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A BASIS FOR THE SELECTION OF THE ALLOY GRADE
FOR ALUMINUM BRIDGE STRUCTURES

by

S. A. Popov

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Having examined the basic and additional factors which effect the choice of a grade of alloy, we can justifiably select them for aluminum structures for different purpose. Help in making such a selection is provided by the data complied by the author ~~in Table 13~~, in which values are given for the relative estimation of the properties of aluminum alloys suitable for manufacturing bearing structure or combining enclosing functions as well. The estimation of sheet and profile metal is given either in general, or separately [for those alloys for which the performance of sheets or their quality differs from the performance (quality) of the shaped metal].

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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

* ye initially, after vowels, and after ъ, ь; e 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.

Acronyms and Abbreviations

СНиП	—	Construction Norms and Regulations
ТУ	—	Technical Specifications
ГОСТ	—	All Union State Standard
ТУ МХП	—	Technical Specifications Ministry of Chemical Industry
НИИ Мостов	—	Scientific Research Institute of Bridge Construction
ЛИИЖТ	—	Leningrad Institute of Railroad Transportation Engineers
АМТУ	—	Metallurgical Technical Specifications

A BASIS FOR THE SELECTION OF THE ALLOY GRADE FOR ALUMINUM BRIDGE STRUCTURES

GENERAL RECOMMENDATIONS

S. A. Popov, Doctor of Technical Sciences

In the selection of the alloy grade for a construction it is necessary to proceed soundly, taking into account not only low weight and high strength, but also the rest of the properties of the metal - deformativity, durability, plasticity, manufacturability, and the service conditions of the material in the structure (the presence of a corrosive environment, shock effects, stress concentrators, etc.). In so doing, the principles of selection of the alloy grade for the enclosing and bearing structures can be different.

For bearing structures one should not be attracted to the use of excessively high-strength alloys which, as a rule, are less corrosion resistant, have reduced durability (an increase in the tensile strength of such alloys is not usually accompanied by a proportional increase in the fatigue limits), are sensitive to shock loads and concentrators.

It is necessary to strive to design aluminum bearing structures for strength, by simultaneously observing the requirements of rigidity. To do this, it is necessary to reexamine the structural forms of aluminum structures in accordance with the recommendations of the author [1, 2] and other researchers [4, 9, 10, 12]. The selection of the grade of alloy plays a major role, whereby in recent years abroad there has been a marked change from alloys of the type of duraluminum to the more technologically effective avials, magnaliums or alloys with zinc, especially for welded structures.

In remarking on the working features of material in construction, the majority of the authors (A. Kh. Khokharin [3], V. P. Sukhanov and S. A. Tamashev [4] et al.) indicated only part of the properties influencing the selection of the grade of aluminum alloy. The degree of influence of these properties depends upon the purpose of the construction: some of them are important for enclosures, others (durability, cold resistance, and others) - for bridges which are located in the north of the country. Therefore one must take into account all properties of alloys for bridge constructions recommended by Construction Norms and Regulations СНиП II-В.5-64 and the Technical Specifications [ТУ] [5].

COMPARATIVE ESTIMATION OF ALLOYS DURING THEIR WORK ACCORDING TO FIRST AND SECOND LIMITING STATES

When selecting the grade of alloys, in the first place, it is necessary to evaluate the strength, stability, and durability of the basic aluminum alloys which determine their bearing strength according to the first limiting state.

By comparing these alloys with one another, it is possible to relate their strength, stability, and durability to the static strength of the strongest of the traditional alloys recommended by СНиП - Д16-Т and thus to evaluate the relative bearing strength of these alloys (as compared with the strongest).

Table 1 gives a comparison of the strength of aluminum of the basic grades (sheets and profiles). In the numerator there is shown R_o in kgf/cm^2, in the denominator - the R_o ratio (in percent) for the given alloy to R_o for the alloy Д16-Т. The asterisk designates strength of clad duralumin sheets.

Table 1.

Form of Article	Alloy grade							
	АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
Profiles	1400/54	1800/69	1700/65	1600/62	1900/73	2500/96	1950/75	2600/100
Sheets	1400/54	1600/62	1700/65	1600/62	1700/65	1900/73	1800*/69	2400*/92

By comparing constructions from different alloys with each other only in respect to static strength, we can evaluate the expenditure of metal for the construction, by using Table 1. In such a calculation this expenditure will be inversely proportional to the relative strength of the material.

But on the bearing ability of the aluminum construction, calculated from the first limiting state, stability and durability of its component elements exerts a great influence.

When evaluating the effects of stability of elements on the bearing strength of constructions made from different alloys, as a criterion it is advantageous to use not simply the bearing strength reduction ratio ϕ given in СНиП and ТУ, taking into account the initial distortion and random eccentricities, but also the product of $R_o\phi$, where R_o - the basic rated strength for pressed profiles from the given alloy.

Table 2 gives the values of products $R_o\phi$ for eight compared alloys and an estimation of their strength is given (in the denominator) in relative figures (in % to the static strength of profiles made from alloy Д16-Т). The values of the ϕ ratio have been taken for aluminum bridge structures [5].

Table 2.

Flexibility λ	Grade of alloy							
	АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
	$R_o\phi$							
0	1400/54	1800/68	1700/65	1600/62	1900/73	2500/96	1950/75	2600/100
40	1080/42	1305/50	1230/47	1160/45	1200/46	1615/42	1265/48	1680/65
50	910/35	1120/43	1050/40	995/38	1000/38	1300/50	1060/41	1350/52
60	770/30	900/35	850/33	800/31	805/31	1040/40	865/33	1050/42
70	615/24	730/28	687/26	647/25	558/25	810/31	715/28	810/32
80	490/19	605/23	570/22	537/21	536/21	650/25	592/23	575/26
90	420/16	495/19	468/18	440/17	456/18	525/20	502/19	535/20
100	350/13	415/16	391/15	368/14	390/15	425/16	400/15	442/17

As can be seen from Table 2, the bearing strength ($R_o\phi$) of compressed aluminum rods is considerably inferior to the bearing strength of elongated ones (see Table 1), especially in flexibility exceeding 80-100, in connection with which, the use in the building constructions of compressed aluminum rods with a flexibility of 100 and more (and in bridges - a flexibility of more than 80) is even inexpedient and not allowed by the norms.

Estimation of the effect of the durability of material on bearing strength is especially important for bridge structures which work under a load under considerably more severe conditions as compared with the majority of building structures.

The criterion of estimation of the effect of durability on bearing strength is the product of γR_0, where R_0 - the basic rated strength, and γ - the rated reduction ratio in calculations on durability [5].

Table 3 gives the values of factor γ for the basic grades of aluminum with various values of the coefficient of cycle asymmetry ρ, the product γR_0, and also an estimation of the durability of the parent metal of the elements (far from nodes and joints) with a value of the effective coefficient of concentration $\beta = 1.0$ and with preferred elongation.

As can be seen from the last four lines in Table 3, the durability of high-strength alloys increases not proportionally to the growth in strength: where $\rho = -1$ durability of profiles made from B92-T and Д16-T alloys proves to be even less than the durability of elements made from the less durable alloy Д1-T, and where $\rho = 0$ and $\rho = 0.1$ the durability of elements of all three alloys is approximately identical. Therefore in bridges, especially railroad bridges whose elements require checking for durability, the application of more durable alloys instead of less durable does not always give the expected effects (a reduction in the weight of metal). This depends upon the system of span structure and weight ratio of the elements, in the calculation of which it is respectively necessary and not necessary to introduce the coefficient γ.

For justification of the selection of a grade of alloy it is necessary also to consider deformativity of structures made of various grades of aluminum in order to estimate their working from the point of view of the second limiting state.

Table 3.

Characteristic		Grade of alloy							
		АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
R_0, kgf/cm^2		1400	1800	1700	1600	1900	2500	1950	2600
a		0,96	0,96	0,79	1,04	1,04	1,14	0,82	1,14
b		0,25	0,25	0,29	0,32	0,32	0,26	0,23	0,26
γ	$\rho=-1$	0,522	0,522	0,634	0,506	0,506	0,596	0,440	0,440
	$\rho=0$	0,827	0,827	0,928	0,735	0,735	0,715	0,952	0,715
	$\rho=0{,}1$	0,875	0,875	0,971	0,775	0,775	0,765	1,01	0,765
	$\rho=0{,}25$	0,971	0,971	1,040	0,848	0,848	0,848	1,11	0,848
γR_0	$\rho=-1$	730	940	1080	810	960	1100	1190	1145
	$\rho=0$	1160	1490	1580	1175	1400	1790	1855	1860
	$\rho=0{,}1$	1230	1575	1650	1240	1470	1915	1950	1990
	$\rho=0{,}25$	1360	1750	1700	1355	1610	2120	1950	2200
$\frac{\gamma R_0}{R_0^{Д16\text{-}Т}}$, %	$\rho=-1$	28	36	48	31	37	42	46	44
	$\rho=0$	45	57	61	45	54	69	71	72
	$\rho=0{,}1$	47	61	64	48	57	74	75	77
	$\rho=0{,}25$	52	67	65	52	62	82	75	85

With the complete utilization of rated strength, trusses made of aluminum of the stronger grades will have greater deformativity since their elements have smaller areas of cross section which enter into the denominator of Mohr's formula.

Allowing only for static strength, the reduction of the areas of cross section and the increase in the total sag of the trusses will be proportional to an increase in the rated strength of the alloy (see Table 1).

However, a reduction of areas of cross section of elements is restricted in actual trusses in addition to the general requirements of rigidity of trusses and again to the requirements of general and local stability, by checking on the durability of elements, etc. Therefore, in actual trusses the expenditure of metal and their deformativity are not proportional to the change in rated strength, as is shown in Table 1, but differ somewhat from this regularity in reserve rigidity as a result of the effect of factors of stability, and durability, and others on the area of section of the elements.

If we consider that one half of the elements of trusses work on compressing with an average flexibility of $\lambda = 60$, and the second half of the elements work on durability with preferred elongation (where $\rho = 0.1$) and that the area of cross section of these elements will be increased inversely proportional to the products of $R_0\phi$ and γR_0 taken from Table 2 (when $\lambda = 60$) and Table 3 (where $\rho = 0.1$), then the expenditure of metal in the truss will be increased inversely proportional to the third line in Table 4, and the sag of such trusses will be inversely proportional to the last line in Table 4, where an estimation is made of the deformativity of trusses made from different alloys in % (the deformativity of trusses made from aluminum AMr6 is taken as 100%).

The least sag was obtained for a truss made from the alloy AMr6: it had the greatest expenditure of metal and, therefore, the lowest (line 3) estimate in respect to its expenditure. The sag

Table 4.

Characteristic	Grade of alloy							
	АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
Estimate of stability ($\lambda=60$) . . .	30	35	33	31	31	40	33	42
Estimate of durability ($\rho=+0,1$) . . .	47	61	64	48	57	74	75	77
Total estimation of the expenditure of metal	77	96	97	79	88	114	108	119
Estimation of deformativity (in % of a truss made from АМг6) . .	100	80	79	98	87	68	71	65

of the rest of the trusses will be greater than for АМг6; consequently, the estimation of their deformativity turns out to be lower (line 4).

Analysis of the deformativity of aluminum rod structures shows that very great maximum theoretical values of their deformations are not actually attained as a result of the unavoidable effect of constructional factor (the estimate of stability, durability and other factors) on an increase in areas of cross section of elements and the accompanying reduction in sag.

ESTIMATING THE CHARACTERISTICS OF REALIZATION AND WORKING OF A CONNECTION

Recommendations in regard to the choice of the grade of alloy necessarily must be supplemented by an estimation of the static strength and durability of riveted, bolted and welded connections of elements from alloys of different grades.

The static strength of riveted connections always can be provided for; however, in this case one must take into account the weakening of sections by the rivet holes by 15% (factory rivets), and for field connections - a reduction in the quality of field connections by 10%.

An estimation of the static strength of factory butt joints is given in Table 5, the durability of riveted and bolted joints - in Table 6 and welded butt joints - in Table 7. Here the effective coefficients of concentration have been taken as equal to 1.2 for butt welded and 1.4 for riveted and regular bolted connections. The durability of welded lap joints proves to be considerably lower than the durability of butt joints, in connection with which for critical aluminum structures (bridges) lap joints are not recommended.

Table 5.

Characteristics	Type of welding	Grade of the base metal							
		АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
		Grade of additional alloy							
		АМг6	АМг61	СвАК5	СвАК5	СвАК5	В92 / СвАК5	В61, АК	В61, АК
Estimation of the strength of connection, in % of strength of base metal	Manual	90—100	93	47—56	58—70	51—52	83—85	—	—
	Semi-automatic	92—100	83	—	72	—	—	—	—
	Automatic	96 / 100	85 / 88	57 / 66	66 / 71	66 / 71	74—95 / 56—66	60—70	60—75
рсв СНиП, %		100	89	59	62	53	68 / 60	—	—
Butt to butt $R^{св}$		1400	1600	1000	1000	1000	1700 / 1500	—	—

A comparison of the data in Tables 6 and 7 makes it possible to reach very interesting conclusions regarding the efficiency of one or another form of connection for an alloy of a specific grade. Thus, for elements made of alloy AMr working on durability, it is more expedient to use welded joints since the product of γR_0 for those cases of alternating and variable load (ρ = -1.0-+0.25) proves

Table 6.

Characteristic		Grade of structure alloy: АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
		Grade of rivet alloy: АМг6	АМг61	АВ-Т1	АД33-Т1	АД33-Т1	В92-Т	Д-18-Т1 В65-Т	Д18-Т1 В65-Т
R_o, Kgf/cm²		1400	1800	1700	1600	1900	2500	1950	2600
a		0,96	0,96	0,79	1,04	1,04	1,14	0,84	1,14
b		0,25	0,25	0,29	0,32	0,32	0,26	0,35	0,26
γ	$\rho=-1$	0,370	0,370	0,450	0,312	0,342	0,312	0,376	0,312
	$\rho=0$	0,625	0,625	0,715	0,562	0,562	0,538	0,613	0,538
	$\rho=0,1$	0,670	0,670	0,756	0,599	0,599	0,578	0,649	0,578
	$\rho=0,25$	0,750	0,750	0,840	0,667	0,667	0,653	0,715	0,653
γR_o	$\rho=-1$	518	656	765	548	650	780	734	811
	$\rho=0$	875	1125	1215	900	1070	1335	1195	1400
	$\rho=0,1$	937	1205	1285	960	1140	1445	1270	1505
	$\rho=0,25$	1050	1350	1430	1070	1285	1635	1395	1700
$\frac{\gamma R_o}{R_o^{Д16-Т}}$, %	$\rho=-1$	20	25	29	21	25	30	28	31
	$\rho=0$	34	43	47	35	41	51	46	54
	$\rho=0,1$	36	46	50	37	44	56	49	58
	$\rho=0,25$	40	52	55	41	50	63	54	65

Table 7.

Characteristics		Grade of alloy: АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т
$R_o^{cв}$		1400	1600	1000	1000	1000	1700
γ	$\rho=-1$	0,435	0,435	0,526	0,400	0,400	0,365
	$\rho=0$	0,715	0,715	0,806	0,637	0,637	0,613
	$\rho=0,1$	0,764	0,764	0,850	0,675	0,675	0,657
	$\rho=0,25$	0,846	0,846	0,926	0,746	0,745	0,740
γR_o	$\rho=-1$	610	695	526	[illegible]	400	620
	$\rho=0$	1000	1145	806	637	637	1040
	$\rho=0,1$	1170	1225	850	675	675	1120
	$\rho=0,25$	1185	1355	926	746	746	1260
$\frac{\gamma R_o}{R_o^{Д16-Т}}$, %	$\rho=-1$	23	27	20	15	15	24
	$\rho=0$	38	44	31	25	25	40
	$\rho=0,1$	45	47	33	26	26	43
	$\rho=0,25$	46	52	36	29	29	48

to be higher for welded butt joints than for riveted and bolted, in which the section will be still further weakened by rivets or by bolts (the calculation is conducted on γF_{HT}).

For alloy АМг61 the product of γR_0 for all values of ρ are practically identical for welded and riveted (bolted) connections; however, since for the latter there will be weakening of section by rivets or by bolts, welded butt joints of elements made from alloy АМг61, working on durability, are more expedient than the riveted or bolted joints.

For all alloys of the avial type (АВ-Т1, АД33-Т1 and АД35-Т1) the reduction in rated strengths in welding is so significant (see Table 5) that rivets or bolts for connecting the elements of bridges in allowing for durability prove to be more expedient than welding, even despite the weakening of sections by rivets or by bolts (see Tables 6 and 7) for all values of ρ.

Here it must be noted that riveted and bolted connections of elements made from alloys of the avial type may prove to be less economical in allowing for durability than according to the data in Table 6, where the values have been taken for the effective coefficents of concentration $\beta = 1.4$, since the investigations of bridges conducted by the Scientific Institute of Bridge Construction [NII Mostov] (НИИ Мостов) showed that for samples made of alloy АВ-Т1 with an opening $\beta = 1.15$, and for a joint made from alloy АД33-Т1 on rivets from the same material $\beta = 1.80$, which is considerably higher than the standard value $\beta = 1.4$. For riveted connections from alloy Д1-Т the coefficient of $\beta = 1.5$ was obtained, and from alloy АМг61 with rivets of alloy В65-Т the coefficient of $\beta = 1.7$ was obtained [6].

For duralumin СНиП [7] recommends only riveted and bolted connections. Welding of elements from these alloys is not permitted.

Finally, for alloy В92-Т it turns out that elements from profiles with riveted and bolted joints (for profiles R = 2500 kgf/cm^2), allowing for durability, are obtained an expenditure of metal almost equivalent to sheet structures from this alloy (R = 1700 kgf/cm^2) with welded butt joints.

In connection with this, when selecting the type of connection for aluminum structures, it is necessary to give up the template approach (for structures from heat-treatable alloys - only rivets or bolts, for non-heat-treatable alloys - only welding). Selection of the type of connection must be made by taking into account the service conditions of the structure (durability, shock loads, stress concentration) taking into account the data in Tables 6 and 7, and also the conditions of factory preparation of structures and assembly requirements.

As field joints for aluminum structures, the most advisable are high-strength friction bolts.

ESTIMATION OF THE MANUFACTURABILITY OF ALUMINUM ALLOYS

The concept of manufacturability of various aluminum alloys must include, in the first place, simplicity and the absence of technical difficulties in manufacture (pressing and rolling) the semi-finished products (manufacturability in the preparation of the semi-finished products), in the second place, manufacturability in cold working of profiles and sheets (cutting, drilling holes, planing of ends, finishing of weld grooves, etc.,) and, thirdly, manufacturability in the preparation of the connection (weldability).

An estimation of the manufacturability of aluminum alloys under all three headings is given in Table 8.

The concept of manufacturability in pressing aluminum profiles may also include conditionally the possibility of factory preparation of the given profile by means of that equipment which is located at the factory. The conditionality consists of the fact that the

Table 8.

Estimation of manufacturability (in %)		Grade of alloy							
		АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
In rolling (pressing)	Sheets	90	85	100	100	100	85	95	95
	Profiles	63	50	100	100	100	70	70	70
In machining		70	70	70	80	80	80	100	100
In preparation (weldability)	Sheets	95	89	60	65	55	85	50	50
	Profiles	95	89	55	60	55	80	40	40

difficulties in the production of profiles of specific types and grades are more frequently organizational than technological (for example, a given factory may lack the necessary press, and the factory does not specialize in pressing profiles of the given alloy).

The practice of pressing profiles in our factories shows that the obtaining of profiles of any cross section inscribing a circle of 530 mm diameter, from the traditional alloys which have been mastered by our factories, (the alloys Д1-Т, Д16-Т, АВ-Т1) presents no technological difficulties, but it is 1.5 times more costly, and for profiles of 830 mm diameter it is 5 times more costly than for profiles obtained through a die with d = 320 mm.

Profiles with a thickness of wall of more than 4 mm are pressed without special difficulties. The pressing of bridge profiles from alloy АМг61 with sections which inscribe a circle of 530 mm diameter, also do not cause special difficulties, but the cost of profiles from this alloy proves to be 1.5 times higher, while the labor involved in their manufacture is 1.4 times greater as compared with cost and the labor of similar profiles from alloy Д16-Т [8].

If we take the labor involved in the pressing of profiles from the traditional alloy Д16-Т as one, then the labor factor in pressing for the remaining mastered alloys will be for grades АВ and АД - 0.7; for grade АМг6 — 1.1. Depending on the configuration of the profile, the labor in pressing can increase from 1 to 5 times even for the mastered alloy Д16-Т (the factor 5 pertains to thin-walled profiles of box section and tubes) [8].

Alloys of the avial type are pressed more easily than duralumin; alloys АД33 and АД35, and also alloy В92, have already undergone production testing and mastering. A new alloy of this group, grade 01915 differs in its higher speed of pressing and according to this index is more manufacturable.

ESTIMATION OF CORROSION RESISTANCE

When selecting grades of alloys under various operating conditions of structures it is necessary to proceed from the capability of ensuring long service life; therefore it is certainly advisable to consider increasing the resistance of alloys to corrosion even at the expense of a slight reduction in strength indices. An example can be the limitation on the copper content in alloy АВ-Т introduced in 1960, which increases its resistance to corrosion, but lowers rated strength by approximately 100 kgf/cm^2. It is recommended that alloy АВ-Т1 be replaced by alloy АД33-Т1 which does not contain copper and which possesses greater corrosion resistance, but less rated strength [9].

The fact is that high resistance of alloys to corrosion not only lowers maintenance costs during the operating life of the structure, but also leads to a direct reduction in the cost of construction, since the reduction of area of cross section of elements as a result of constant corrosive destruction decreases the strength of the construction and should be taken into account in calculations.

In structures made from corrosion-resistant aluminum alloys during prolonged operation the corrosive destruction penetrates to a depth of not more than 0.05 mm, which with a thickness of 2 mm does not exceed 2.5%. In compression and shear, the bearing strength of thin-walled structural elements is proportional to the cube of the thickness of material, as a result of which a reduction in thickness because of the effect of corrosion sharply reduces the strength of the structure: the reduction in the effective thickness of elements of aluminum structures, usually not exceeding 5%, reduces the compression strength reserve from 100% in all to 72%, while the 20% reduction in thickness which can take place in steel structures gives rise to a drop in the safety factor from 100 to 4% [10]. This, strictly, explains the refusal to employ thicknesses of less than 2 mm in steel structures, whereas for aluminum structures a thickness of 1 mm or less is considered.

Closed and box sections, multiweb elements with openings and others unavailable for maintenance of the element which offer many structural advantages are not usually used in steel structures while aluminum alloys which are corrosion-resistant open wide possibilities in regard to the utilization of these measures for the purpose of increasing strength and reducing the weight of constructions [10].

An estimation of relative corrosion resistance of aluminum alloys is given in Table 9.

Table 9.

Form of articles	Grade of alloys							
	АМг0	АМг61	АВ·Т1	АД33·Т1	АД35·Т1	В92·Т	Д1·Т	Д16·Т
	Corrosion resistance							
Sheets	85	80	70*	85	80	75	60	60
Profiles	85	80	70*	85	80	75	50	50

* With a copper content of less than 0.1% - resistance 80%.

EFFECTS OF THE REMAINING PROPERTIES OF ALUMINUM ALLOYS ON SELECTING THEIR GRADE. ESTIMATION OF THE EFFECTS OF CREEP

Until recently it was considered [1, 3] that the necessity to take into account the phenomenon of creep in structures made from aluminum alloys comes up only under conditions at increased temperatures, since during the working of the structure under conditions where the change in their temperature is from -50 to +60° the phenomenon of creep practically does not take place.

However D. S. Bogoyavlenskiy's recent studies [11] which present the results of a three-year test of creep of elements made from alloy АМг6 at room temperature in tension, compression, and bending showed that the creep of this alloy during compression is approximately 5 times higher than in elongation, and it begins to be noted even under stresses close to rated strength, whereas in elongation during 1000 days creep was observed only under stresses of more than 1825 kgf/cm^2.

In spite of this fact, he has made the encouraging conclusion that creep discovered during the working of a structure in the course of 200 years does not lead to structural failure if the material works under stresses equal to rated strength; however it can lead in the course of 10 years to a reduction of 10-15% in the stability of compression members.

In connection with the properties displayed by alloy АМг6 at room temperature, the effect of creep can be estimated for it by a correction factor of 0.85, while taking this factor for alloy АМг61 as equal to 0.95, and for the remaining alloys - as one, since in them creep of such dimensions has not been established.

ESTIMATION OF THE SENSITIVITY OF ALLOYS TO SHOCK LOADS AND TO STRESS CONCENTRATORS

As experimental studies have shown [12], the impact toughness number of aluminum alloys is highest in commercial aluminum grade A1 (7.5-9.4 kg-m/cm^2), is very high in alloy AMr-M (9 kg-m/cm^2) and lowest in the high-strength alloys (in alloys B95-T1 it amounts to a total of 1.1 kg-m/cm^2). For the rest of the alloys, their values are given in Table 10.

Table 10.

Characteristic	Grade of alloys							
	АМг6	АМг61	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
$a_к$, kg-m./cм^2	4,0	3,5	2,8	3,5	3,0	2,8	2,6	1,9
Estimation,%	100	88	70	88	75	70	65	48

Sensitivity to stress concentrators (notches, openings, weld seams, and others) in high-strength alloys is also considerably increased as compared with the low-strength alloys: it is especially high in alloy grade B95-T1, and lowest - in commercial aluminum alloy A1.

Therefore the estimation provided in Table 10 in respect to indices of impact toughness number can sufficiently adequately characterize the sensitivity of various alloys to the stress concentrators.

As studies made at the NII Mostov of the Leningrad Institute of Railroad Transportation Engineers [LIIZhT] (ЛИИЖТ) [12] have shown, the impact toughness across the rolled product is 20-40% less than the impact toughness along the rolled product (see Table 10). Hardening has practically no effect on the value of impact toughness of the aluminum alloy. With an increase in work hardening, impact toughness is reduced approximately equally for all the aluminum alloys given in Table 10.

ESTIMATION OF THE PLASTICITY OF MATERIAL

The plasticity of material affects both the manufacturability of pressing of semi-finished products and also the working of material in a structure, protecting the material from brittle rupture under load. This plasticity can be estimated from the amount of relative elongation of samples of various alloys which are standardized in All-Union State Standards [GOST] and in Aviation Metallurgical Technical Specifications [AMTU] (pressed profiles, Table 11).

Table 11.

Characteristic	Grade of alloy							
	АМг6-М	АМг61-М	АВ-Т1	АД33-Т1	АД35-Т1	В92-Т	Д1-Т	Д16-Т
% according to ГОСТу & АМТУ	15	11	10	10	10	13	12	10
The same, typical	20–22	11	16	12–15	10–13	15–20	15	12
Estimation of plasticity,%	100	50	73	68	59	91	68	55

When estimating plasticity (in %) 100% is taken as the relative elongation (22%) for the most plastic of the given alloys (АМг6). If we take as 100% the relative elongation (typical or per GOST) of carbon steel of grade St. 3 (23%), then the estimation of the plasticity of aluminum alloys will be still lower. True, as numerous experiments have shown, as well as observations of the working of structures during the period of service, the reduced plasticity (as compared with its values for steel) of aluminum alloys is not expressed in essential form in the working of structures under static and dynamic loads. The maximum permissible work hardening (3%) lowering impact toughness not more than 20%, requires taking minimum radii of bending and straightening of aluminum sheets equal to 16 thickness of the element being bent or straightened [12].

COST ESTIMATE OF ALUMINUM SEMI-FINISHED PRODUCTS

The high cost of aluminum is sometimes considered as one of the main disadvantages in this new building material. However, its cost is a market-controlled value which is dependent on the cost of basic material, electric power, the melting and pressing technology employed, and will change with time in connection with reduction of prices of electric power (since 1965, all the main aluminum combines have received the cheapest hydroelectric power) and the reduction in the cost of ingots, the perfection of technology of manufacturing profiles, and the reduction in prices of new grades of alloys, etc.

Therefore, it is also advantageous to estimate the cost of semi-finished products not in absolute values (roubles) but in relative (in %). Such an estimation also will not be free from errors, but they will be, as a rule, of a second order of smallnesses and will be insignificantly expressed in a relative estimation of semi-finished products from the various grades of alloys.

The question of the cost of semi-finished products and metal has been examined by various authors. Thus, A. Kh. Khokharin [3] compared the cost of the semi-finished products of different brands on a ten-point system; N. G. Malinina [8] pointed out that the cost of billets from various alloys (the cost of ingots) can be estimated by using cost factors depending on the grades of the alloys. V. P. Sukhanov and S. A. Timashev [4] compiled from foreign data (thin sheets up to 1.4 mm and plate) a graph of the dependence of the cost of semi-finished products upon the strength of alloys. For plate, they obtained a direct dependence, since strength, just as cost, depends on the quantity of alloying additives as well as the volume of the thermal and mechanical treatment of the semi-finished products. From this, the authors reached the conclusion that economic factors contribute to the preferred use of alloys of average strength.

In the author's book [1], besides the cost of semi-finished products, the point is also made that the cost of bridge constructions from aluminum, takes into account the costs of factor preparation, assembly, transport, scaffoldings, temporary structures, and overhead costs which then affect the wholesale price lists.

Today, it is necessary to estimate the cost of semi-finished products made from aluminum in accordance with price list No. 02-06 of wholesale values for rolled-drawn and pressed articles from non-ferrous metal and alloys effective 1 July 1967. These prices are given in Table 12 in roubles per ton: for sheets - in width up to 1.5 m and thickness of 3-5 mm and above; for profiles - II (average complexity), solid (without openings) in area cross-section from 25 to 90 cm^2; for tubes - with diameter of 91-140 mm with thickness of wall of 5-9 mm.

Table 12.

Range	Grade of alloy						
	АМг6	АМг61	АВ-Т1	АД33-Т1 АД35-Т1	В92-Т	Д1-Т	Д16-Т
Sheets, roubles	1200	1420	1100	1200	1400	890	900
The same, %	74	62	81	74	64	100	99
Profiles, roubles	1450	1190	1010	950	1550	920	1010
The same, %	61	60	88	94	57	97	88
Tubes, roubles	1380	3800	990	1400	1550	900	980
The same, %	64	23	90	64	57	99	91
Tubes Ø=221–280 10-15 mm, roubles	1350	1770	960	950	1200	890	950
The same, %	66	50	93	94	74	100	91

Prices in Table 12 are given without surcharge (i.e., for an order of not less than 500 kg of an article of one form with length of sheets 4 m, tubes 5.5 m, profiles 6 m). With an order for less than 500 kg, a 10-20% surcharge is collected and for a length of profiles from 6 up to 9 m - a 10% surcharge, from 9 up to 12 m - 20% surcharge, and for more than 12 m - 30%. The cost of artificial aging (60-70 roubles per ton of finished product) is not included in the costs given in Table 12.

Besides the [illegible]t in roubles in ever line (for sheets, profiles, and tubes) the cost estimate is given in percent: expensive articles are rated at a lower percent inversely proportional to the cost of 1 ton of sheets from alloy Д1-T taken as 100%.

The cost of transport and assembly (disassembly) of structures also acts as an additional factor affecting the choice of the grade of the alloy.

Since the cost of transport is directly proportional to the weight of the metal, we can consider that other conditions being equal, without allowing for stability and fatigue limit, the weight of structures from alloys of different grades is inversely proportional to the strength of the alloy (structures from a more durable alloy weighs less and requires less expenses for transport and assembly). Therefore, transport and assembling expenses can be approximately estimated (relatively in %) in accordance with the data in Table 1, since disregarding the effect of the phenomena of stability and durability on these expenses leads to certain error which, it is true, in a comparison of alloys of different grades is on the second order of smallness.

RECOMMENDATIONS FOR SELECTION OF THE GRADE OF ALLOY

Having examined the basic and additional factors which effect the choice of a grade of alloy, we can justifiably select them for aluminum structures for different purpose.

Help in making such a selection is provided by the data compiled by the author in Table 13, in which values are given for the relative estimation of the properties of aluminum alloys suitable for manufacture bearing structures or combining enclosing functions as well. The estimation of sheet (1) and profile (2) metal is given either in general, or separately [for those alloys for which the performance of sheets or their quality differs from the performance (quality) of the shaped metal].

Table 13.

Property characteristic	Grade and state of alloy — Form of semifinished product															
	AMr6		AMr61		AB T1		AД33-T1		AД35-T1		B92-T		[illegible]		Д16-T	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
I. Estimation of Properties of the Parent Metal																
1. Static strength	54	54	62	69	65	65	62	62	65	73	73	96	69	75	92	100
2. General stability of compression members (when $\lambda = 60$).		30		35		33		31		31		40		33		42
3. Durability of elements (when $\rho = 0.1$)		47		61		64		48		57		74		75		77
4. Deformativity of structure		100		60		70		98		87		68		71		65
5. Effect of creep		85		95		100		100		100		100		100		100
6. Sensitivity to shock loads and concentrators		100		88		70		88		75		70		65		48
7. Plasticity of material		100		50		73		66		59		91		68		55
II. Estimation of Properties of the Connection																
1. Static strength:																
a) factory riveted		85		95		85		85		85		95		85		85
b) butt welded	100		89		59		62		53		68			—		—
2. Durability (when $\rho = 0.1$):																
a) riveted		36		46		59		37		44		56		40		58
b) butt welded	45		47		33		26		26		43			—		—
III. Estimation of Manufacturability																
1. In pressing (rolling)	90	63	85	50	100	100	100	100	100	100	85	70	95	70	95	70
2. In cold working of metal	70	70	70	70	70	70	80	80	80	80	80	80	100	100	100	100
3. In preparation (weldability)	95	95	89	89	60	55	65	60	55	55	85	80	50	40	50	40
IV. Estimation of Corrosion Resistance	85	85	80	80	70	70	85	85	80	80	75	75	60	50	60	50
V. Estimation of Cost:																
a) semifinished products	74	61	62	60	81	83	74	94	74	94	64	57	100	97	99	85
b) transport and assembling expenses	54	54	62	69	65	65	62	62	65	73	73	96	69	75	92	100

Table 13 is constructed so that the large figure in the table corresponds to a positive property of the alloy: that alloy can be considered best which has a large sum of evaluations of all its properties (in % or, which is the same thing, in points on the hundred-point scale).

However, simple addition of all estimates in a vertical line for each alloy will be incorrect not only because the properties enumerated in Table 13 are nonequivalent, but also because for each particular case (riveted or fabricated structure) not all estimations should be taken into account, but only those pertaining to a given form of connection.

Using Table 13, we can soundly select the alloy of the grade necessary for a structure for any purpose which is being designed under any local conditions, by taking into account these requirements and all features of the properties of the given alloy. In so doing, one ought to take into account the recommendations in Table 4 of СНиП II-В.5-64 [7].

For constructions which combine bearing and enclosing functions, СНиП most highly recommends alloys АМГ, АД31-Т (less loaded) and АД31-Т1, АД33-Т, АД33-Т1 (more loaded elements); it is also possible to use grades АД35-Т and АВ-Т.

For supporting structural and bridge structures which do not require increased corrosion resistance, it is possible to use alloy Д1-Т (riveted constructions). Under average and high corrosion requirements for welded and riveted constructions alloys АМг5 and АД33-Т1 are recommended, but it is possible to use АМг6 and АВ-Т1.

For critical riveted structures of permanent bridges which do not require increased corrosion resistance, it is possible to recommend mainly alloy Д1-Т.

Alloy Д16-Т can be recommended for structures in which it is required to use high strength and light weight, but for which questions of rigidity or durability are not of serious significance (prefabricated highway bridges, exhibition pavilions, drilling derricks, stock storage structures, high superstructure coverings of hangars, stadiums, etc.).

For critical constructions which require increased corrosion resistance, it is best to use chrome-aluminum alloys АД35-Т and АД33-Т1 (avials), and also alloy Б92-Т (riveted constructions) or АМг61 and В92-Т (welded sheet constructions).

For draw bridges which are usually constructed in large cities and require the observance of strict standards of rigidity, the use of avial type alloys is advantageous and even alloys of the АМг type (magnalium).

For the riveted span structures of temporary bridges which work under corrosion-free conditions, if sheetmetal predominates in the structure, it is advantageous to use alloy Д16-Т, and with a preferred preponderance of pressed profiles - alloy Д1-Т with rivets of alloy Д18-Т.

In the manufacture of riveted structures predominantly from pressed profiles avial type alloys (АД35-Т1 and АВ-Т1) and duralumin type (Д16-Т and Д1-Т) are practically identically valuable. In this respect alloy АД35-Т1 is more resistant to corrosion and the construction made from it (with rivets of alloy АД33-Т1) is more durable. Therefore, preference should be given to it for structures intended for operation in a corrosion hazardous atmosphere or for prolonged service life.

For welded bridge structures one should recommend alloy АМг61, and for weld seams - semi-hardened welding wire of 1.6-5 mm diameter from the same alloy or from aluminum-magnesium alloy per Structural Technical Regulations [STU] 13-5-58 with argon arc welding of composition No. 1 per Technical Regulations of the Ministry of Chemical Industry TU MKhP 4315-54.

If any of the versions calls for a combination of welded structures of pressed profiles or tubes, then in this case it is possible to recommend the use of alloy В92-Т, and for weld seams - welding wire from the metal. In this case it is possible to allow the use of not only machine welding with a melting electrode, but also hand welding with a tungsten electrode taking into account in the calculations the decrease in the strength of the weld joints (including butt welds) as compared with the strength of the parent metal.

For permanent bridges it is most advantageous to use: for riveted structures - alloy АД35-Т1 with rivets made of alloy АД33-Т1; this alloy is equally advisable for use in sheet structures and in structures with a preponderance of pressed profiles because of its manufacturability and long service life; for welded structures - alloy В92-Т with welding wire of the same material (with a combination of sheets and pressed profiles). For sheet welded structures, alloys АМг6 or АМг61 should be recommended, and for weld seams - semi-hardened welding wire of 1.6-5 mm diameter made from the same alloy. Today, for building constructions special grades of aluminum alloys are being developed which are relatively low in cost, possess good weldability and corrosion resistance and relatively high strength (АМг4 type aluminum-zinc alloy of the 01915 type and others); however as yet it is difficult to hope, that in the immediate years welding in aluminum constructions will occupy the same monopolistic position which it occupies in steel constructions.

Therefore the use of specific grades of alloys for riveted constructions, rivets, and bolts will remain the same for a certain period of time, and further perfection of both these grades of alloys and the forms of connections of aluminum constructions with them is necessary.

For welded connections, the following are used as welding wire and filler material: in structures made from alloy АМц - wire from the same alloy; in structures made from alloys of the АМг type - wire from magnalium with a higher magnesium content as compared with the parent metal or from the parent metal (for alloys АМг6 and АМг61); in structures from alloys of avial type of all grades - wire of the AK type; in structures from В92 alloys - wire made from the same alloy.

For rivets, alloys Д18 or В65 are recommended (for structures from duralumin type alloys) and alloy АД33-Т (for structures made from magnalium), АД33-Т1 (for structures from avials) and Д16 and В94 (for structures from duralumin and alloy В95).

For high-strength bolts heat-treated steel with tensile strength not below 100 kgf/mm^2 the following are used: grade St. 5 per GOST 380-60, grade 35 per GOST 1050-60, and alloy steel 40 Kh per GOST 4543-48 with tensile strength of 120 kgf/mm^2.

For bolts with compression rings (lock-bolts, rivet-bolts) for rod bolts of rigid alloy are used, for example, В65, and for the compression ring - plastic alloy, for example, АВ.

In special cases, with the corresponding technical and economical foundation, it is possible to allow the use of high-strength В95 alloys (with rivets from alloy В94), but in this case one must take into account their reduced resistance to shock loads and stress concentrators and their other characteristics noted above.

Bibliography

1. Попов С. А. Строительные конструкции из алюминиевых сплавов М., изд-во «Высшая школа», 1963.

2. Попов С. А. Некоторые вопросы проектирования разводных мостов из алюминиевых сплавов. Труды МИИТа, вып. 227 «Исследование новых конструкций и условий эксплуатации металлических мостов», М., изд-во «Транспорт», 1966, стр. 91—106.

3. Хохарин А. Х. О выборе марки алюминиевого сплава для строительных конструкций и изделий. «Промышленное строительство», 1962, № 1, стр. 54—56.

Bibliography (Continued)

4. Суханов В. П., Тимашев С. А. К выбору марки алюминиевого сплава для строительных конструкций. «Промышленное строительство», 1962 № 8, стр. 35--38.

5. Попов С. А. Основные положения Технических условий проектирования мостов из алюминиевых сплавов (дополнения и изменения к СН 200-62) Труды МИИТа, вып. 227 «Исследование новых конструкций и условий эксплуатации металлических мостов», М., изд-во «Транспорт», 1966, стр. 29—67.

6. Новожилова Н. И. О выносливости авиалей в клепаных и болтовых соединениях. Труды ЛИИЖТа, вып. 208, ТЖДИ, Л., 1963, стр. 167—18[illegible]

7. СНиП II-В.5-64. Алюминиевые конструкции. Нормы проектирования М., Госстройиздат, 1965.

8. Малинина Н. Г. К вопросу установления стоимости прессованных профилей для строительных конструкций. В сб. ЦНИИСК «Строительные конструкции из алюминиевых сплавов» под ред. проф. С. В. Тарановского. М. Госстройиздат, 1962, стр. 334—338.

9 Тарановский С. В. Подготовка к широкому применению алюминиевых сплавов в строительстве. «Известия АСиА СССР», 1961, № 3

10. Научно-техническое совещание по эффективному применению и защите от коррозии алюминия и его сплавов. 21—23/XII 1961. Тезисы докладов ВДНХ, М., 1961.

11. Богоявленский Л. С. Исследование ползучести алюминиево-магниевых сплавов (t - 18° С) Труды Воронежского инженерно-строительного института. Сборник № 11, вып. 2. Изд. ВГУ, Воронеж, 1965.

12 Сатаев Ю. И О механических свойствах строительных алюминиевых сплавов и некоторых зависимостях между ними. Труды ЛИИЖТ вып. 208, ТЖДИ, Л., 1963, стр. 157—166.