to be 5.5 times lighter than normal steel riveted truss in project of Giproaviaprom [State Institute for the Design and Planning of Aircraft Plants] [7] and 4.3 times lighter than welded truss of NIIPS [8]. Such great reduction of weight of aluminum prestressed trusses is explained not only as influence of prestress and low volumetric weight of aluminum alloy, but also sharp decrease of weight of enclosing structures.

Comparison of expenditure of materials and weight of transverse frames as a whole (Table 4) reveals concurrent capability of combined prestressed transverse frame with aluminum crossbar-truss and reinforced concrete combined columns.

Combined transverse frame with metallic crossbar and reinforced concrete columns quite completely and originally reveals positive peculiarities of the whole idea of prestress. But this structure is not free from deficiencies: location of cables outside uprights of frame forces walls of building to outside in such a manner that cables turned out to be inside building (walls here are expediently suspended from consoles of trusses), but in this case size of building may be unduly increased, or it becomes necessary to take special measures for protection of cables from atmospheric influences with location of them outside building.

Table 3. Weight of Truss-Crossbar of Frame With Span of 60 m

| Truss | Enclosing structures | Weight | |
|---|---|---|---|
| | | t | % |
| Without prestress, from steel 15KhSND, riveted according to design of Giproaviaprom | Steel flooring with light heater | 70 | 100 |
| The same, welded according to design of NIIPS | Reinforced concrete plates heated by foamy cement | 54.76 | 78 |
| Without prestress, from alloy D16-T, riveted | Two-layered aluinum plates heated by foam plastic | 16.6 | 24 |
| Prestressed, from alloy D16-T, riveted | The same | 12.7* | 18 |

*Including 2.45 t of steel cable.

Table 4. Weight of Transverse Frames With Span of 60 m

| Frame | Weight, in t | | |
|---|---|---|---|
| | Girder | Column | Frame |
| Without prestress, all of steel 15KhSND, truss riveted according to designed of Giproaviaproma . . | 70 | 22 | 144 |
| Without prestress, all of steel 15KhSND, truss welded according to design of NIIPS . . . . . . . | 54.76 | 22 | 98.76 |
| Without prestress, truss from alloy D16-T, columns of steel 15KhSND . . . . . . . . . . . . | 16.6 | 19 | 54.6 |
| Prestressed, combined (truss from alloy D16-T, reinforced concrete columns) . . . . . . . | 12.7 | 21 | 53.7 |

## 4. Conclusions

1. Prestress is in principle a new, effective means of saving material and control of stresses and deformations of open structures from aluminum alloys. The most valuable results of prestress of aluminum structures - possibility of control of deformations and lowering of weight.

2. Technico-economic effect of prestress of open aluminum structures is caused by artificial creation of initial state of strain of reverse sign by means of tension of high-strength steel fittings. Straining elements should be disposed in such a way that in process of prestress in all or in majority of beams of structure there appear stresses of reverse sign. Therefore there should be recommended for application in coverings of industrial buildings trusses with ties and struts extending beyond the limits of basic structure: trusses with "tied arch," strutted trusses, truss-crossbars of combined transverse frames.

3. Positive economic effect of application of prestressed trusses from aluminum alloys increases with increase of spans of structures.

4. The most favorable prospects are offered by prestress of combined structures from aluminum, high-strength steel, and reinforced concrete.

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## ON QUESTION OF DETERMINATION OF COST OF PRESSED PROFILES FOR BUILDING PARTS

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One of basic obstacles to wide application of aluminum parts in construction remains their high cost. Cost of metal constitutes a very large part of cost of aluminum structures.

One of methods of lowering cost of structures from aluminum alloys is selection of the most economical pressed profiles.

According to aluminum factories the cost of 1 t of pressed profiles similar in assignment to profiles for building parts varies within considerable limits (to 5 times and more, and labor-consumingness to 20 times).

Basic technological factors affecting cost and labor-consumingness of manufacture of profile from aluminum alloy are: brand of alloy, transverse and longitudinal geometry of profile, method of pressing, tools, heat treatment, productivity of press, size of order, and several others.

Not remaining on description of technological process of production of profiles from aluminum alloys by pressing, description of which is given in a number of literary sources [1] and [2], the attention of designers should be turned to below-mentioned conditions:

1. Productivity of process first of all depends on given output speed of metal through die and on method of pressing.

Especially high productivity is obtained by heavy press with pressing of profile in die with several holes.

Least productivity is obtained by press with pressing of profiles of variable section (method of pressing in combined die) and hollow profiles with application of die with protruding ridge (in factories this is called "tongue die").

2. Labor-consuming nature of straightening operation of longitudinal and especially transverse geometry first of all depends on configuration of profile, and then on grade of alloy.

Correction of longitudinal geometry by extension on expansible machine is the most productive method of straightening and ensures accuracy of longitudinal geometry on order of 1-2 mm per 1 running meter.

Distortions of geometry of cross section are straightened on roller machine manually. If profile has large distortions, this operation can exceed, in labor-consumption, all remaining operations.

Profiles with various thicknesses of wall and flanges during pressing have very large distortions of longitudinal geometry (profile emerges twisted), since metal in cuts of die of different thickness flows with different speed.

3. Expenditures on tool (equipment of working part of press) and their share in workshop prime cost of profile vary within significant limits (from 2 to 50% and more), depending upon method of manufacture, type of tool, and size of order.

Considering high cost of tool prepared from expensive high-strength steels, designers, especially in initial period of mastering of production and introduction of aluminum into building practice, have to strive to apply the most economical mass profiles, resorting, in exceptional cases, to section of profile which is complicated in methods of manufacture.

Analysis of technological charts on manufacture of different profiles in factories of the aluminum industry (analogous in assignment to profiles of the building assortment) allowed us to outline a number of coefficients, with help of which it is possible to consider, with variant designing of structures, the influence of separate above-indicated factors on labor consumption and cost of profile.

Coefficients offered in this article for labor-consumption and cost ($k_{Tp}$ and $k_{CT}$) should be considered as coefficients of first approximations, which will be subjected to more precise determination in process of further accumulation of experience and study of technology of manufacture of pressed profiles for building purposes.

## Coefficients Considering Influence of Grade of Alloy ($k^{MC}$)

Influence of grade of alloy on labor-consuming nature of manufacture of one and the same profile is considered the coefficient obtained as a result of comparison of labor-consumption of manufacture of profile from different groups of alloys with labor-consumption of manufacture of profile from duralumin D16-T, taken as one.

Coefficients of labor-consumption

| Profile from alloy: | $k^{MC}_{Tp}$ |
|---|---|
| duralumin of type D16-T | 1 |
| types AV and AD | 0.7 |
| magnalium group of type AMg6-T | 1.1 |
| the same, type AMg61 | 1.4 |

Cost Coefficients Depending on Grade of Alloy

| Blank from alloy ingot: | $k^{MC}_{CT}$ |
|---|---|
| D16-T | 1 |
| AV-T1 | 1.18 |
| AD31-1 | 1.21 |
| AMg6-T | 1.34 |
| AMg61 | 1.50 |

## Coefficients Considering Influence of Configuration of Profile ($k^{T}$)

Influence of transverse geometry of profile on labor-consuming nature of its manufacture can be determined by means of comparison of labor-consumption of manufacture of given profile with labor-consumption of manufacture of profile taken as standard.

From analysis of structures of experimental designing and from recommendation of technologists of factories preparing profile metal, as a standard for determination of technological effectiveness we take profile of angular section with dimensions 125 X 125 X 10 mm (area of cross section, 24.11 $cm^2$).

Having grouped profiles by principle of influence of transverse geometry on labor-consuming nature of process of their manufacture into six basic groups, we calculated, in order of first approximation, the coefficients of technological effectiveness of profiles in respect to labor-consumption $k^{T}_{Tp}$ and cost of treatment of profile $k^{T}_{CT}$ (Table 1).

Here one should consider that coefficients $k^{T}_{CT}$ and $k^{T}_{Tp}$ are not proportional, since cost coefficient of technological effectiveness considers influence of a number of factors not depending on and not proportional to amounts of labor expenditures; these are: expenditure on electric power, on manufacture of tool, on package, on packing etc.

For profiles prepared from an alloy other than group of alloys of type D16-T, $k^{T}_{Tp}$ and $k^{T}_{CT}$ have to be multiplied by corresponding coefficients $k^{MC}_{Tp}$ and $k^{MC}_{CT}$ depending on grade of alloy.

For tentative calculation of cost of profile with variant of designing, it is necessary in design calculation of cost of manufacture of profile taken as standard, to introduce recommended coefficients corresponding to that group of profiles to which planned profile, belongs, and to that alloy from which structure is to be built.

Depending upon alloy, in calculation the percentage of yield of suitable metal of semifinished product changes.*

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*Data on change of percentage of yield of suitable metal, depending upon grade of alloy, technological group of profile, and area of cross section of profile(within each group, are not given in this article.

Table 1. Coefficients of Labor-Consumption and Cost of Different Groups of Profiles From Alloy D16-T, Depending on Technological Factors

| No. of group | Characteristic of group of profiles | Coefficient of labor-consumption $k^{T}_{Tp}$ | Cost coefficient $k^{T}$[illegible] |
|---|---|---|---|
| Standard I | Corner profile 125 X 125 X 10 mm . | 1 | 1 |
| | Corner profiles, tees with thickness of wall of 5-10 mm . . . . . . . | 1.35 | 1.25 |
| | Beaded corner profiles, type of channels and I-beam with thickness of wall: | | |
| II | more than 10 mm . . . . . . . . . | 1.5 | 1.35 |
| III | less than 10 mm . . . . . . . . . | 1.8 | 1.5—2 |
| IV | Profiles with different thicknesses of elements of section . . . . . . . . | 3 | 2—2.5 |
| V | Profiles with large scattering of dimensions of elements of section . . | 3.6 | 2.5—3 |
| VI | Thin-walled profiles of box-like section and tubing . . . . . . . . . | 5 | 3—5 |

By the shown method, for instance, there was calculated cost of 1 t of profile of group III from alloy AMg6.

Results of comparison of its cost and cost of standard profile are given in Table 2. If one were to consider that expenditures on metal constitute nearly 70% of cost of building part concerned, it is possible to assume that planned structure will be almost 65% more expensive than structure from angle metal in alloy D16-T.

Data given in Tables 1 and 2 are tentative and will change in time with improvement of technology of manufacture of profiles, increase of wages, reduction of cost of ingots and of different grades of alloys. However, given method of calculation of cost of pressed profiles is valid with other values of coefficients and relative costs given in this article.

Table 2. Comparative Calculation of Cost (in Percents of Production Cost of Standard) Profiles From Aluminum Alloys

| No. | Elements of expenditures | Cost in % of production cost of standard | |
|---|---|---|---|
| | | Standard-corner 125 X 125 X 10 mm from alloy D16-T | Profile of group III (Table 1) from alloy AMg6-T |
| 1 | Blank (ingot) | 150 | 182 |
| 2 | Waste | 79 | 52 |
| 3 | Cost of metal, net (item 1 after subtracting item 2) | 71 | 130 |
| 4 | Electric power | 5 | 5 |
| 5 | Special equipment (tool | 2 | 4.5 |
| 6 | Wages of industrial workers, workshop and all-factory expenditures | 14.5 | 41 |
| 7 | Packing and package | 3.5 | 2.5 |
| 8 | Factory prime cost | 96 | 183 |
| | Commercial expenditures | 1 | 2 |
| 9 | Commercial cost | 97 | 145 |
| | Planning capital | 3 | 5 |
| | Output cost (sum of items 3-9). | 100 | 190 |

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