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## FOREIGN TECHNOLOGY DIVISION



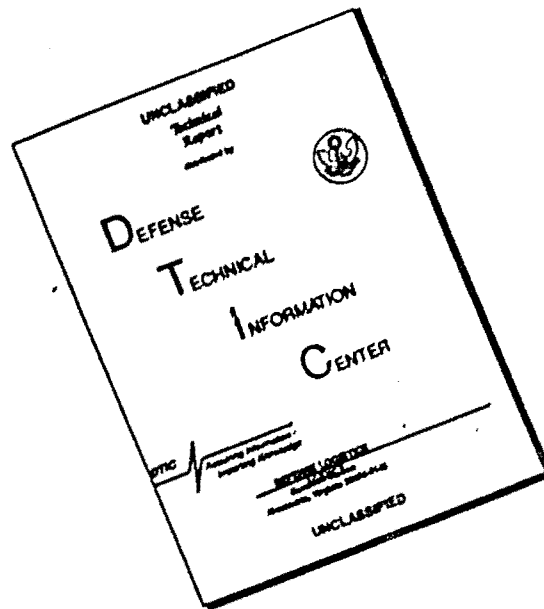
ALUMINUM CASTING ALLOYS, THEIR PROPERTIES, TECHNOLOGY  
OF SMELTING, CASTING, AND HEAT TREATMENT.  
COLLECTION OF ARTICLES



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FTD-MT-24-345-67

# EDITED MACHINE TRANSLATION

ALUMINUM CASTING ALLOYS, THEIR PROPERTIES, TECHNOLOGY  
OF SMELTING, CASTING, AND HEAT TREATMENT. COLLECTION  
OF ARTICLES

English pages: 206

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LITEYNYYE ALYUMINIYEVYYE SPLAVY

(svoystva, tekhnologiya plavki, lit'ya  
i termicheskoy obrabotki)

Sbornik Statey

Pod redaktsiyey

dokt. tekhn. nauk I. N. Fridlyandera  
i kand. tekhn. nauk M. B. Al'tmana

Gosudarstvennoye  
Nauchno-Tekhnicheskoye Izdatel'stvo  
Oborongiz

Moskva - 1961

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DATA HANDLING PAGE				
01-ACCESSION NO. TT8500542	98-DOCUMENT LOC	20-TOPIC TAGS aluminum alloy, heat theory, melting point, metal hardening, heat stress, grain structure, solid solution, solubility, metal crystallization tensile stress, high temperature metal		
09-TITLE BASIC PRINCIPLES OF ALLOYING OF CAST ALUMINUM DEPENDING ON WORKING TEMPERATURE AND THEIR AREA OF APPLICATION				
47-SUBJECT AREA 11				
42-AUTHOR/CO-AUTHORS KOLOBNEV, I. F.				10-DATE OF INFO -----61
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67
				69-PROJECT NO. 72302-78
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76-REEL/FRAME NO. 1884 0689	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 12
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None
STEP NO. 02 UR/2724/61/000/000/0005/0015			ACCESSION NO. TT8500542	
ABSTRACT  This article describes the basic principles of alloying cast aluminum, depending on working temperature and their area of application. Principles of alloying alloys are predetermined by conditions of their work: medium, operation cycle and the value of stresses, temperature and time of its action. The theory of heat resistance of metallic alloys were created. Table 1 gives characteristics of certain structural components in aluminum alloys, and development of alloy ATsR-1, were considered. Typical mechanical properties of casting aluminum alloys are given in Table 2. Orig. art. has: 2 tables.				

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500543		98-DOCUMENT LOC		39-TOPIC TAGS weldability, heat resistance, castability, manganese, copper, solubility, solid mechanical property, titanium, chromium, vanadium, temperature characteristic	
06-TITLE COMPOSITION, STRUCTURE AND PROPERTIES OF ALLOY AL19					
47-SUBJECT AREA 11					
43-AUTHOR/CO-AUTHORS KOLOBNEV, I. F.; SHVYREVA, L. V.; ARISTOVA, N. A.; MISHIN, G. YA.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
				69-PROJECT NO. 72302-78	
63-SECURITY AND DOWNGRADING INFORMATION UNCL, 0			64-CONTROL MARKINGS NONE		97-HEADER CLASN UNCL
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51-STEP NO. 02 UR/2724/61/000/000/0016/0027			ACCESSION NO. TT8500543		

## ABSTRACT

This article describes the development of a new alloy AL19, its composition and structure. The alloy base should be the system aluminum - copper, ensuring highest strength characteristics. A content of copper in the alloy less than 4.5% does not ensure maximum strength and plasticity at room temperature. The component of alloy should have high interatomic bond, minimum coefficient of diffusion in hard aluminum and high solubility at room and operating temperatures 300-350°. The author concludes the given data show that alloy AL19 is distinguished by high heat resistance, high mechanical properties at room temperature and good weldability. However it has lower casting properties, which one should consider when developing casting technique for parts of every type. Orig. art. has: 9 tables and 3 figures.

DATA HANDLING PAGE				
01-ACCESSION NO.	90-DOCUMENT LOC	30-TOPIC TAGS		
TT8500544		metal melting, castability, heat resistance, melting furnace, aluminum alloy, metal casting/(U)aluminum alloy AL19		
09-TITLE MELT AND CASTING TECHNOLOGY OF ALLOY AL19				
47-SUBJECT AREA				
11				
42-AUTHOR/CO-AUTHORS KOLOBNEV, I. F.; MISHIN, G. YA.; ARISTOV, N. A.; SHVYREV, L. V.; MEL'NIKOYA, V. A.				10-DATE OF INFO -----61
43-SOURCE LITEYNYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67
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76-REEL/FRA ME NO.	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA	NO. OF PAGES
1884 0691			UR	9
CONTRACT NO.	X REF ACC. NO.	PUBLISHING DATE	TYPE PRODUCT	REVISION FREQ
94-00	65-		Translation	None
STEP NO.		ACCESSION NO.		
02-UR/2724/61/000/000/0028/0035		TT8500544		
ABSTRACT				
<p>This article describes the melt and casting technology of Alloy AL19. Aluminum and alloys are distinguished by their high chemical activity, during melt they interact with gases of the furnace atmosphere, in the melt gaseous and hard nonmetallic inclusions are formed. Getting into castings, these inclusions lower their strength and density. The author concludes that during preparation of alloy AL19 for preventing of liquation and raised porosity it is necessary to thoroughly mix and refine it. During development of technology of casting parts it is necessary to anticipate intensive feeding, dispersed feed of metal, application of yielding rods. The dimension of air holes and their quantity must be selected taking into account massive places of the casting. It is necessary to consider that the air hole system used during casting of parts from alloys of type Silumin, is unfit for casting from alloy AL19. Alloy AL19 has twice as high a viscosity, therefore very high air holes insufficiently well impregnate the casting. It is expedient frequently to set low air holes of ellipse like section. Orig. art. has: 3 tables and 2 figures.</p>				

## DATA HANDLING PAGE

01-ACCESSION NO.	02-DOCUMENT LOC	03-TOPIC TAGS		
TT8500545		heat treatment, metal deformation, alloy, hardening/(U)aluminum alloy AL19		
04-TITLE NEW HEAT TREATMENT REGIME FOR ALLOY AL19 EN- SURING STABILITY OF DIMEN- SIONS OF CASTINGS <sup>1</sup>				
07-SUBJECT AREA  11				
05-AUTHOR/CO-AUTHORS LOKTIONOVNA, N. A.; RASTVOROVA, N. M.; BERESLAVTSEVA, O. P.; LARIKOVA, M. I.; STROGANOV, G. B.		10-DATE OF INFO -----61		
06-SOURCE LITEYNYE ALYUMINIYEVYIE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)		68-DOCUMENT NO. FTD-MT-24-345-67		
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63-SECURITY AND DOWNGRADING INFORMATION  UNCL, 0		64-CONTROL MARKINGS  NONE		97-HEADER CLASN  UNCL
76-REEL/FRAME NO.  1894 0692	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA  UR	NO. OF PAGES  8
CONTRACT NO.  94-00	X REF ACC. NO.  65-	PUBLISHING DATE	TYPE PRODUCT  Translation	REVISION FREQ  None
STEP NO. UR/2724/61/000/000/0036/0042		ACCESSION NO. TT8500545		

## ABSTRACT

In this article are described results of the development of a new regime of heat treatment of parts of complex configuration made from Alloy AL-19 ensuring stability of geometric dimensions in the process of heat treatment. With section thickness to 75 x 60 mm alloy AL19 practically is not sensitive to a lowering of the cooling rate during hardening. Mechanical properties of castings in freshly hardened state at room temperature practically are not changed with an increase of temperature of the water during hardening from 45 to 96°, when in artificially aged state tensile strength and relative elongation drop somewhat. Mechanical properties at 250° (short-term tests) practically are not changed with an increase of temperature of water during hardening to 96° and do not depend on the form of heat treatment. General corrosion resistance of alloy AL19 hardened in water with a temperature of 45 and 96° practically is identical in freshly hardened state and after artificial aging. Hardening of complex large castings in boiling water creates such insignificant warping of castings that it practically is not required to make any correction after heat treatment. Shift of a series of large complex castings to hardening in boiling water solved the question about a sharp decrease of warping, lowering of difficulty of manufacture and increase of quality of parts made from alloy AL19. Hardening in boiling water preserves the flow diagram of treatment and does not require additional equipment. For hardening in boiling water usual tempering tanks are used with simple additional equipment for heating them. Orig. art. has: 6 tables, 2 fig.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500546	98-DOCUMENT LOC	39-TOPIC TAGS aluminum alloy, manganese, titanium, alloy heat treatment, metal hardening, cast alloy, solid mechanical property		
09-TITLE CASTING ALUMINUM ALLOY VAL <sup>4</sup> (VL15) <sup>1</sup>				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS AL'TMAN, M. B.; LOTAREVA, O. B.; POSTNIKOV, N. S.; SPIRIDONOVA, S. B.				10-DATE OF INFO -----61
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67 69-PROJECT NO. 72302-78
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76-REEL/FRAME NO. 1884 0693	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 8
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE 1	TYPE PRODUCT Translation	REVISION FREQ None
STEP NO. 02		ACCESSION NO. TT8500546		
ABSTRACT <p>This article describes casting of alloy VAL4. The author concludes there has been developed a new highly durable corrosion resistant alloy VAL4 of the system Al-Mg-Zn, which in mechanical properties exceeds in poured and heat treated stite such standard aluminum alloys as AL2, AL6, AL13, AL3, AL9 and AL7. Technological properties of the alloy permit using it for part of complex configuration and various dimensions. The alloy is distinguished by stability of mechanical properties on a section of casting. The alloy responds well to cutting, polishing, welding and soldering, which makes it possible to use it for complex parts of electrical and radio equipment. Orig. art. has: 3 tables and 4 figures.</p>				

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500547		90-DOCUMENT LOC		30-TOPIC TAGS aluminum alloy, corrosion resistance, pressure casting, zirconium, titanium beryllium, manganese	
08-TITLE CAST ALUMINUM- MAGNESIUM ALLOYS					
47-SUBJECT AREA  11					
42-AUTHOR/CO-AUTHORS BELOUSOV, N. N.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
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63-SECURITY AND DOWNGRADING INFORMATION  UNCL, 0			64-CONTROL MARKINGS  NONE		97-HEADER CLASS  UNCL
76-REEL/FRAME NO. 1884 0694	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 15	
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None	
STEP NO. 02 UR/2724/61/000/000/0052/0065			ACCESSION NO. TT8500547		

## ABSTRACT

This article describes the development of a new alloy for casting in sand and metal molds, suitable for casting without heat treatment. The developed alloy for casting under pressure, containing 6-8% Mg; 0.5-1.0% Si; 0.25-0.6% Mn, the rest Al, in terms of strength and corrosion resistance exceeds the widely used alloy AL2 for casting under pressure. The developed alloy for casting in sand and metallic forms contains 6-7% Mg, 0.05-0.1% Be; 0.05-0.15% Ti; 0.05-0.2% Zr; the rest Al, and it is used without heat treatment. During manufacture from aluminum of high purity, strength and corrosion characteristics of the alloy in cast state exceed properties of alloy AL9 and do not yield to alloy AL4 in the heat treated state. Strength characteristics of the alloy are positively influenced by zirconium (0.05-0.2%) and titanium (0.05-0.15%), and corrosion resistance of the alloy by titanium, beryllium (to 0.2%) and manganese (to 0.2%). The group of heat treated alloys of the system Al-Mg proposed for casting of shaped parts with additions of beryllium, zirconium, titanium and manganese based on aluminum of brands A00 and AV000, in terms of constructional strength and corrosion resistance significantly exceed alloy AL8.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500548	98-DOCUMENT LOC	39-TOPIC TAGS tensile stress, metal aging, metal hardening, alloy, solid mechanical property		
09-TITLE INFLUENCE OF NATURAL AND ARTIFICIAL AGING ON MECHANICAL PROPERTIES OF PARTS AND SAMPLES MADE FROM ALLOY AL8				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS LOTAREV, O. B.; LOKTIONOV, L. I.			10-DATE OF INFO -----61	
43-SOURCE LITEYNYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)			68-DOCUMENT NO. FTD-MT-24-345-67	
			69-PROJECT NO. 72302-78	
63-SECURITY AND DOWNGRADING INFORMATION  UNCL, 0		64-CONTROL MARKINGS  NONE	97-HEADER CLASN  UNCL	
76-REEL/FRAE NO. 1884 0695	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 4
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None
STEP NO. 02		ACCESSION NO. TT8500548		
<b>ABSTRACT</b> <p>The article investigates the influence of natural and artificial aging on mechanical properties of parts and samples made from Alloy AL8. Natural aging of alloy AL8 after hardening increases tensile strength and lengthening, especially in the first period of aging (up to 15 months). During aging for up to 40 months, properties remain higher than properties of an alloy not subjected to natural aging. After artificial aging at 100° for 3 hours and holding for 8 months, mechanical properties of alloy AL8 are considerably higher than immediately after hardening. The general level of mechanical properties of alloy of system Al-Mg-Zn is considerably higher than for alloy AL8. Artificial aging at 100° (3 hours), 115° (3 hours), 125° (3 hours) and 150° (3 hours) permits one for 1.5 years to preserve lengthening of hardened alloy Al-Mg-Zn at a level of 50-60% of the initial value of this characteristic. Orig. art. has: 2 tables and 1 figure.</p>				



# DATA HANDLING PAGE

01-ACCESSION NO. TT8500549		99-DOCUMENT LOC		30-TOPIC TAGS tensile stress, alloy heat treatment, solid solution, metal hardening, solid mechanical property	
08-TITLE INFLUENCE OF HEATING ON PROPERTIES OF PARTS MADE FROM ALLOY AL8					
47-SUBJECT AREA 11					
42-AUTHOR/CO-AUTHORS GLAZUNOV, S. G.; LOTAREVA, O. B.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
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63-SECURITY AND DOWNGRADING INFORMATION UNCL, C			64-CONTROL MARKINGS NONE		97-HEADER CLASH UNCL
76-REEL/FRAME NO. 1884 0596	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	N.O. OF PAGES 5	
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## ABSTRACT

This article describes the characteristic peculiarities of heating on properties of parts made from alloy AL8. The solid solution of hardened alloy AL8 at temperatures higher than 100° is unstable, in consequence of which it can easily disintegrate, accompanied by a sharp lowering of mechanical properties. The decrease of plasticity here is so big that the alloy becomes absolutely unfit for usual fields of application (loaded parts, subject to shock influences). Therefore heating of the hardened alloy higher than 100° is absolutely impermissible. Heating at 125° for 5 hours leads to a small increase of tensile strength, a noticeable growth of hardness, and a fall of lengthening. At higher temperatures of heating (150-225°) mechanical properties descend, approaching properties of a thermally untreated alloy. Disintegration of the solid solution can be clearly observed on microsections (at x1500) after heating at 180° for 30 minutes. Orig. art. has: 7 figures.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500550	98-DOCUMENT LOC	39-TOPIC TAGS alloy heat treatment, titanium alloy, beryllium alloy, metal casting, metal melting, solid mechanical property		
09-TITLE TECHNOLOGICAL PECULIARITIES OF MANUFACTURE OF ALLOY AL8				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS KARELOV, G. K.			10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)			68-DOCUMENT NO. FTD-MT-24-345-67	
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63-SECURITY AND DOWNGRADING INFORMATION  UNCL, C		64-CONTROL MARKINGS  NONE		97-HEADER CLASN  UNCL
76-REEL/FRA ME NO. 1884 0697	7-SUPERSEDES ✓	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 5
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None
STEP NO. 02-UR/2724/61/000/000/0075/0078		ACCESSION NO. TT8500550		
ABSTRACT  This article describes the technological peculiarities of manufacture of alloy AL8. The complexities of casting and heat treatment of this alloy has prevented its wide application. On the basis of experimental work the author concludes: the introduction of beryllium and titanium alloy and application of a new flux during melting ensures obtaining good quality casting made from alloy AL8. Application of special paint makes it possible to prepare quality alloy in cast iron crucibles. During strict fulfillment of technology of smelting, casting and heat treatment, mechanical properties of alloy AL8 can considerably exceed the requirements of technical conditions.				

# DATA HANDLING PAGE

61-ACCESSION NO. TT8500551		98-DOCUMENT LOC		39-TOPIC TAGS metal melting, solid mechanical property, metal hardening, metal casting, steel microstructure	
68-TITLE LARGE CASTINGS FROM ALLOY AL8					
47-SUBJECT AREA 11					
42-AUTHOR/CO-AUTHORS PETRUNIK, A. M.				60-DATE OF INFO -----61	
43-SOURCE LITEYNYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
				59-PROJECT NO. 72302-78	
63-SECURITY AND DOWNGRADING INFORMATION UNCL, 0			54-CONTROL MARKINGS NONE		37-HEADER CLASN UNCL
76-REEL/FRAME NO. 1884 0698	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 9	
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None	
STEP NO. 02 UR/2724/61/000/000/0079/0087			ACCESSION NO. TT8500551		

## ABSTRACT

In this article the author concludes: methods of melting and casting of alloy AL8 which ensure good quality large castings are proposed. A composition of core mixture which permits easy punching of cores from castings which does not cause oxidation of the metal in the form in the process of hardening is recommended. The basic influence on mechanical properties of alloy AL8, besides other factors, is its microstructure. Orig. art. has: 2 figures.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500552	98-DOCUMENT LOC	39-TOPIC TAGS metal casting, mechanical fracture, beryllium, titanium, boric acid, corrosion protection		
08-TITLE MEANS OF REMOVING "BLACK FRACTURE" IN CASTINGS MADE FROM ALLOY AL8				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS STEPANOVA, M. G.			10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)			68-DOCUMENT NO. FTD-MT-24-345-67	
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63-SECURITY AND DOWNGRADING INFORMATION  UNCL, 0		64-CONTROL MARKINGS  NONE		97-HEADER CLASS  UNCL
76-REEL/FRAME NO. 1884 0699	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA  UR	NO. OF PAGES  7
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ABSTRACT A process for removing "Black Fracture" in castings made from alloy AL8 was investigated, and the following conclusions were made: 1) Obtaining a clean fracture in a casting made from alloy AL8 with small section (up to 20 mm) is ensured by introduction in the composition of the molding sand of a 4-5% protective addition; 2.) Obtaining a clean fracture for castings of massive section (50 mm and more) is possible only during introduction in the alloy of 0.05% beryllium and a 4-5% protective addition in the molding sand; 3.) As protective addition boric acid or addition VM can be used. Orig. art. has: 2 figures and 4 tables.				

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500553		38-DOCUMENT LOC		39-TOPIC T A S aluminum alloy, solid mechanical property, isothermal flow, metal hardening, plasticity, tensile stress, metal aging	
02-TITLE INCREASING PLASTIC PROPERTIES OF ALLOY B300					
47-SUBJECT AREA 11					
42-AUTHOR/CO-AUTHORS KOLOBNEV, I. F.; LOKTIONOVA, N. A.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYE ALYUMINIYEVYIE SPLAVY; SVOYSTVA, TECHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
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## ABSTRACT

This article describes the increasing plastic properties of alloy B300. In data obtained the author concludes: Alloy B300, containing manganese and chromium at a lower limit in terms of technical conditions, possesses raised plasticity (relative elongation 1.5-2.5%). The content of magnesium in alloy B300 should not exceed 1.2%. Plasticity of alloy B300 may also be increased by application of new conditions of heat treatment. Step heating prior to quenching is recommended: heat at 500° with holding 2-3 hours, then raise temperature to 525-530° with holding 2-3 hours. Cooling during hardening is conducted in saltpeter heated to 250-275°, with holding at this temperature for 5 hours, without subsequent artificial aging. In this case is ensured tensile strength higher than 20 kg/mm<sup>2</sup> and relative elongation 1.2-2% at a value of prolonged strength within the limits of technical conditions. Orig. art. has: 2 figures and 2 tables.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500554	98-DOCUMENT LOC	99-TOPIC TAGS cyclic strength, alloy heat treatment, aluminum alloy, metal hardening		
09-TITLE INCREASING CYCLICAL STRENGTH OF CAST ALUMINUM ALLOYS				
47-SUBJECT AREA 11				
42-AUTHOR/CO-AUTHORS LALAYAN, E. A.; MALINKOVICH, A. N.			10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOCIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)			77-DOCUMENT NO. FTD-MT-24-345-67	
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STEP NO. 02-UR/2724/61/000/000/0099/0110		ACCESSION NO. TT8500554		
<b>ABSTRACT</b> <p>In this article investigations were made of increasing cyclical strength of cast aluminum alloys. The author concludes that cast aluminum alloys AL19 and AL21 after heat treatment possess lower fatigue strength than usual carbon steels. Shot-blast cold hardening is an effective means of increasing the strength of these alloys (fatigue strength increases more than 200%, i.e., approximately to the level of steel 35L). Replacement of steel by highly durable cast aluminum alloys permits a 50-60% lowering of the weight of parts working and cyclical application of loads. Orig. art. has: 2 tables and 9 figures.</p>				

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500555		28-DOCUMENT LOC		39-TOPIC TAGS annealing, pressure casting, aluminum alloy, metal stress, alloy heat treatment	
09-TITLE INFLUENCE OF ANNEALING AND COLD TREATMENT ON STABILITY OF DIMENSIONS OF PRESSURE CASTINGS MADE FROM ALUMINUM ALLOYS					
47-SUBJECT AREA 11					
42-AUTHOR/CO-AUTHORS LOKTIONOVA, N. A.; MANGUBI, N. M.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TECHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
				64-PROJECT NO. 72302-78	
63-SECURITY AND DOWNGRADING INFORMATION UNCL, C			64-CONTROL MARKINGS NONE		97-HEADER CLASN UNCL
76-REEL/FRAME NO. 1884 0702	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NO. OF PAGES 9	
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STEP NO. 02-UR/2724/61/000/000/0111/0117			ACCESSION NO. TT8500555		

## ABSTRACT

In this article investigations were made on the influence of annealing and cold treatment on stability of dimensions of pressure castings made from aluminum alloys. The authors conclusions are: For the purpose of removal of residual stresses it is necessary to subject to annealing all forms of pressure castings made from aluminum alloys of brands AL2, AL3 and AL9. Secondary annealing of parts after machining is necessary in the following cases: a) in the presence of complex contour of parts, and also sharp differences in sections; b) during raised requirements for stability of dimensions of a part; c) during large ratios of machined surface to unmachined. Heat treatment is primary for castings and secondary for certain forms of parts after machining for the purpose of stability of dimensions and should be conducted according to the following conditions: annealing at  $300 \pm 10^{\circ}$ , holding for 2-4 h, cooling in air. Castings and parts during and after annealing, and also during transportation should not be subjected to any external forces as blows, shaking, compression. etc. Treatment at  $-50^{\circ}$  of castings and parts made from aluminum alloys of brands AL2, AL3, AL9, not hardenable by heat treatment, does not affect the value of deformation. Orig. art. has: 1 table and 5 figures.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500556	98-DOCUMENT LOC	39-TOPIC TAGS alloy heat treatment. tin containing alloy, solid mechanical property, metal hardening, steel microstructure, plasticity		
09-TITLE INFLUENCE OF AN IMPURITY OF TIN ON PROPERTIES OF ALLOY AL9 DURING HEAT TREATMENT				
47-SUBJECT AREA 11				
42-AUTHOR/CO-AUTHORS SMIRNOVA, T. I.			10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)			64-DOCUMENT NO. FTD-MT-24-345-67	
			69-PROJECT NO. 72302-78	
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CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None
02-SYEP NO. UR/2724/61/000/000/0118/0124		ACCESSION NO. TT8500556		
ABSTRACT This article investigates the influence of an impurity of tin on properties of alloy AL9 during heat treatment. The authors conclusions were: Tin within the limits of investigated contents of 0.01-0.5% lowers the strength of cast and heat treated alloy AL9, somewhat increasing its plasticity. Increase of ions of chlorine in saltpeter baths from 0.2 to 2.7% lowers strength of samples during heat treatment by 3-4 kg/mm <sup>2</sup> , obviously due to corrosion. Contents of ions of chlorine in saltpeter baths should not exceed 0.3-0.5%. Orig. art. has: 2 tables and 2 figures.				



# DATA HANDLING PAGE

01-ACCESSION NO. TT8500557		98-DOCUMENT LOC		39-TOPIC TAGS steel microstructure, solubility, solid mechanical property, melting point,	
09-TITLE APPLICATION OF FLUXES DURING MELT OF ALUMINUM CASTING ALLOYS					
47-SUBJECT AREA  11					
42-AUTHOR/CO-AUTHORS AL'TMAN, M. B. & SMIRNOVA, T. I.; SYROMYATNIKOVA, M. A.; ITS KOVICH, YE. A.; *				10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE AL'UMINIYEVYYE SPLAVY; SVOYSTVA; TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
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STEP NO. 02 UR/2724/61/000/000/0125/0133			ACCESSION NO. TT8500557		
<p>ABSTRACT #16 Cont. SHTEYMAN, YE. P.</p> <p>The authors conclusions in this article were: The protective action of fluxes (the investigation was conducted on alloy AL9) is ensured by chlorides which improve the wetting ability of fluxes, and fluorides which increase strength of the flux film. Melt under fluxes increases yield of the suitable alloy by 2-6%. Melt under fluxes made from fluoride and chloride salts leads to burning out of magnesium in alloys containing small quantities of this component (AL4, AL9). Treatment of alloys AL1, AL2, AL3, AL4, AL5 and AL9 by fluxes permits obtaining a melt of the same quality as during treatment with chlorine. Castings made from the prementioned alloys, in terms of contamination with nonmetallic impurities (gaseous and solid) completely meet technical specifications, and in terms of mechanical properties, macro- and microstructure they completely fulfill All-Union Government Standard 2685-53. Orig. art. has: 4 figures and 6 tables.</p>					

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500558	98-DOCUMENT LOC	99-TOPIC TAGS elastic oscillation, mechanical fracture, aluminum alloy, degassing niobium		
09-TITLE DEGASSING OF ALUMINUM AND ITS ALLOYS BY ULTRA- SONIC OSCILLATIONS				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS AL'TMAN, M. B.; SLOVIN, V. I.; STROMSKAYA, N. P.; ESKIN, G. I.; LOKTIONOVA, L. I.				10-DATE OF INFO -----61
43-SOURCE LITEYNYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67 69-PROJECT NO. 72302-78
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STEP NO. 02-UR/2724/61/000/000/0134/0143		ACCESSION NO. TT8500558		
ABSTRACT This article investigates the influence of elastic oscillation on the degree of degassing of aluminum melts. The authors conclusions are: Treatment of a melt of aluminum and its alloys by ultrasonic oscillations is an effective method of degassing. Treatment of melt, before pouring in forms, by ultrasonic oscillations increases density and mechanical properties of castings. During treatment of melt by ultrasonics there occurs saturation of the melt by the material of certain vibrators as a result of their dispersion under the influence of elastic oscillations and temperatures. This phenomenon can be used for direct modification and alloying of alloys. It was determined that of tested materials for waveguides the most stable is niobium, which it is possible to recommend for manufacture of waveguides. Orig. art. has: 4 figures and 2 tables.				

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500559		98-DOCUMENT LOC		38-TOPIC TAGS boron, chloride, solid mechanical property, metal casting, aluminum alloy, metal zone refining	
08-TITLE REFINING OF CAST ALUMINUM ALLOYS BY BORON CHLORIDE					
47-SUBJECT AREA  11					
42-AUTHOR/CO-AUTHORS AL'TMAN, M. B.; STROMSKAYA, N. P.; BAYKOVA, L. T.; KOROL'KOVA, L. M.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY				68-DOCUMENT NO. FTD-MT-24-345-67	
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76-REEL/FRAME NO. 1884 0706	77-SUPERSEDES	78-CHANGES	90-GEOGRAPHICAL AREA UR	NO. OF PAGES 6	
CONTRACT NO. 94-00	1 REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None	
STEP NO. 02-UR/2724/61/000/000/0144/0149			ACCESSION NO. TT8500559		
<b>ABSTRACT</b> <p>Refining by boron chloride of alloys AL4, AL10-V, AL1 and AL8 rendered a positive influence on density and mechanical properties of castings. Parts cast from alloys AL4, AL10-V, AL8, refined by boron chloride by density exceed series parts by 1-2 points. Parts with a rough weight near 80 kg poured from alloy AL1 refined by boron chloride, by density and mechanical properties do not yield to similar castings poured with application of the autoclave. The method of refining by boron chloride can be recommended for increasing density of castings made from alloys AL4, AL10-V, AL1 and AL8, and in separate cases in exchange for autoclave when casting parts requiring a density of 2-3 points. Orig. art. has: 1 table and 2 figures.</p>					

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500560	38-DOCUMENT LOC	39-TOPIC TAGS vacuum refining, aluminum alloy, solid mechanical property		
08-TITLE REFINING OF ALUMINUM ALLOYS IN A VACUUM				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS AL'TMAN, M. B.; BAYKOVA, L. T.; KRY SIN, B. T.; KOROL'KOVA, L. M.; SMIRNOVA, T. I.; KITARI, G.*				10-DATE OF INFO -----61
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67
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STEP NO. 02-UR/2724/61/000/000/0150/0156		ACCESSION NO. TT8500560		
<p>ABSTRACT *(42)Authors-Cont - G.; SHITOV, M. I.; SHARUDA, V. F.; TYUKIN, I. T.; SYROMYATNIKOVA, M. A.</p> <p>We developed a method for refining aluminum alloys with application of a vacuum and flux, and we designed and mastered in production a vacuum installation for aluminum alloys, allowing one to refine a melt with a weight of up to 300 kilograms. Refining with the aid of a vacuum lowers porosity of aluminum alloys by 2 points on a 5-point scale of porosity and increases mechanical properties by 10-15%, which permits in a number of cases elimination of crystallization of poured parts in an autoclave. Application of double refining: vacuum with addi- tion of a small quantity of flux (0.20% of the weight of the alloy) increases effectiveness of degassing of aluminum alloys as compared to vacuum treatment without flux. Orig. art. has: 6 figures and 5 tables.</p>				

# DATA HANDLING PAGE

01-ACCESSION NO. TT8500561		02-DOCUMENT LOC		35-TOPIC TAGS solid mechanical property, aluminum alloy, metal casting, metal hardening	
60-TITLE PROPERTIES OF ALUMINUM ALLOYS DURING DIFFERENT METHODS OF CASTING					
47-SUBJECT AREA 11					
42-AUTHOR/CO-AUTHORS LOTAREVA, O. B.; POSTNIKOV, N. S.; LOKTIONOVA, L. I.				10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)				68-DOCUMENT NO. FTD-MT-24-345-67	
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76-REEL/FRAHE NO. 1884 0708	77-SUPERSEDES	78-CHANGES	45-GEOGRAPHICAL AREA UR	NC. OF PAGES 13	
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None	
STEP NO. 02-UR/2724/61/000/000/0157/0170			ACCESSION NO. TT8500561		

## ABSTRACT

Mechanical properties of alloys AL2, AL3, AL4, AL5, AL7, AL8 and AL9, obtained during casting in ethylsilicate molds, by investment patterns and in shell molds, satisfy requirements of All-Union Government Standard 2685-53. Temperature of molds up to 200° comparatively little affects mechanical properties of investigated alloys. At higher temperatures of molds a lowering of mechanical properties is observed. Fluidity of alloys during casting in shell and ethylsilicate molds is somewhat higher than in earthen molds. Mechanical properties of samples 5 mm in diameter made from alloy AL9 during casting in gypsum molds do not differ from properties of this alloy poured in earthen molds. On samples with a diameter of 8 mm and 12 mm a small lowering of mechanical properties is noted. Mechanical properties of alloys AL19 and AL21 decrease during casting in gypsum forms by nearly 10-15%. Heating of gypsum molds lowers mechanical properties of 8 mm and especially 12 mm samples made from these alloys; properties of samples with a diameter of 5 mm are not changed. Fluidity of aluminum alloys during casting in gypsum (cold and heated) molds a few times exceeds the fluidity during casting in earthen molds. Orig. art. has: 7 tables and 6 figures.

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500562		98-DOCUMENT LOC		39-TOPIC TAGS  aluminum alloy, yield strength, gravitation, metal forming, vacuum casting, solid mechanical property, vacuum degassing, steel microstructure
02-TITLE METHODS OF INCREASE OF QUALITY OF A PRECISION CASTING MADE FROM ALUMINUM ALLOYS		47-SUBJECT AREA  11		
42-AUTHOR/CO-AUTHORS SLOTIN, V. I.; 16-EKSIN, G: I.		10-DATE OF INFO -----61		
43-SOURCE LITEYNYYE ALYUMINIYEVYYE SPLAVY; SVOYSTVA, TEKHNLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)		68-DOCUMENT NO. FTD-MT-24-345-67		69-PROJECT NO. 72302-78
63-SECURITY AND DOWNGRADING INFORMATION  UNCL. C			64-CONTROL MARKINGS  NONE	97-HEADER CLASS  UNCL
76-REEL/FRAME NO. 1884 0709	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA  UR	NO. OF PAGES 11
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STEP NO. 02 UR/2724/61/000/000/0171/0180			ACCESSION NO. TT8500562	
ABSTRACT The method of casting turbine rotor disks in gypsum molds permits the most exact reproduction of aerodynamics of profile. During melt of aluminum alloys intended for manufacture of castings of important assignment, ultrasonic degassing turns out to be the most effective method. Ultrasonic treatment in the process of hardening increases mechanical properties and improves the structure of castings. Orig. art. has: 2 tables and 7 figures.				

## DATA HANDLING PAGE

01-ACCESSION NO. TT8500563	98-DOCUMENT LOC	39-TOPIC TAGS metal casting, phenol formaldehyde resin, alloy heat treatment, orthophosphoric acid, resin, phrolysis		
02-TITLE FORMING AND AUXILIAHY MATERIALS USED DURING CASTING IN SHELL FORMS				
47-SUBJECT AREA  11				
42-AUTHOR/CO-AUTHORS ARBUZOV, B. A.; KURAKINA, V. A.		64-DATE OF INFO -----01		
43-SOURCE LITEYNYE ALYUMINIYEVYIE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)		68-DOCUMENT NO. FTD-MP-24-345-67 69-PROJECT NO. 72302-70		
63-SECURITY AND DOWNGRADING INFORMATION  UNCL, 0		64-CONTROL MARKINGS  NONE		37-HEADER CLASS  UNCL
76-REEL/FRAE NO. 1884 0710	77-SUPERSEDES	78-CHANGES	44-GEOGRAPHICAL AREA UR	NO. OF PAGES 10
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STEP NO. UR/2724/61/000/000/0181/0191		ACCESSION NO. TT8500563		

## ABSTRACT

As forming materials for production of quality castings one should use sands washed of clay or sands subjected to heat treatment at a temperature of 800-1000°. Maximum strength properties are attained during the use of sands of brands 1K01A and 1K0063A, in the ratio of 7:3. As binding material for shell forms and cores best results are obtained with the use of drying oil oxidized phenol-formaldehyde resin No. 180. As separating compounds it is possible to recommend methylsilicone oil SKT-3 and SKT-2, still residues during pyrolysis and rectification of methylsilicone polymers. Best wetter additions are an esteraldehyde fraction and furfural in amount of 0.5-1% of the weight of the mixture. The best composition of glue used for gluing shells is as follows:

resin MF-17 (technical specs MKhP 2538-55) 75-85%;

dextrin 25-15%;

orthophosphoric acid (20% solution) 6% over 100%.

Orig. art. has: 5 tables

DATA HANDLING PAGE				
01-ACCESSION NO. TT8500564	98-DOCUMENT LOC	39-TOPIC TAGS resin, sand test, castability, tensile stress, yield strength, porosity, polymerization, metal hardening		
09-TITLE METHODS OF CONTROL AND INVESTIGATION OF SAND-RESIN MIXTURES FOR CASTING IN SHELL MOLDS				
47-SUBJECT AREA 11, 07				
42-AUTHOR/CO-AUTHORS ARBUFOV, B. A. 46-STEPANOVA, N. M.; SOBOLEVA, N. L.			10-DATE OF INFO -----61	
43-SOURCE LITEYNYYE ALYUMINLYEVYYE SPLAVY; SVOYSTVA, TEKHNOLOGIYA PLAVKI, LIT'YA I TERMICHESKOY OBRABOTKI. SBORNIK STATEY (RUSSIAN)			68-DOCUMENT NO. FTD-MT-24-345-67	
			69-PROJECT NO. 72302-78	
63-SECURITY AND DOWNGRADING INFORMATION UNCL, 0		64-CONTROL MARKINGS NONE	97-HEADER CLASN UNCL	
76-REEL/FRAME NO. 1884 0711	77-SUPERSEDES	78-CHANGES	40-GEOGRAPHICAL AREA UR	NC. OF PAGES 11
CONTRACT NO. 94-00	X REF ACC. NO. 65-	PUBLISHING DATE	TYPE PRODUCT Translation	REVISION FREQ None
STEP NO. 02-UR/2724/61/000/000/0192/0203		ACCESSION NO. TT8500564		
ABSTRACT  The developed methods of control constitute a whole complex of determinations of the quality of shell forms and can be recommended for use in workshop practice. At present these methods of control and investigation of sand-resin mixtures have found application at a series of plants. Orig. art. has: 6 figures.				



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In the collection questions of the metal science and technology of casting aluminum alloys are examined.

Methods are given in melting, casting, and refining alloys from gaseous and hard nonmetallic inclusions, ensuring raised characteristics of parts made from constructional alloys, and in particular from alloys Al-Mg; a series of articles is dedicated to heat strength, properties and production of parts cast from new alloys; heat treatment for the purpose of hardening parts and stabilization of dimensions; properties and control of forming materials, exact methods of casting.

The collection is intended for a wide circle of scientific and engineering-technical workers and plant designers, technologists and foremen. It can also serve as an aid for students of higher educational institutions and technical schools in foundry courses.

## PREFACE

The growth of production of aluminum and the ever widening industrial application of shaped casting from aluminum alloys increase the requirements for these materials. Dimensions and weight of castings are being increased, their configuration is being complicated, the level of strength characteristics and accuracy of dimensions increases. If one were to add that parts cast from aluminum alloys have to work also under various temperature and corrosion conditions, then the great problems confronting scientific and engineering-technical workers, who are occupied with metal science, melting technology, casting and heat treatment of cast aluminum alloys becomes understandable.

Various conditions of exploitation first of all place the question about creation of special constructional, heat-durable, corrosion-resistant alloys.

It is known that the properties of parts obtained by the method of casting depend not only on chemical composition and structure of the material, but, to no lesser degree, on the technology of melting, casting and heat treatment.

Aluminum and alloys based on it are distinguished by their high chemical activity, during melt they interact with gases of the furnace atmosphere, in the melt gaseous and hard nonmetallic inclusions are formed. Getting into castings, these inclusions lower their strength and density. Therefore there exists a series of methods of refining for removal of such harmful impurities from the melt. On the effectiveness of these methods depends the purity of an alloy, and consequently the quality of the castings.

The method of casting is very significant. At present, along with casting in sand and metallic forms, there exist methods of casting in shell forms, metallic models and in ceramic forms with smelted patterns.

Casting in metallic and in shell forms, and especially casting smelted patterns, permits securing higher quality and greater accuracy of dimensions of castings.

Finally, heat treatment significantly affects properties of cast parts. The majority of casting alloys are strengthened after hardening and artificial aging. However, heat treatment connected with a sharp change of temperatures of parts frequently leads to their warping, warpage, disturbance of dimensions. Necessary is the selection of special conditions of hardening and aging in order to avoid these defects. Consequently, creation of quality shaped parts from aluminum alloys requires the solution of many complex theoretical and practical questions.

Related to such questions are: creation of new constructional casting alloys which respond to requirements of different branches of industry; wide application of advanced methods of melt, treatment of liquid metal and casting (heating in vacuum, induction, low-frequency furnaces and resistance furnaces; vacuum refining and refining by ultrasonics, chill casting, casting under pressure, shell and precision casting); maximum mechanization and automation of the foundry; creation of new, improved methods of investigation and control of liquid metal, auxiliary materials, parts.

A number of questions touched here are beyond the scope of the present collection. In it only some of them are examined. Thus are illuminated the properties of new casting aluminum alloys: heat-durable and highly durable alloy AL19, self-hardened alloy VAL4, corrosion resistant alloys based on the system aluminum - magnesium. There are described contemporary methods of melt and casting, refining of alloys from gaseous and hard nonmetallic inclusions, conditions of heat treatment ensuring stability of dimensions of articles; also, materials are given on properties and methods of control of forming materials.

We request that all remarks about the collection be addressed to the publishing house.

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BASIC PRINCIPLES OF ALLOYING OF CAST ALUMINUM  
DEPENDING ON WORKING TEMPERATURE AND  
THEIR AREA OF APPLICATION

I. F. Kolobnev

Principles of alloying alloys are predetermined by conditions of their work: medium, operation cycle and the value of stresses, temperature and time of its action.

Creation of the theory of heat resistance of metallic alloys were the subject of work of a number of Soviet scientists, A. A. Bochvara,<sup>1</sup> G. V. Kurdyumov,<sup>2</sup> I. A. Oding<sup>3</sup> and others.

Results of these works indicate that heat resistance of metallic alloys is most essentially affected by the following factors:

- 1) interatomic bonds,
- 2) the degree of supersaturation and the nature of the solid solution,
- 3) grain structure of the solid solution,
- 4) melting point of the eutectic,
- 5) structure of grain boundaries and
- 6) nature, dimension and character of distribution of particles of second phases in alloys. Joint consideration of these factors

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<sup>1</sup>A. A. Bochvar, Metal science, Metallurgy Publishing House, 1956. A. A. Bochvaya, News of Academy of Sciences of USSR, OTN, 1948, No. 5.

<sup>2</sup>G. V. Kurdyumov, ZhTF, 1954, No. 7.

<sup>3</sup>I. A. Oding, V. I. Ivanova, V. V. Burdugskiy, V. M. Geminov, Theory of creep and prolonged strength of metals, Metallurgy Publishing House, 1959.

permits a sufficiently correct estimate of the degree of heat resistance of alloys and a more exact determination of the rationality of their alloying by both elements.

It is known that heat resistance characterizes resistivity of a material to creep and destruction during extended high temperatures and loads. Therefore the temperature level of heat resistance to a great degree is determined by forces of interatomic bonds which in alloys can be substantially increased by means of corresponding alloying.

Increase of heat resistance especially promotes the versatility of an alloy. In this case the strength of interatomic bonds during corresponding alloying can be larger, and mobility of atoms less than for alloys with a smaller number of alloying elements during an equal degree of supersaturation of the solid solution. Convincing examples are the less stable binary alloys of type [AL7] (AL7) and stabler complex alloys of type AL19 and B300.

Realization of forces of an interatomic bond to a considerable measure depend on the state of the crystal lattice and the mosaic block structure. In works of G. V. Kurdyumov and his colleagues,<sup>1</sup> V. K. Kritskoy<sup>2</sup> and in other works it is established that formation of submicroscopic heterogeneity of the crystal structure increases the degree of utilization of an interatomic bond in crystals such that forces of an interatomic bond in crystals of a solid solution can be strongly changed depending on the form of heat treatment. It was established that the annealed state of alloys nickel - aluminum and nickel - copper is characterized by a low level of bonding forces, but the hardened state has a high level of forces, which by means of secondary heating of alloys to a temperature of 250-300° with subsequent fast cooling in water, it is possible to attain a considerable increase in the forces of the interatomic bond (this conclusion should be checked on aluminum alloys).

One of the most important characteristics of forces of an interatomic bond is the value of energy of sublimation necessary for breakaway of an atom from the crystal lattice. By this criterion metals can be arranged in the following ascending order: cadmium (26.8 Cal/mole → (27.4) → magnesium (37.3) → calcium (47.8) → aluminum (55) → manganese (74) → beryllium (75) → copper (81.2) → nickel (85) → chromium (88) → iron (94) → molybdenum (160) → tungsten (210)). Forces of an interatomic bond even with the same phase composition can be essentially distinguished. The larger

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<sup>1</sup>G. V. Kurdyumov, V. A. Il'in, V. K. Kristskaya, I. I. Lysak, Problems of metal science and physics of metals, collection No. 4, Metallurgy Publishing House, 1955.

<sup>2</sup>V. K. Kritskaya. Theses of reports of the All-Union Scientific and Technical Conference on theoretical questions of metal science, NTO Mashprom, 1958, p. 25.

these forces realized, the greater the strength of the alloys.

In alloys intended for work at high temperatures (350-400°), more preferable as alloy additions can be those elements for which the value of heat of sublimation is higher than for aluminum.

The majority of these elements have not only a higher melting point, but also smaller diffusion mobility. It is especially useful to add such elements which participate in formation of stable particles of complex phases during disintegration of solid solutions. This is very important for heat resistance of an alloy.

It is known that one of the most common elementary processes determining a change of structure and consequently also the property of alloys, is the process of diffusion.

The more complex the chemical composition of a solid solution, especially in that case when it includes atoms of refractory metals, all the more stable is the structure of the alloy. This conditions a slow process of regrouping of atoms and formation of particles of the second phases. By this it is possible to explain the prolonged existence in a number of alloys of fine structure of the solid solution and microheterogeneity of the second order at raised temperatures.<sup>1</sup>

As illustrating materials we have double alloys of the system Al-Cu with a fast disintegrating solid solution and coagulation of particles of phase  $\text{CuAl}_2$ , accompanied by destruction of microheterogeneity, and triple alloys of the system Al-Cu-Mn with a fairly stable solid solution. From this it follows that for increase of heat resistance of alloys it is necessary, besides hardening of grain boundaries, to complicate the composition of the solid solution in order to delay its disintegration.

However, such a mechanism of hardening is not necessary for alloys, intended for short-term action of high temperatures, when the process of disintegration of the solid solution does not manage to occur.<sup>2</sup>

The level of temperature allowing prolonged preservation in alloys of the fine structure and microheterogeneity inside grains of the solid solution is determined by the nature of the alloying elements as well as excess second phases (see Table 1 on p. 4), for example:

- a)  $\text{MgZn}_2$ ,  $\beta(\text{Al}_3\text{Mg}_2)$ ,  $\text{T}(\text{Al}_{12}\text{Mg}_3\text{Zn}_3)$  within the limits of up to

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<sup>1</sup>Microheterogeneity of the second order, as an important factor increasing heat resistance of aluminum alloys was first described in the work of A. A. Bochvar and O. S. Zhadayeva as early as 1945.

<sup>2</sup>I. F. Kolobnev, Heat treatment of aluminum alloys, Metallurgy Publishing House, 1961.



Table 1. Basic Characteristics of Certain Structural Components in Aluminum Alloys

System of alloys	Designation of sec. phase forming in aluminum alloys	% solubility of second component in hard aluminum		Melting point of second phase in °C	Melting point of eutectic in °C	% of second component in eutectic	Degree of participation of the solid solution in formation of stable microstructure (up to 400°)	Characteristic of crystallization of the second phase	Casting properties	Air tightness
		at 20°	at 400° and at hardening temperature							
Al-Mg	Al <sub>3</sub> Mg <sub>2</sub>	1.8-2.5	11-13.5 <sup>1</sup> 12-15.1	465	449	33	Low	Fragile big particles, borders of grains The larger the % Mg, the bigger the particle	Lowered	Lowest
Al-Mn	Al <sub>6</sub> Mn	0.05	0.30	710	658	1.95	Raised	Particles of laminar form located on borders of grains	Lowered	Average
Al-Ni	Al <sub>3</sub> Ni	0.01	1.92 0.05	852	640	5.7		Coarse particles of plate form	Average	Average
Al-Si	Si	0.1	0.30 1.65	1432	577	11.6	Low	Small particles both inside grains and on their borders	High	High
Al-Ce	Al <sub>3</sub> Ce	0.01	0.05	1220	638	10-13	High			
Al-Cu	CuAl <sub>2</sub>	0.1	1.3 5.5	590	548	33	Raised	Fragile big particles located on borders of grains and partially inside grains of the solid solution	Lowered	Lowered

<sup>1</sup>From various sources.

100-150° (in alloys of type AL8 and B95);

b)  $\text{CuAl}_2$ ,  $\text{Mg}_2\text{Si}$  to temperatures 150-200° (in alloys of type AL7, AL4, AL9);

c)  $\text{W}(\text{Al}_x\text{Mg}_5\text{Cu}_4\text{Si}_4)$  up to 200-270° (in alloys of type AL3, AL5) and phase  $\text{S}(\text{Al}_2\text{CuMg})$  up to 250-300° (in alloys of type AL1, AL6);

d)  $\text{T}(\text{Al}_{12}\text{Mn}_2\text{Cu})$  to 300-350° (in alloys of type AL19);

e)  $\text{T}(\text{Al}_6\text{Cu}_3\text{Ni})$ ,  $\text{S}[\text{Al}_3(\text{CuNi})_2]$  to 350-400° (in alloys of type B300).

The given examples show that temperature ranges of application predetermine the methods of alloying of aluminum alloys. In an increase of heat resistance of alloys an especially great role can be played by the smallest particles of second phases. It is known that interlocking of shifts by particles of one or another phase strengthens tens and hundreds of times stronger than interlocking by the atoms which form a solid solution with the basic metal.

For confirmation of these expressions it is possible to give the fact that particles of phase  $\text{T}(\text{Al}_{12}\text{Mn}_2\text{Cu})$  promote very strong hardening of a series of aluminum alloys.

During alloying of alloys it is necessary to consider the quantity of second phases which create stable microheterogeneity inside grains of the solid solution as well as those crystallized in branched form on grain boundaries of the solid solution, stable at high temperatures.

In literature there is an indication that the volume of ultradispersed particles of second phases may not exceed 15% of the volume of the solid solution, since a greater quantity causes a sharp lowering of plastic properties of the alloy.<sup>1</sup>

The raised degree of microheterogeneity inside grains of the solid solution which is created by the smallest particles (dimension  $10^{-7}$ - $10^{-4}$  cm) of second phases, renders a strong braking influence on deformation of the material. By this it is possible to explain the sharp increase of the yield point of hardened alloys with a supersaturated solid solution which is past the stage of age-hardening. Thus, for example, in hardened state alloy AL19 has tensile strength 30-34 kg/mm<sup>2</sup> and the yield point is 18-20 kg/mm<sup>2</sup> (see Table 2 on p. 6), whereas after incomplete artificial aging (175° for 5 hours) tensile strength increases by 20-30% to 36-43 kg/mm<sup>2</sup>, and yield

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<sup>1</sup>L. Jeffries, Trans. ASME, 1919, v. 60, p. 474.

Table 2. Typical Mechanical Properties of Casting Aluminum Alloys Depending on Heat Treatment or Test Conditions

Make of alloy	Condition of heat treatment <sup>1</sup>	Mechanical properties at room temperature				Mechanical properties at raised temperatures					
		$\sigma_b$	$\sigma_s$	$\delta$	HB	tensile strength in kg/mm <sup>2</sup> , sudden loading			tensile strength (10 hours) in kg/mm <sup>2</sup>		
		kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	%	kg/mm <sup>2</sup>	200°	250°	300°	200°	250°	300°
AJ1	T5	25	20	0,6	100	18	16	14	13	7	5,5
	T7	22	18	1,2	90	—	—	—	—	—	—
AJ2	T2	16	9	5	50	15	13	8	7	4	2,8
AJ3	T1	20	17	1,0	70	—	—	—	—	—	—
	T2	18	14	1,5	55	—	—	—	—	—	—
	T5	24	18	0,8	75	18	15	10	9	6	3,5
	T7	21	—	1,0	70	—	—	—	—	—	—
AJ4	T1	18	14	2	65	—	—	—	—	—	—
	T5	22	17	4	70	—	—	—	—	—	—
	T6	24	18	3,6	75	16	14	10	8	5	2,8
AJ5	T1	18	15	—	65	—	—	—	—	—	—
	T6	24	18	0,8	75	18	15	10	9	6	3,5
	T7	20	—	1,5	70	—	—	—	—	—	—
AJ6	T2	17	11	2	55	—	—	—	—	—	—
AJ7	T4	24	16	7	65	18	14	10	10	6	3
	T5	25	18	3	85	—	—	—	—	—	—
AJ8	T4	30	17	10	90	22	15	9	8	4	1,5
AJ9	T4	19	14	5	50	—	—	—	—	—	—
	T5	22	16	3	65	14	11	9	6	4,5	2,8
AJ11	T2	22	15	2	80	—	—	—	—	—	—
AJ12	T2	18	13	1,5	75	15	13	10	—	—	—
AJ13	T2	17	11	3	60	—	—	—	—	—	—
AJ19	T4	32	16	8	80	26	19	15	16	12	6,5
	T5	36	25	4	100	26	19	15	16	12	6,5
BM-11-3	T4	26	18	4	90	20	18	14	9	5	2
B14A	T6	30	23	0,8	80	—	—	—	—	—	—
	T7	21	19	0,8	65	20	10	13	14	9	5,5
B300	T2	21	—	1,2	65	—	—	—	—	—	—
	T6	30	27	0,7	80	—	—	—	—	—	—
	T7	24	20	1,5	75	21	20	16	16	11	7-8

<sup>1</sup>Conditions: T1 - aging of alloy in cast state; T2 - annealing; T4 - tempering; T5 - hardening and incomplete aging; T6 - hardening of aging for production of maximum strength; T7 - hardening and high-temperature temper.

point by 40-60% to 26-32 kg/mm<sup>2</sup>.

The higher the degree of supersaturation of the solid solution, and the fuller strengthening phases will cross to it, and the freer the grains of the solid solution from particles of the second phases, then the higher will be tensile strength and the value of resilience. However, the value of the yield point remains low.

The most typical example can be alloy AL8, which in hardened state has a tensile strength to 40 kg/mm<sup>2</sup>, and yield point on the order of 20 kg/mm<sup>2</sup>. But if this alloy is subjected to additional alloying (for example, zirconium, boron and others), in such a way as to obtain a fine structure of the solid solution with the initial stage of age-hardening, then during an insignificant increase of tensile strength (on the order of 10-15%) it is possible to significantly increase yield point (by 50-60%).

Hardening of alloys intended for work at temperatures of 20-100°, may be attained, by means of an increase of the degree of disorientation of grains with a strongly distorted crystal lattice especially in boundary zones: the finer the grain structure of the alloy and the more mosaic the structure of the grain of the solid solution, the higher will its strength and resilience be. N. N. Belousov and A. A. Dodonov,<sup>1</sup> proved that an application of high pressure (up to 2000 [(gage) atm]) in the process of crystallization ensures high mechanical properties of castings.

Especially great success in this direction can be attained by means of introduction of refractory additions with simultaneous use of ultrasonics in the process of formation of particles of metallic compounds, as crystallization centers of castings. In certain alloys (for example, [ATsR1] (AlP1) growth of particles of second phases can occur under influence of ultrasonics, which is necessary to consider during selection of conditions of ultrasonic treatment.

The level of the working temperature of alloys of the same system depends not only on the nature of alloying elements, but also on their numerical ratios. For example, an addition of zinc to alloys of aluminum slightly alloyed with magnesium (i.e., to alloys in which magnesium is less than zinc) promotes an increase of heat resistance (alloy of type B15). But this addition in alloys with maximum supersaturated solid solution Mg in Al (alloy of type AL8) accelerates disintegration of the solid solution and, consequently, lowers their heat resistance.

With an increase of the working temperature and duration of its action one can lower the degree of supersaturation of the solid

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<sup>1</sup>N. N. Belousov, Contemporary technological processes of manufacture of castings from nonferrous alloys, Leningrad House of technical propaganda, 1958; Bulletin of exchange of industrial experience, 1959, No. 2.

solution to ensure a stabler structure of the alloy.

At temperatures not exceeding the temperature of dispersion-hardening, indices of quality of the material are basically tensile strength and yield point.

During prolonged tests (or exploitation) under conditions of action of high temperatures and loads, indices of quality of the material and principles of alloying the alloy have to be different.

In this case prolonged tensile strength and the limit of creep most fully characterize the degree of fitness of the material. Here prolonged tensile strength (p.t.s.) predetermines the creep limit. The dependence of these two characteristics can be expressed by the following approximate formula:  $\sigma_{0.2} = 0.7\sigma_{100}$  p.t.s. (for alloys AL1, AL5, AL19, [V14A] (B14A), B300 and others) or  $\sigma_{0.2} = 0.4\sigma_{100}$  p.t.s. (for alloys with lowered heat resistance: AL2, AL4, AL9, etc.).

For given conditions of tests (or exploitation) a decisive role in structure is played by the following factors:

- a) Stability of the solid solution.
- b) Degree of microheterogeneity of the second order inside grains of the solid solution, created by ultradispersed particles of stable second phases: the less they interact with the solid solution, the higher the heat resistance of the alloy.
- c) Structure of second phases, creating a network in boundary layers of grains of the solid solution: the more durable the network (or frame) and the more branched the crystallites of stable second phases (or eutectic layer), the higher the heat resistance of the alloys. This can explain the lower heat resistance of alloy AL7 as compared to alloy AL19, and the latter in comparison with alloy B300.

The more prolonged the existence of the fine structure at raised temperatures, ([ZGP] (ЗГП), particle of metastable phases, etc.), and also of microheterogeneity of the second order inside grains of the solid solution of the alloy base, the higher will be the heat resistance of the alloy.

The temperature level of stability of the fine structure depends mainly on the nature of second phases (see Table 3).

With an increase of the operating temperature are developed diffusion processes, concentration of vacancies, movement of dislocations and formation of microscopic cracks. At temperatures higher than 0.7 absolute melting point these processes are especially strongly developed in peripheral zones. For braking these processes it is necessary to strengthen the borders of grains of the solid solution by stable particles of phases which have a thin branch structure (for example, phase  $Al_6Cu_3Ni$ ).

Thus, depending on conditions of a test (or exploitation) one can recommend different methods of alloying, methods of their casting and heat treatment.

However in all cases it is necessary to consider the harmful influence of large particles of the second phases. The larger they are, then in greater measure are they concentrators of stresses, strongly lowering resistivity of the materials to destruction, causing formation of cracks in places of stress especially along edges of particles.

Here one should note that depending on the field of application of parts and temperature regime of their exploitation, the influence of grain size of the solid solution can be different.

Earlier it was said that for a once-only action of parts high temperatures, when weakening processes do not run to completion, and also for parts working under conditions of prolonged operational temperatures (lower than temperatures of recrystallization and age-hardening), a fine-grained structure (with a mosaic sub-structure of grains of the solid solution) is the most preferable.

For parts made from alloys of a type of solid solution, during prolonged influence of high temperatures, a coarse-grained structure is stabler. Naturally, the more coarse-grained the structure of parts under these circumstances of a test (or exploitation), the less is diffusion mobility of atoms. However polyphase alloys of type B300 and others, in which at raised temperatures intense phase transitions do not occur behave differently.

Experimental data show that a fine-grained structure of complex alloys ensures higher limits of prolonged strength and creep. This is explained by the more favorable action of small particles of the second phases and the lowered degree of interaction of them with the solid solution.

Below are given examples of use of given positions during selection of fields of application of alloys.

1. For heavily loaded parts working in hard vibration conditions at temperatures not higher than  $100^{\circ}$ , the best of all are alloys of type AL7 and AL8, which have the highest strength characteristics, including raised resilience. In this case additional alloying of shown alloys (with zirconium, vanadium, cadmium, lithium, antimony and other elements) should be directed towards a safeguard of the raised stability of the strongly supersaturated solid solutions. Such alloys can also be successfully used for objects used only once at higher temperatures, since in these conditions an intense disintegration of the solid solution does not occur.

However during the usual method of casting one should not recommend the shown alloys for parts which are subjected to the influence of high pressures of gas or liquid, since all alloys of this type of solid solution possess low airtightness, caused by the presence of thin shrinkage "channels," formed in the process of

crystallization and reduction of the volume of primary crystals.

The lowered heat resistance of alloys of the magnalium type (AL8 and others) is explained:

- a) by the great mobility of atoms of Mg in hard aluminum;
- b) by the intense process of interaction of phase  $\beta$  with the solid solution of aluminum;
- c) by fast coagulation of particles of phase  $\beta$ .

2. For casting such parts, and also for casting very thin-walled (with a thickness of 2.5-3.5 mm) and very complex parts in terms of configuration, the most successful can be alloys of the eutectic type developed on a base of systems Al-Si, Al-Ce and others.

Their high airtightness is created by a sufficient quantity of liquid-fluid eutectic, completely filling intergranular shrinkage vacuums.

However all binary alloys with a great quantity (more than 35%) of eutectic due to the small degree of alloying of the solid solution and a coarse crystal structure possess low strength at room temperature and practically are not strengthened by heat treatment.

An increase of strength of alloys of the eutectic type (for example, alloys of type Silumin) can be attained in the following two basic directions:

- a) by introduction of insignificant quantities of modifiers for breaking up the structure (sodium, titanium and others);
- b) by alloying with copper, magnesium, beryllium and other additions, which ensure creation of a supersaturated solid solution without formation of large particles of second phases or phases with a laminar form of crystallization.

Such alloying is accompanied by raised strength and fairly high plasticity (alloys AL9, AL4, AL5 and others). Plasticity of alloys can be several times increased by means of a sharp lowering of the content of iron and an increase of the crystallization rate of castings.

The basic causes of lowered heat resistance of all alloys of type Silumin (AL2, AL3, AL4, AL5, AL9 and others) having a silicon phase are:

- a) raised coefficient of diffusion of Si in hard aluminum;
- b) during disintegration of the solid solution, phase Si is formed considerably faster than the complex composition phases (for example, phase  $\text{Al}_2\text{CuMg}$  and others);
- c) particle of silicon coagulate comparatively fast, which promotes a lowering of heat resistance of the alloys;

d) particles of silicon in alloys of the Silumin type usually are crystallized in the form of plates. This does not promote good blocking of borders of grains of the  $\alpha$ -solid solution and conditions a lower heat resistance of alloys of the Silumin type;

e) in modified alloys, ultradispersed particles of silicon with a round form promote an increase of diffusion processes and sharply lower the heat resistance of the alloys;

f) inasmuch as coefficient of linear expansion of aluminum is five times more than for silicon, then with an increase of operation cycles of work of an article, microcavities and formation of cracks increase.

3. For parts working a prolonged time at high temperatures, among existing standard casting aluminum alloys in terms of the limit of prolonged strength and especially creep at temperatures 300-350°, alloys AL19, B300 and [VAL1] (BA11) deserve special attention.

During comparison of heat-resistant alloys of various systems it is possible to see that some alloys, for example AL1, V14A, B300, possess lowered plasticity, whereas other alloys, for example AL19, have greater plasticity and ductility, where alloy AL19 is very durable even at room temperature ( $\sigma_b = 36-43 \text{ kg/mm}^2$ ).

When taking into account the expounded considerations it is possible to elaborate heat-resistant alloys which will possess very high indices of strength and plasticity at room temperature.

Alloys of the solid solution type (AL7, AL19, VAL1 and others) can have maximum heat resistance in the heat treated state on hardening, whereas alloys of eutectic composition or with a great quantity of eutectic (AL2, AL3, AL4, AL5, AL9, [LOU-IKS] (ЛЮУ-ИКС), [ATsR1] (АТсР1) and others) in the poured state. This situation has an extraordinarily important value for industry, and also theoretical interest, which was considered during development of alloys ATsR1 and VAL1.

4. It is necessary to note that for parts, working a prolonged time at high temperatures (350-400°) there may be recommended a very limited number of aluminum alloys, for example, alloy ATsR-1, which possesses the highest indices of heat resistance and airtightness. Furthermore, alloy ATsR-1 has good casting properties (not worse than alloy AL9) and exceeds in terms of prolonged strength at temperatures 350-400° all other known aluminum alloys. Alloy ATsR-1 contains alloying additions which ensure:

a) a sufficient quantity of eutectic, determining good airtightness;

b) stability of solid solution of alloy base;



c) creation of particles of second phases which at operating temperatures (350-400°) practically do not interact either among themselves or with grains of the solid solution.

During development of alloy ATsR-1, data of Table 1 were considered.

Typical mechanical properties of casting aluminum alloys are given in Table 2.

## COMPOSITION, STRUCTURE AND PROPERTIES OF ALLOY AL19

I. F. Kolobnev, L. V. Shvyreva, N. A. Aristova,  
and G. Ya. Mishin

During development of the new alloy the following were considered:

1. The alloy base should be the system aluminum - copper, ensuring highest strength characteristics at room and raised temperatures.

2. Content of copper in alloy must not exceed 5.5%, since the  $\text{CuAl}_2$  phase forming due to a surplus of copper during heat treatment promotes embrittlement of the alloy at room temperature, and at raised temperatures, development of diffusion plasticity which sharply lowers heat resistance. A content of copper in the alloy less than 4.5% does not ensure maximum strength and plasticity at room temperature.

3. The third component of the alloy should have:

- a) a comparatively high interatomic bond;
- b) minimum coefficient of diffusion in hard aluminum;
- c) fairly high solubility at room and operating temperatures 300-350°);

d) ability to form phases which are complex in terms of structure and chemical composition, and, which participate in creation of a refractory eutectic, strengthen the grain boundaries of the solid solution, and also which in the form of tiny solid particles create a microheterogeneity inside grains of the solid solution which is, comparatively stable at high operating temperatures.

Such an alloy structure promotes braking of processes of deformation and prevents movement of dislocations.

The shown requirements are readily filled by manganese. The

solubility of manganese in aluminum at a temperature of 300-350° reaches 0.4-0.6%. The coefficient of diffusion of manganese is the lowest as compared to the coefficient of diffusion of copper, magnesium, zinc and other alloying elements which are, able to form a solid solution with aluminum. Manganese participates in creation of complex phase T(Al<sub>12</sub>Mn<sub>2</sub>Cu), which has raised hardness and lowered inclination to coagulation during a prolonged effect of temperature. The tiny particles of this phase, forming in the process of disintegration of the α-solid solution, are fairly evenly distributed inside grains of the latter, promoting an increase of strength at room and raised temperatures.

Phase T(Al<sub>12</sub>Mn<sub>2</sub>Cu) participates in formation of a triple eutectic with high melting point, also favorably affecting heat resistance of the alloy.

#### Influence of Copper and Manganese

In Table 1 are represented mechanical properties of alloys of the system Al-Cu-Mn with different contents of copper, including alloys

Table 1. Mechanical Properties of Alloys of the System

No. of batch	Chemical composition %		Conditions of heating under hardening (temperature in °C and holding time in hours)	Mechanical properties at 20°	
	Cu	Mn		σ <sub>b</sub> k/mm <sup>2</sup>	δ %
1	4.55	0.91	515°, 20 h	23.3	3.8
			535°, 5 h + 545°, 7 h	30.5	9.0
2	4.95	0.92	515°, 20 h	24.0	3.5
			535°, 5 h + 545°, 7 h	32.0	11.5
3	5.3	0.96	515°, 20 h	25.0	5.0
			535°, 5 h + 545°, 7 h	30.0	8.0
4 <sup>1</sup>	6.25	0.33	515°, 20 h	20.0	2.9
			535°, 5 h + 545°, 7 h	20.0	2.6 <sup>2</sup>
5	6.0	0.6	515°, 20 h	20.8	2.4
			535°, 5 h + 545°, 7 h	27.0	3.0
6	6.15	0.92	515°, 5 h + 545°, 7 h	25.0	3.3
			535°, 5 h + 545°, 7 h	24.0	3.0 <sup>2</sup>
7 <sup>3</sup>	7.0	0.61	515°, 20 h	21.3	2.0
			535°, 5 h + 545°, 7 h	22.5	2.5 <sup>2</sup>

<sup>1</sup>Alloy RR57.

<sup>2</sup>Overburning.

<sup>3</sup>Alloy D20.

of the type of English RR57 and domestic D20. Tests in this case as well as in the rest of the work were conducted on separate dirt cast samples with a diameter of 10 mm with casting crust.

From the data of Table 1 it follows that with a content of copper greater than 5.5% tensile strength, and especially the lengthening factor decrease, indicating a phase margin of  $\text{CuAl}_2$  causing fragility of the alloy. A raised content of copper (more than 5.5%) does not permit using a high temperature for hardening ( $545^\circ$ ), since such alloys are prone to overburn.

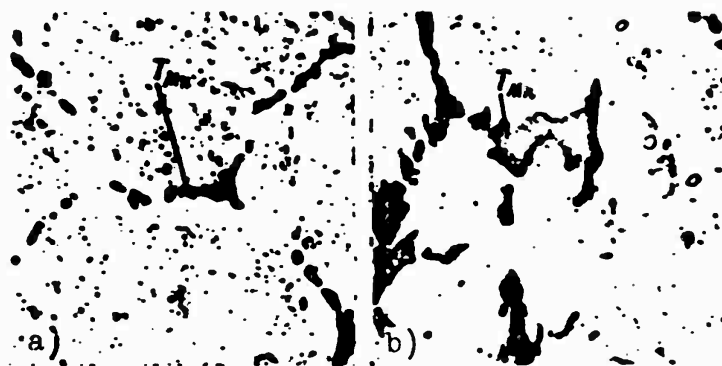
As can be seen from Table 2, the most noticeably increased are properties of an alloy with a content of manganese from 0.6 to 1.0%.

Table 2. Mechanical Properties of an Alloy of Aluminum with 5.0% Cu Depending on Content of Manganese (Hardened State)

Chemical composition, %		Mechanical properties at $20^\circ$		Mechanical properties <sup>1</sup> at a temperature in $^\circ\text{C}$			
copper	manganese	tensile strength, $\text{kg/mm}^2$	lengthening, %	175		200	
				residual strength, $\text{kg/mm}^2$	lengthening, %	residual strength, $\text{kg/mm}^2$	lengthening, %
4.92	—	27.0	7.0	30.0	2.3	27.5	2.8
4.87	0.28	28.0	7.3	30.8	—	27.7	—
5.3	0.56	30.0	10.0	33.5	2.6	28.6	2.3
4.75	0.61	29.5	10.5	30.8	4.0	28.0	3.5
4.75	0.84	30.0	9.5	30.7	3.0	30.0	3.5
4.55	0.91	30.5	11.5	31.0	3.0	28.6	5.0
4.95	0.92	29.5	9.0	30.1	3.5	30.7	3.0
4.75	1.06	28.2	5.3	29.5	2.3	29.0	2.0
5.0	1.14	28.5	6.0	28.0	—	26.0	2.5
4.75	1.24	28.0	5.0	28.0	1.5	27.5	2.0

<sup>1</sup>The test was done by a special method which consists of the fact that a sample at corresponding temperature and constantly applied stress, equal to  $0.25\% \sigma_b$ , is tested for 100 hours. Then the stress is increased to  $0.5\% \sigma_b$  and the sample is tested for 1 hour. Further on there is a test of the sample for extension at the same temperature, with determination of residual strength and relative elongation.

A content of manganese over 1.0% leads to lowering of properties at both room and raised temperatures. This is explained by depletion of the  $\alpha$ -solid solution by copper, enlargement of particles of the triple phase  $T_{\text{Mn}}(\text{Al}_{12}\text{Mn}_2\text{Cu})$ , leading to embrittlement of the alloy (Fig. 1).



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Fig. 1. Microstructures of hardened alloys of aluminum  $\times 450$ , etching 0.5% HF: a) with 5% Cu and 0.7% Mn; b) with 5.0% Cu and 1.24% Mn.

#### Influence of Titanium, Chromium and Vanadium on Properties of an Alloy of Aluminum with 5.0% Cu and 0.9% Mn

For the purpose of increasing plasticity and heat resistance of the alloy of system Al-Cu-Mn, we studied the influence of additions of titanium (from 0.05 to 0.5%), chromium (from 0.05 to 0.3%) and vanadium (from 0.05 to 0.3%). Tests were made:

- 1) for short-term fracture at temperatures of 20, 175, and 200° with determination of tensile strength and relative elongation;
- 2) for prolonged strength at a temperature of 200° and a stress of 15.0 kg/mm<sup>2</sup> and at a temperature of 300° and a stress of 6.0 kg/mm<sup>2</sup>.

Analysis of obtained results, represented in Tables 3 and 4, make it possible to affirm the following:

1) the most effective increase in mechanical properties is with titanium. With an increase of its content to 0.3-0.5% tensile strength and relative elongation at temperatures of 20, 175 and 200°, and prolonged strength at temperatures of 200 and 300° are increased.

2) Addition of chromium leads to a certain lowering of mechanical properties at temperatures of 20, 175 and 200°, but prolonged strength at 200 and 300° essentially is not changed.

3) With an increase of the content of vanadium mechanical properties at temperatures of 20, 175 and 200° practically are not changed, and prolonged strength at temperatures of 200 and 300° is somewhat increased. Consequently, introduction of additions of vanadium and chromium in the composition of the new alloy is inexpedient (see Table 3).

Table 3. Change of Mechanical Properties of Alloys of System Al-Cu-Mn in Hardened State Depending on Content of Titanium, Chromium and Vanadium

No. of samples	Chemical composition, in %					Test for short-term fracture at temperatures in °C					
	Cu	Mn	Ti	Cr	V	20		175		200	
						$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
8	4.75	0.84	—	—	—	29.7	9.5	26.0	9.3	23.7	10.5
13	5.0	0.9	0.05	—	—	29.1	7.2	25.5	8.1	23.2	9.8
20	4.85	0.88	0.10	—	—	30.6	9.0	25.9	10.5	24.0	11.8
21	4.80	0.86	0.21	—	—	31.0	9.5	25.6	11.0	24.6	11.5
22	5.20	0.89	0.38	—	—	34.5	10.5	26.7	11.3	26.1	11.0
28	4.83	0.86	0.38	—	—	32.2	10.5	27.5	12.0	25.4	12.5
34	4.89	0.87	0.47	—	—	32.8	9.5	26.0	11.3	25.8	11.1
24	4.85	0.90	—	0.05	—	29.0	6.5	24.8	8.7	22.8	7.6
25	4.90	0.85	—	0.07	—	30.0	5.5	22.4	4.3	22.5	8.5
26	4.80	0.89	—	0.18	—	28.3	6.0	22.2	5.0	20.0	5.7
27	4.85	0.85	—	0.22	—	30.2	5.0	23.0	4.0	20.3	6.0
38	4.85	0.83	—	—	0.074	29.0	7.8	25.1	7.5	23.5	7.7
31	4.85	0.89	—	—	0.11	30.0	7.5	24.6	7.4	23.0	8.2
32	5.05	0.90	—	—	0.23	28.5	7.5	25.9	7.4	24.1	8.0
33	5.10	0.92	—	—	0.34	30.4	8.0	25.5	7.2	23.8	7.0

Table 4. Prolonged Strength of Alloys of Aluminum with 5% Cu and 0.9% Mn with Addition of Titanium, Chromium and Vanadium at Temperatures 200 and 300°

No. of samples	Duration of life of samples in hours			
	when $\sigma = 200^{\circ}$ and $\sigma = 15.0$ kg/mm <sup>2</sup>		when $\sigma = 300^{\circ}$ and $\sigma = 6.0$ kg/mm <sup>2</sup>	
	mean value <sup>2</sup>	$\delta$ %	mean value <sup>2</sup>	$\delta$ %
8	127 (45—204)	2.0	108 (83—153)	4.0
13	90 (63—141)	2.5	90 (72—110)	4.8
20	126 (66—274)	3.0	125 (66—200)	4.9
21	79 (58—101)	2.0	120 (75—199)	3.4
22	150 (68—225)	2.2	253 (75—322)	4.0
28	184 (118—265)	3.2	308 (118—400)	3.8
34	201 (113—276)	—	171 (86—256)	3.6
24	110 (89—146)	—	101 (78—124)	—
25	110 (88—145)	2.2	137 (55—191)	2.4
26	86 (60—118)	2.0	105 (64—168)	3.5
27	66 (48—90)	2.2	103 (65—131)	2.8
38	—	—	113 (86—141)	—
31	133 (40—205)	3.5	84 (81—101)	11.0
32	129 (40—264)	4.0	151 (84—276)	7.0
33	214 (173—186)	2.0	194 (112—256)	—

<sup>1</sup>Chemical composition, see Table 3.

<sup>2</sup>In parentheses is shown range of values of prolonged strength obtained on separate samples.

The highest properties at room and raised temperatures can be had with an alloy containing 4.5-5.3% Cu; 0.6-1.0% Mn; 0.25-0.45% Ti (see Table 4). This new alloy has been named [AL19] (AL19).

#### Influence of Impurities of Silicon, Iron and Magnesium on Properties of Alloy AL19

We investigated the influence of impurities of silicon from 0.15 to 1.5%; iron from 0.15 to 1.0%; magnesium from 0.05 to 0.3% on a change of mechanical properties at temperatures of 20 and 300°, and prolonged strength at 300°, and also on a change of casting properties of alloy AL19 (inclination to crack formation and fluidity).

The following was established:

1) With a content of silicon higher than 0.3% there is a sharp drop of prolonged strength of the alloy at 300°,<sup>1</sup> some decrease also of mechanical properties at room temperature. Casting properties with a content to 1.0% silicon practically remain without change; a greater content of it noticeably improves casting properties. But a raised content of silicon leads to overburning of alloy AL19 in the process of heating it under hardening, connected with formation of a new phase  $Al_{10}Mn_2Si$ , which together with the  $\alpha$ -solid solution and phase  $CuAl_2$  gives a triple eutectic with low melting point (525-520°C).

2) With content of iron higher than 0.3% there is a noticeable drop of mechanical properties at room temperature, prolonged strength at 300°; casting properties essentially are not changed.<sup>2</sup> Lowering of mechanical properties is caused, apparently, by depletion of the  $\alpha$ -solid solution by copper and manganese due to formation of phase  $AlCuMnFe$ .

3) With a content of even small quantities of magnesium (0.07%) there is a sharp drop of plasticity of alloy AL19, and with a raised content of it (>0.05%) overburning of the alloy occurs during heating under hardening. This, apparently, is explained by appearance of phase  $S(Al_2CuMg)$  and formation of a triple eutectic  $\alpha + CuAl_2 + S$  with melting point 507°.

<sup>1</sup>Prolonged strength of alloy AL19 at 300° for 100 hours depending on content of silicon is changed thus:

% Si	0.25	0.5	0.75	1.0
$\sigma_k, \text{kg/mm}^2$	7	6.5	4.5	4

<sup>2</sup>Influence of iron on mechanical properties of alloy AL19:

iron in %	0.1	0.2	0.3	0.4	0.5	0.6
$\sigma_k, \text{kg/mm}^2$	43	40	37	34	30	28

Proceeding from obtained results in alloy AL19, we set the following content of impurities: iron to 0.3%, silicon to 0.3%, magnesium to 0.05%.

#### Heat Treatment of Alloy AL19

Depending on requirements of the parts, castings from alloy AL19 can be heat treated under two conditions: T4 (hardening) and T5 (hardening and aging).

Regime T4 consists of two-stage heating under hardening: at a temperature of  $530^{+5^{\circ}}$ , holding for 7-9 hours, raise temperature to  $540^{+5^{\circ}}$ , holding for 7-9 hours, cooling in water.

For decrease of internal stresses, and consequently also warping of parts, cooling after heating under hardening should be done in water, heated to  $90-100^{\circ}$ .

Regime T5 consists of hardening as in regime T4 and artificial aging at a temperature of  $175^{\circ}$  for 3-5 hours with subsequent cooling in air.

Treatment by regime T4 ensures obtaining a tensile strength of  $30-35 \text{ kg/mm}^2$  and relative elongation 8-12% at room temperature, and a fairly high value of prolonged strength at temperatures up to  $350^{\circ}$ . Treatment by regime T5 permits obtaining of tensile strength of  $34-43 \text{ kg/mm}^2$ , relative elongation 3-6% and a high value of yield point and hardness. This regime is recommended for parts working in conditions of greater stress.

The set relationship of basic components (copper and manganese) in alloy AL19 permitted using high-temperature conditions of hardening. Phase  $\text{CuAl}_2$ , which is contained in the cast alloy, at a temperature of  $540^{+5^{\circ}}$  completely passes to a solid solution, conditioning high strength and plasticity of the alloy.

Considering that the cast structure in thick sections of castings can contain great accumulations of complex eutectic, it is recommended to use two-stage heating under hardening, during which there is a gradual transition of phase  $\text{CuAl}_2$  to solid solution and overburning of the alloy is absent.

Observance of conditions of heat treatment and technology of casting permits obtaining high mechanical properties of the alloy (see Tables 5, 6 and 7).

Comparative data of mechanical properties of alloy AL19 and other cast aluminum alloys are given in Table 8.

In Table 9 are represented physical properties of alloy AL19.



Table 5. Mechanical Properties of Alloy AL19 at Room Temperature

Properties	Hardened state (regime T4)	Hardened and aged state (regime T5)
Ultimate tensile strength in $\text{kg/mm}^2$	30-36	34-43
Yield point in $\text{kg/mm}^2$	15-20	22-32
Relative elongation in %	8-15	3-7
Resilience in $\text{kgm/cm}^2$	0.8-1.0	0.75-0.85
Brinell hardness in $\text{kg/mm}^2$	70-90	100-110
Proportional limit in $\text{kg/mm}^2$	9-10.5	17-19.5
Fatigue strength in $\text{kg/mm}^2$ (on smooth angled samples with variable bend on the basis of $20 \cdot 10^6$ cycles on a Weiler machine)	7	7
Elastic modulus in $\text{kg/mm}^2$	6900	6900
Shear modulus in $\text{kg/mm}^2$	2500	2600

Table 6. Mechanical Properties of Alloy AL19 at Low and Raised Temperatures (according to S. Ye. Belyayev).

Properties <sup>1</sup>	Temperature in °C						
	-40	-70	-175	+200	+250	+300	+350
Tensile strength in $\text{kg/mm}^2$	27-29 31-33	28-29 30-32	25-26 26-27 19-20	26-27 26-27 22-23	17-18.5 17-19 10-11	14-15 14-15 7.9-7.5	7.5-9.0 7.5-9.0 5.0-6.0
Yield point in $\text{kg/mm}^2$	—	—	20-21	22-23	11-12	7.5-8.0	5.0-6.0
Relative elongation in %	6.0-7.5 5.0-7.0	7.0-8.0 5.0-7.0	4.0-5.0 3.5-4.0	2.0-3.0 2.0-3.0	4.0-5.0 4.0-5.0	4.0-6.0 4.5-6.0	7.5-10.0 6.5-9.0
True tensile strength in $\text{kg/mm}^2$	32-33 34-37	32-33 33-36	26-28 26-28	27-28 26-27	18-20 16-18	12-14 12-15	8-9 8-9
Relative reduction of area in %	—	—	5-7 5-7	3-6 2.5-5.5	5-6 7.0-8.5	8-10 9-13.5	11.5-15 11-14.0
Resilience in $\text{kgm/cm}^2$	0.8-1.2 0.7-0.85	0.7-1.25 0.65-0.80	—	—	—	—	—
Limit of creep for 100 h in $\text{kg/mm}^2$	—	—	9 9 13	—	—	—	—
a) general deformation	—	—	13	—	—	—	—
b) permanent deformation	—	—	5200 5000	5200 5100	5000 4600	4000 4600	—
Elastic modulus in $\text{kg/mm}^2$	1.22 1.06	1.36 1.12	—	—	—	—	—
Notch sensitivity (static, defined on smooth samples $\phi 10$ mm, cut to $\phi 7$ mm $\angle = 60^\circ$ )	—	—	7 5.5	7 7	—	—	—
Fatigue strength in $\text{kg/mm}^2$ (determined on smooth samples with variable bend on the basis of $20 \cdot 10^6$ cycles on a Shanka machine; 3000 changes per minute).	—	—	—	—	—	—	—

<sup>1</sup> In the numerator are shown properties of the alloy after heat treatment by regime T4, and in the denominator, by regime T5.

Table 7. Prolonged Strength of Alloy AL19 at Different Temperatures and Holding

Temperature °C	Prolonged strength in kg/mm <sup>2</sup> <sup>1</sup>				
	100 h	50 h	20 h	10 h	5 h
175	18.5	—	—	—	—
	18.5				
200	15.0	15.5	16.0	17.0	18.0
	15.5	16.0	17.0	18.0	19.0
250	11.0	11.5	12.0	12.5	13.0
	11.0	11.5	12.0	13.0	14.0
300	6.5	7.0	7.5	8.0	9.0
	6.5	7.0	7.5	8.0	9.0
350	3.5	3.7	4.0	5.0	6.0
	3.5	3.7	4.0	5.0	6.0

<sup>1</sup>  
In the numerator is shown prolonged strength of the alloy after heat treatment by regime T<sup>4</sup>, and in the denominator, by regime T<sup>5</sup>.

Table 8. Mechanical Properties of Alloy AL19 and Certain Other Cast Aluminum Alloys at Various Temperatures

Alloy	Regime of heat treatment	$\sigma_{0.2}$	$\sigma_b$	$\delta$	$a_H$ kg/mm <sup>2</sup>	Prolonged strength kg/mm <sup>2</sup> for 100 h at a temperature of in °C			Short-term rupture of kg/mm <sup>2</sup> at a temperature in °C		
		kg/mm <sup>2</sup>	kg/mm <sup>2</sup>	%							
						200	250	300	200	250	300
AL19	T4	15—20	30—34	8—15	1.0	15	12	6.5	26	19	14
	T5	22—32	34—43	3—6	0.8	16	12	6.5	26	19	14
AL14	T6	18—22	23—27	3—5	0.5	8	5	3	16	11	8
AL15	T5	18—22	20—25	0.5—2	0.2	10	6	3.5	20	15	12
AL17	T4	13—15	20—28	6—8	—	10	6	3	21	15	10
AL18	T4	17—20	29—35	9—12	—	8	4	1.5	22	15	9
AL19	T5	11—13	20—22	2—4	0.3	6	4.5	2.8	15	11	7

Table 9. Physical Properties of Alloy AL19

Properties	Hardened state (regime T4)				Hardened and aged state (regime T5)			
	25°	100°	200°	300°	25°	100°	200°	300°
Thermal conduction in Cal/cm s °C	0,25	0,28	0,32	0,34	0,27	0,29	0,32	0,35
Coefficient of linear expansion $\alpha \cdot 10^{-6}$	—	20— 100°	100— 200°	200— 300°	20— 100°	100— 200°	200— 300°	—
	—	19,51	21,77	25,62	19,51	22,83	26,50	—

### Technological and Casting Properties of Alloy AL19

Weldability of the alloy is satisfactory. Workability by cutting is good, especially in state T5, i.e., better than for alloys AL4, AL5, AL7 and AL9. Corrosion resistance, as also for all alloys with a large content of copper, is not high, but higher than for alloy AL7.

Airtightness is the same as for alloy AL7: a leak appears during hydrotests for 60 atm.

Temperature of casting is set for every part separately within the limits 700-750°. Inclination to crack formation is less than for alloy AL7: at a temperature of 710° the width of the ring is equal to 32.5 mm, and for alloy AL7, 35 mm.

Fluidity is higher than for alloy AL7: at 700° the length of a rod is equal to 205 mm, and for alloy AL7, 163 mm.

Linear shrinkage is equal to 1.25%.

### Microstructure of Alloy AL19

Poured state. In accordance with constitution diagrams of systems Al-Cu-Mn and Al-Ti during crystallization of the alloy, following phases will be formed:  $\alpha$ -solid solution;  $\text{CuAl}_2$ ; phase  $T_{\text{Mn}}(\text{Al}_{12}\text{Mn}_2\text{Cu})$ ;  $\text{Al}_3\text{Ti}$ .

On Figure 2 is represented the microstructure of the alloy in cast state.

Phase  $T_{\text{Mn}}(\text{Al}_{12}\text{Mn}_2\text{Cu})$  with a given etching is colored black, is mainly on borders of grains, has a rather branched form.

Phase  $\text{CuAl}_2$  is well outlined, uncolored, located on borders of grains in the form of branched formations.

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Fig. 2. Micro-structure of alloy AL19 in cast state;  $\times 450$ , etching 0.5% HF.

Phase  $Al_3Ti$  is a gray color, crystallized in the form of plates or small crosses.

Heat treated state. During heating under hardening at a temperature of  $540 \pm 5^\circ$  phase  $CuAl_2$  must be completely dissolved and transferred to solid solution. The phase composition of the alloy in hardened state is  $\alpha$ -solid solution, alloyed by copper and manganese on account of diffusion of phase  $CuAl_2$  and partial diffusion of manganese in the process of crystallization, phase  $T_{Mn}(Al_{12}Mn_2Cu)$  and phase  $TiAl_3$  (Fig. 3a). It is necessary to note that the presence of large laminar particles of phase  $TiAl_3$  (see Fig. 3b) is undesirable, since they are concentrators of stresses.

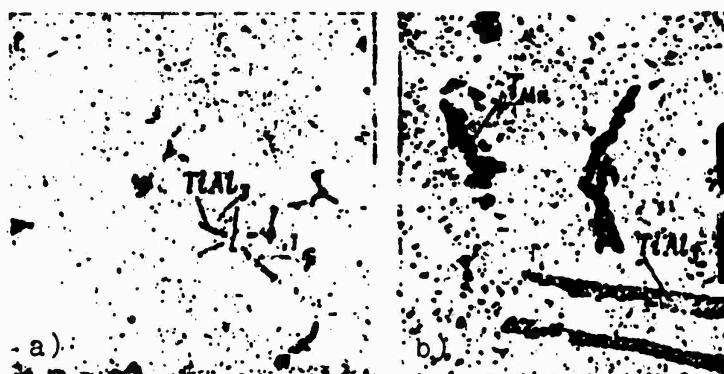


Fig. 3. Microstructure of alloy AL19 in heat treated state; etching 0.5% HF;  $\times 120$  (a) and  $\times 450$  (b).

If after heating under hardening at a temperature of  $530-535^\circ$  due to insufficient holding or disturbance of temperature rate there remains nondissolved phase  $CuAl_2$ , then overburning of the alloy can occur in the process of heating it at the following step at  $540^\circ$  (Fig. 4).



Fig. 4. Overburning of alloy AL19;  $\times 450$ , etching 0.5% HF.

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As a result of overburning, tensile strength of the alloy will drop to a level of  $22-25 \text{ kg/mm}^2$ , and relative elongation to 2-4%.

Metallographic investigation of the phase composition of alloy AL19 in heat treated state showed that phase  $T_{Mn}(Al_{12}Mn_2Cu)$  is on borders of grains in the form of branched formations, as well as inside the grain of the solid solution in the form of finely dispersed point separations.

These smallest particles are products of disintegration of manganous  $\alpha$ -solid solution in the process of heating under hardening at temperatures of  $500-550^\circ$ . It is known that manganese is inclined toward formation of a supersaturated solid solution in aluminum. Hoffman and Falkenhagen,<sup>1</sup> using high speeds of cooling (more than  $25,000^\circ/\text{s}$  for crystallization of liquid alloy and  $5000^\circ/\text{s}$  for cooling in solid state), observed in the surface layer of castings from double Al-Mn alloys supersaturation of the  $\alpha$ -solid solution by manganese up to 9.2% (weight), which is 6.7 times larger than the value of equilibrium solubility.

Microstructure of alloy AL19 in state T5 does not differ from the microstructure of the alloy in state T4.

#### Conclusion

The given data show that alloy AL19 is distinguished by high heat resistance, high mechanical properties at room temperature and good weldability.

However it has lower casting properties, which one should consider when developing casting technique for parts of every type.

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<sup>1</sup>W. Hofman u. G. Falkenhagen, Zeitschrift für Metallkunde, 1952, B. 43.

## MELT AND CASTING TECHNOLOGY OF ALLOY AL19

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### Melting Furnaces

For preparation of alloy [AL19] (AJI19) it is possible to use all types of furnaces used for melting standard aluminum alloys. Electric resistance furnaces, especially induction furnaces, are better than reflective or crucible furnaces with gas (petroleum) heating, since they ensure higher mechanical properties and minimum porosity of castings. This is explained by the fact that the atmosphere in electric furnaces is the most favorable (weakly oxidizing), and the process of melting is accelerated.

The most advanced method of melting is the method of induction heating by currents of high and industrial frequency, allowing one to obtain high-quality metal. Positively effecting the quality of the metal is not only the faster melt process, but also intense mixing of the melt, small mirror metal surface, etc.

### Preparation of Preliminary Alloy

To ensure uniformity in properties and chemical composition, and also for production of good structure it is necessary to prepare a preliminary alloy.

For preparation of the preliminary alloy the following initial materials are used: aluminum pig brands [AV1] (AB1), AV2 or AV3 (All Union Government Standard 3549-55); alloy: aluminum 50% + copper 50% (electrolytic MO, M1, All Union Government Standard 3549-55); alloy: aluminum 90% + manganese 10% ([MgO] (MrO), All Union Government Standard 6008-51); alloy: aluminum 96% + titanium 4%. Special attention should be given to the quality of alloy Al-Ti, which should be dense, without blowholes and not contain inclusions of hydrides in fracture. All initial materials have to be dry, pure, without traces of corrosion and have a certificate.

Calculation of the charge for preparation of the preliminary alloy must be done for the optimum chemical composition ensuring maximum mechanical properties at room and raised temperatures: copper - 5.0%, manganese - 0.8%, titanium - 0.3%.

It is necessary to consider following circumstance: if in the alloy copper is at the lower limit (4.6%), and manganese at the upper (1.0%) or conversely, copper is 5.3% and manganese 0.6%, then such combinations of components of the alloy are unfavorable; they lower strength characteristics of the alloy.

It is necessary to consider that losses of components of the alloy can considerably oscillate depending on the state of the charge, melting unit used, duration of melt, etc., (Table 1).

Table 1. Loss of Metals in % Depending on State of Charge and Type of Melting Furnace<sup>1</sup>

Metals	Pure charge		Strongly oxidized and contaminated charge	
	in electric furnaces and crucible furnaces	in electric furnaces and hearth furnaces	in electric furnaces and crucible furnaces	in reflective flame furnaces and in hearth furnaces
Aluminum	0.5-1.0	1.0-2.0	2.0-3.0	2.0-4.0
Copper	0.5-1.0	1.0-1.5	1.0-2.0	2.0-3.0
Manganese	0.1-0.5	0.5-1.0	1.0-2.0	2.0-3.0
Titanium	0.75-2.0	1.5-2.5	1.5-3.0	2.5-5.0

<sup>1</sup>The sharp increase losses of titanium during melt in reflective flame furnaces and hearth furnaces is caused by formation of a hydride of titanium and an increase in the degree of oxidation. Losses of copper and manganese are included in loss of these metals connected in compounds, for example AlMnFeSi, which can settle to the bottom of the furnace.

The order of melt is as follows: at first load approximately half the batch of aluminum and all of alloys Al-Mn and Al-Ti. According to melting, load the remaining part of the aluminum and Al-Cu alloy (or the fourfold alloy). Bring the temperature of the melt to 740-750° and thoroughly mix for 2-3 minutes. Heating to shown temperatures is necessary for full diffusion of alloys Al-Cu, Al-Mn, Al-Ti and uniform distribution of copper, manganese and titanium in the melt.

Refine the melt by gaseous chlorine or anhydrous chloride of manganese. Chlorous manganese is introduced in the melt in the quantity 0.1% (zinc chloride 0.2%) of the weight of the melt with the aid of a bell. In the process of refining the bell is moved in

the metal bath to a height  $1/5$  from the bottom of the crucible for 4-5 minutes.

After termination of refining the alloy is 5-8 minutes, after which slag is removed from the surface of the melt and pouring is begun. The alloy is poured into casting molds at a temperature of  $690-720^{\circ}$ . Overheating the alloy higher than  $720^{\circ}$  should be avoided. From every melt a sample is taken before the beginning, in middle and at the end of pouring for spectral or chemical analyses.

The preliminary alloy is controlled for fracture (2-3 pigs). Upon detection of strongly expressed porosity and contamination the alloy must be remelted and thoroughly refined.

An appraisal of the quality of the preliminary alloy is produced by fracture of pigs and by mechanical properties of separately poured samples in cast state ( $\sigma_b = 16-20 \text{ kg/mm}^2$ ;  $\delta = 2.5-5\%$ ).

#### Preparation of Working Alloy

For composition of a charge of working alloy the following materials are used:

- 1) preliminary pig alloy of known chemical composition (30-50% of weight of charge);
- 2) double alloys Al-Cu, Al-Mn, Al-Ti and aluminum of make AV2 or A00 (if charge preparation is necessary);<sup>1</sup>
- 3) tailings (return) of production: air hole, sand-blast rejected parts, heavy skims and pits, etc.

During determination of the quantity of tailings in a charge it is necessary to be guided by chemical analysis so that the content of harmful impurities in the working alloy will not be more than permissible.

It is necessary to consider that with a content of iron greater than 0.3% both tensile strength and the limit of prolonged strength drop. Therefore for preparation of alloy AL19 it is necessary to use only aluminum of brands AV1, AV2 and A00.

Magnesium is also an undesirable and harmful impurity, its content in the alloy limited to 0.05%. A higher content of magnesium lowers plasticity and weldability of the alloy.

The charge is calculated for optimum chemical composition.

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<sup>1</sup>Instead of a double we recommend using a fourfold alloy (copper 30%, manganese 5%, titanium 1.8%, aluminum the rest). Application of a fourfold alloy considerably increases the quality of castings.



The order of loading a charge is as follows:

- a) production tailings;
- b) alloy Al-Cu, Al-Mn, Al-Ti (if charge preparation is necessary);
- c) preliminary alloy (in pigs).

The technology of preparation of preliminary and working alloys does not essentially differ, with the exception that the preliminary alloy must be heated to a temperature 740-750°.

The necessity of higher heating can appear only when filling a thin-walled casting of complex configuration. Usually the temperature for casting parts from alloy AL19 should be within the limits of 690-750°, while a lower temperature is used for casting thick-walled parts in a chill mold.

With optimum chemical composition of the alloy, low content of impurities and correct management of the melt one can obtain high mechanical properties of alloy AL19. An essential influence on mechanical properties is rendered not only by the quality of preparation of the melt, but also by the method of casting the parts (samples), the used forming materials, and also heat treatment.

#### General Indications on the Method of Casting

Data which determine casting properties of the alloy (interval of crystallization 100°, linear shrinkage 1.25%, hot brittleness - 32.5 mm), indicate that the alloy is inclined toward formation of hot cracks and pores. Therefore during casting of complex parts it is necessary to anticipate smooth transitions in wall sections and minimum nonuniformity of the casting. During planning of accessories and technological process of casting it is necessary to ensure intensive feeding (massive air holes, internal air holes - "cocks"), cooling of lower zones of casting by installing cooling units, dispersed feed of metal, application of yielding rods, incisions (depth of 1.0-1.5 mm and more) on molds in those places opposite which formation of cracks in a casting is probable. It is preferable to use lower dispersion feed of metal by a divergent system.

Below typical examples of casting shaped parts, are given, taking into account peculiarities of alloy AL19.

#### Example 1. Development of method of molding a "wheel."<sup>1</sup>

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<sup>1</sup>In mastering the technology of casting alloy AL19, A. Z. Zakharov, E. A. Lalayan, N. A. Avdeyeva, S. S. Azimkov, A. V. Volik, A. I. Pshebel'skaya and others took part.

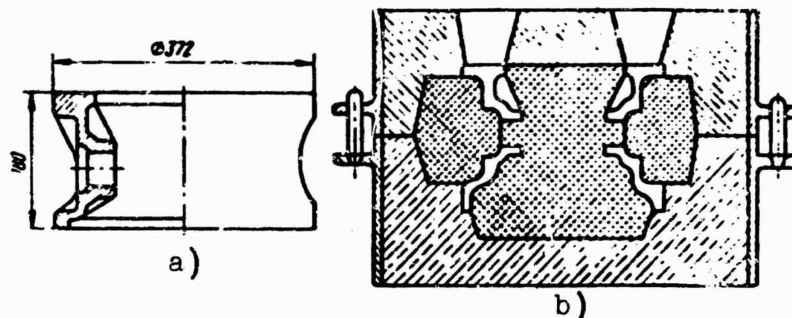


Fig. 1. Sketch of a "wheel" (a) and method of molding this part (b).

Figure 1a, represents a sketch of this part. According to initial technology the molding was produced with a dry rod by the method shown in Fig. 1b.

Feed of metal was carried out by two schemes: slot feed and feed along the joint line.

Filling temperature of the alloy is  $740^{\circ}$  (such a high filling temperature was caused by thinness of casting walls, 4.5 mm). After knockout of parts from the form it turned out that for castings flooded by both schemes there were cracks, where for castings flooded by the second scheme the crack was larger. Thus, it was not possible to pour the given part with a dry rod.

Therefore the dry rod was replaced by a damp "blockhead," which in configuration corresponded to a dry rod. Filling was produced also by the two shown schemes. Casting by these schemes did not have cracks and other defects and were thus recognized as suitable. Consequently, both methods of feed of metal turned out to be acceptable.

Example 2. Mastery of technology of casting of a complex part (Fig. 2). Gradual mastery of the technology of casting these parts is given in Table 2.

Example 3. Mastering of technology of casting of part of "frame" type. Figure 3 shows that this part is very complicated in configuration and has large dimensions  $\phi 800 \times 400$ . During mastery of the technology of casting the following variants were tested (see Fig. 4 and Table 3).

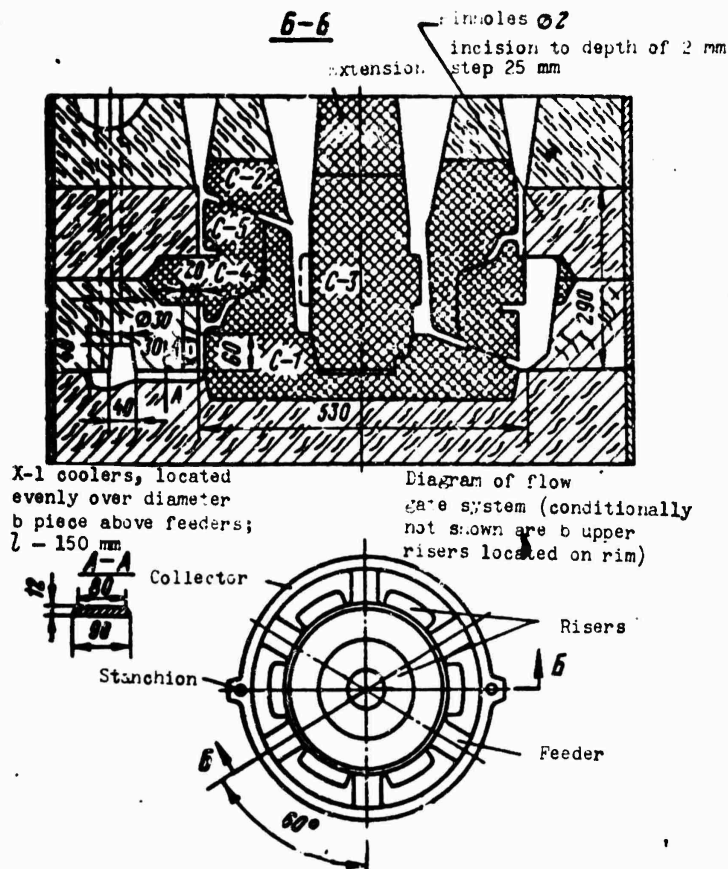
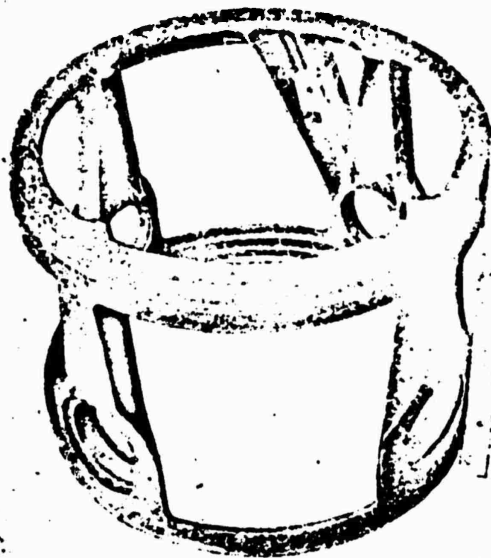


Fig. 2. Method of molding of complex shaped part.

Table 2. Technology of Casting by Stages

Stages of experimental work (part of 2-3 components)	Peculiarities of technology of molding	Characteristic of castings
I	Casting without cooling units, "cocks" and rises on upper rim	Castings had raised shrinkage porosity and wormholes sharpened on upper rim
II	Under lower rim are set cooling units with a clearance of 50 mm	Casting had crack of rims and shrinkage pores in upper rim
III	Rises are made on the upper rim, upper and lower rims are united by slots-bypasses, under lower rim are set cooling units	Casting had shrinkage cavity in pockets of lower rim
IV	Technology of molding is by method shown in Figure 2	Casting suitable by visual inspection and X-ray control



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REPRODUCIBLE**

Fig. 3. Part made from alloy AL19 ("frame").

Table 3. Methods of Testing a "Frame"

Stages of experimental work	Peculiarities of technology of molding	Characteristic of casting
I	Holes in bosses were shaped by sand rods. Refrigerators were not used. "Cocks" were set in face of bosses from internal side. Flow gate system is vertical-slot	Casting had pores on bosses and open gas pits in upper ring and a crack in the lower ring
II	Modified flow gate system and rod 1 is cut into 4 parts	Pores on the joint radius and feeders
III	Refrigerators are added on ribs and on external contours of lower part of casting	Pores on feeders, rents on lower ring
IV	Parts were poured according to method (with bosses of lower ring of casting 5 mm), shown in Fig. 4	Part suitable by visual inspection and X-ray control

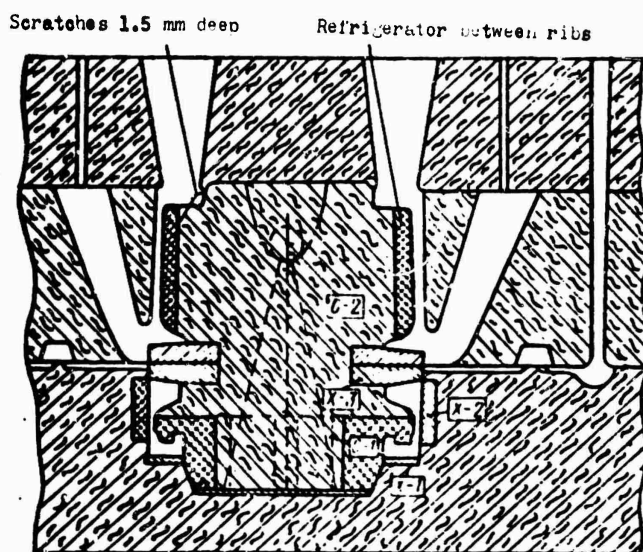


Fig. 4. Method of molding "Frame."

#### Conclusion

1. During preparation of alloy AL19 for preventing of liquation and raised porosity it is necessary to thoroughly mix and refine it.
2. During development of technology of casting of parts it is necessary to anticipate intensive feeding, dispersed feed of metal, application of yielding rods.
3. Basic type of flow gate system for casting alloy AL19 should be a system with lower feed of metal. For high castings of cylindrical form a vertical-slot system with two wells is recommended.
4. For large dimension castings basic parameters of flow gate systems are as follows:
  - a) diameter of stanchions 18-25 mm (it is desirable under stanchion to set flow gate grids, and also a sufficient volume hearth-skim gate);
  - b) the section of collectors is larger than the section of a stanchion by 2-3 times; the quantity of skim gates in the collector is determined by the metal consumption of the form, its extent and complexity;
  - c) the total section of feeders is larger than the section of a stanchion by 3-4 times, width of feeder is not more than 6-8 mm.
5. The dimension of air holes and their quantity must be selected taking into account massive places of the casting. It is necessary to consider that the air hole system used during casting of parts from alloys of type Silumin, is unfit for casting from alloy AL19.

Alloy AL19 has twice as high a viscosity, therefore very high air holes insufficiently well impregnate the casting. It is expedient frequently to set low air holes of ellipse-like section.

## NEW HEAT TREATMENT REGIME FOR ALLOY AL19 ENSURING STABILITY OF DIMENSIONS OF CASTINGS<sup>1</sup>

N. A. Loktionovna, N. M. Rastvorova, O. P. Bereslavytseva,  
M. I. Larikova, and G. B. Stroganov

In this article are described results of the development of a new regime of heat treatment of parts of complex configuration made from alloy [AL19] (AJI19) ensuring stability of geometric dimensions in the process of heat treatment.

### Laboratory Investigations

The character of distribution and value of residual stresses, and consequently also deformation of castings, are greatly influenced by the speed of their cooling during hardening.<sup>2</sup> For investigation of the influence of speed of cooling on deformation and properties of alloy AL19, castings were hardened in water at different temperatures. Deformation was determined on cast ring-shaped samples of variable section (Fig. 1). During hardening samples were put in the cooling medium in a horizontal position.

The variable section of the ring creates a condition of nonuniform cooling during hardening, and in the ring considerable residual stresses appear. A cut of the ring in a thin or thick part relieves stress and the ring spontaneously is deformed by a value which depends on residual stresses available in it. In this

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<sup>1</sup>Besides the authors L. S. Zoltukhin, A. P. Fomin, A. R. Chesnokova, L. Ye. Entin, I. A. Osipov, S. M. Ambartsumyan, N. S. Pantyushkova, T. V. Privezentsev participated in the work.

<sup>2</sup>N. A. Loktionova, V. I. Isayev, V. I. Kulakov, M. Ya. Telis, V. P. Kozlovskaya, "New regime of heat treatment for reducing warping of parts made from aluminum alloys," TsITEIN, M-60-19/2, 1960.

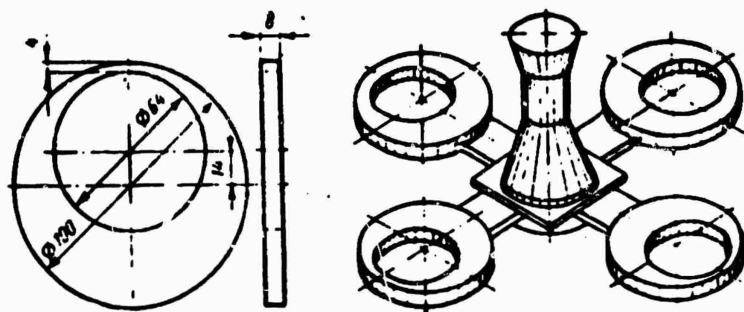


Fig. 1. Sample for determination of deformation.

case deformation is measured after cut of a thin section of the ring by a handsaw.

Samples for mechanical tests were cast in industrial conditions by series technology; heat treatment was also conducted in industrial conditions.

Samples heated under hardening in a shaft electric furnace of type [ETA-6] (3TA-6) in step conditions. Loading was done in a furnace heated to  $300^{\circ}$ , then the temperature was raised to  $535 \pm 5^{\circ}$ . Samples were held at this temperature 9 hours, after which the temperature was raised to  $545 \pm 5^{\circ}$  and held 7 hours. Samples were cooled in a tank with a capacity of  $2 \text{ m}^3$  located directly under the furnace. In the case when hardening was conducted at  $96^{\circ}$ , water in the tempering tank was heated by live steam.

Part of the samples were tested in a freshly hardened state, others in an artificially aged state. Artificial aging was conducted at  $175^{\circ}$  for 3 hours. Dependence of deformation of cast samples on conditions of heat treatment is given in Table 1.

Data of this table show that deformation of samples under the impact of stretching residual stressed in poured state is very insignificant.

Hardening in water at a temperature of  $45^{\circ}$  causes in the sample great compressing residual stresses. With an increase of temperature of the water in the tempering tank residual stresses sharply descend and deformation of the sample decreases 7 times. Artificial aging insignificantly decreases deformation of samples as compared to the freshly hardened state (from 0.7 to 0.54 mm).

Investigation of the influence of water temperature during hardening on mechanical properties of alloy AL19 was conducted at 20 and  $250^{\circ}$  on separately poured samples 12 mm in diameter in freshly hardened and artificially aged states.



Table 1. Degree of Deformation of Samples Depending on Conditions of Heat Treatment

State of alloy	Deformation in thin section of sample $\mu m$
Poured in sand	$\pm 0.02$
Hardening in water, 45° (freshly hardened state)	-0.70
Hardening in water, 96° (freshly hardened state)	-0.10
Hardening in water, 45° (artificially aged state)	-0.54

<sup>1</sup>Sign (+) indicates increase of groove of poured sample under the impact of residual pull stresses.

Sign (-) indicates decrease of groove under the impact of compressing residual stresses.

Conditions of heating under hardening of samples remained constant, only temperature of the cooling medium (45 and 96°) was changed.

In Table 2 are represented values of mechanical properties of alloy AL19 at room temperature. In a freshly hardened state

Table 2. Mechanical Properties<sup>1</sup> of Alloy AL19 at Room Temperature Depending on Conditions of Heat Treatment

State of samples	Temperature of tempering water °C	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
Freshly hardened	45	30.8 (30.0—33.0)	10.9 (7.8—12.9)
	96	30.5 (29.2—32.5)	11.0 (8.4—12.3)
Artificially aged	45	36.1 (35.2—36.7)	7.6 (6.9—8.5)
	96	34.9 (34.4—36.6)	6.2 (5.0—7.0)

<sup>1</sup>In parentheses is shown scattering of results of tests of separate samples.

mechanical properties of samples hardened in water at temperatures of 45 and 96° are practically identical. After artificial aging tensile strength and relative elongation of samples hardened in water at a temperature of 96° are lower than after hardening in

water at a temperature of 45°.

Mechanical properties of alloy AL19 at a raised temperature (250°) were determined on samples 10 mm in diameter. Simultaneously a test was conducted at room temperature. Results of these tests (see Table 3) show that mechanical properties at room temperature after hardening in boiling water are obtained lower than at water temperature 45°.

This pertains to freshly hardened and aged state of samples.

Table 3. Mechanical Properties<sup>1</sup> of Alloy AL19 at Raised and Room Temperatures Depending on Conditions of Heat Treatment

State of samples	Temperature of water in tempering tank °C	Tensile strength in kg/mm <sup>2</sup>		Unit elongation in % at	
		20°	250°	20°	250°
Freshly hardened	45	33,9 (32,9—34,8)	23,0 (23,0)	10,8 (8,9—12,0)	7,6 (5,0—10,0)
	96	32,0 (31,4—38,0)	23,4 (22,7—23,8)	9,1 (7,7—11,6)	7,5 (5,2—10,2)
Artificially aged	45	38,6 (36,8—40,0)	25,7 (24,9—26,7)	7,0 (5,8—8,8)	5,9 (4,5—7,0)
	96	36,3 (33,4—38,4)	25,6 (23,7—27,9)	5,0 (3,6—7,0)	5,0 (4,5—5,5)

<sup>1</sup>In parentheses is shown scattering of results of tests of separate samples.

At a test temperature of 250° the temperature of the water in the tempering tank practically does not influence mechanical properties, only relative elongation falls 0.9% after hardening in boiling water as compared to hardening in water at 45°.

Mechanical properties at room temperature and 250°, although they somewhat decrease with an increase of water temperature in the tempering tank, nevertheless remain higher than requirements of technical conditions.

Hardening in boiling water does not cause noticeable changes in the microstructure of the alloy as compared to hardening in water at a temperature of 45°. The structure of all samples consists of an  $\alpha$ -solid solution alloyed by copper and manganese, phase  $T_{Mn}(Al_{12}Mn_2Cu)$  and phase  $Al_3Ti$ .

Tests of corrosion resistance of alloy AL19 after hardening in water at 96° were conducted on cast samples with casting crust in a 3% solution of table salt with an addition of 0.1%  $H_2O_2$  for 60 days.

Conducted investigations showed (see Table 4) that corrosion resistance of alloy AL19 hardened in water at temperatures 45° and 96° is practically identical in both freshly hardened and in artificially aged states.

Table 4. Influence of Corrosion on Mechanical Properties of Samples Made from Alloy AL19

State of samples	Temperature of water in tempering tank °C	Before corrosion		After corrosion		Losses in %	
		tensile strength kg/mm <sup>2</sup>	relative elongation %	tensile strength kg/mm <sup>2</sup>	relative elongation %	tensile strength	relative elongation
Freshly hardened	45	30,1	11,8	27,4	6,0	9,5	49,0
	96	30,1	11,4	26,0	6,5	13,6	43,0
Artificially aged	45	36,5	8,5	26,1	4,0	28,5	53,0
	96	34,4	6,5	27,5	3,3	20,1	49,4

#### Industrial Testing

Investigation of the influence of hardening on deformation and mechanical properties of industrial parts made from alloy AL19 was conducted on planar thin-walled ribbed part cast in and without allowance for machining (Fig. 2), and a series of other parts.

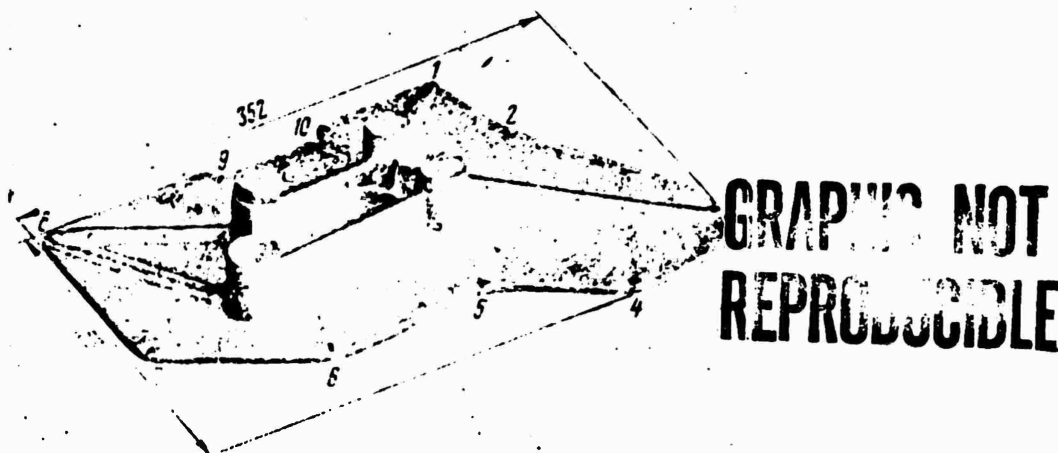


Fig. 2. General view of part made from alloy AL19 and places of measurement of warping.

Deformation was measured after hardening in water with different temperatures (45 and 96°). A diagram of measurement of deformation of the part is represented in Fig. 2. For a base of measurements we took tongues in the form of bosses located in the

central part of the component which preliminarily was mechanically treated. Dimensions of the part allowed measurements in laboratory conditions with great accuracy. Deformation of the part, after different conditions of hardening is given in Table 5.

Table 5. Degree of Deformation of Part Depending on Conditions of Heat Treatment

Place of measurement of warping (see Fig. 2)	Deformation in mm		Change of warping in mm during hardening in water at 96° as compared to hardening in water at 45°
	hardening in water 45°	hardening in water 96°	
1	0	0	0
2	-1.2	-0.1	-1.1
3	-3.0	-0.1	-2.9
4	-1.4	-0.4	-1.0
5	-2.0	+0.3	-1.7
6	+1.8	+0.1	-1.7
7	+1.6	-0.3	-1.3
8	-2.5	0.0	-2.5
9	-1.7	-0.2	-1.5
10	+0.2	+0.3	+0.1

Obtained data show that hardening in boiling water creates smaller deformation than hardening in water with a temperature of 45°. During hardening in water with a temperature of 45° maximum deformation was 3 mm, and after hardening in water with a temperature of 96° it was only 0.4 mm, i.e., 7 times less.

Simultaneously there were conducted comparative investigations of these castings of another melt after repeated hardening in water at a temperature of 96°. Maximum hardening strain in water with a temperature of 45° was 4.7 mm, after repeated hardening of the same part in boiling water it decreased to 1.1 mm, i.e., more than 3 times.

Thin-walled castings of variable section with wall thickness 60 mm, length 1015 mm during hardening in water with a temperature of 45° were strongly warped, and due to the complexity of their configuration it was impossible to control it. After shift of the parts to hardening in boiling water warping was decreased and rejects were lowered considerably.

Hardenability of alloy AL19 during hardening in water with a temperature 45° and 96° was determined on a shaped massive casting of variable section: maximum section 75 × 60 mm, minimum 38 × 20 mm.

Mechanical properties of samples cut at the surface and from the center of maximum section of the part, depending on temperature of the water during hardening, are given in Table 6.

Table 6. Mechanical Properties<sup>1</sup> of Samples Cut from Part, Depending on Conditions of Heat Treatment

Place of location of samples in casting	Temperature of tempering water °C	Freshly hardened state		Artificially aged state	
		$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
Samples cut at the surface	45	23,3 (21,5—27,8)	6,2 (4,8—10,0)	28,0 (25,0—33,2)	5,7 (2,3—7,5)
	96	25,6 (23,2—25,7)	8,1 (4,3—10,6)	27,4 (25,8—29,5)	4,2 (2,3—5,4)
Samples cut from the center	45	22,4 (22,0—22,8)	5,8 (5,1—6,4)	28,6 (28,1—29,2)	6,0 (6,0—6,1)
	96	24,9 (24,5—25,2)	5,5 (5,4—5,6)	28,7 (28,2—29,2)	4,9 (4,6—5,3)

<sup>1</sup>In parentheses is shown scattering of results of tests of separate samples.

As can be seen, in freshly hardened state tensile strength and relative elongation of samples cut from the center of the casting are somewhat lower than for samples cut at the surface.

In artificially aged state, mechanical properties of the central part of a casting are conversely somewhat higher than at the surface.

By investigation it is established that an increase of temperature of water during hardening to 96° will barely change mechanical properties all over the section of the casting (75 × 60 mm) as compared to hardening in water with a temperature of 45°.

### Conclusion

1. With section thickness to 75 × 60 mm alloy AL19 practically is not sensitive to a lowering of the cooling rate during hardening.

Mechanical properties of castings in freshly hardened state at room temperature practically are not changed with an increase of temperature of the water during hardening from 45 to 96°, when in artificially aged state tensile strength and relative elongation drop somewhat. Mechanical properties at 250° (short-term tests) practically are not changed with an increase of temperature of water during hardening to 96° and do not depend on the form of heat treatment.

2. General corrosion resistance of alloy AL19 hardened in water with a temperature of 45 and 96° practically is identical in freshly hardened state and after artificial aging.

3. Hardening of complex large castings in boiling water creates such insignificant warping of castings that it practically

is not required to make any correction after heat treatment.

Shift of a series of large complex castings to hardening in boiling water solved the question about a sharp decrease of warping, lowering of difficulty of manufacture and increase of quality of parts made from alloy AL19.

4. Hardening in boiling water preserves the flow diagram of treatment and does not require additional equipment. For hardening in boiling water usual tempering tanks are used with simple additional equipment for heating them.

## CASTING ALUMINUM ALLOY VAL4 (VL15)<sup>1</sup>

M. B. Al'tman, O. B. Lotareva, N. S. Postnikov,  
and S. B. Spiridonova

Alloys of system Al-Mg-Zn belong to a number of cast aluminum alloys possessing comparatively low mechanical properties. Depending on the content of zinc and magnesium these alloys are known abroad under different names.<sup>2</sup>

The most widespread is alloy 42E, containing 0.5-0.7% Mg; 4.75-5.75% Zn; 0.4-0.6% Cr; 0.15-0.25% Ti. Mechanical properties of this alloy after 21 days of natural aging are such:  $\sigma_b = 24 \text{ kg/mm}^2$ ,  $\sigma_s = 17.5 \text{ kg/mm}^2$ ; HB 75 kg/mm<sup>2</sup>;  $\delta = 5\%$ .

Alloy 40E is used in aircraft parts and in the food industry, when simultaneously are needed corrosion resistance, strength and high surface quality.

Widely known is alloy of system Al-Mg-Zn of brand A612F<sup>3</sup> of somewhat modified composition: 6-7% Zn; 0.6-0.8% Mg; 0.35-0.65% Cu; 0.05% Mn; 0.15% Si; 0.2% Ti. Typical mechanical properties after 30 days of aging are as follows:  $\sigma_b = 24.6 \text{ kg/mm}^2$ ;  $\sigma_s = 17.6 \text{ kg/mm}^2$ ;  $\delta = 5\%$ ; HB 75 kg/mm<sup>2</sup>. Minimum permissible properties:  $\sigma_b = 22.5 \text{ kg/mm}^2$ ;  $\delta = 2\%$ .

Since examined alloys possess only satisfactory mechanical properties, our investigations were directed towards search of an

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<sup>1</sup>The alloy was developed by I. F. Kolobnev, M. B. Al'tman and O. B. Lotareva.

<sup>2</sup>Metallurgia, 1955, v. 51, No. 306.

<sup>3</sup>Aluminum Company of America, Aluminum Handbook, 1957.

alloy of system Al-Mg-Zn with higher strength characteristics. For investigation we selected a quasibinary cut Al-T ( $\text{Al}_2\text{Mg}_3\text{Zn}_3$ ) of ternary diagram Al-Mg-Zn. We studied alloys with different content of phase T. Therefore there preliminarily was made chemical compound  $\text{Al}_2\text{Mg}_3\text{Zn}_3$  which then as an alloy was introduced into the melted aluminum in quantities 5; 7.5; 10; 15 and 20%. Mechanical properties, fluidity and inclination of alloys to corrosion under stress were determined.

Obtained results showed that the best combination of tensile strength and lengthening is obtained with 7.5%  $\text{Al}_2\text{Mg}_3\text{Zn}_3$ , which corresponds to the following chemical composition of the alloy: 4.55% Zn; 1.7% Mg; the remainder — aluminum. In poured state after natural aging for 10 days tensile strength is equal to  $20 \text{ kg/mm}^2$ , and lengthening 3.5%. Alloying of the alloy by additions of manganese and titanium increases tensile strength to 22-23  $\text{kg/mm}^2$  with lengthening 2-3%. After hardening and aging tensile strength of the alloy attains 30-35  $\text{kg/mm}^2$  with lengthening 2-3%.

Addition of manganese to this alloy was tested on the basis of source material, in which the fact is indicated that manganese improves resistance of the alloy to corrosion (obviously on account of formation of durable surface films) and increases mechanical strength. Furthermore, manganese in quantities to 0.5% promotes crushing of the grain and strengthens the effect of ageing of alloys of this system. An attempt to increase the content of manganese to 1% and more did not lead to desirable results, since the alloy became brittle. Therefore the content of manganese in the alloy of investigated composition was set at 0.2-0.5%.

Addition of titanium within limits 0.1-0.2% improves mechanical properties of the alloy thanks to reduction of the grain of the solid solution.<sup>1</sup> It is necessary, however, to note the role of titanium in formation of the porosities of castings during incorrect preparation of the alloy. This peculiarity consists of the fact that at 400-500° titanium is able to form hydrides with hydrogen. During the melt, with an increase of temperature hydrides disintegrate and hydrogen passes into the melt. Therefore it is recommended, first, that titanium alloy be prepared in induction furnaces, secondly, that the liquid alloy be thoroughly refined with subsequent secondary melting and control of quality of alloy for fracture.

Simultaneously with basic components the influence of impurities of iron and silicon was investigated. The content of iron is limited to 0.5%, since with a greater quantity big insoluble particles of phase AlMnFe will be formed which lower strength and plasticity of the alloy.

For improvement of fluidity we tried to introduce silicon into the alloy. But the presence of it in quantities of 0.5-1.0%

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<sup>1</sup>M. V. Mal'tsev, "Founding," 1956, No. 6.



considerably worsened mechanical properties of the alloy in poured and heat treated state, obviously due to formation of the brittle compound  $Mg_2Si$ .

Thus, as a result of study of the influence of basic components and impurities we determined the following composition of the alloy: 3.5-4.25% Zn; 1.5-2% Mg; 0.2-0.5% Mn; 0.1-0.2% Ti; the remainder — aluminum. The alloy was named brand [VAL4] (BAI4).

### Heat Treatment

On the diagram of the isothermal cut  $Al-Al_2Mg_3Zn_3$  (Fig. 1)<sup>1</sup> it is possible to see that an alloy of composition VAL4 has critical points at 592° (solidus) and at 623° (liquidus). Therefore for

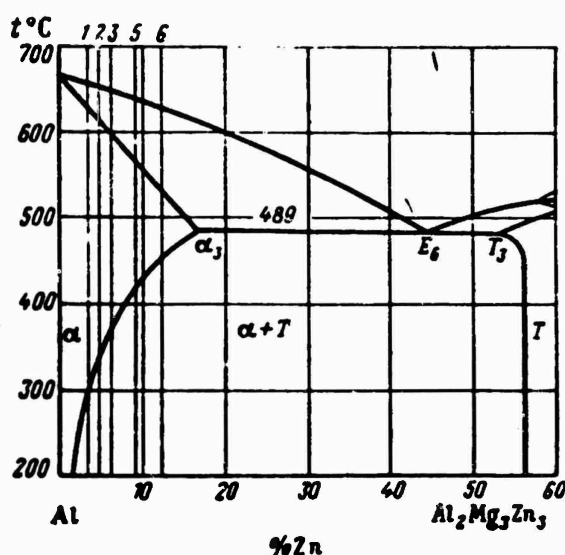


Fig. 1. Constitution diagram of  $Al-Al_2Mg_3Zn_3$ .

heating before hardening we selected a temperature of 580°. Inasmuch as in complex parts there can be separation of double eutectic  $Al-MgZn_2$  and  $Al-Al_2Mg_3Zn_3$  with melting points 470° and 489°, it is expedient to use two-stage heating before hardening by the regime 475° for 2 hours + 580° for 3 hours. If a part is thin-walled and without local bosses, then heating at 475° can be excluded and heating is done only at 580° for 5 hours.

Aging of hardened samples at 120° for 8 hours leads to a further increase of strength. We investigated also the possibility

<sup>1</sup>V. D. Turkin and M. V. Rummyantsev, Structure and properties of nonferrous metals, Metallurgy Publishing House, 1947.

of hardening in air, which opens broad prospects for application of this alloy in parts with raised requirements for stability of geometric dimensions. Heating for hardening in air was conducted by the same conditions, i.e., at 580° for 5 hours. For the purpose of acceleration of the technological process of manufacture of parts, work was carried out on selection of conditions of artificial aging without preliminary hardening. After a number of experiments the following regime was selected: heating to 200°, holding for 8-10 hours and cooling in air. Table 1 gives mechanical properties

Table 1. Mechanical Properties of Alloy VAL4 in Poured and Heat Treated State

State of alloy	$\sigma_b$	$\delta$
	kg/mm <sup>2</sup>	%
Without hardening, natural aging 10 days	22.7	3.0
Artificial aging: 200° (8 h)	22.5	2.1
Hardening by regime: 580° (5 h), cooling in water heated to 60-80°	26.3	8.2
Hardening by regime: 580° (5 h), cooling in air; aging 120°, 8 h	30.0	3.5
Hardening by regime: 580° (5 h), cooling in water; aging at 120°, 8 h	33.7	2.5

of alloy VAL4 depending on conditions of heat treatment, and in Table 2 its properties are compared with standard aluminum alloys.

Table 2. Comparative Mechanical Properties of Cast Aluminum Alloys

Make of alloy	State of alloy	Mechanical properties, not less than		
		$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>
BAJ14	Cast	23	3	70
BAJ14	T4	30	2	80
AJ12	Cast	15	2	50
AJ13	T5	21	—	75
AJ15	T5	20	—	70
AJ16	Cast	15	1	45
AJ17	T5	22	3	65
AJ18	T4	28	9	60
AJ19	T5	20	2	60
AJ113	Cast	15	1	55

### Microstructure

Microstructure of the alloy in cast state consists of grains of solid solution, on the borders of which in small quantity are located phase MgZn<sub>2</sub> and impurities (Figs. 2 and 3). After heat



Fig. 2. Alloy VAL4 in poured state. Etching by reagent 0.5% HF, x200.

**GRAPHIC NOT  
REPRODUCIBLE**



Fig. 3. Alloy VAL4 in poured state. Etching by Keller reagent. a) x120, b) x800.

treatment phase  $MgZn_2$  is not observed, and the quantity of phase T considerably decreases.

#### Technological Properties

Fluidity of alloy VAL4, as all wide-interval alloys, is lower than for a eutectic, but at the same time sufficiently high for obtaining complex casting configurations. Length of a spiral at  $700^\circ$  is equal to 515 mm, i.e., larger than for alloy [AL7] (AI7) length of spiral 400 mm).

Inclination to crack formation was determined by the method of casting of rings of different width with a metallic rod in the center. The larger the section or width of the ring with which first cracks appear, the more hot-short the alloy.

As can be seen from Table 3, inclination to crack formation of alloy VAL4 is less than for alloys AL1, AL8 and AL7.

Table 3. Hot-Shortness of Aluminum Alloys

Alloy	Width of ring, mm	Alloy	Width of ring mm
AL1	27,5	AL9	No cracks
AL7	35,0	AL2	The same
AL8	22,5	BA74	20,5

#### Sensitivity to Thickness of a Casting Section

In castings of complex configuration with a combination of thin and massive sections, it is difficult to have identical conditions of feeding. Therefore, as a rule, a difference is observed in mechanical properties of samples cut from massive and thin sections.

For showing this difference the following experiment was done. Four cylinders with diameters 15, 30, 45 and 60 mm were made with a common flow gate system, which ensured identity of conditions of casting. From the cylinders were turned samples and determined mechanical properties. Dependence of mechanical properties of alloy VAL4 on the section of a casting is shown in Fig. 4. From the graph it is clear that a fall of mechanical properties with a change of section from 15 to 60 mm is 10-20%.

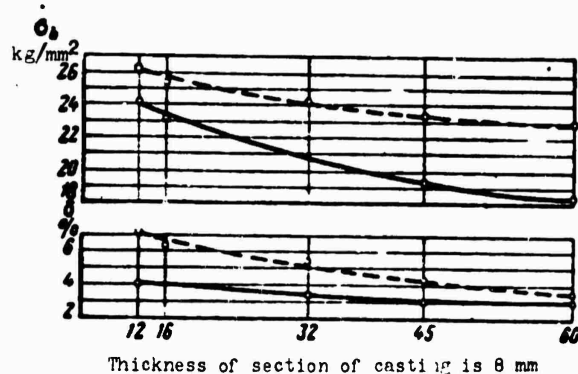


Fig. 4. Dependence of mechanical properties of alloy VAL4 on thickness of sections of castings (dotted line — properties after heat treatment, solid line — without heat treatment).

### Corrosion Resistance

Destruction of aluminum alloys in solutions of electrolytes depends on the presence in alloys of second phases with various electrode potentials. The more microcells formed by second phases on the metal - electrolyte interface, the faster the process of corrosion. Therefore alloys with heterogeneous structure behave in electrolytes most actively, and alloys of type of solid solutions (homogeneous structure) are least subject to corrosion. Alloy VAL4 has the structure of a solid solution. A test of the alloy for corrosion resistance was conducted in a solution of 3% sodium chloride +0.1%  $H_2O_2$ .

After three month holding mechanical properties of samples were determined. Tests showed that corrosion resistance of alloy VAL4 is close to the corrosion resistance of AL2 and AL13 and exceeds that of standard casting alloys containing copper.

### Weldability

Weldability of the alloy is satisfactory. Welding of samples was produced with argon arc welding with fused electrode. Electrodes were poured in the form of rods from uniform alloy.

### Airtightness

Tests for airtightness were conducted on cylindrical samples with a diameter of 37 mm, height 57 mm, thickness of wall 3 mm on a hydraulic press developing a pressure to 300 atm. As all wide-interval alloys, alloy VAL4 did not give high indices for airtightness: it sustains without leak a pressure of not more than 60-80 atm. Thus, airtightness of alloy VAL4 is the same as for alloys AL7 and AL8.

### Testing of Alloy in Industrial Conditions

Testing of alloy VAL4 at the plants permitted revealing a series of positive peculiarities of this material. At one of the plants which make parts of instruments which do not carry great loads but are very complex in configuration and require great accuracy during machining, they previously were cast from alloy AL9.

During machining of these parts cutters made even from very hard alloys frequently dropped out and did not give the needed surface cleanness. Replacement of alloy AL9 by alloy VAL4 permitted positive solution of the question of machining of parts, where it was revealed that alloy VAL4 yields even to polishing.

At another plant, parts of electrofittings required galvanic plating and soldering during installation. Not one tested standard aluminum alloy gave desirable results, since surface looseness of

the alloy did not allow one to obtain a reliable connection during soldering and hampered galvanic plating of the surface. Introduction of alloy VAL4 solved these problems.

Many parts of instruments and fittings require great accuracy of machining, where dimensions have to be stable in time. Most alloys, especially alloys inclined to prolonged natural aging, do not ensure the necessary accuracy of dimensions of castings, since structural transformations occurring in the process of aging are connected with defined volumetric changes which have effect later on dimensions of the parts. Furthermore, during sharp cooling of parts (hardening in water) residual stresses appear which in time disturb dimensions of the parts.

Application of alloy VAL4 for such parts permitted almost complete exclusion of influence of these two factors, since the relatively slow disintegration of the  $\alpha$ -solid solution of magnesium and zinc in aluminum made it possible to replace "hardening in water" by "hardening in air," and natural aging of the alloy by artificial at 200° for 8-10 hours. During development of alloy VAL4 there was considered first of all the possibility of replacement by it of such widely-known alloys as AL2 and AL9. One would think that during introduction into production there had to appear difficulties connected with certain peculiarities of the alloy: wide interval of crystallization, presence of light-oxidized components of magnesium and zinc, inclination to crack formation. However the proposed technology of preparation of the alloy (melt under layer of flux, refining, treatment of melt potassium fluozirconate) and small changes in technology of the actual casting (increase of radii of conjugation, intensive feeding, dispersed metal feed and others) permitted obtaining quality parts. Given data show that alloy VAL4 has a series of important advantages in terms of mechanical, corrosional and technological properties. The alloy is fully useful for casting shaped parts of various dimensions and configurations.

### Conclusion

1. There has been developed a new highly durable corrosion resistant alloy VAL4 of the system Al-Mg-Zn, which in mechanical properties exceeds in poured and heat treated state such standard aluminum alloys, as AL2, AL6, AL13, AL3, AL9 and AL7.

2. Technological properties of the alloy permit using it for parts of complex configuration and various dimensions.

The alloy is distinguished by stability of mechanical properties on a section of a casting.

3. The alloy responds well to cutting, polishing, welding and soldering, which makes it possible to use it for complex parts of electrical and radio equipment.

## CAST ALUMINUM-MAGNESIUM ALLOYS

N. N. Belousov

### Alloys for Manufacture of Castings Without Subsequent Thermal Treatment

Of aluminum alloys for shaped casting, aluminum-magnesium alloys [AL8] (AL18) and AL13 are used.

In recent years a new aluminum-magnesium alloy, [VI11-3] (BM11-3),<sup>1</sup> was developed for casting under pressure, and a group of Leningrad specialists has offered alloy [45Mg2] (45Mn2)<sup>2</sup> for manufacture of shaped castings in sand and metallic forms.

Increasing requirements of industry have conditioned a search for new aluminum-magnesium alloys possessing raised mechanical and corrosional properties.

### Alloy for Casting Under Pressure

During the last few years in certain branches of industry there appeared a need for a light alloy useful for casting under pressure and possessing higher corrosion resistance as compared to Silumin. In connection with this mechanical, corrosion, casting and certain

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<sup>1</sup>I. F. Kolobnev, O. B. Lotareva. Collection "Advanced industrial technical experiment," ITEIN Academy of Sciences of USSR, series 19, 1956.

<sup>2</sup>R. N. Gorelik, A. M. Kryukova, Collection "Advanced technology in founding," 1956.

other properties of alloys on an aluminum-magnesium base<sup>1</sup> were investigated.

Mechanical properties were determined on Gagarin samples, made from dense cylindrical chill mold blanks without air porosity, characteristic for parts cast under pressure.

According to the results of investigation it is established that with an increase of the content of magnesium to 6-8% in double aluminum-magnesium alloys, tensile strength attains 24-25 kg/mm<sup>2</sup>; with a higher content of magnesium, strength of the alloy noticeably drops. Relative elongation with an increase of content of magnesium gradually decreases, although it remains satisfactory (12-5% with content of magnesium in alloy within limits of from 6 to 8%). Such a change of mechanical properties agrees well with changes of microstructure of the investigated alloys.

With an increase of the content of magnesium, in the structure of the alloys there is an increase of the quantity of the  $\beta$ -phase, due to the brittleness of which there is a drop of plastic properties, and with a considerable content of this phase, also a drop of strength properties of alloys.

Analogous results on the influence of magnesium content on mechanical properties of aluminum-magnesium alloys were obtained during tests of flat samples 3 mm thick cast under pressure. Besides, it turned out that tensile strength in such samples, in spite of the presence in them of a certain air porosity, was 2-3 kg/mm<sup>2</sup> higher than tensile strength of an alloy of the same composition in dense samples made from chill mold blanks, and it reaches 26-29 kg/mm<sup>2</sup>.

In accordance with obtained results, for further investigation an alloy was selected with magnesium content from 6 to 8%.

During study of the influence of additions of iron and silicon on mechanical properties of this alloy it was established that additions of iron and silicon separately and jointly to 1.1% (each) do not essentially lower tensile strength of the alloy, but relative elongation equals 4-8%.

Proceeding from the fact that such a value of relative elongation is satisfactory, and also considering inevitability of enrichment of the alloy by iron in the process of its prolonged delivery from the furnace during casting under pressure, the content of iron in the alloy was allowed to 0.9%. Since silicon lowers inclination of aluminum-magnesium alloy to crack formation, the lower limit of content of it was accepted at 0.5%, and the upper limit - 1.0%.

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<sup>1</sup>The work was fulfilled jointly with A. A. Ivankin, K. G. Kovvi and N. V. Yeremeyevskiy.



Addition of manganese from 0.2 to 1.0%, titanium from 0.03 to 0.30%, beryllium from 0.01 to 0.10%, did not render an essential influence on mechanical properties of the alloy. For increase of corrosion resistance, the content of manganese in the alloy was set from 0.25 to 0.60%, and beryllium, protecting the liquid alloy from intense oxidation, to 0.01%. Thus, in the recommended alloy, conditionally designated [AMg7L] (AMg7Л), there are: 6-8% Mg; 0.5-1.0% Si; 0.25-0.60% Mn; up to 0.9% Fe and up to 0.01% Be.

During additional investigation of alloy AMg7L corrosion resistance and workability by cutting were determined.

Corrosion tests were conducted by means of submersion of cylindrical samples for one month in a 3% aqueous solution of sodium chloride with an addition each 5 days of 0.1% hydrogen peroxide. Corrosion resistance was determined by loss of weight of samples in comparison with casting alloy AL2. Average losses of weight after corrosion tests were (in  $\text{g}/\text{m}^2$  hour): for samples made from alloy AL2 - 0.0169; for samples made from alloy AMg7L - 0.0022. Thus, minimum losses of weight under the influence of corrosion were observed for samples made from the new alloy AMg7L.

Ability to be worked by cutting was set by means of determination of the coefficient of relative workability and visual appraisal of cleanness of the treated surface (coefficient of relative workability shows how far it is necessary to multiply cutting speed accepted for machining parts made from alloy AL2, so that during treatment of another alloy one will obtain the same cutter stability). During tests it was established that alloy AMg7L is worked by cutting better than alloys AL2, AL11 and AL13.

Different parts made by the method of casting under pressure from alloy AMg7L during industrial testing showed satisfactory results. During casting usual scooping of the ready alloy from the delivery furnace was used. Thanks to the addition of beryllium, the surface of the alloy during melt and pouring was not protected by flux. Temperature of casting was kept at the lowest possible level, 630-660°, and the temperature of the press-form within the limits of 180-250°. During casting of small parts it is necessary to use electrical heating of the presses-form.

#### Alloy for Casting in Sand and Metallic Forms<sup>1</sup>

Sometimes in industrial conditions for manufacture of castings in sand and metallic forms it is expedient to use aluminum alloys

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<sup>1</sup>In the work of this and the following sections of the article engineers A. A. Dodonov, V. A. Yegorov, A. A. Ivankin, V. S. Kolesnikova, Ye. N. Mikheyeva, M. N. Sarafanova, I. A. Sitnikova took part.

not requiring special heat treatment, as for example eutectic Silumin AL2, zinc Silumin AL11 and aluminum-magnesium alloy AL13. However alloys AL2 and AL13 have comparatively low mechanical properties, and AL11 has insufficient corrosion resistance. Therefore there appeared the problem of finding a new aluminum alloy which would possess in cast state relatively high mechanical properties and stability against corrosion.

The search for a new alloy for shaped casting in sand and metallic forms was produced by means of alloying an aluminum-magnesium base (with magnesium content 5 and 7%) by small additions of titanium, zirconium and beryllium, ensuring modification and lowering of oxidizability of the alloy.<sup>1</sup>

Experiments were conducted with application of aluminum of usual technical cleanness (A00) and high cleanness [AV000] (AB000).

Results of mechanical tests of samples cast in a chill mold show that a double aluminum-magnesium alloy of high cleanness, containing 7% magnesium, has good mechanical properties in cast state without heat treatment: tensile strength is near 25 kg/mm<sup>2</sup>, relative elongation near 15% and resilience 5 kgm/cm<sup>2</sup>.

The negative influence on mechanical properties of the alloy of an increasing content of additions of silicon appears to a larger degree than an increasing content of additions of iron. Thus, for example, resilience during an addition of up to 0.3% silicon (or joint addition of 0.3% each of silicon and iron) dropped 2-3 times (from 5 to 1.2-2 kgm/cm<sup>2</sup>). Annealing 400° positively affects plastic properties of the investigated alloys. For example, for an alloy poured in chill mold with 7% magnesium and with small additions of titanium, resilience under the influence of annealing was increased from 4-5 to 7-9 kgm/cm<sup>2</sup>.

The best combination of mechanical and corrosional properties is in an alloy of the following composition: 6-7% Mg; 0.05-0.1% Be; 0.05-0.15% Ti; 0.05-0.2% Zr, the rest - Al (this alloy is conditionally called make AMg6L).

High properties of this alloy were found during preparation of it from aluminum of high cleanness AV000 (content of silicon and iron not more than 0.05% each), and also from aluminum of technical cleanness A00 (with content of impurities of silicon and iron not more than 0.2% each).

Mechanical properties were determined at room, low and raised temperatures; corrosion stability and technological properties -

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<sup>1</sup>In the article results are given of experiments only with alloys containing 7% Mg.

during manufacture of castings from alloy AMg6L in damp sand forms. It was established that the alloy in poured (without heat treatment) state has mechanical properties practically no different than typical properties of the alloy of make AL9 in hardened state. During compression tests the alloy exceeds by strength alloys AL8, AL4 and AL9, but yield point on compression is somewhat less than special Silumin AL4 and AL9.

During casting in sand forms, resilience for the alloy noticeably dropped as compared to casting in metallic forms. By value of specific work during impact tension the alloy is on the level of alloy AL2 and somewhat yields to the alloy of make AL4. The value of energy of destruction during shock torsion of samples made from the new alloy was obtained 3 times greater (4.4-4.5 kgm) than for alloy AL4 (1.5 kgm).

Mechanical properties of the alloy at low and raised temperatures are given in Table 1. From these data it follows that at negative temperatures (to  $-100^{\circ}$ ) mechanical properties of alloy AMg6L practically are not changed. Further lowering of the temperature to  $-194^{\circ}$  leads to significant lowering of relative elongation and relative reduction of area. With an increase of temperature to  $300^{\circ}$  indices of mechanical properties are sharply changed: strength properties drop approximately 2 times, but plastic properties (relative elongation and relative reduction of area) increase almost 3 times.

Table 1. Mechanical Properties of New Alloy AMg6L at Low and Raised Temperatures

Properties	Temperature of test in $^{\circ}\text{C}$												
	-194	-100	-60	-40	-20	0	+20	+50	+100	+150	+200	+250	+300
Yield point in $\text{kg}/\text{mm}^2$	15.5	13.7	13.5	13.6	13.9	13.8	14.1	14.3	13.8	13.7	13.3	12.2	10.0
Tensile strength in $\text{kg}/\text{mm}^2$	22.7	24.4	25.0	25.1	25.3	24.5	24.9	26.0	25.7	21.7	18.2	14.7	10.4
Relative elongation in %	2.7	8.2	8.8	9.0	8.7	7.5	6.9	8.4	10.1	11.3	9.3	15.0	20.7
Relative reduction of area in %	4.5	8.3	8.5	9.0	9.0	9.5	6.4	7.3	10.4	13.7	16.4	21.4	19.7
Resilience in $\text{kgm}/\text{cm}^2$	0.3	0.4	0.3	0.4	0.6	0.5	0.5	0.6	0.7	0.7	0.7	0.6	0.7

By corrosion tests of samples during submersion in synthetic sea water it was established that the new alloy made from aluminum AV000, has a very high corrosion resistance (loss of weight  $0.0078 \text{ g}/\text{m}^2 \text{ hour}$ ). Sample made from the same alloy but manufactured from aluminum A00 had average losses of weight  $0.0388 \text{ g}/\text{m}^2 \text{ hour}$ ,

whereas loss of weight of samples made from alloy AL4 was  $0.4157 \text{ g/m}^2$  hour. During a corrosion test under stress for 1 year in atmospheric conditions and in sea water for samples made from the investigated alloys, cracks were not revealed.

During investigation of technological properties it was established that the alloy has approximately the same value of free linear shrinkage (1.12%) as alloy AL2 (1.19%). Fluidity of the alloy at  $700^\circ$  (length of rod, 264 mm) was less than for alloy AL2, and only with an increase of the casting temperature to  $750^\circ$  did fluidity of the alloy become equal to fluidity of alloy AL2 (335 mm).

For setting a rational temperature for annealing the alloy containing 7% magnesium and different additions of beryllium, zirconium and titanium, a special investigation was conducted. Under the influence of annealing at  $250^\circ$ , mechanical properties (especially plasticity) drop. This phenomenon is apparently connected with the fact that at  $250^\circ$  occurs disintegration of the solid solution and separation of a considerable quantity of the  $\beta$ -phase.

After annealing at  $350^\circ$  mechanical properties of investigated alloys are increased and attain values which are peculiar to the cast state, which apparently is caused by solution of the  $\beta$ -phase in the solid solution at this temperature.

With an increase of temperature of annealing to  $400^\circ$  there is a considerable increase of resilience, but other mechanical properties remain at the former level. Thus in separate cases the application of annealing for the purpose of increasing resilience of the new alloy can be useful. As optimum conditions of annealing it is possible to recommend heating at  $400^\circ$  with holding for 10 hours and subsequent cooling in air.

For industrial testing at the plant there were selected parts, made from the new alloy, and for comparison with them — parts made from Silumin AL2 and AL4. All parts made from the new alloy after machining were obtained dense, while parts cast from Silumin had considerable porosity. Good workability by cutting of castings from the new alloy as compared to castings from Silumin was established.

Results of mechanical tests of samples cut from the investigated parts are given in Table 2. With an increase of the content of magnesium in alloys from 6.0 to 6.5%, mechanical properties of castings do not undergo noticeable changes. Further increase of the content of magnesium to 7.5% leads to a certain increase of yield point and to simultaneous lowering of tensile strength, relative elongation and resilience.

Aluminum alloy AMg6L has in cast state approximately the same tensile strength as alloy AL4 used in a hardened and artificially aged state, but yields to the latter in terms of yield point, exceeding it in plastic properties (relative elongation and resilience).

Table 2. Results of Mechanical Tests of Samples Made from Aluminum Alloys Cut from Cast "Bracket" Parts

Make of alloy	Content of alloying elements %				Make of initial aluminum	Mechanical properties				
	Mg	Be	Zr	Ti		yield point kg/mm <sup>2</sup>	tensile strength kg/mm <sup>2</sup>	relative elongation %	resilience kg/cm <sup>2</sup>	Brinell hardness kg/cm <sup>2</sup>
AMr6Л	6.0	0.05	0.15	0.20	A00	12.5	21.0	6.3	1.2	73.4
	6.5	0.05	0.15	0.20	A00	12.6	19.4	5.1	1.0	71.4
	7.0	0.05	0.15	0.20	A00	13.3	19.0	3.6	0.6	78.4
	7.5	0.05	0.15	0.20	A00	12.8	16.8	1.5	0.4	77.8
AMr6Л	6.0	0.05	0.15	0.20	AB000	13.3	23.0	9.4	1.9	75.0
	6.5	0.05	0.15	0.20	AB000	12.7	21.5	7.0	1.7	72.5
	7.0	0.05	0.15	0.20	AB000	13.1	19.7	4.6	1.0	79.1
	7.5	0.05	0.15	0.20	AB000	14.0	20.2	4.0	0.6	77.6
AЛ2	—	—	—	12.0 (SI)	A1	9.7	14.8	4.1	0.2	72.5
AЛ4	0.25	—	0.35 (Ma)	9.5 (SI)	A1	16.8	18.0	1.9	0.4	86.1

<sup>1</sup>Mechanical properties of alloys AMg6L and AL2 are given for cast state without heat treatment; alloy AL4 — for hardened and artificially aged state.

### New Heat Treated Cast Aluminum-Magnesium Alloys

Of standard cast aluminum alloys, the stablest against corrosion is aluminum-magnesium alloy AL8 in hardened state. However, even this alloy in a number of cases does not satisfy the increasing requirements with respect to corrosion resistance which are presented now to cast parts or components made from light alloys. In connection with this appeared the problem of finding a means of increasing corrosion resistance of aluminum-magnesium alloys with preservation of their high mechanical properties.

The investigation was conducted in the direction of alloying aluminum-magnesium alloys containing 11% magnesium by additions of beryllium, zirconium, titanium, manganese and others. Additions were introduced into the investigated alloys separately and in different combinations.

For preparation of alloys, aluminum of technical purity (make A00) and high purity (make AV000) were used. During the work, influence of harmful impurities of iron and silicon on mechanical properties and corrosion resistance of aluminum-magnesium alloys were studied.

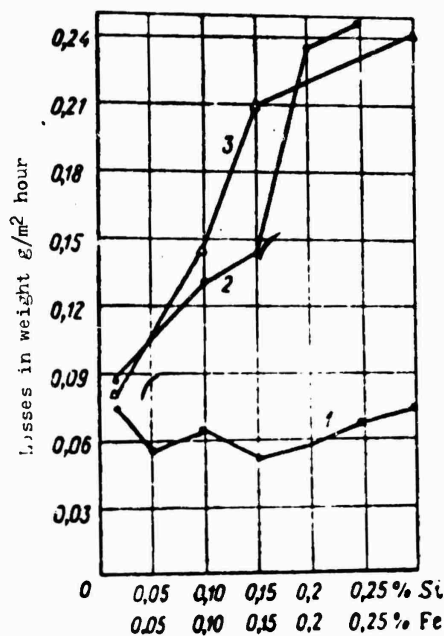


Fig. 1. Change of corrosion resistance aluminum-magnesium (11% Mg) alloys depending upon content of silicon and iron (cast in metallic molds): 1 - with addition of silicon, 2 - with addition of iron, 3 - with addition of silicon and iron equally.

Results of mechanical tests indicate that an increase of separate or joint content of silicon and iron within the limits of 0.001-0.3% considerably lowered mechanical properties: tensile strength from 37 to 28 kg/mm<sup>2</sup>; yield point from 21 to 17 kg/mm<sup>2</sup>; relative elongation from 25 to 5% and resilience from 6 to 1.5 kgm/cm<sup>2</sup>.

Corrosion tests show that iron more considerably lowers corrosion resistance of aluminum-magnesium alloys than the same quantity of silicon (Fig. 1). Results of the investigation permitted showing the advantage of aluminum-magnesium alloys of high purity, for which high mechanical properties and raised corrosion resistance are successfully combined.

#### Influence of Separate Additions of Zirconium, Titanium, Beryllium and Manganese

When alloying aluminum-magnesium alloys by zirconium the following results were obtained.

An addition of zirconium to 0.4% positively affects mechanical properties of the alloy. Especially it is necessary to note the stability and high level of mechanical properties of samples cut directly from castings 15 and 60 mm thick. This is partially explained by stable break-up of the macro and microstructure of the alloy in castings under the influence of an addition of zirconium 0.1-0.2% and more. Small additions of zirconium did not cause a noticeable change of corrosion resistance of a hardened aluminum-magnesium alloy.

Addition of titanium to 0.25% breaks up the micro and macrograin, and also noticeably increases tensile strength and yield strength of alloys. During addition of 0.5% Ti mechanical properties remain at a sufficiently high level, but more considerable additions of titanium did not give positive results — the alloys were very brittle. The highest corrosion resistance was shown by alloys containing 0.1-0.3% titanium.

During addition of up to 0.5% Be mechanical properties are preserved at approximately the same level as for the initial alloy. An exception is resilience, which drops with an increase of beryllium content.

In the process of corrosion tests of samples made from aluminum-magnesium alloys with additions of 0.005-0.15% Be, we observed a positive influence of small and negative influence of large additions of beryllium.

During an introduction of manganese from 0.005 to 0.2%, aluminum-magnesium alloys obtain raised corrosion resistance as compared to alloy AL8 (Fig. 2). Losses in weight of the investigated alloys with additions of manganese approach that of pure aluminum.

It is known that hardened aluminum-magnesium alloys with 9-11% Mg are inclined to natural aging. Introduction in such alloys of 0.2% Mn promotes a certain increase of stability of mechanical properties and corrosion resistance of cast parts during prolonged exploitation and during storage. An increase of the addition of Mn more than 0.2% lowers at first plastic, and then strength properties of alloy.

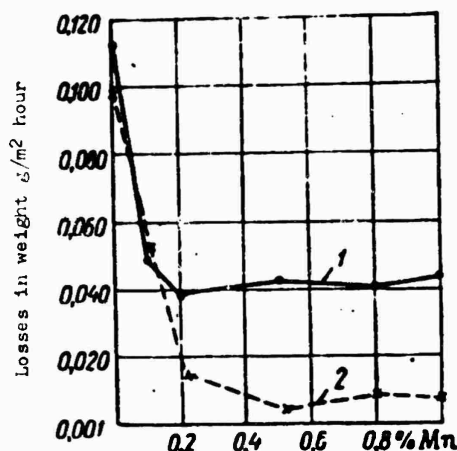


Fig. 2. Change of corrosion resistance of aluminum-magnesium (11% Mg) alloys depending on manganese content: 1 - cast state, 2 - hardened state.

#### Influence of Joint Additions of Titanium, Beryllium, Zirconium and Manganese

Considering the positive results of separate introduction of additions of zirconium, titanium, beryllium and manganese, a further search was conducted with application of joint additions of these in a quantity of several tenth fractions of a percent to aluminum-magnesium alloys of usual and high purity.

During alloying of alloys of high purity with joint additions of beryllium, titanium and zirconium there was a considerable increase in resilience of alloys with preservation at a high level of all other indices of mechanical properties. During addition to an alloy of high purity of 0.1% Be and casting it in metallic forms especially high indices of specific resilience are obtained, from 12 to 14 kgm/cm<sup>2</sup> (Menazhe samples with cut).

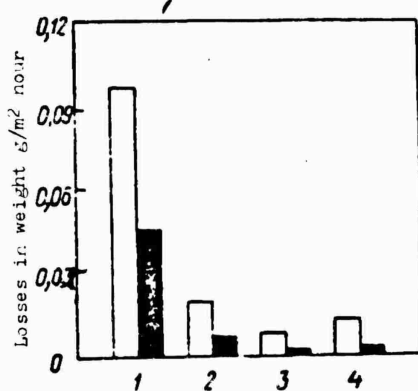


Fig. 3. Change of corrosion resistance of aluminum-magnesium (11% Mg) alloys depending on content of zirconium, beryllium and titanium: 1 -- without additions, 2 -- with addition of 0.1% zirconium, 3 -- with addition of 0.1% zirconium and 0.2% beryllium, 4 -- with addition of 0.1% zirconium, 0.2% beryllium and 0.1% titanium; □ -- cast state; ■ -- hardened state.



Joint additions of beryllium, titanium and zirconium considerably increase corrosion resistance of aluminum-magnesium alloys (Fig. 3).

Results of the investigation of structure, mechanical properties and corrosion resistance of a large quantity of alloys of different composition on an aluminum-magnesium base permitted selection of three alloys for industrial testing whose chemical compositions are given in Table 3.

Table 3. Chemical Composition of New Alloys in %

Number of alloy	Mg	Be	Zr	Ti	Mn	Impurities more than		Make of initial aluminum
						Si	Fe	
1 <sup>1</sup>	9.5-11.5	0.05-0.15	0.05-0.2	0.05-0.15	—	0.05	0.05	AB000
	9.5-11.5	0.05-0.15	0.05-0.2	0.05-0.15	—	0.2	0.2	A00
2	9.5-11.5	0.05-0.15	—	—	0.15-0.35	0.2	0.2	A00
3	9.5-11.5	0.05-0.2	0.05-0.2	—	—	0.05	0.05	AB000

<sup>1</sup>Alloy No. 1, made from aluminum of high purity of make AV000, is designated [AL8U] (AL8y), and the same alloy prepared from aluminum of make A00, is designated AL8U t.p. (technical purity).

#### Results of Study of Mechanical Properties of New Alloys at Room Temperature

Mechanical properties of new alloys at room temperature were determined during static and dynamic application of load as compared with alloy AL8 prepared by improved technology (with addition of 0.005% Be).

As can be seen from Table 4, the new alloys and standard alloy AL8 with addition of 0.005% Be have higher mechanical properties as compared to typical properties of alloy AL8.

Since aluminum-magnesium alloys possess raised resilience as compared to other cast aluminum alloys, it was interesting to obtain data about mechanical properties with other methods of dynamic tests. With this goal we conducted tests of shock tension and shock torsion (Table 5).

During the shock tension test the new alloys have approximately the same characteristics of strength and plasticity as alloy AL8, but the value of specific work expended on destruction of the sample exceeds it by almost 40%. By value of the shown characteristic the new alloys 2.5 times exceed casting alloys AL4 and AL13 and highly durable wrought alloy B95, approaching alloys A1, [AMg] (AMr) and AMg7.

Table 4. Mechanical Properties of New Aluminum-magnesium Alloys at Room Temperature

Number or make of alloy	Make of ini- tial alu- minum	Tension				Resili- ence kg/cm <sup>2</sup>	Brinell hard- ness kg./mm <sup>2</sup>	Compression (dur- ing 50% comp.)		Torsion		Fatigue limit kg/mm <sup>2</sup>
		yield point kg/mm <sup>2</sup>	tensile strength kg/mm <sup>2</sup>	relative elonga- tion %	relative reduc- tion of area %			yield point kg/mm <sup>2</sup>	tensile strength kg/mm <sup>2</sup>	yield point kg/mm <sup>2</sup>	shear resis- tance kg/mm <sup>2</sup>	
1	A00	19.9	37.6	17.7	25.5	3.1	98.0	30.3	119.7	14.4	20.7	6
2	A00	19.6	33.1	19.1	27.7	2.3	94.6	29.7	85.8	14.2	26.8	5
3	AB000	20.0	38.7	22.6	27.8	3.8	99.4	29.5	121.9	14.4	27.6	6
AJ18 with 0.005% Be	A00	20.2	38.0	18.0	33.9	1.8	104	32.8	120.1	—	28.6	6
AJ18	A00	17	30.0	12.0	—	1.0	70.0	—	—	6.3	23.0	5

Table 5. Mechanical Properties of Alloys  
During Dynamic Tests

Number or make of alloys	Shock tension				Energy of destruction during shock torsion
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\psi$ %	$\sigma_d$ kgm/cm <sup>2</sup>	
1	40.0	16.8	27.0	8.1	10.8
2	40.8	21.7	28.5	8.2	8.7
3	41.0	19.9	28.3	8.2	9.4
AL8 with 0.005% Be	43.6	13.8	19.0	6.0	8.7
АЛ4	—	—	—	3.3	1.5
АЛ13	—	—	—	3.3	—
В95	—	—	—	6.9	5.7
Д16	—	—	—	12.2	8.9
Д1	—	—	—	9.5	—
АМг7	—	—	—	9.6	15.6
АМг	—	—	—	9.7	—

For new alloys and alloy AL8 are obtained approximately the same values of energy of destruction during shock torsion (8.4-10.8 kgm), as for alloy D16 (8.9 kgm) and higher values as compared to alloy B95 (5.7 kgm).

#### Results of the Investigation of Mechanical Properties of New Alloys at Low and Raised Temperatures

Results of mechanical tests at low and raised temperatures are shown in Fig. 4. From the graph it is clear that at negative temperatures (to  $-100^{\circ}$ ) properties of all investigated alloys practically are not changed, with the exception of the value of resilience, which drops significantly and at  $-100^{\circ}$  for all investigated alloys is equal to 0.4-0.5 kgm/cm<sup>2</sup>.

Further lowering of temperature to  $-194^{\circ}$  leads to a certain increase of the yield point with a noticeable fall of tensile strength and plasticity (of relative elongation and relative reduction of area).

With an increase of temperature there is considerable lowering of strength properties and growth of plasticity of the alloys.

During heating to 300-350<sup>o</sup> all characteristics of plastic properties of the new alloys were obtained 2-4 times higher than for alloy AL8. These results give reason to expect good ability of the new alloys for plastic deformation in a heated state.

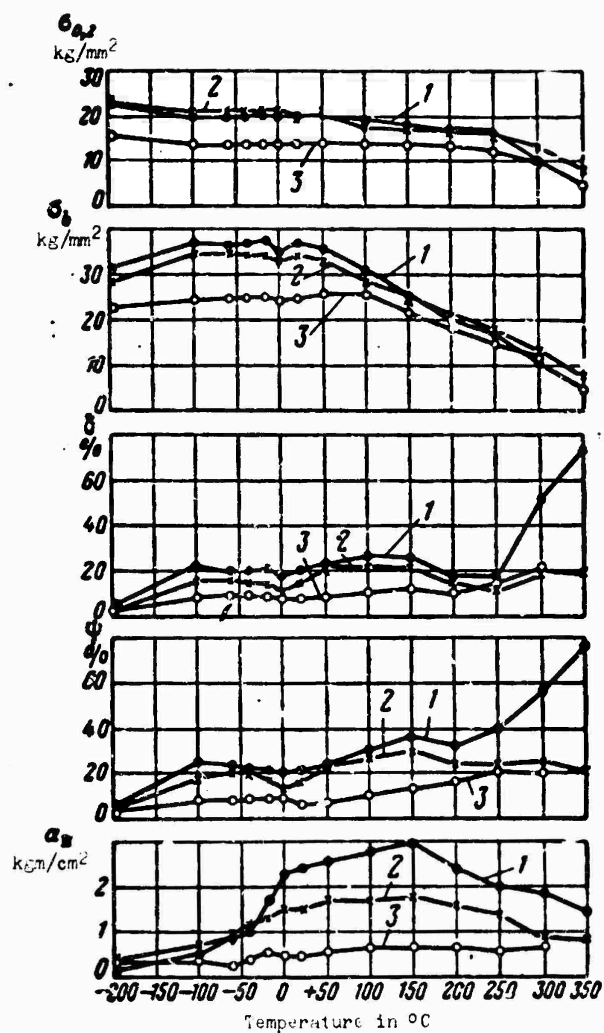


Fig. 4. Mechanical properties of alloys at low and raised temperatures. 1 - alloy AL8U, 2 - alloy AL8, 3 - alloy AMg6L.

### Conclusions

1. The developed alloy for casting under pressure, containing 6-8% Mg; 0.5-1.0% Si; 0.25-0.6% Mn, the rest Al, in terms of strength and corrosion resistance exceeds the widely used alloy AL2 for casting under pressure.

2. The developed alloy for casting in sand and metallic forms contains 6-7% Mg, 0.05-0.1% Be; 0.05-0.15% Ti; 0.05-0.2% Zr; the rest Al, and it is used without heat treatment.

During manufacture from aluminum of high purity, strength and corrosion characteristics of the alloy in cast state exceed properties of alloy AL9 and do not yield to alloy AL4 in the heat treated state.

Strength characteristics of the alloy are positively influenced by zirconium (0.05-0.2%) and titanium (0.05-0.15%), and corrosion resistance of the alloy by titanium, beryllium (to 0.2%) and manganese (to 0.2%).

3. The group of heat treated alloys of the system Al-Mg proposed for casting of shaped parts with additions of beryllium, zirconium, titanium and manganese based on aluminum of brands A00 and AV000, in terms of constructional strength and corrosion resistance significantly exceed alloy AL8.

INFLUENCE OF NATURAL AND ARTIFICIAL AGING ON MECHANICAL  
PROPERTIES OF PARTS AND SAMPLES MADE  
FROM ALLOY AL8<sup>1</sup>

O. B. Lotarev, N. P. Stromshaya, and L. I. Loktionov

Alloy [AL8] (AL8) is subjected to hardening for the purpose of converting into solid solution phase  $Mg_5Al_8$ , which is barely soluble at room temperature. After hardening the alloy constitutes a supersaturated solid solution. Being in a metastable state, it strives by means of disintegration to return to a stable state. Works dedicated to aging of alloys of the system Al-Mg are not numerous. In certain of them the influence of additions on the process of aging is examined. Thus, the work of V. I. Arkharov and others<sup>2</sup> mentions acceleration of processes of aging of alloys of this system depending on additions of zinc or silver (investigated addition of zinc and silver in quantities to 1% to alloys with 8 and 10% Mg).

N. N. Belousov and others investigated alloys with a content of from 1 to 14% Mg. It was determined that after natural aging for one year for alloys containing up to 9% Mg the mechanical properties remain constant. For alloys with 10.7% Mg and more, the mechanical properties for this period are noticeably changed.

We investigated the influence of natural aging during prolonged intervals of time on mechanical properties of alloy AL8, and the influence of zinc on mechanical properties of the alloy after natural and artificial aging.

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<sup>1</sup>G. K. Karelov participated in the work.

<sup>2</sup>V. I. Arkharov, I. P. Berenova, L. M. Magat, (Physics of metals and metal science).

Natural aging of alloy AL8 was investigated for plant hardened parts stored for different times at room temperature. The most prolonged storage was 40 months.

From parts, depending on their configuration, Gagarin ( $\phi$  3-5 mm) or flat samples were cut.

Mechanical properties of samples cut from parts, after different times of natural aging are shown in Fig. 1.

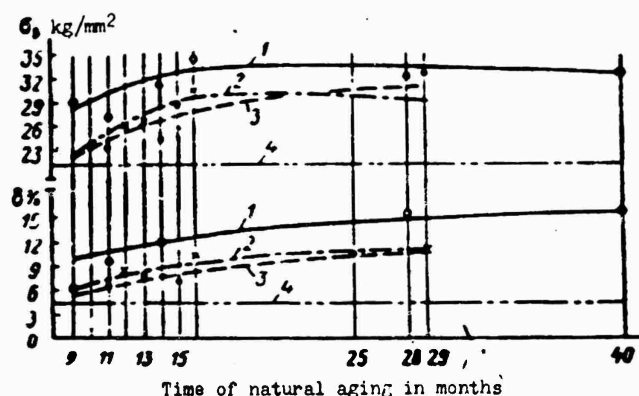


Fig. 1. Change of mechanical properties of alloy AL8 depending on time of natural aging (samples are cut from parts). 1 - flat samples, 2 - Gagarin samples  $\phi$  5 mm, 3 - the same,  $\phi$  3 mm, 4 - according to technical specifications.

From the graphs it is clear that tensile strength and lengthening of alloy AL8 in the process of natural aging (especially in the first period of approximately 15 months) are somewhat increased and during 40 months remain higher than properties to which alloy AL8 should correspond in terms of technical conditions. Growth of relative elongation is more weakly expressed than growth of tensile strength.

Investigation of artificial aging was conducted on alloy AL8 and on alloy of composition 11% Mg; 0.8% Zn; 0.15% Be; 0.20% Ti; remaining Al. Aging was conducted at 100, 115, 125, 150, 175, 200, 250 and 300° for 3 hours.

Mechanical properties were determined on separately poured samples 10 mm in diameter immediately after aging and after holding at room temperature.

Results of the test, given in Table 1, show that after natural aging for 8 months strength of alloy AL8 considerably increases (from 32.7 to 44  $\text{kg/mm}^2$ ), and lengthening remains practically without change.

Table 1. Mechanical Properties of Alloy AL8 after Hardening and Aging

State of alloy	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
Immediately after hardening	32.7	12.9
Hardening and natural aging 1 month	36.2	14.2
Hardening and natural aging 8 months	44.0	13.1
Hardening +100° (3 hours) and natural aging 1 month	37.0	13.0
Hardening +100° (3 hours) and natural aging 8 months	40.8	15.2

Table 2. Mechanical Properties of Alloy of System Al-Mg-Zn after Artificial Aging and Holding at Room Temperature

State of alloy	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
Immediately after hardening	39.0	24.2
Hardening and artificial aging at 100° (3 hours)	40.4	21.9
Hardening and artificial aging at 115° (3 hours)	40.8	25.6
Hardening and artificial aging at 125° (3 hours)	40.2	26.0
Hardening and artificial aging at 150° (3 hours)	41.3	25.8
Hardening and artificial aging at 175° (3 hours)	38.0	14.0
Hardening and artificial aging at 200° (3 hours)	34.8	1.9
Hardening and artificial aging at 250° (3 hours)	27.5	0.5
Hardening and artificial aging at 300° (3 hours)	24.7	0.5
Hardening and artificial aging at 100° (3 hours). Tested 1 year later after holding at room temperature	46.1	15.4
Hardening and artificial aging at 100° (3 hours). Tested 1.5 year later after holding at room temperature	47.0	10.9
Hardening and artificial aging at 125° (3 hours). Tested 10 months later after holding at room temperature	44.6	19.3
Hardening and artificial aging at 125° (3 hours). Tested 1.5 year later after holding at room temperature	46.7	14.7
Hardening and natural aging for 1.5 years	46.1	5.5



After artificial aging at  $100^{\circ}$  (3 hours) a hold at room temperature also creates an increase in mechanical properties of the alloy.

In the alloy of system Al-Mg-Zn with beryllium and titanium (Table 2) after artificial aging at 100, 115, 125 and  $150^{\circ}$  tensile strength and lengthening are somewhat increased.

Holding of samples after aging at  $100^{\circ}$  again increases tensile strength, but lengthening noticeably lowers.

The same is observed during hold of alloy artificially aged at  $125^{\circ}$  (3 hours): after 1.5 years of aging tensile strength attains  $46.7 \text{ kg/mm}^2$ , and lengthening descends to 14.7%. After natural aging of this alloy for 1.5 years without preliminary artificial aging tensile strength of the alloy is equal to  $46 \text{ kg/mm}^2$ , but lengthening is then only 5.5%.

### Conclusions

1. Natural aging of alloy AL8 after hardening increases tensile strength and lengthening, especially in the first period of aging (up to 15 months). During aging for up to 40 months, properties remain higher than properties of an alloy not subjected to natural aging.

After artificial aging at  $100^{\circ}$  for 3 hours and holding for 8 months, mechanical properties of alloy AL8 are considerably higher than immediately after hardening.

2. The general level of mechanical properties of alloy of system Al-Mg-Zn is considerably higher than for alloy AL8.

Artificial aging at  $100^{\circ}$  (3 hours),  $115^{\circ}$  (3 hours),  $125^{\circ}$  (3 hours) and  $150^{\circ}$  (3 hours) permits one for 1.5 years to preserve lengthening of hardened alloy Al-Mg-Zn at a level of 50-60% of the initial value of this characteristic.

## INFLUENCE OF HEATING ON PROPERTIES OF PARTS MADE FROM ALLOY AL8

S. G. Glazunov and O. B. Lotareva

One of the characteristic peculiarities of alloy [AL8] (AL8) is the extraordinarily great difference between its properties in cast state and after heat treatment. Thus, the cast alloy has a tensile strength of 15-17 kg/mm<sup>2</sup> and lengthening 0-1%; after heat treatment (heating at 430°, holding 10-20 hours, cooling in water) tensile strength increases to 28-35 kg/mm<sup>2</sup> with lengthening 9-20%.

Low properties of the cast alloy are explained by the presence of a brittle phase  $\beta(\text{Al}_8\text{Mg}_5)$  or, as certain authors consider,  $\text{Mg}_2\text{Al}_3$ , which is on the borders of grains. During prolonged heating during heat treatment the  $\beta$ -phase passes into solid solution, the brittle network on borders of grains vanishes and the alloy obtains the structure of a solid solution with intermittent phase  $\text{Mg}_2\text{Si}$ , whose quantity depends on the degree of contamination of the alloy by silicon (Fig. 1).



Fig. 1. Microstructure of alloy AL8 after hardening;  $\times 200$ . Etching by a reagent of 10 cm<sup>3</sup> HF, 15 cm<sup>3</sup> HCl, 90 cm<sup>3</sup> H<sub>2</sub>O.

**GRAPHIC NOT  
REPRODUCIBLE**

In spite of the fact that alloy AL8 in hardened state possesses high strength and plasticity, during assembly and especially riveting, in parts made from this alloy cracks are observed. During clarification of causes of brittleness of parts it was established that in the majority of such cases heating of hardened parts was produced either for drying paint or for shrink fit. It is known that the solid solution of magnesium in aluminum obtained by means of homogenization and hardening is stable only at a temperature not higher than  $100^{\circ}$ .

During heating higher than  $100^{\circ}$  disintegration of the hard solution occurs, leading to a sharp lowering of mechanical properties, especially lengthening. Disintegration of the solid solution can be easily revealed by fracture and microstructure. Fracture of hardened alloy AL8 has a dull feature, after heating (lower than the temperature of hardening) it becomes light and brilliant, obtaining a form characteristic for brittle material.

The microstructure of alloy AL8, subjected to heating after hardening, is characterized by the appearance of separations of the second phase all over the field of the grain (Fig. 2).



Fig. 2. Microstructure of alloy AL8 subjected to heating after hardening;  $\times 200$ . Etching by reagent  $10 \text{ cm}^3 \text{ HF}$ ,  $15 \text{ cm}^3 \text{ HCl}$ ,  $90 \text{ cm}^3 \text{ H}_2\text{O}$ .

**GRAPHIC NOT  
REPRODUCIBLE**

For confirmation of the conclusion that brittleness of parts is a result of heating after hardening, causing a process of disintegration of the solid solution which, as it is known, is reversible, one of the cracking parts was subjected to repeated hardening under usual conditions. During investigation of the microstructure of this part it turned out that separation of the second phase vanished and the structure took a form typical for hardened alloy AL8. This part was subjected to aging at  $180^{\circ}$  (1 hour), after which disintegration of the solid solution was revealed anew. In order to establish the degree of fall of mechanical properties of alloy AL8 depending on temperature of heating of the hardened alloy, round samples with a diameter of 12 mm were cast. Part of the samples were tested after hardening without subsequent heating, others were subjected to heating for 5 hours at 100, 125, 150, 175, 200 and  $225^{\circ}$ .

As can be seen from Fig. 3, mechanical properties of samples after hardening considerably exceed the requirement of All-Union

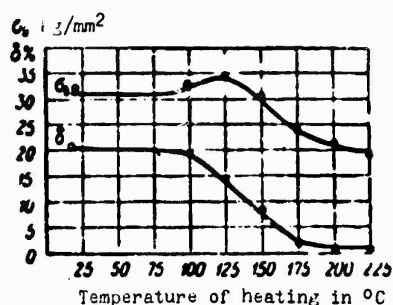


Fig. 3. Mechanical properties of alloy AL8 after hardening and subsequent heating.

Government Standard 2685-55. Heating at 100° practically does not change mechanical properties of alloy AL8.

With an increase of temperature of heating to 125° it is possible to note a certain increase of tensile strength and a lowering of lengthening. Further increase of the temperature of heating leads to a sharp fall of tensile strength and especially lengthening. After heating at 200° and above lengthening is equal to zero. Hardness with an increase of temperature of heating is increased, attaining at 200° a maximum, after which it starts to descend (Fig. 4).

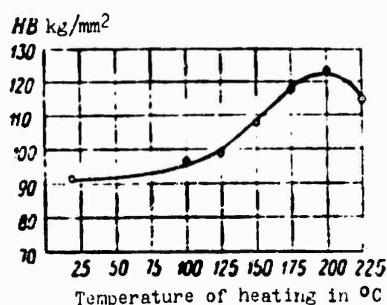


Fig. 4. Influence of heating (for 5 hours) on hardness of hardened alloy AL8.

The microstructure of samples ( $\times 200$ ) after hardening without aging constitutes a field of solid solution with weakly outlined thin borders of grains. After aging at 125° a visible change of structure during the given increase is not observed. Aging at 150° leads to disintegration of the solid solution, characterized by the appearance of small, distinctive particles inside the grains. After aging at 175° the degree of disintegration is sharply increased, here almost all the field of grain is studded by small separations of the second phase. At a temperature of aging 200° coagulation of the falling particles occurs.

Thus, at  $\times 200$  disintegrations of the solid solution can be revealed after aging at  $150^{\circ}$ . At higher aging temperatures the color of grains of solid solution becomes darker, and etching of them occurs considerably faster.

For establishing the disintegration rate of solid solution of hardened alloy AL8 we selected an aging temperature of  $180^{\circ}$  at which samples were held for 5, 10, 20, 30, 40 and 60 minutes. Investigation of the microstructure was produced at  $\times 1500$  after etching by a reagent of composition  $10 \text{ cm}^3 \text{ HF}$ ,  $15 \text{ cm}^3 \text{ HCl}$ ,  $90 \text{ cm}^3 \text{ H}_2\text{O}$ . Duration of etching was 35 s.

In Fig. 5 is given the structure of alloy AL8 before heating. On the light background of the  $\alpha$ -solid solution it is possible to see only phase  $\text{Mg}_2\text{Si}$ .



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REPRODUCIBLE

Fig. 5. Microstructure of hardened alloy AL8 before heating;  $\times 1500$ .



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Fig. 6. Microstructure of hardened alloy AL8 after heating at  $180^{\circ}$ , 40 minutes;  $\times 1500$ .

After heating for 5 and 10 minutes, noticeable changes in structure are not revealed, except weakly etched borders of grains. Heating for 20 minutes somewhat strengthens the etch of borders of



Fig. 7. Microstructure of hardened alloy AL8 after heating at  $180^{\circ}$ , 1 hour;  $\times 1500$ .

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grains, except that against the background of grains of solid solution it is possible to note the appearance of weakly appearing points which obviously correspond to separations of the second phase. When the duration of heating is 30 minutes, the quantity of points and intensity of their color noticeably increase. An increase of the time of heating to 40 minutes promotes coagulation of separate points of separations, which start to obtain a needle-shaped form (Fig. 6). After heating for 1 hour the quantity of separations of the second phase is sharply increased (Fig. 7).

#### Conclusions

1. The solid solution of hardened alloy AL8 at temperatures higher than  $100^{\circ}$  is unstable, in consequence of which it can easily disintegrate, accompanied by a sharp lowering of mechanical properties. The decrease of plasticity here is so big that the alloy becomes absolutely unfit for usual fields of application (loaded parts, subject to shock influences). Therefore heating of the hardened alloy higher than  $100^{\circ}$  is absolutely impermissible.

2. Heating at  $125^{\circ}$  for 5 hours leads to a small increase of tensile strength, a noticeable growth of hardness, and a fall of lengthening.

At higher temperatures of heating ( $150-225^{\circ}$ ) mechanical properties descend, approaching properties of a thermally untreated alloy.

3. Disintegration of the solid solution can be clearly observed on microsections (at  $\times 1500$ ) after heating at  $180^{\circ}$  for 30 minutes.

## TECHNOLOGICAL PECULIARITIES OF MANUFACTURE OF ALLOY AL8

G. K. Karelov

Of cast aluminum alloys an interesting alloy is [AL8] (AJ8) with magnesium content 9.5-11.5%. High specific strength and corrosion resistance condition effectiveness of its application for machine parts. Although this alloy possesses high strength ( $\sigma_b \approx 28 \text{ kg/mm}^2$  when  $\delta \geq 9\%$ ), mechanical properties in complex thick-walled castings are low due to formation of blackness.

The complexity of casting and heat treatment of this alloy has prevented its wide application. As a result of its inclination to strong oxidation in the melted state and high requirements for purity of composition of the alloy in industrial processes, usually a series of measures was provided: the alloy was melted only under protection of a flux (carnallite); for preventing contamination by iron graphite crucibles were used; industrial waste was preliminarily remelted into pigs; parts before heat treatment were smeared with a mixture of fireclay and sand for protection from oxidation. All these measures complicated the industrial process.

It was determined that addition of beryllium and titanium to alloy AL8 sharply decreases formation of "blackness" in casting, permits melting without a protective flux, and heat treatment of a part without protective plastering, creating wide possibilities of melting, casting and heat treatment of parts from alloy AL8.

The liquid covering flux used during melt (carnallite, sometimes with an addition of up to 20% fluorspar) possessed refining ability.

Lowering oxidizability of the alloy permits using a hard flux during melt, consequently promising an increase of its refining ability. Obviously, most useful from this point of view is a flux which is sufficiently rich in fluorides.

Furthermore, it is known that it was not possible to melt

alloy AL8 in cast-iron crucibles. Protective paints used for coloring crucibles were rapidly destroyed under the impact of the liquid flux, alloy was not isolated from the crucible and was saturated by iron in impermissible quantities. Addition of beryllium and titanium to alloy AL8 permits melting without a covering flux. Consequently, the cause of destruction of the protective paint is removed and melting in cast-iron crucibles is fully possible.

However refining the alloy in cast-iron crucibles remained impracticable and solution of this problem has presented great industrial interest.

Taking into account the high productivity of cast-iron crucibles and the economic expediency of their application during limited scales of production, experimental work was conducted on melting alloy AL8 in these crucibles.

In the basis of melt technology the following condition were assumed: the alloy should be as free as possible from oxides and the melt should be highly productive. Therefore experiments were conducted in two directions: first, we searched for a more refractory refining flux based on magnesium chloride, secondly, we selected for crucibles a protective paint which was more stable against flux.

Of those fluxes used in industry for aluminum and magnesium alloys, not one satisfied the presented requirements. When selecting the composition of flux, we chose the system  $MgCl_2KCl-CaF_2$ , as the most acceptable during melt of aluminum-magnesium alloy.

During selection of the percentage relationship of salts in the flux, we considered it necessary to introduce the highest possible quantity of fluoride in order to increase the marginal wetting angle of the flux and thereby lower its destructive action on crucible paints.

It was established that these requirements were best satisfied by a flux consisting of 60% carnallite and 40% fluorspar. Such a flux on the surface of the liquid metal is baked into a monolithic solid substance. After refining the flux forms hard pieces, and until the end of pouring it, serves as a good cover and does not destroy the protective layer of paint.

As basic material for paint we selected graphite as the stablest material against the action of melted salts.

During selection of the composition of the protective paint we considered the necessity of stability of it against cracking during heating and during sharp oscillations of temperature, ability to endure grasping after being applied to a crucible, not to crumble and to form a smooth surface. Experiments showed that in terms of content of components the best composition for paint is the mixture from which graphite crucibles are prepared; therefore paint was prepared from a crushed mixture of graphite crucibles.

On the basis of experimental works the following technological



process of preparation of alloy AL8 was accepted.

The alloy was melted in a resistance electric furnace with a cast-iron stationary crucible 100-125 kilograms in capacity. The internal surface of the crucible was covered by an insulating layer of fireproof paint, which by brush was deposited in a thin layer on preliminarily heated (to 100-120°) crucible and was polished until formation of a smooth surface.

The paint was prepared in the following way: pieces of graphite crucibles were crushed in a mortar and passed through sieve No. 40. The composition of the paint was 25-35% graphite powder and 5% water glass, the remaining water (by weight). This mixture was thoroughly mixed and heated to boiling. After cooling, the paint was ready for use.

Before every melt the crucible was thoroughly cleaned of remainders of the preceding melt, any place where the layer of paint was damaged was painted, after which the furnace was turned on. The charge was loaded into the crucible and heated to 600-700°.

The preliminary alloy was prepared with content of magnesium 11-11.5%, beryllium and titanium 0.05-0.07% each. The order of preparation of the preliminary alloy was as follows: in the beginning we melted pure aluminum, with submersion of last pigs of aluminum we loaded beryllium and titanium alloys. Not expecting full melting of alloys and the last pigs of aluminum, the metal was then covered by the flux in the quantity 2% of the total weight of the charge.

As the covering and refining flux we used a powdery mixture made from 60% dehydrated carnallite and 40% fluorspar. The flux was stored in a hermetically sealed box.

After achievement of temperature of the metal 700° the crust of flux was chopped by a slagstripper and the metal carefully mixed. Then with the aid of tongs we introduced magnesium, the pig of which was preliminarily heated for removal of traces of moisture and oil. After termination of the introduction of magnesium the temperature of the alloy drops to 630-640°. For increase of temperature the alloy was held a certain time in the crucible with the furnace turned off. At a temperature of 660-670° after mixing and refining, not removing the flux, the alloy was poured into casting molds.

Preparation of the working alloy is produced in the following way: good quality waste of its production (flow gates, casting reject) is used in the charge without preliminary remelting and without limitation of quantity. Loading the charge of the working alloy is conducted in the following order: in the beginning we load a pig of preliminary alloy, then the large waste material of its production and lastly small waste. After melting the last portions of the charge the furnace is disconnected; not removing the slag, the metal is covered by flux in the quantity of 1.5-3% of the weight of the

charge (1.5% flux is introduced during melt of the working alloy prepared only from preliminary alloy).

Further increase of temperature of the metal occurs on account of inertia of the furnace. At a temperature of metal 640-650° refining is produced. For this the crushed flux is mixed by the slagstripper with frequent shallow submersion under the surface of the metal.

Formation of a mirror surface on the metal and full separated from it of flux bears witness about termination of the process of refining. After that, without taking the flux from the surface of the metal, the alloy is poured into forms. Pouring spoons and ladles before use are thoroughly cleaned from rust and cinder, heated to a dark red color and sprinkled with flux.

After pouring, the spoons and ladles are washed in water and dried in the furnace. For removal of harmful action of moisture of the form on metal in the forming facing mixture we add 4-5% boric acid. To the rod mixture we add 1% boric acid.

When planning a model set for parts made from alloy AL8 one should anticipate (as far as this is possible) location of the casting in the lower mold-box, so that filling will be produced at the lowest temperature.

During development of the flow gate system one must strictly sustain conditions of series crystallization of casting. For this feeders are located under air holes or air holes are located nearer to feeders. Temperature of filling should be not more than 700-720°. If the configuration of a part allows, then desirably the temperature will be lowered to 670-700°.

Heat treatment of parts was produced in shaft furnace [PN-34] (ПН-34) with automatic adjustment of temperature under conditions: holding 20 hours at a temperature of  $435 \pm 5^\circ$ ; hardening in water at a temperature of 70-80°.

Protective coating of parts is not produced. Mechanical properties of alloy AL8 on separately poured samples are obtained within the limits  $\sigma_b = 35-40 \text{ kg/mm}^2$  and  $\delta = 12-20\%$  with multiple use of industrial waste. Tensile strength of samples cut from parts:  $\sigma_b = 26-37 \text{ kg/mm}^2$  and  $\delta = 7-18\%$ .

### Conclusions

1. Introduction of beryllium and titanium into the alloy and application of a new flux during melting ensures obtaining good quality castings made from alloy AL8.

2. Application of special paint makes it possible to prepare good quality alloy in cast-iron crucibles.

3. During strict fulfillment of technology of smelting, casting and heat treatment, mechanical properties of alloy AL8 can considerably exceed the requirements of technical conditions.

## LARGE CASTINGS FROM ALLOY AL8<sup>1</sup>

A. M. Petrunik

### Preparation of Alloy Before Filling

Lowered technological properties and predisposition to oxidation in liquid state introduce a series of peculiarities into the technological process of production of castings from alloy [AL8] (AL8). These peculiarities must be considered at all stages of the technological process, starting from melt of the metal and finishing by knockout of castings and their heat treatment.

Melting of alloy AL8 is usually produced in electric shaft furnaces in graphite crucibles with a capacity of 100-120 kilograms. Cast-iron crucibles are also used. During casting of large parts, when filling of forms is produced from groove crucibles, crucibles welded from sheet steel are used.

For protection of the melt from saturation by iron, cast-iron and steel crucibles and melting tools are covered by an even layer of fireproof paint. The paint consists of 35-40% borax, 5-7% magnesium oxide, 35-40% boric acid, 20-25% graphite, the remaining water. According to the experience of certain enterprises, good protective properties are shown by paint consisting of 45-50% magnesite, 4-6% white clay, 30-35% fire clay, 4-6% graphite, 2-3% boric acid, the remaining water. Paint is deposited by brush after heating a crucible thoroughly purified from slags and carbons to a temperature of 120-150°.

Melt of alloy AL8 should be conducted as fast as possible. This

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<sup>1</sup>Certain recommendations of A. M. Petrunin differ from proposals of G. K. Karelov (see his article in the present collection, p. 74), which is explained by different industrial conditions. (Editor's note).

is promoted by preliminary heating of the crucible to a temperature of 600-700° and application of the charge in the form of comparatively small pieces. The melt is produced under a layer of covering and refining flux consisting of 60% dehydrated carnallite and 40% fluorspar.

For decreasing oxidation of alloy AL8 in liquid state, breaking up the macrograin and removal of blackness which is observed especially in massive parts of castings, beryllium and titanium (0.05-0.07% each) are added to the alloy.

During all the process of melt the metal may not be overheated higher than 700°. Overheating the melt higher than this temperature involves an increase of macrograin and, mainly, intensive saturation of the alloy by gasses.

Oxide inclusions observed in fractures of castings will be formed mainly in the melt process and get into the casting together with the liquid metal when filling the form.

The question of purity of the liquid metal during work with alloy AL8 is especially important, since oxide inclusions lower not only strength properties of cast parts, but also their corrosion stability.

Therefore all charge materials — aluminum, magnesium, alloy and production waste — before melting are subjected to thorough purification by metallic brushes, and big oxide scales are removed by cutting with pneumatic hammers. Mixers and pouring ladles before use have to be purified from oxides and contaminations by means of washing in a flux crucible.

Salts for covering fluxes used during melt of alloy AL8 have to be stored in a dry, specially assigned place in tightly closed packing.

During melt of alloy AL8 it is necessary to avoid unnecessary mixing of the melt and transfer of it from one crucible to another. During the whole process of melt the mirror surface of the metal should be completely covered by a layer of flux.

Forms with rough weight of castings from alloy AL8 up to 100 kg may be poured with hand ladles. Filling of heavier castings should be produced from groove crucibles with application of large pouring basins. This ensures continuous filling of the form with liquid metal in the process of filling and thereby decreases the danger of formation of oxide inclusions, scales and other defects which cause irregularities of flow of metal in the flow gate system.

When filling large castings the alloy must be melted simultaneously in two stationary graphite or cast-iron crucibles, and after melting it must flow into welded groove crucibles, in which it is finally worked, and from which with the aid of a crane it is poured into the form. One must not completely pour the alloy into the

form from crucibles, in avoidance of hitting the form with particles of slag settled on the bottom of the crucible and other nonmetallic contaminations. After pouring the remainder of the metal in casting molds, the walls and bottom of groove crucibles are thoroughly cleaned by scrapers for preparation of the following melt.

### Mould and Core Mixtures

For production of castings from alloy AL8 one can use usual molding sand for aluminum castings only with the difference that as a protective addition in them there is added boric acid in a quantity of 3-5%. Moisture content of the molding sand may not exceed 4-5%.

Core mixtures and cores during casting of alloy AL8 have higher requirements than during casting of aluminum-silicon alloys. These requirements emanate from the technological peculiarities of alloy AL8 and the character of its crystallization. Cores have to possess good compliance, in order not to cause formation in the casting of hot (shrinkage) cracks.

One of the methods of dealing with hot cracks in castings from alloy AL8 is application of hollow cores. Such cores can be prepared by molding on core boxes of special construction or can be obtained by means of cutting internal cavities directly in dry cores.

However application of hollow cores is possible when they are simple in form and when they do not have to be very strong. Otherwise hollow cores under the weight of higher cores of the form can sag and lead to destruction of the form and spoilage of castings in terms of geometric dimensions.

Good compliance of cores is especially necessary when pouring castings with a closed cylindrical contour, in which shrinkage stresses are very strong.

Along with good compliance and easy removal from castings, cores also have to possess high gas permeability and low gas-forming ability. Therefore when casting alloy AL8 the question of selection of binding materials for cores is very important. Binder "M," widely used in magnesium castings, when casting large castings from alloy AL8, is undesirable to use. In spite of the fact that cores made from binder "M" had good compliance and were easily removed, castings obtained with application of cores made with binder "M," had oxidized fractures and lowered density. A core mixture made with oil binder "[4GU] (4ГУ)" also cannot be recommended for casting of shaped castings from alloy AL8, since cores obtained from it had small yield and were difficult to remove from the castings.

For large castings from alloy AL8 we experimentally selected a core mixture with additions as binding of 2.5% sulfide lye and 0.75% pectic glue, and as a protective addition 1.0% boric acid, with moisture content of the mixture 3.5-4.0%. The mixture was prepared from Lyubertsy sand with an addition of 5% Tambov clay. Cores made from such a mixture had good compliance, were easily removed and

did not cause oxidation of metal in the form as had been observed, as a rule, on the side of cores in slowly hardening parts of castings.

The technology of casting of shaped castings from alloy AL8 should be designed in such a way that shrinkage stresses in castings will be as low as possible not only during hardening of the casting, but also during its cooling in the form. Therefore knockout of castings from mold boxes must be done after cooling them to a temperature of 50-75°. This is especially important for castings with complex internal cavities. The hold time of castings in the form after filling is determined by their weight and wall thickness: for castings with weight 400-500 kg with wall thickness 50-70 mm it should be not less than 12-16 hours, for castings with weight 100-150 kg and with wall thickness 20-40 mm, 4-6 hours.

Castings should not be dropped on metallic plates of the floor of the workshop, or subjected to blows of a pneumatic hammers or other metallic objects. Blows by pneumatic hammers as necessary can be inflicted only on header parts of castings. Working parts of castings should not have nicks and burrs, since these defects can serve as the beginning of formation of cracks in the process of hardening.

For easing removal of cores from deep places of internal cavities, castings can be soaked in hot water or heated in the furnace for 3-4 hours at a temperature of 300-350°, after which the cores are softened.

Vertical slot feeders are removed not by blows but by cutting on band saws. Other elements of the flow gate system, less durably attached to a casting, can be separated from the casting by light blows of a hammer only after preliminary boring with a portable drill or careful notching with a pneumatic chisel.

Before hardening, the surface of internal cavities of castings should be thoroughly protected by cutters, and external surfaces turned on lathes for evening off wall thicknesses and removal of burrs and unevenness.

#### Peculiarities of the Flow Gate Systems and Filling of Forms

Flow gate systems during casting of alloy AL8 have to be constructed on the principle of free overflow, the ratio of the sum of areas of sections of stanchions, collectors and feeders should be accordingly 1:2:3. This principle must be observed during siphon (lower) feed of the metal into the form as well as during feed of the metal through vertical slot feeders. With such a ratio of elements of the flow gate system filling will be calm, without eddies, and thanks to this there is a decrease of the possibility of formation in castings of defects causing rupture of the oxide film on the liquid metal during its travel through casting conduits.

For a decrease of hampered shrinkage the flow gate system should not be rigidly joined with the casting and should ensure necessary conditions for minimum mechanical braking of shrinkage.

When selecting the type of stanchions it is necessary to be guided by the height of the form. With low forms it is expedient to use round stanchions easily fulfilled during molding.

When filling high forms it is recommended to use "spiral separators" or stanchions of rectangular section. Such stanchions in the form of dry core packings are prepared as special boxes made from the core mixture used for manufacture of the cores. Stanchions of rectangular section are set in the form in a vertical position, but if the mold-box permits, with a slope of  $10-15^{\circ}$ .

The section and quantity of stanchions are selected from calculation of specific outlay of metal depending on the metal capacity of the form and wall thickness of the casting. Practice shows that satisfactory quality of castings from alloy Al8 is obtained during input of metal into the form with a speed 1.5-2.0 kg/s with castings 25-50 kg in weight; 2.5-3.0 kg/s with castings 50-150 kg in weight; and 3.5-4.5 kg/s with castings over 150 kilograms in weight. The diameter of round stanchions should be within limits of 12-15 mm. During application of stanchions of large dimensions there is an increase in the formation of slag inclusions in the metal and oxide scales in the process of filling the form. The section of rectangular stanchions should be within limits of  $6 \times 40$ ,  $8 \times 40$ ,  $8 \times 60$  mm<sup>2</sup>.

With thin-walled castings forms should be filled as fast as possible. This is especially necessary when filling high forms, where slow filling leads to formation in the casting of shrinkage porosity and cleavage. When casting castings with thick walls slow filling can cause oxidation of the metal due to local overheating of the form.

Castings of cylindrical form with walls 8-10 mm thick and over 400 mm high must be filled through vertical slot feeders. To obtain such castings with bottom feed of the metal is difficult. Siphon filling of similar castings from alloy Al8 is expedient to use for castings with wall not less than 20-30 mm thick and not more than 400 mm high. Feed of the metal must be carried out in the thinnest parts of casting in order not to cause local overheating. Siphon filling of high castings does not ensure good casting quality. Lower zones of castings in terms of location of metal feed as a rule are ruined by shrinkage porosity, lowering mechanical properties of the alloy.

Castings of large dimensions with a weight of 400-450 kg and forms up to 1000-1200 mm high should be flooded by using simultaneously horizontal and vertical slot feeders. Such a flow gate system is shown in Fig. 1.

Good results are obtained by filling molds of large castings with the aid of a two-row system of headers with horizontal (lower



vertically above the walls of the casting. Lateral feeder heads are not very effective and do not ensure good casting quality. Closed feeder heads (if they are used) have to be connected with the atmosphere with the aid of the largest possible number of vertical channels with a diameter of not less than 30-40 mm. Feeder heads are usefully divided into several parts (segments) with clearances between them of not more than 25-30 mm. Application of segmented feeder heads makes casting less rigid and favorably effects hampered shrinkage.

When casting alloy AL8 it is necessary to allot a great deal of attention to refrigerators. Low-quality preparation of refrigerators can lead to gas defects — blisters and gas pits. Therefore, before filling, refrigerators have to be thoroughly heated for full removal of moisture. Refrigerators are set in on bosses, inputs and other metal-containing places of castings where possibly delayed hardening is possible. Clearances between refrigerators must not exceed 8-10 mm. With large clearances in casting in places between refrigerators, hot cracks can appear. Making refrigerators out of sand is best done with an oil binder. Application for this purpose binder "M" and other binders with high gas products is undesirable.

#### Heat Treatment and Mechanical Properties of Castings Made From Alloy AL8

Heat treatment consists of heating castings from alloy AL8 in furnaces with circulation of air at a temperature of  $435 \pm 5^{\circ}$  for 15-20 hours and cooling them in water at a temperature of  $95-100^{\circ}$  or in oil at a temperature of  $40-50^{\circ}\text{C}$ .

Heating and hardening of thin-walled castings in avoidance of warping have to be produced with application of special fixing attachments made of steel. Castings are covered on special suspensions equipped in the upper part of the furnace, or packed in even piles on steel plates with an even horizontal surface. Heating under hardening of big castings should be produced individually, since when stacking castings on one another it is possible to warp them in the process of heating, as is formation of cracks. Under the necessity of stacking in the furnace for heating under hardening of several big castings, places adjoining them should be preliminarily ground until one obtains an even horizontal surface.

To place a casting in a furnace heated higher than  $100-120^{\circ}$  is not recommended in avoidance of a sharp temperature gradient, as a result of which cracks can appear. The heating rate of castings under hardening must not exceed  $50-75^{\circ}/\text{hour}$ .

Of great value during hardening is the time of transfer of castings from the furnace to the quenching bath. This is especially important for castings with a great difference in wall thicknesses. Practically, transfer of castings from a furnace to a quenching bath

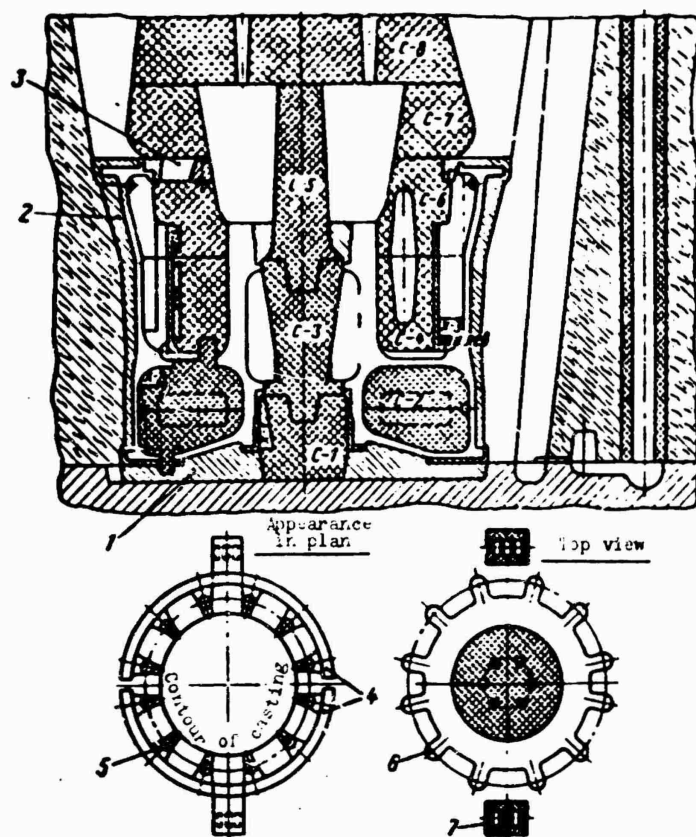


Fig. 1. Flow gate system of large part cast in sand from alloy AL8. 1 - aluminum pan, 2 - technological allowance, 3 - feeders, 4 piece, 4 - header conduit, 5 - horizontal slots, 6 - vertical slots, six for every header conduit, 7 - rod backing with 3 stanchions with a section of  $8 \times 40$  mm each.

header) and vertical (upper header) feeders, connected with the feeder heads.

Big castings have to be flooded through metal pouring basins. The basin hole before filling is closed by a plug 5-7 mm thick turned from a piece of alloy AL8. After melting the plug the metal rapidly fills the flow gate system, and thanks to this, injection of air during travel of the metal through the stanchion and during entrance into the cavity of the form decreases. The flow gate systems when casting alloy AL8 have to ensure such filling and such thermal balance of the mold that hardening of the casting will flow strictly directionally.

Operational experience shows that when casting alloy AL8 it is necessary to use metal-containing open feeder heads and to set them

can be carried out in 20-30 s. This time must always be kept, since lengthening of it to 60-90 seconds leads not only to lowering of mechanical properties, but also to appearance in casting of tempering cracks in places of transition of thin sections into thick.

Big castings are kept in the bath not less than 15-20 minutes. For small castings this time can be lowered to 10-12 minutes. Castings whose hardening was produced with the use of attachments must be freed from the attachments after they are fully cooled to the temperature of the surrounding air.

Many foundry workers are of the opinion that mechanical properties of castings made from aluminum alloys are determined only by macrostructure of the alloy.

Such an opinion is impossible to recognize as correct. A small macrograin undoubtedly promotes an increase of density and an improvement of mechanical properties of castings. At the same time even a large macrostructure in aluminum alloys is not a defect if crystallization of the casting flowed under conditions of high speeds of cooling and, thanks to this, the cast macrograin obtained a fine internal structure.

Investigations show that the dimension of the macrograin in heterogeneous aluminum alloys sometimes renders smaller influence on mechanical properties of castings than its internal structure, i.e., the dimension of the micrograin. This to a well-known degree pertains even to homogeneous aluminum alloys to which alloy AL8 is related.

A lowering mechanical properties of aluminum alloys, including alloy AL8, with an increase of wall thickness is caused mainly by changes in the character of the dendrite structure. The dimension of the micrograin with an increase of wall thickness, as this can be seen on the microphotographs of Fig. 2, is changed over very wide limits. The dimension of the macrograin here renders a smaller influence, since the macrostructure of cast alloy AL8, poured in sand at temperatures from 650 to 700°, is fine-grained and practically identical in thin as well as in thick sections of the casting.

Curves shown in Fig. 2 of tensile strength and relative elongation of alloy AL8, hardened according to technical specifications are drawn from tests of a great quantity of samples cut from different places of large castings of 10 various melts. The density of investigated castings in terms of gas porosity oscillated within limits of 2-3 units on the scale of porosity.

Industrial practice of casting large castings from alloy AL8 in sand shows that in walls over 50 mm thick it is not always possible to obtain a tensile strength more than 20 kg/mm<sup>2</sup> and relative elongation more than 3.0-3.5%. Application in this case of even the lowest temperatures of casting on the order of 630-640° for the purpose of obtaining the smallest macrostructure leads sometimes not to an increase, but to a lowering of mechanical properties due to

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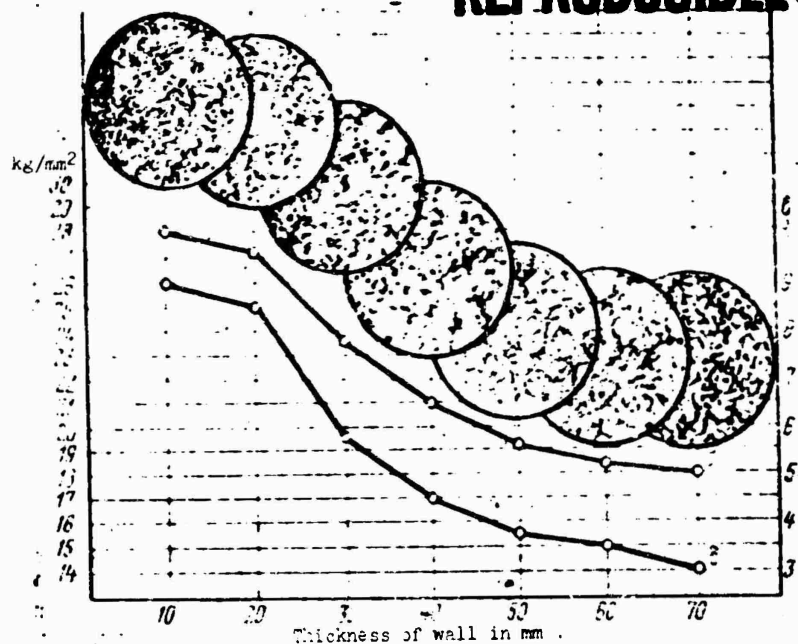


Fig. 2. Dependence of mechanical properties of sand castings made from alloy AL8 on wall thickness (dimension of micrograin).

impairment of fluidity of the alloy and an increase of shrinkage holes.

The only means of increasing mechanical properties of castings in thick sections when casting in sand is application of refrigerators, i.e., an increase of the speed of cooling, allowing one to obtain a cast structure with thinner dendrite structure.

### Conclusions

1. Methods of melt and casting of alloy AL8 which ensure good quality large castings are proposed.
2. A composition of core mixture which permits easy punching of cores from castings which does not cause oxidation of the metal in the form in the process of hardening is recommended.
3. The basic influence on mechanical properties of alloy AL8, besides other factors, is its microstructure.

## MEANS OF REMOVING "BLACK FRACTURE" IN CASTINGS MADE FROM ALLOY AL8

M. G. Stepanova

Alloy [AL8] (AL8) (All-Union Government Standard 2685-53) possesses high corrosion resistance, it works well by cutting and has high mechanical properties.

In shaped casting made from alloy AL8 very frequently in fractures is observed so-called "blackness," which sharply lowers mechanical properties of the alloy. According to Whitaker<sup>1</sup> "blackness" is the result of interaction of melt with moisture of the mold that is, oxidation of the melt. "Black fracture" most frequently will be formed in massive parts of a casting in places of concentration of shrinkage porosity, i.e., during a delayed process of crystallization. It has been established that in this case there will be formed a chemical compound of the spinels type ( $MgO \cdot Al_2O_3$ ), whose black color is caused by the presence in the alloy of impurities of iron.<sup>2</sup>

For protection from oxidation the alloy is prepared under a flux made from a mixture of carnallite (60%) with fluorspar  $CaF_2$  (40%). Introduction in the alloy of beryllium in a quantity of 0.05-0.07% considerably lowers oxidizability of the alloy. However beryllium enlarges the structure of the casting; therefore, for production of a fine-grained structure to the alloy one also adds titanium. In the molding sand we introduce a protective addition, boric acid or

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<sup>1</sup>M. Whitaker, Foundry Trade Journal, 1953, August, p. 13.

<sup>2</sup>I. F. Kolobnev, M. B. Al'tman, Gazy v alyuminievykh splavakh (Gases in aluminum alloys), Oborongiz, 1948.

an addition of [VM] (BM).<sup>1</sup>

In this article data are given on investigation of the influence of the composition of refining fluxes and protective additives on removal "black fracture" in castings made from alloy AL8.

Experimental melts were conducted in a crucible electric furnace in a graphite crucible with a capacity of 25 kilograms. The alloy was prepared from pig metals. Initially aluminum was melted, after removal of slag the melt was covered by a flux. Then magnesium was introduced and in certain alloys beryllium and titanium in the form of 5% alloys of aluminum-beryllium and aluminum-titanium. The melt was refined at a temperature of 700°.

In experiments two compositions of fluxes were used: carnallite and carnallite (60%) with calcium fluoride (40%). Compositions of molding sand are given in Table 1.

Table 1. Composition of Molding Sand

Components of mixture	Number of mixture and its composition in weight %			
	1	2	3	4
Inverse mixture for aluminum casting	100	70	70	75
Sand of make 1K02A	—	30	30	25
Boric acid	—	2	4	—
Addition BM	—	—	—	5
Water	6.0	5.0	5.0	5.0

From every mixture forms were prepared for standard 12-millimeter samples for fracture and for samples for technological testing.

Filling temperature of the alloy was equal to 700-720°.

Properties of molding mixtures both with boric acid and with addition VM were analogous. Mixture No. 1, not containing the addition, due to the absence of quartz sand in its composition had lower gas permeability (Table 2).

The quality of castings was determined by means of study of fracture macro- and microstructure, and testing of mechanical properties of separately poured samples.

<sup>1</sup>Addition VM consists of technical urea (60%), aluminum sulfate (25%) and boric acid (15%).

Table 2. Properties of Experimental Mixtures

Properties	Number of mixture			
	1	2	3	4
Moisture in %	5.3-5.6	4.5-4.6	5.2-5.5	4.3-5.2
Gas-permeability	24.2-25.8	36-38	34	33-36
Compression strength in kg/mm <sup>2</sup>	1.0-1.15	1.25	1.1	1.1-1.2
Collapsibility of the sample in grams	0.8-1.1	2.2-2.5	0.6-1.1	0.6-2.3

External inspection established the presence of spots of oxide on technological 50 mm samples, poured in forms from the mixture without the protective addition and without introduction of beryllium in the melt. In all remaining cases castings had a pure brilliant surface. However in fracture of samples "blackness" was revealed, especially well revealed after heat treatment.

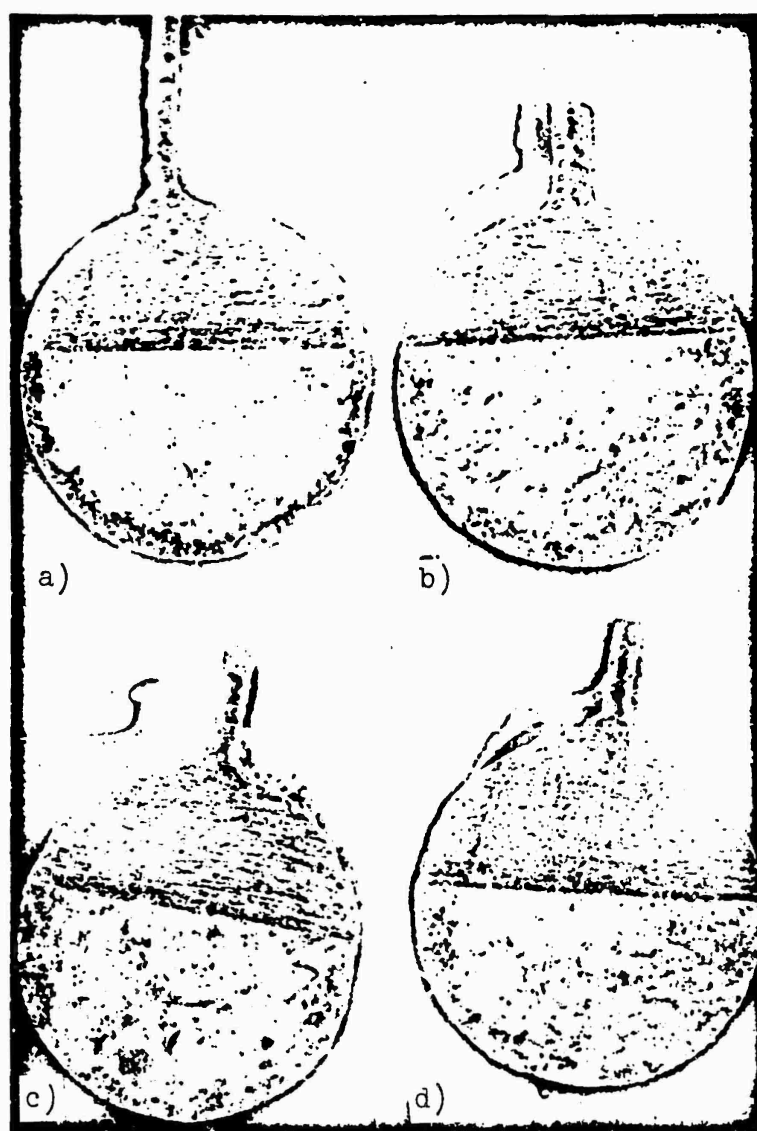
A study of fracture of technological samples showed that when filling with a melt refined by carnallite, "blackness" appears in the form of a clearly outlined ring at the surface of the casting. Addition to the molding sand of 4% boric acid or a 5% addition of VM somewhat lowered the intensity "blackness," however the ring of "blackness" was observed in all samples.

Refining of the melt by flux consisting of 60% carnallite and 40% fluorspar gives a cleaner fracture, especially in the case when in the mixture there is a protective addition, although it does not remove "blackness" completely. In fracture of a sample poured in a form from a mixture not containing the protective addition, clearly outlined "blackness" in the form of a ring (Fig. 1) was observed.

The presence in an alloy of beryllium and titanium, as it is known, renders a positive influence on the state of fracture. "Blackness" was observed in the fracture of a sample poured in a form from a mixture not containing a protective addition, but its intensity was considerably less than in preceding experiments (Fig. 2a). During introduction in the mixture of 2% boric acid, in the fracture of samples there were observed only small sections of "blackness" at the surface (Fig. 2b). A clean fracture was obtained on samples poured in forms from a mixture containing 4% boric acid or a 5% addition of VM.

Thus, other things being equal, application of a flux consisting of carnallite and fluorspar ensures obtaining a cleaner fracture than a melt under carnallite. For massive section of a sample 50 mm in diameter in view of considerable time of a crystallization obtaining a clean fracture is possible only in the presence of beryllium in the alloy and a 4-5% protective addition in the molding sand.

On samples 20 mm in diameter the intensity of oxidation is less,



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Fig. 1. Fracture of samples made from alloy AL8; refining by flux, casting in damp sand form. a) mixture without addition, b) mixture with 2% boric acid, c) mixture with 4% boric acid, d) mixture e with 5% addition VM.





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Fig. 2. Fracture of samples made from alloy AL8 with beryllium and titanium; casting in damp sand forms. a) mixture without addition, b) mixture with 2% boric acid.

since the process to a considerable degree is paralyzed by acceleration of the time of a crystallization.

For production of clean fracture on samples with a diameter of 20 mm from an alloy containing beryllium, it is sufficient to introduce into the mixture 2% boric acid. When refining the alloy by a flux made from carnallite and fluorspar, samples made from alloy AL8 which do not contain beryllium have a clean fracture when casting in forms made from a mixture with a 5% addition of VM or 4% boric acid. Samples obtained from alloy AL8 refined only with carnallite in all cases had "blackness" in the fracture.

Obtaining a clean fracture of a casting made from alloy AL8 is possible during use of an addition of VM in exchange for boric acid.

Any influence of an addition of VM on structure of samples was not revealed. Both macrostructure and microstructure of samples poured in forms made from the mixture with boric acid and from a mixture with an addition of VM are analogous. Also not revealed was a difference, during application of different additives, in mechanical properties of the alloy (see Table 3).

Samples poured with application of boric acid and addition VM were tested for corrosion under conditions of full submersion in a 3% solution of NaCl containing 0.1%  $H_2O_2$  for two months. Tests were conducted on samples 8 mm in diameter with and without casting crust (Table 4).

Table 3. Influence of Protective Additives on Mechanical Properties of Alloy AL8<sup>1</sup>

Addition	Tensile strength kg/mm <sup>2</sup>	Relative elongation %
Without addition	27.8	5.8
2 boric acid	37.3	17.4
4 boric acid	38.6	20.2
5 addition of VM	38.8	17.0
6 fluoride addition	35.9	14.2

<sup>1</sup>All samples were poured from one melt. The melt was refined with a flux made from  $MgCl_2 \cdot KCl$  and  $CaF_2$  (60:40). Samples were subjected to heat treatment under conditions T4.

Table 4. Results of Corrosion Tests of Samples Made From Alloy AL8

Addition	State of surface	Tensile strength kg/mm <sup>2</sup>		Loss of strength %
		before corrosion	after corrosion	
4% boric acid	With casting crust	27.7	21.7	2.2
	Without casting crust	24.8	13.7	44.9
5% addition of VM	With casting crust	27.6	23.8	1.4
	Without casting crust	25.2	15.3	39.3

Conducted comparative tests show that corrosion resistance of alloy AL8 poured in forms made from the mixture with 4% boric acid and a 5% addition of VM is practically identical.

Preliminary testing on industrial parts (weight on the order of 120 kg) confirmed the obtained results.

#### Conclusions

1. Obtaining a clean fracture in a casting made from alloy AL8 with small section (up to 20 mm) is ensured by introduction in the composition of the molding sand of a 4-5% protective addition.

2. Obtaining a clean fracture for castings of massive section (50 mm and more) is possible only during introduction in the alloy of 0.05% beryllium and a 4-5% protective addition in the molding sand.

3. As protective addition boric acid or addition VM can be used.

## INCREASING PLASTIC PROPERTIES OF ALLOY B300

I. F. Kolobnev and N. A. Loktionova

Alloy B300 has a high limit of prolonged strength: at  $300^{\circ}$  for 100 hours,  $7 \text{ kg/mm}^2$ ; at  $350^{\circ}$  for 100 hours, up to  $4 \text{ kg/mm}^2$ . From other cast aluminum alloys, alloy B300 especially differs by its great creep resistance: at  $300^{\circ}$  for 100 hours with a permanent deformation of 0.2% its creep limit is equal to  $5 \text{ kg/mm}^2$ ; at  $350^{\circ}$  for 100 hours,  $2.5 \text{ kg/mm}^2$ . However, lowered plasticity limits its area of application.

Low plasticity of alloy B300 is caused in the first place by the presence of large particles of insoluble phases of type  $\text{Al}_6\text{Cu}_3\text{Ni}_3$ ;  $\text{Al}_3(\text{CuNi})_2$  and others containing chromium, manganese and iron, and also by the character of their location. The higher the content of chromium, the more fragile is the alloy. Therefore the upper limit of content of chromium is 0.25%.

Addition of up to 0.5% manganese to alloy B300 increases its prolonged strength. But as a result fragility of the alloy is also increased.

All these data, and also the negative influence on plasticity of the alloy of a raised content of magnesium, were considered when carrying out the present work. Furthermore, we took into account results of works on application of hot media of cooling during hardening (water  $80^{\circ}$  and oil  $150^{\circ}$ ), increasing plasticity of alloys [AL4] (AL4) and AL9, especially with a lowering in them of the content of magnesium.

The same influence of magnesium is observed in alloy B300, although magnesium participates too in formation of different strengthening phases (in alloy AL4 phase  $\text{Mg}_2\text{Si}$ , and in alloy B300 phase  $\text{S}(\text{Al}_2\text{CuMg})$ ).

The present work was conducted in two directions:

1. We studied the influence of chemical composition on mechanical properties of alloy B300.
2. We established an optimum regime of heat treatment of alloy B300.

#### Influence of Chemical Formations<sup>1</sup>

As indicated above, with an increase of the content of manganese and chromium in alloy B300 its plasticity drops. It was necessary to definitize to what degree mechanical properties of alloy B300 are changed depending on the content of magnesium in those cases when manganese and chromium are at upper and lower limits.

Alloys were prepared in an electric resistance furnace on the basis of aluminum of make A00. Properties of alloy B300 depending on chemical composition are represented in Fig. 1.

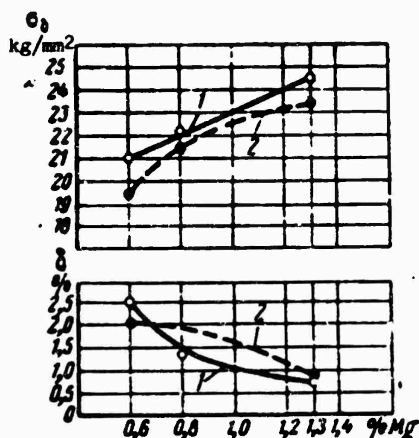


Fig. 1. Influence of chemical composition on mechanical properties of alloy B300 with content of manganese and chromium. 1 — at upper limit, 2 — at lower limit.

It is established that alloy B300 containing manganese and chromium at both lower and upper limits has lower strength (tensile strength on the order of 20-21 kg/mm<sup>2</sup>) and raised plasticity (relative elongation 2-2.5%) if the content of magnesium is at the lower limit. Thus, alloy B300 can have fairly good plasticity with strength within the limits of technical conditions. However, then the limit of prolonged strength for 100 hours at 300° drops to 6 kg/mm<sup>2</sup>.

According to an increase in alloy B300 of the content of magnesium, tensile strength increases to 3-4 kg/mm<sup>2</sup> with lowering of

<sup>1</sup>L. V. Shvyreva and T. V. Boytsova took part in carrying out the experimental work.

relative elongation by more than 2 times, where the limit of prolonged strength at 300° for 100 hours attains 7 kg/mm<sup>2</sup>.

Consequently, in the case when there is an extreme need to increase plasticity of alloy B300, it is possible to hold to the following chemical composition: 5% Cu, 3% Ni, not higher 1.2% Mg, not higher than 0.3% Mn and not higher than 0.2% Cr. Such a composition, in terms of tensile strength and prolonged strength, fully satisfies requirements of technical conditions.

#### Influence of Temperature of Heating Prior to Quenching<sup>1</sup>

We checked the influence of different conditions of heating prior to quenching on plasticity and strength of alloy B300. We investigated two compositions of the alloy containing magnesium at the lower limit (according to technical conditions), and manganese and chromium at upper and lower limits.

Analysis of obtained results of the test of mechanical properties (Table 1) permits establishing that tensile strength of the alloy of both compositions insignificantly increases with an increase of the temperature of hardening up to 530° (at a water temperature of 20°), and then drops for alloys containing manganese and chromium at the lower limit.

This is connected with the fact that lowering the content of manganese increases sensitivity of the alloy to overburning.

In an artificially aged state alloys behave the same way.

Obtained results confirm that the upper limit of temperature of heating prior to quenching is 530°.

A relative elongation of not less than 2.4% can be obtained by means of lowering the content of manganese and chromium to the lower limit shown in technical conditions.

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<sup>1</sup>L. V. Shvyreva and T. V. Boytsova took part in experimental work.

Table 1. Influence of Conditions of Heating Prior to Quenching on Strength and Plasticity of Alloy B300

Conditions of heat treatment	Mechanical properties	
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
Composition of alloy: 4.9% Cu; 0.78% Mg; 2.97% Ni; 0.38% Mn; 0.27% Cr		
Step hardening: 500° (2 hours) + 525° (3 hours); cooling in water 20°	30.5	1.4
Hardening is the same + temper 300° (5 hours);	23.6	2.0
Hardening: 500° (4 hours) + 525° (3 hours), cooling in water 20°	29.2	1.5
Hardening is the same + temper 300° (5 hours)	23.0	1.4
Hardening: 500° (4 hours) + 525° (5 hours), cooling in water 20°	28.6	1.1*
Hardening is the same + temper 300° (5 hours)	23.4	1.4
Hardening: 500° (4 hours) + 530° (3 hours), cooling in water 20°	30.7	1.6
Hardening is the same + temper 300° (5 hours)	22.6	1.3
Hardening: 500° (4 hours) + 535° (3 hours), cooling in water 20°	29.6	1.6
Hardening is the same + temper 300° (5 hours)	23.6	1.5
Hardening: 500° (4 hours) + 540° (3 hours), cooling in water 20°	30.0	1.3
Hardening is the same + temper 300° (5 hours)	23.5	1.6
Composition of alloy: 4.9% Cu; 0.78% Mg; 2.97% Ni; 0.1% Mn; 0.1% Cr		
Hardening: 500° (2 hours) + 525° (3 hours), cooling in water 20°	25.3	1.8
Hardening is the same + temper 300° (5 hours)	19.4	2.0
Hardening: 500° (4 hours) + 525° (3 hours), cooling in water 20°	26.0	1.7
Hardening is the same + temper 300° (5 hours)	19.4	2.0
Hardening: 500° (4 hours) + 525° (5 hours), cooling in water 20°	25.9	1.6
Hardening is the same + temper 300° (5 hours)	20.5	2.3
Hardening: 500° (4 hours) + 530° (3 hours), cooling in water 20°	26.0	1.6

Table 2 (contd). Influence of Conditions of Heating Prior to Quenching on Strength and Plasticity of Alloy B300

Conditions of heat treatment	Mechanical properties	
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
Hardening is the same + temper 300° (5 hours)	19.8	2.5
Hardening: 500° (4 hours) + 535° (3 hours), cooling in water 20°	25.3	2.0
Hardening is the same + temper 300° (5 hours)	20.0	2.6
Hardening: 500° (4 hours) + 540° (3 hours), cooling in water 20°	25.1	2.1
Hardening is the same + temper 300° (5 hours)	20.2	2.0

#### Influence of Temperature of the Quenching Medium<sup>1</sup>

Mechanical properties of alloy B300 after quenching in water at a temperature of 80-100° satisfy requirements of technical conditions. However plasticity of the alloy remains insufficient (see Fig. 2).

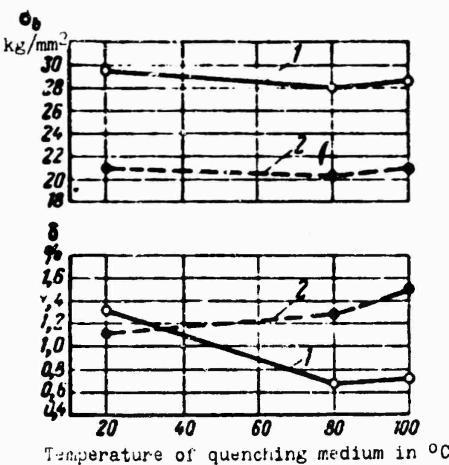


Fig. 2. Dependence of mechanical properties of alloy B300 on temperature of quenching medium. 1 — fresh hardened state, 2 — hardening and softening temper at 300° for 5 hours.

In Table 2 it is shown that application of isothermal hardening permits obtaining higher plastic properties of the alloy.

<sup>1</sup>N. S. Pantyushkova and T. V. Privezentseva participated in experimental work.



Table 2. Change of Mechanical Properties of Alloy B300 Depending on Temperature and Duration of Holding During Isothermal Hardening

Duration of holding hours	Mechanical properties after isothermal hardening, temperature of cooling medium in °C											
	200		250		275		300		325		350	
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %
0	28,7	0,6	29,7	0,5	28,0	0,6	29,4	0,7	26,6	0,3	27,6	1,8
2	29,3	0,7	26,6	0,2	20,8	1,5	18,4	2,0	18,2	2,2	19,6	2,6
5	27,6	—	22,6	1,2	20,3	2,1	18,9	2,0	18,1	2,6	17,9	2,2
10	—	—	22,0	0,7	19,3	2,4	18,1	2,6	17,8	3,1	18,1	2,1
15	—	—	22,1	0,8	18,8	2,3	18,3	3,0	17,2	2,3	18,9	1,8

### Conclusions

1. Alloy B300, containing manganese and chromium at a lower limit in terms of technical conditions, possesses raised plasticity (relative elongation 1.5-2.5%). The content of magnesium in alloy B300 should not exceed 1.2%.

2. Plasticity of alloy B300 may also be increased by application of new conditions of heat treatment. Step heating prior to quenching is recommended: heat at 500° with holding 2-3 hours, then raise temperature to 525-530° with holding 2-3 hours. Cooling during hardening is conducted in saltpeter heated to 250-275°, with holding at this temperature for 5 hours, without subsequent artificial aging.

In this case is ensured tensile strength higher than 20 kg/mm<sup>2</sup> and relative elongation 1.2-2% at a value of prolonged strength within the limits of technical conditions.

## INCREASING CYCLICAL STRENGTH OF CAST ALUMINUM ALLOYS

E. A. Lalayan and A. N. Malinkovich

At present in different branches of machine building research-design work is being conducted on investigation of the possibility of lowering weight of heavily loaded parts by manufacturing them from cast aluminum alloys. However, fatigue strength of these alloys even on smooth samples does not exceed  $6-7 \text{ kg/mm}^2$ .

The lowered strength of parts, made from these alloys, in comparison with carbon and average alloyed steels, is a serious obstacle confronting introduction of aluminum alloys for parts working under variable load conditions.

The goal of this work was to establish the effectiveness of surface cold hardening on cyclical strength of alloys [Al<sup>19</sup>] (Al19) and AL21.

### Method and Materials of Investigation<sup>1</sup>

Alloys AL19 and AL21 were smelted in graphite crucible with a capacity of 45 kg in an electric resistance furnace.

Blanks 16 mm in diameter and 230 mm long were subjected to heat treatment according to the following conditions:

a) alloy AL19: heating to  $530 \pm 5^\circ$ , holding 9 h, raise temperature to  $540 \pm 5^\circ$ , holding 7 h, hardening in water; aging at  $175 \pm 5^\circ$  for 3 h, cooling in air;

b) alloy AL21: heating to  $430 \pm 5^\circ$ , holding 20 h, hardening in hot water ( $80-100^\circ$ ).

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<sup>1</sup>O. B. Lotareva and G. Ya. Mishin participated in the experimental part of the work.

Table 1. Chemical Composition and Mechanical Properties of Prepared Alloys

Make of alloy	Number of melt	Chemical composition in %							Impurities in %			Mechanical properties	
		Cu	Mn	Ti	Be	Mg	Zn	Al	Fe	Si	$\sigma_{0.2}$ kg/mm <sup>2</sup>	$\delta$ %	
AЛ19	—	4.5—5.3	0.6—1.0	0.25—0.45	—	—	—	remain- ing	<0.3	<0.4	34.0	3.0	
AЛ19	149	5.35	1.08	0.25	—	—	—	The same	0.14	0.4	35.8	4.3	
AЛ19	148	5.25	0.98	0.27	—	—	—	.	0.15	0.21	37.1	5.1	
AЛ19	2	5.35	0.96	0.25	—	—	—	.	0.13	0.10	36.4	8.3	
AЛ19	4	5.30	0.86	0.29	—	—	—	.	0.10	0.22	36.6	5.3	
AЛ21	—	—	—	0.1—0.2	0.07—0.15	10—11.5	0.5—0.8	.	<0.3	<0.3	36.0	5.0	
AЛ21	152	—	—	0.12	0.12	11.15	0.61	.	0.15	0.18	36.1	12.2	

Chemical composition and mechanical properties of control samples of investigated melts are represented in Table 1.

Cyclical strength of samples was studied under two conditions of strain: 1) bend of cylindrical samples of smooth and with annular cut (Fig. 1) on a Schoen machine at a load frequency of 1300 cycles per minute and 2) during repeated blow on universal machine [KPU-2] (KПУ-2) with blows of striker on sample with a section of  $10 \times 10$  mm and length 55 mm, at a frequency of 620 cycles per minute.

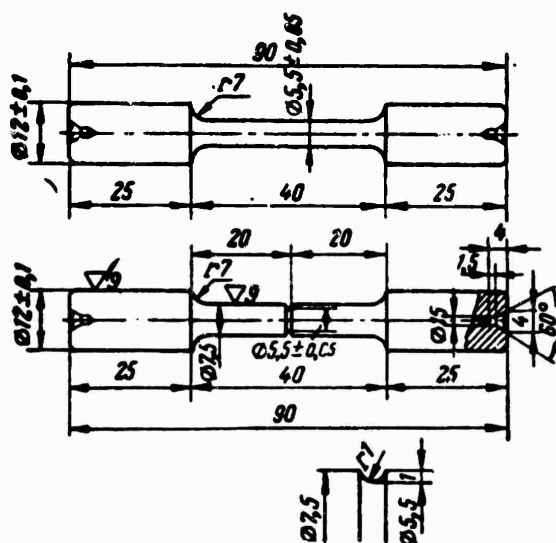


Fig. 1. Form and dimensions of samples for cyclical bend test.

We investigated polished samples (initial state) and samples subjected to shot-blast cold hardening.

Cold hardening of samples was produced on shot blasting machines of mechanical type of construction [TsNIITMASH] (ЦНИИТМАШ) and construction [ZIL] (ЗИЛ) with dispersed and concentrated blow of shot (steel shot with a diameter of 0.6-1.2 mm).

Depth of the strengthened layer was determined by the method of measurement of microhardness on instrument [PMT-3] (ПМТ-3) with loads of 10 and 20, g on slanting slides.

Metallographic analysis of samples before and after shot-blast cold hardening was produced on an optical microscope at powers of 200 and 600. For etching of slides we used an etching agent of HF - 1 ml, HCl - 1.5 ml, HNO<sub>3</sub> - 10 ml, H<sub>2</sub>O - 87.5 ml.

### Development of an Optimum Cold Hardening Regime

Conditions of shot-blast cold hardening were set for samples made from alloy AL19. We investigated 9 variants of cold hardening (Table 2) depending on the number of turns  $n$  of the rotor of the shot blast machine, consumption of shot and duration of treatment.

Table 2. Regimes of Shot-Blast Cold Hardening of Samples

No of regime	$n$ r/min.	Consump- tion of shot $q$ kg/min	Time of blast in min.		Construction of installa- tion
			test for cyclical bend	test for repeated blow	
1	2900	100	0,5; 1; 2	0,5; 1; 2	ЦНИИТМАШ
2	1900	100	1; 3; 5	1; 2; 4	ЦНИИТМАШ
3	2200	40	2; 3; 5	0,5; 1; 2	ЗНЛ

The change of duration of cold hardening in conditions No. 3 during test for cyclical bend as compared to the test for repeated blow is explained by the fact that in the first case occurs dispersed blow of the shot, and in the second case, concentrated.

Samples strengthened in the forementioned conditions, and for comparison nonstrengthened, were tested at two stresses or energies of blow until destruction. On every variant of treatment no less than four samples were tested. Results of these tests are given graphically in Fig. 2 in coordinates: duration of cold hardening, number of blows until destruction.

Analysis of the given data shows that:

1. Limited service-life during the bending test of samples subjected to shot-blast cold hardening, was considerably higher than nonhardened samples. At a stress of  $16 \text{ kg/mm}^2$  it is 5 million cycles, whereas in the initial state it is only around 200 thousand cycles or 25 times less.

At a stress of  $18 \text{ kg/mm}^2$  shot-blast cold hardening by conditions 1 and 2 (Table 2) also increases the service life of samples more than 25 times, but according to an increase of duration of cold hardening, service life descends approximately to 4 million cycles.

2) After shot-blast cold hardening to a considerable degree service life increases even under repeated blows. At a blast energy of  $6.1 \text{ kg}\cdot\text{cm}$  limited service life is increased from 30 thousand cycles to 100-140 thousand cycles, i.e., 3-4 times, but at a blast energy of  $8.66 \text{ kg}\cdot\text{cm}$  it is increased from 10 thousand cycles to 20-25 thousand cycles, i.e., 2-2.5 times.

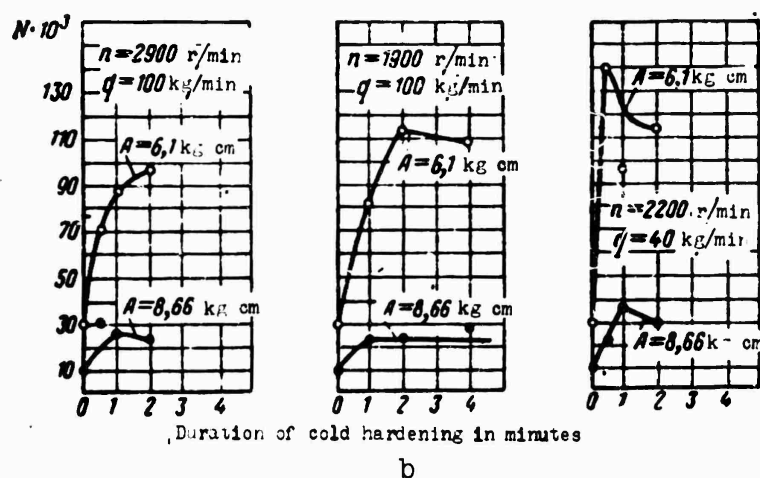
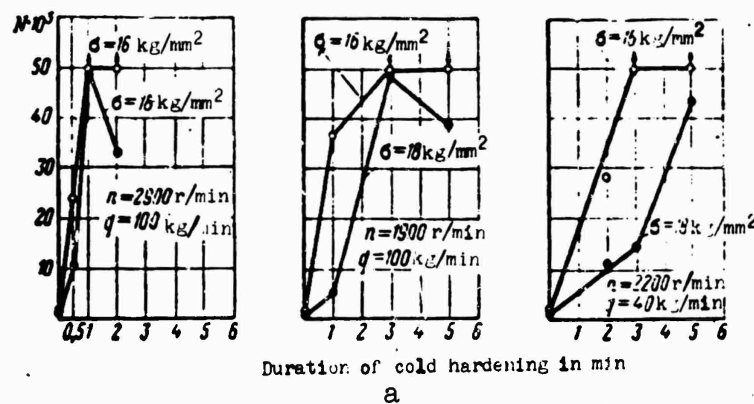


Fig. 2. Influence of regime of shot-blast cold hardening on limited service-life of alloy AL19. a) with cyclical bend of samples with cut, b) with repeated blow.

#### Influence of Shot-Blast Cold Hardening on Cyclical Strength of Alloys AL19 and AL21

On the basis of obtained data we selected conditions of cold hardening for a fuller investigation of cyclical strength of alloys AL19 and AL21.

Cold hardening of samples was produced on the shot-blast machine ZIL with rotor speed 2200 r/min and shot consumption 40 kg/min. Duration of cold hardening during dispersed shot-blast (for round samples) was 5 min, and during concentrated shot-blast (samples of square section) 0.5 min.

According to the results of the test, curves of strength for smooth and cut samples in initial and strengthened states were drawn.

During the test it turned out that even in the initial state, fatigue strength of samples with an annular cut was higher than for smooth samples (Fig. 3). Such results contradict numerous practical data and can be explained only by the fact that the process of

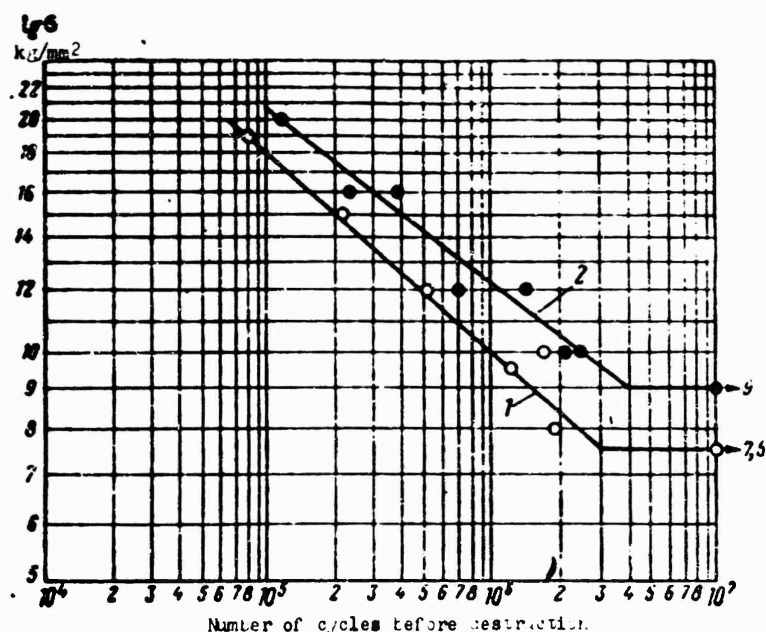


Fig. 3. Curves of strength during bend of nonstrengthened samples made from alloy AL19. 1 - smooth samples, 2 - samples with cut.

machining created cold hardening of the cut and due to this fatigue strength increased.

Therefore subsequent machining of samples was conducted before heat treatment for removal of preliminary cold hardening.

In Fig. 4 curves are given of strength of samples for which the annular cut was made before and after heat treatment.

In the same place are given curves of strength of such samples hardened by shot.

As can be seen, removal of cold hardening created by machining lowers fatigue strength by 2-3 kg/mm<sup>2</sup> in both the initial state and after shot-blast cold hardening.

Curves of strength during bend of smooth samples and samples with a cut made from alloy AL19 and smooth samples made from alloy AL21 are represented in Figs. 5 and 6.

As can be seen, shot-blast cold hardening increases fatigue strength of smooth samples approximately 2 times (from 7.5 kg/mm<sup>2</sup> to 14 kg/mm<sup>2</sup> for alloy AL19 and from 6 kg/mm<sup>2</sup> to 12 kg/mm<sup>2</sup> for alloy AL21), and for samples with concentrators of stresses, made from alloy AL19 more than 2 times (from 7 kg/mm<sup>2</sup> to 16 kg/mm<sup>2</sup>).

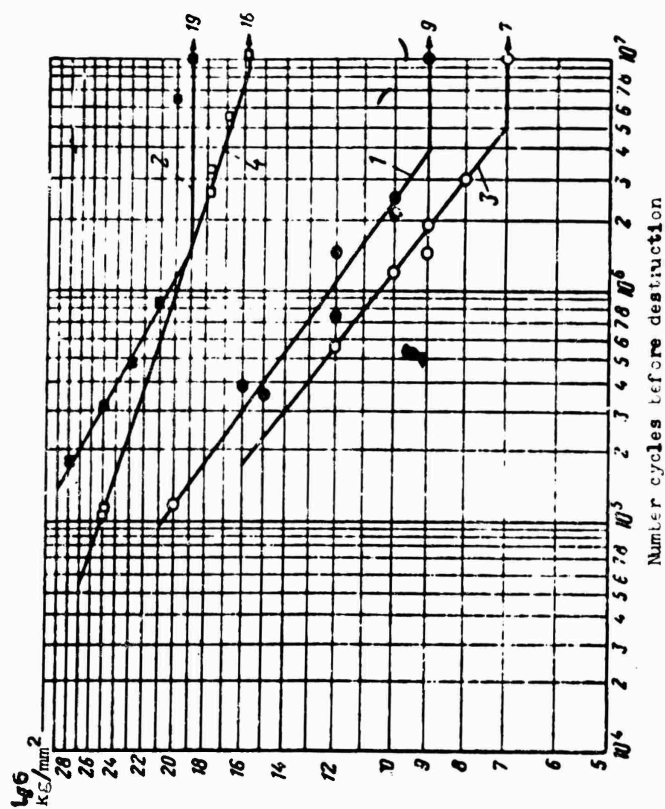


Fig. 4. Curves of strength of samples with annular cut made from alloy AL19 in initial state (curves 1 and 3) and after shot-blast cold hardening (curves 2 and 4). 1 and 2 - heat treatment before machining, 3 and 4 - heat treatment after machining.

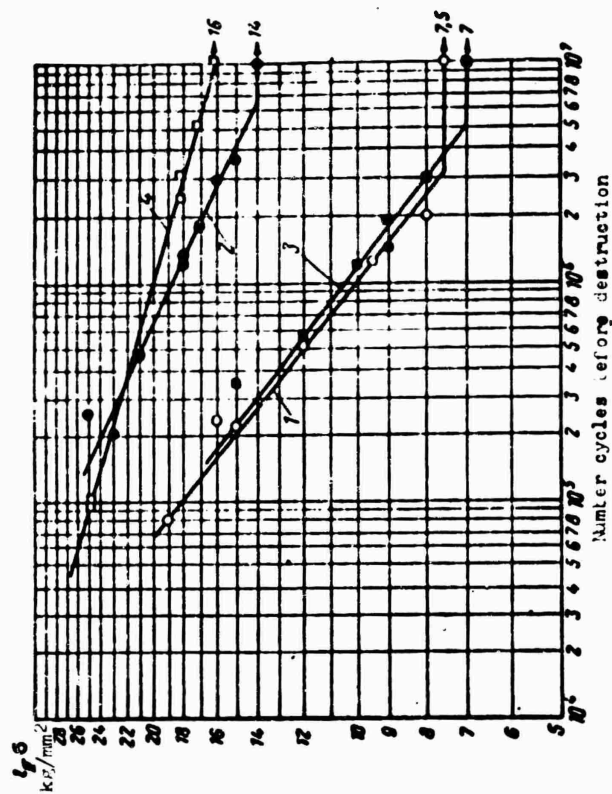


Fig. 5. Influence of shot-blast cold hardening on cyclical strength during bend of samples made from alloy AL19. 1 - smooth samples before cold hardening, 2 - smooth samples after cold hardening, 3 - samples with cut before cold hardening, 4 - samples with cut after cold hardening.



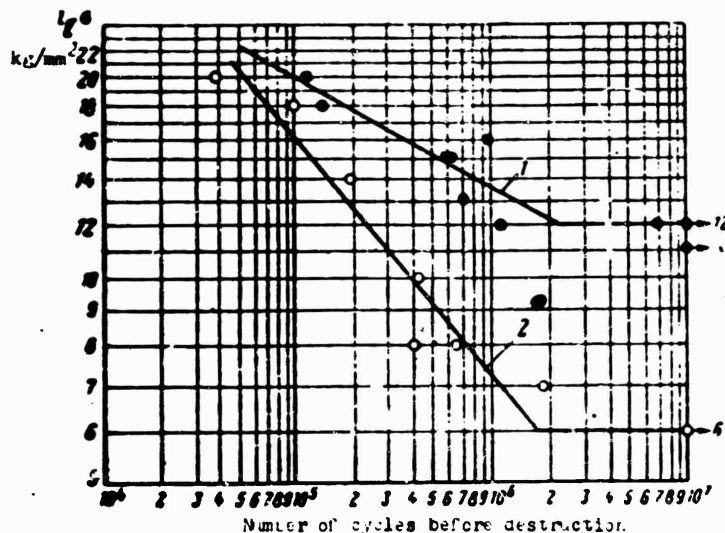


Fig. 6. Influence of shot-blast cold hardening on strength during bend of smooth samples made from alloy AL21. 1 — after cold hardening, 2 — before cold hardening.

Effective stress concentration factor  $\beta_K$  (relation of fatigue strength of a smooth sample to fatigue strength of a sample with cut) is equal to:

a) for initial samples made from alloy AL19

$$\beta_K = \frac{7.5}{7.0} = 1.07;$$

b) for samples made from alloy AL19, strengthened by shot-blast,

$$\beta_K = \frac{14}{16} = 0.9,$$

i.e., shot-blast cold hardening even somewhat decreases sensitivity of the alloy to concentrators of stresses.

Samples of steel 35L ( $\sigma_b = 50 \text{ kg/mm}^2$ ) after usual heat treatment (hardening and tempering) in the same test conditions have fatigue strength on smooth samples  $\sigma_{-1} = 21 \text{ kg/mm}^2$ , and on samples with an annular cut  $\sigma_{-1}^H = 18 \text{ kg/mm}^2$  ( $\beta_K = 1.16$ ). Thus, cold hardening permitted raising fatigue strength of samples made from alloy AL19 to approximately the level of steel 35L.

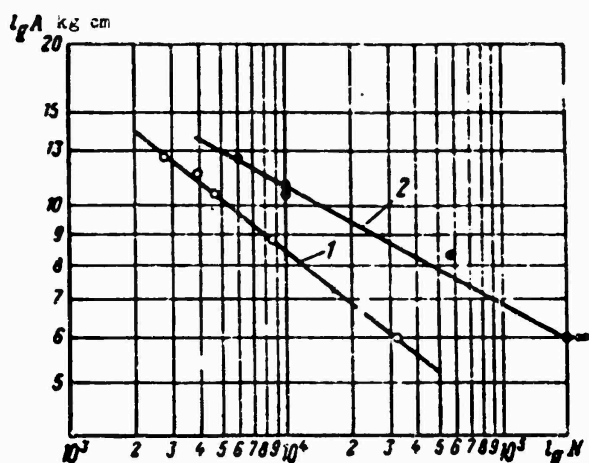


Fig. 7. Influence of shot-blast cold hardening on strength during repeated blows of samples made from alloy AL19. 1 - before cold hardening, 2 - after cold hardening.

The test for repeated blow also revealed the considerable effectiveness of shot-blast cold hardening.

As can be seen from Fig. 7, limited service life was increased at blast energy 12.7 kg.cm more than 2 times, and at blast energy 6.1 kg.cm more than 6 times.

#### Hardness and Depth of Strengthened Layer

Metallographic analysis of samples, subjected to shot-blast cold hardening permitted revealing in surface layers traces of plastic deformation (Fig. 8).



Fig. 8. Microstructure of edge of sample made from alloy AL19, hardened by shot ( $\times 250$ ).

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As can be seen from the graphs in Fig. 9, shot-blast cold hardening increases hardness of the surface layer from 120-140 units to 180-200 units for samples made from alloy AL19 and to 180-230

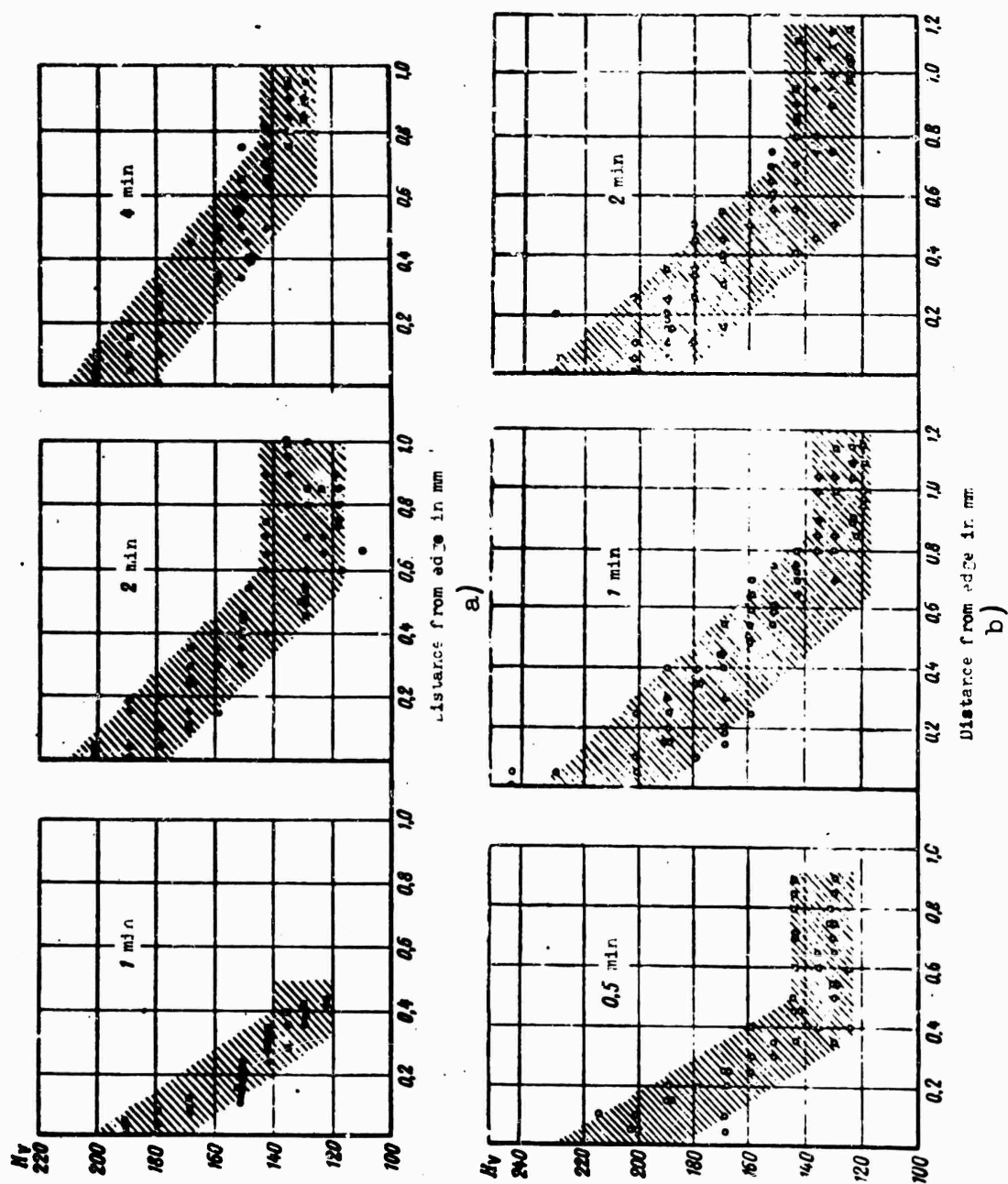


Fig. 9. Change of microhardness at depth of cold hardened layer of samples made from alloys Al19 a) and AL21 b) for different times of cold hardening.

units for alloy AL21.

The depth of the cold hardened layer with duration of cold hardening up to 0.5-1.0 min (accordingly for alloys AL19 and AL21) is 0.3-0.4 mm; with a duration of cold hardening of 2 min. depth of the layer increases to 0.5-0.6 mm. Upon a further increase of duration of cold hardening the depth of the layer is practically unchanged.

### Conclusions

1. Cast aluminum alloys AL19 and AL21 after heat treatment possess lower fatigue strength than usual carbon steels.
2. Shot blast cold hardening is an effective means of increasing the strength of these alloys (fatigue strength increases more than 20%, i.e., approximately to the level of steel 35L).
3. Replacement of steel by highly durable cast aluminum alloys permits a 50-60% lowering of the weight of parts working under cyclical application of loads.

INFLUENCE OF ANNEALING AND COLD TREATMENT ON  
STABILITY OF DIMENSIONS OF PRESSURE  
CASTINGS MADE FROM ALUMINUM  
ALLOYS<sup>1</sup>

N. A. Loktionova and N. M. Mangubi

In domestic and foreign literature there are data on the expediency of application of cold treatment of aluminum castings which are hardenable by heat treatment. Regarding castings subjected to annealing (conditions T2) for the purpose of removal of residual casting stresses, in this case carrying out cold treatment is groundless, although it is used at a number of plants.

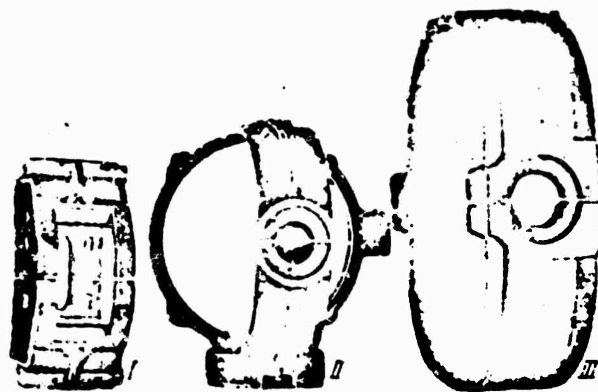
This work had as its goal a check of the expediency of cold treatment of parts cast under pressure made from aluminum alloys which were not subjected to strengthening heat treatment, and also development of optimum conditions of annealing of castings and parts made from aluminum alloys [AL2] (AJ2), AL3, AL9 which would stabilize dimensions after casting and machining.

For investigation we selected characteristic parts corresponding to the method of tests (see Fig. 1). All parts were poured in industrial conditions under pressure from alloys AL2 and AL3, and part 1, furthermore, from alloy AL9. Chemical composition and hardness of castings corresponded to All-Union Government Standard 2685-53.

Annealing of castings at 300° was conducted in chamber electric furnaces with subsequent cooling in air; cold treatment was fulfilled in a cooling chamber at -50°. For preventing corrosion of castings after unloading from the cooling chamber due to condensation of moisture from the air, they were loaded in a thermostat (constant temperature chamber) and held at 50° for 2 h.

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<sup>1</sup>Work was conducted with participation of L. Yu. Rodicheva, A. F. Chuvikova and T. I. Suvorova.



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REPRODUCIBLE

Fig. 1. General view of investigated parts of types I, II, III.

In the process of heat treatment due to relaxation of residual stresses castings were deformed. The value of deformation was the criterion of appraisal of the value of residual stresses.

Quantitative calculation of residual stresses was not done due to the complexity of cast shapes.

The method of determining deformation is as follows. On the surface of a casting or part in corresponding places (convenient for measurements) there were arbitrarily drawn two parallel scratches which were crossed by a third perpendicular scratch. The distance between intersection points was the control variable  $a$  (Fig. 2).

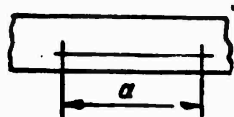


Fig. 2. Diagram of location of scratches on experimental castings.

Measurements of control scratches were made on a large tool microscope (make [PMI] (EMM)) with a precision of  $\pm 0.01$  mm.

The sequence of operations during determination of the value of deformation on samples of experimental lots was as follows:

- placement of two parallel scratches and intersecting perpendicular control scratch on selected place of experimental sample after casting or machining;
- cut of casting or part perpendicularly to control scratch;
- first measurement of value of control scratch on casting or on part ( $a_1$ );
- carrying out experimental conditions of stabilizing heat treatment of sample lot;

- second measurement of value of control scratch on casting or on part ( $a_2$ );

- calculation of deformation:  $d = a_2 - a_1$  (if  $a_2 > a_1$ ) or  $d = a_1 - a_2$  (if  $a_1 > a_2$ ).

Diagrams and graphics were constructed according to average values of deformations of samples of every lot. In an experimental lot there were not less than four castings.

In the process of carrying out the work it was established that the thin section and complex contour geometry of experimental parts make them very sensitive to concussions, light blows, external pressure, etc. Therefore when carrying out experiments we observed necessary measures of precaution, protecting castings, from any external forces.

Experiments were conducted on castings and on machined parts.

Investigations on castings included:

1) Determination of the expediency of application of cold treatment. For this nearly 30 lots of castings made from alloys AL2, AL3 and AL9 were held at  $-50^\circ$  for 3, 6, 9, 12, 15 and 30 h.

Besides determination of the influence of duration of holding at negative temperature, we also checked the influence of repeated holdings; for this purpose in the course of 15 h, ever 3 or 5 h deformation was measured on samples.

2) Clarification of the influence of duration of holding at a temperature of  $300^\circ$  on stability of dimensions of castings made from alloys AL2 and AL3. For this purpose castings were annealed in air furnaces at  $300^\circ$  for 0.5; 2; 4; 6 and 8 h.

3) Study of constancy of dimensions of castings depending on alternation of operations fulfilled at positive and negative temperatures. With this goal heat treatment of experimental lots was conducted in the following variants:

a) annealing at  $300 \pm 10^\circ$  for 4 h;

b) annealing at  $300 \pm 10^\circ$  for 4 h, then cold treatment at  $-50^\circ$  for 3 h;

c) cold treatment at  $-50^\circ$  for 3 h, then annealing at  $300 \pm 10^\circ$  for 4 h.

For clarification of the possibility of appearance of residual stresses in the process of machining, castings made from alloys AL2 and AL3 were subjected to annealing at  $300^\circ$  for 4 h, and then machining was conducted according to design requirements. Ready parts were subjected to secondary heat treatment at  $300^\circ$ ,

with a different sequence of treatment at positive and negative temperatures according to the variants indicated above.

For comparison one lot of parts was made from castings without annealing after casting, which was conducted after final machining.

### Investigation of Deformation of Castings

Influence of cold treatment. An investigation of the influence of cold treatment at  $-50^{\circ}$  on deformation of castings made from alloys AL2, AL3 and AL9 was produced during single holds of different duration and during repeated holding.

Results of measurements of numerous lots of castings showed that after cold treatment  $-50^{\circ}$ , independently of duration of holding (3, 6, 9, 12, 15 and 30 h), deformation of castings does not occur. Analogous results are obtained after intermittent cold treatment each 3 and 5 h.

Thus, obtained experimental data show that if made from aluminum alloys are required to have an accuracy of dimensions within limits of 0.01 mm, then subjecting such castings to cold treatment at  $-50^{\circ}$  is useless.

Influence of duration of annealing at  $300^{\circ}$ . Values of deformations of castings of three types made from alloys AL2 and AL3, annealed at  $300^{\circ}$  for 0.5; 2; 4; 6 and 8 h, are represented in Fig. 3.

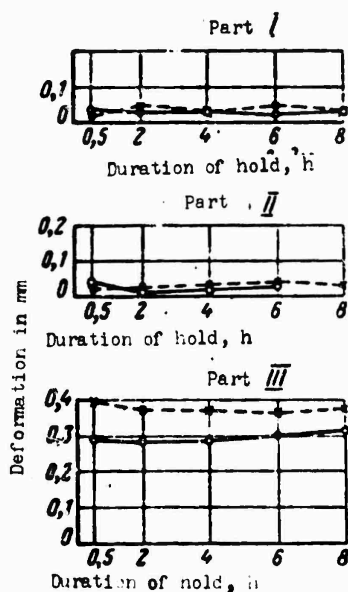


Fig. 3. Influence of duration of holding at a temperature of  $300^{\circ}$  on deformation of castings (solid line - alloy AL3; dotted - alloy AL2).

Comparing values of deformation of castings, it is possible to note that dimensions of experimental samples render great influence on deformation: the greater the dimensions of a casting, the bigger the value of deformation.



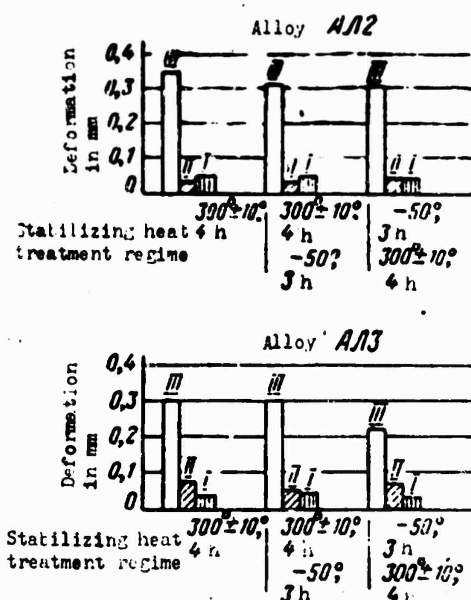


Fig. 4. Deformation of castings made from alloys AL2 and AL3 after different conditions of heat treatment.

Increase of holding from 0.5 to 8 h almost does not change the value of deformation of experimental castings. Thus, for example, the maximum difference in deformation of castings III made from alloy AL2 during holding in the shown interval does not exceed approximately 0.03 mm.

Thus, annealing of castings at 300° for 30 min is sufficient for removal of main residual stresses and protection of parts from warping. However, considering that the majority of parts has more massive sections and larger dimensions than experimental samples, it follows that duration of holding during annealing should be not less than 2-4 h.

Influence of alternation of positive and negative temperatures during heat treatment. Results of measurement of deformation of castings depending on the sequence of treatment at positive and negative temperatures (see Fig. 4), show that different combinations of treatment of castings by cold and annealing almost do not change the value of deformations of castings. This again confirms that for stabilization of dimensions of castings made from alloys AL2 and AL3 it is sufficient only to anneal them at 300°.

The biggest deformation is in casting of type III, deformation of casting I and II, as in the preceding series of experiments, being small and within the limits of 0.08-0.03 mm. This is explained by the fact that parts I and II have smaller dimensions as compared to casting III.

From a comparison of deformation of castings of type III made from alloys AL2 and AL3 (see Table 1) it is clear that it practically does not depend on make of the alloy, and it oscillates in small limits from 0.372 to 0.294 mm. This pertains to castings of type I and II in equal measure.

Table 1. Deformations of Castings Made from Alloys AL2 and AL3

Type of casting	Length of perimeter mm	Deformation mm	
		AL2	AL3
I	225	0,030	0,026
II	250	0,030	0,018
III	380	0,372	0,294

Consequently, deformation basically depends on dimensions of castings and almost does not depend on the composition of the investigated alloys.

#### Investigation of Deformation of Parts After Machining

Machining of annealed castings. Machining of castings (drilling, milling, cutting, etc.) is accompanied by a defined tool pressure on the part, in consequence of which in upper layers of the metal residual stresses appear. Furthermore, removal of crust from a casting redistributes stress and can subsequently lead to warping of parts.

Therefore it was necessary to establish deformation of parts after full machining of castings. For this goal castings were subjected to annealing at 300° for 2 h. Then they were machined according to design. Machined parts were heat treated according to the conditions shown earlier.

Results of measurements of deformation of parts are shown in Fig. 5.

From an analysis of the data it follows that the sequence of application of treatment of parts at positive and negative temperatures does not noticeably influence deformation.

It is necessary to note that deformation of a part of the third type, in spite of its large dimensions, is less than deformation of a part of the second type. Machined part II made from alloys AL2 and AL3 has larger deformation than the two other parts and is within the limits of 0.08-0.11 mm, when deformation of a part of the first type does not exceed 0.025 mm, although the perimeters of these parts remained identical.

It is possible to explain this peculiarity by the fact that the ratio of the surface subjected to machining to all the surface of the part of the second type is larger as compared to the two other investigated parts.

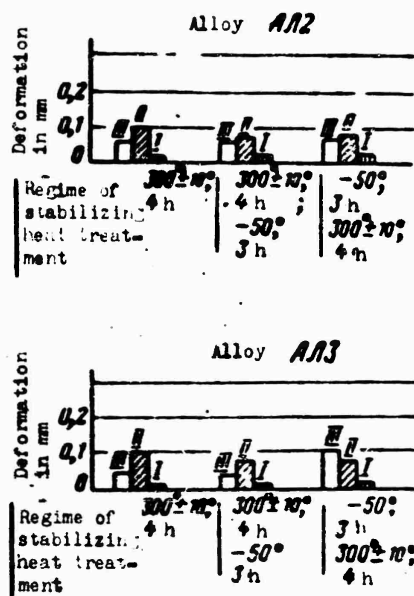


Fig. 5. Deformation of parts made from alloys AL2 and AL3 after repeated heat treatment.

This is confirmed also by the fact that deformation is unequal after annealing of a poured part and after annealing of a machined casting (see Figs. 4 and 5). For example, the average value of deformation of annealed castings of type III made from alloy AL2 is 0.324 mm, but after machining and repeated annealing, deformation is 5 times less 0.063 mm.

Parts of the first type behave as do parts of type III. For part II the index reverses: after machining, deformation of the part is almost 3 times greater (0.090 mm) than for castings (0.035 mm).

The raised deformation of machined parts of the second type, apparently, should be explained by unequal width of contour of the part: the width of the belt of the part is equal to 30 mm, and the diameter of the ring is 88 mm. Removal of casting crust from the ring of castings obviously affects the increase of deformation of such a complex part.

Setting results, it is possible to say that casting made from aluminum alloys after rough machining must be subjected to additional annealing in the following cases:

- 1) in the presence of complex contour of the part, and also sharp differences in sections;
- 2) during raised requirements for stability of dimensions of parts;
- 3) during a large relationship of machined surface to nonmachined.

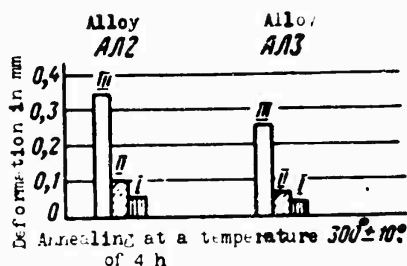


Fig. 6. Deformation of machined parts without preliminary annealing.

Machining of unannealed castings. In order to confirm the necessity of annealing for the purpose of stabilization of dimensions, castings were subjected to machining directly after casting. Then machined ready parts were annealed at  $300^{\circ}$  for 4 h. Results of measurements of deformation of these parts are shown in the diagram of Fig. 6.

Obtained data show that deformation of parts practically is identical with deformation of castings of the same designations which were annealed directly after casting (see Figs. 4 and 6).

Thus, residual stress in castings which are not annealed are preserved in parts after their machining, and this can serve as a cause of warping of parts during assembly of articles and during operation.

#### Conclusions

1. For the purpose of removal of residual stresses it is necessary to subject to annealing all forms of pressure castings made from aluminum alloys of brands AL2, AL3 and AL9.

2. Secondary annealing of parts after machining is necessary in the following cases:

a) in the presence of complex contour of parts, and also sharp differences in sections;

b) during raised requirements for stability of dimensions of a part;

c) during large ratios of machined surface to unmachined.

3. Heat treatment is primary for castings and secondary for certain forms of parts after machining for the purpose of stability of dimensions and should be conducted according to the following conditions: annealing at  $300 \pm 10^{\circ}$ , holding for 2-4 h, cooling in air.

4. Castings and parts during and after annealing, and also during transportation should not be subjected to any external forces as blows, shaking, compression, etc.

5. Treatment at  $-50^{\circ}$  of castings and parts made from aluminum alloys of brands AL2, AL3, AL9, not hardenable by heat treatment, does not affect the value of deformation.

## INFLUENCE OF AN IMPURITY OF TIN ON PROPERTIES OF ALLOY AL9 DURING HEAT TREATMENT

T. I. Smirnova

In plant practice cases have been observed of reject of parts made from aluminum alloy [AL9] (AL9) during heat treatment in saltpeter baths due to corrosion and lowering of mechanical properties.

Investigation has established that the rejected articles made from alloy AL9 contained over 0.01% tin. Occurance of tin in the alloy possibly during melt in crucibles in which before this were melted wastes containing tin.

In literature there is little data about the influence of tin on mechanical, corrosion and other properties of aluminum alloys.<sup>1</sup> For a more precise definition of causes of reject of parts made from alloy AL9 during heat treatment in a saltpeter bath, we investigated the influence of an impurity of tin in amounts of 0.01, 0.05, 0.1 and 0.5% on mechanical properties, microstructure and surface state of samples.

For investigation we prepared pig alloy AL9 of nominal composition according to the All-Union Government Standard 2685-53 and to this alloy added tin in the quantities indicated above.

The melt was conducted in graphite crucibles, in an electrical resistance furnace. Tin was added to the alloy at a temperature of 720°. The alloy was refined with zinc chloride and was modified by a ternary modifier. Samples for mechanical tests were poured in sand forms at a temperature of 690°. The influence of the impurity of tin on mechanical properties of samples was determined for poured and heat treated states (conditions T5). The temperature

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<sup>1</sup>V. V. Zholobov, T. P. Ushakov, (Nonferrous metals) 1951, No. 5; F. Mondolfo, Metallography of aluminum alloys, London, 1943; M. Khansen, (Structure of binary alloys) t. 1, 1945; G. A. Badayeva, R. I. Kuznetsova, izy. AN SSSR, 1950, t. 72, No. 3.

Table 1. Chemical Composition of Saltpeter Baths

No of bath	Content of components:						
	Basic components in %			Impurities in %			
	KNO <sub>3</sub>	NaNO <sub>3</sub>	Na <sub>2</sub> NO <sub>3</sub>	K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	alkali	NaCl	including ions of chlorine
1	49,1	43,3	2,8	0,5	0,60	4,40	2,70
2	47,2	29,9	20,6	0,1	0,62	1,60	1,00
3	38,0	60,0	1,0	0,4	—	0,24	0,14
Recommended composition of saltpeter bath	65—35	35—65	—	3,0	1,0	—	0,50

of heating before hardening was 520 and 535° so that at a temperature of 520° (known to be low for alloy AL9) we would avoid possible overburning due to a temperature gradient in the furnace. Heating was conducted in an electrical resistance furnace with circulation of air in plant saltpeter baths. The chemical composition of saltpeter baths is given in Table 1.

As can be seen from Table 1, saltpeter baths considerably differ in terms of the content of an impurity of sodium chloride.

Sodium chloride in the process of heating dissociates into ions of chlorine and sodium. Considering that ions of chlorine cause corrosion of aluminum alloys, the content of this impurity should be strictly controlled.

### Results of Investigation

Mechanical properties. As can be seen from Table 2, an impurity of tin in amounts of 0.01-0.5% lowers strength of samples made from alloy AL9 in cast and heat treated states.

Heating before hardening in saltpeter baths Nos. 1 and 2 (content of ions of chlorine 2.7 and 1.0% accordingly) does not ensure good heat treatment (properties of strength are lower than requirements of All-Union Government Standard 2685-53): strength of samples not containing tin in this case is 3-4 kg/mm<sup>2</sup> lower than during treatment in an air furnace or saltpeter bath No. 3 (content of ions of chlorine 0.14%). Relative elongation is somewhat increased for samples containing tin. Resilience is practically unchanged. Heating before hardening in saltpeter baths and an air medium identically affects mechanical properties of alloy AL9 with tin.

Microstructure. Investigation showed that a content of tin up to 0.05% does not essentially change the structure of alloy AL9. It is possible to consider that tin here is in solid solution.

Table 2. Influence of Impurity of Tin on Mechanical Properties of Samples made from Alloy AL9

Content of tin %	Heat treatment by conditions T5 in salt peter bath										Heat treatment by conditions T5					
	In cast state		bath No 1				bath No 2		bath No 3		520°		535°			
			535°													
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %		
															520°	
$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %			
—	16,6	3,2	18,0	4,0	19,3	4,9	—	19,7	8,3	22,1	5,6	19,1	3,3	22,2	2,4	0,28
0,01	14,4	5,0	18,4	4,3	18,2	7,2	0,4	18,8	4,1	20,9	7,3	18,7	5,8	20,1	7,4	0,46
0,05	12,7	4,0	17,0	3,9	16,7	5,3	0,4	16,6	8,0	17,1	6,4	16,9	4,7	18,1	5,8	0,46
0,1	13,3	5,0	16,0	4,5	14,0	4,2	0,3	13,9	7,0	16,6	7,0	16,3	5,8	15,9	6,6	0,32
0,5	10,3	4,0	12,6	4,5	10,0	—	0,38	14,3	10,0	15,3	7,0	14,6	5,4	11,1	7,3	0,38
According to All-Union Government	16,0	2,0	—	—	—	—	—	—	—	—	—	—	—	20,0	2,0	—

According to All-Union Government standard 2085-53

NOT REPRODUCIBLE





Fig. 1. Microstructure of alloy AL9 in heat treated state:  $\times 800$ , etching 0.5% HF. a) without tin, saltpeter bath No. 1; b) the same with 0.5% tin.

An increase of the content of tin to 0.5% causes formation of a fusible eutectic which is on borders of grains of the aluminum-silicon eutectic (Fig. 1a, b), leading to a lowering of mechanical properties.

#### External Appearance of Samples After Heat Treatment in Saltpeter Baths and Air Furnace

To appearance of samples after heat treatment in saltpeter baths and an air medium is shown in Fig. 2.

On the surface of samples not containing tin, there are no traces of corrosion. During heating in an air furnace (Fig. 2d) and saltpeter bath No. 3 (Fig. 2c) all samples containing up to 0.5% tin also did not have traces of corrosion on the surface.

During heat treatment in saltpeter bath No. 1, containing 2.7% ions of chlorine, first evidence of corrosion appeared during a content of 0.01% tin. Changes in structure here were not observed. With an increase of the content of tin in the alloy to 0.5% corrosion of the surface of samples was strengthened (Fig. 2a).

In saltpeter bath No 2. (1.0% ions of chlorine) first evidence of corrosion appeared with 0.05% tin. The intensity of corrosion with an increase of the quantity of tin was considerably weaker than for samples treated in saltpeter bath No. 1.

After hardening in saltpeter bath No. 1 from a temperature of  $520^{\circ}$  first evidence of corrosion appeared on samples containing 0.05% tin. At the same time heating in this bath to a temperature of  $535^{\circ}$  caused corrosion of samples even with a tin content of 0.01%. Thus, the intensity of corrosion of samples containing tin is increased with an increase of the temperature of hardening.

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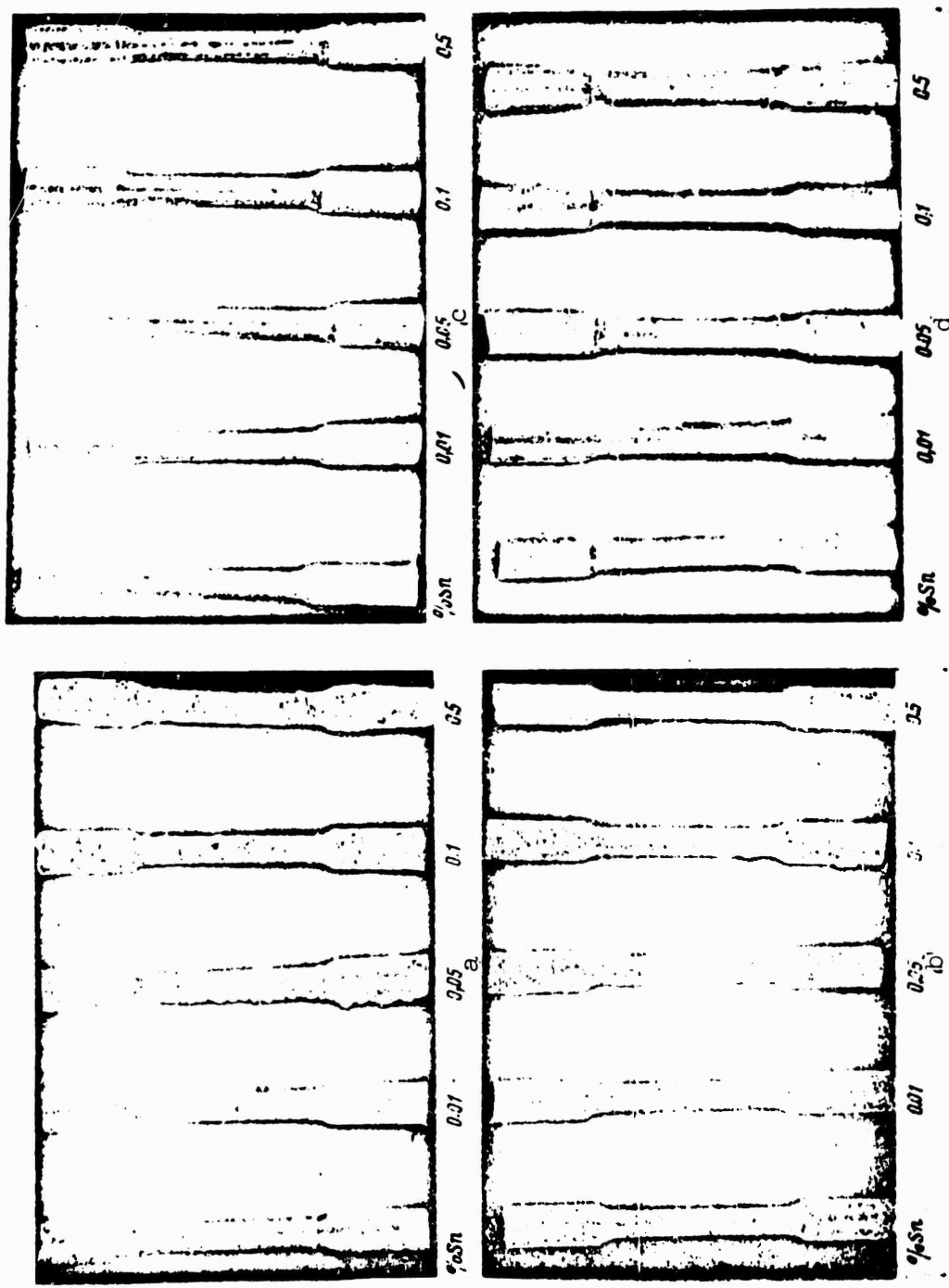


Fig. 2. Appearance of samples after heat treatment in salt-peter baths and air furnace (temperature of hardening 535°C). a) bath No. 1; b) bath No. 2; c) bath No. 3; d) air furnace.

### Conclusions

1. Tin within the limits of investigated contents of 0.01-0.5% lowers the strength of cast and heat treated alloy AL9, somewhat increasing its plasticity.

2. Increase of ions of chlorine in saltpeter baths from 0.2 to 2.7% lowers strength of samples during heat treatment by 3-4 kg/mm<sup>2</sup>, obviously due to corrosion.

Contents of ions of chlorine in saltpeter baths should not exceed 0.3-0.5%.

## APPLICATION OF FLUXES DURING MELT OF ALUMINUM CASTING ALLOYS

M. B. Al'tman, T. I. Smirnova, M. A. Syromyatnikova,  
Ye. A. Itskovich and Ye. P. Shteyman

As protective fluxes for aluminum alloys mixtures of halide salts of alkali and alkali earth metals are used; they are passive with respect to aluminum and alloying metals, possess a low melting point, high wetting ability and other positive properties.

For giving fluxes refining properties, i.e., ability to dissolve and adsorb oxides and remove gas, to chlorous salts are added flourides (cryolite, sodium flouride and calcium flouride). The content of flourides should be not less than 10%, otherwise the refining properties of fluxes drop.

Flourides in a small quantity (10-15%) improve protective properties of the flux, making its film more dense and impenetrable.

Fluxes containing flourides also effectively wet the aluminum oxide and promote its removal. This is explained by the fact that, in small quantity, flourides somewhat increase the surface tension of fluxes on the aluminum oxide and melt interface, and the interphase tension of flux - metal is increased. Fluxes containing flouride salts, in particular cryolite, are able to adsorb up to 10% (weight) aluminum oxide.

Inasmuch as the solubility of aluminum oxide in fluxes is insignificant (not more than 1.2%), one should consider that clearing the melt from aluminum oxide occurs basically not on account of solution of it in the flux, but due to adsorption by the flux.

The flux, dissolving and adsorbing the oxide film on the surface of the melt, promotes merging of reguluses of metal and facilitates the process of removal of gas from the melt. However, not excluded is the possibility of the simultaneous degasifying action of a flux containing cryolite, due to thermal dissociation of cryolite and formation of the volatile compound  $\text{AlF}_3$ . It is

assumed that fluxes containing sodium fluoride promote degassing thanks to the passage of sodium into the melt, its oxidation, and a change of the structure and properties of the oxide film on the surface of metallic bath on account of the content of sodium oxide.

It is also possible to express the assumption that inasmuch as bubbles of hydrogen in the melt are connected, in virtue of different signs of charges, with oxide inclusions, adsorption of endogenous inclusions and removal by the flux leads simultaneously to emergence on the surface and removal of gas pockets. Such a flow of the process is very possible, but requires an experimental check. There is no final explanation of the degasifying action of fluxes in aluminum alloys.

During the use of protective fluxes, frequently not considered is the possibility of a certain loss of aluminum and alloying components in melted fluxes made from chlorides and fluorides.

These losses arise from two basic causes:

- 1) chemical interaction of metals with component parts of fluxes;
- 2) mechanical trapping and dispersion of metal in the mass of the flux.

The struggle with mechanical trapping reduces to a thorough separation of flux from melt before pouring the alloy. Losses of aluminum as a result of chemical reactions are conditioned by formation of chlorides and fluorides of aluminum of low valence (hypochloride and hypofluoride) which exist at a high temperature.



During cooling of the  $\text{AlCl}(\text{F})$  in the layer of the flux interacts anew with the sodium, forming aluminum and halide salts of sodium, where aluminum is lost during removal of the flux.

During melt under flux of alloys with magnesium there is observed a considerable loss of magnesium, especially noticeable for alloys with a limited content of magnesium ( $[\text{Al}^4]$  ( $\text{Al}^4$ ),  $\text{Al}^9$ ).

The goal of this work was investigation of the behavior of fluxes of various compositions during melt of aluminum alloys.

We studied the influence of fluxes on yield of a suitable metal, a change of mechanical properties of an alloy during melt without fluxes and under fluxes, loss of magnesium depending on the quantity of flux, and refining action of fluxes in comparison with chlorination.

### Covering and Covering-Refining Fluxes and Their Influence on Yield of a Suitable Metal

We investigated influence on yield and cleanness of suitable alloys on the basis of system Al-Si of covering and covering-refining fluxes of systems NaCl-KCl, NaCl-NaF, NaCl-NaF-KCl, NaCl-KCl-Na<sub>3</sub>AlF<sub>6</sub> and others.

Selection of systems was determined by the necessity of a combination of protecting, refining and modifying properties. We investigated seven different groups of fluxes.

Fluxes of group I consisted of only chlorous salts. These fluxes are distinguished by the greatest surface activity.

Fluxes of groups II-V contained up to 10% sodium fluoride which was added for increase of marginal wetting angle of the flux on the melt.

Fluxes of group VI contained sodium chloride and up to 40% sodium fluoride.

Finally, in the composition of fluxes of group VII, along with sodium chloride and sodium fluoride, there was potassium chloride which improved the wetting ability of the salt mixtures.

To the flux of every group, giving best results in terms of yield of the suitable metal, we added rhyolite in amounts of 3, 5, 7, 10 and 15%. Investigation of the influence of different groups of covering-refining surface-active fluxes was conducted on alloy AL9. Fluxes related to groups I-V were deposited on the surface of melt after melting the charge, and the alloy was heated under the flux to a temperature of 750° at which was held for one h. Fluxes of groups VI-VII were put in the crucible simultaneously with the charge. Subsequent conditions of melt were the same as during melt with fluxes of groups I-V. After holding, slag was removed from the surface of the melt and the alloy was poured into a steel casting mould. Poured ingots and slag were weighed after cooling.

The chemical composition of fluxes, giving best results in terms of yield of the suitable metal, is given in Table 1.

As can be seen, melt with flux permits lowering loss of the alloy due to oxidation by 2-6%.

It is necessary to note that the presence of sodium fluoride increases the protective properties of fluxes, increasing yield of the suitable metal.

Curves shown in Figs. 1 and 2 show the positive influence of cryolite on protective properties of fluxes which do not contain fluorides. Addition of cryolite to fluxes containing sodium fluoride essentially does not change the protective properties of fluxes.

Table 1. Change of Yield of Suitable Metal Depending on Chemical Composition of Flux

Composition of fluxes	Group of flux	Yield of suitable metal in %
Without flux	—	91,9
30% NaCl+70% KCl	I	95,8
20% NaCl +70% KCl + 10% NaF	II	98,0
30% NaCl + 60% KCl + 10% NaF	III	98,0
40% NaCl + 50% KCl + 10% NaF	IV	97,5
50% NaCl + 40% KCl + 10% NaF	V	98,2
75% NaCl + 25% KCl	VI	97,6
45% NaCl + 40% NaF + 15% KCl	VII	98,1

This should be explained by the fact that protective properties of fluxes depend first of all on their surface activity caused by the presence of chlorides.

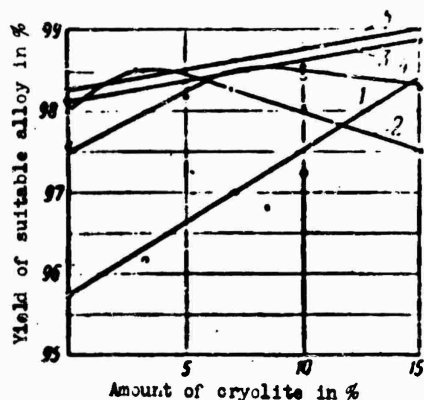


Fig. 1. Dependence of yield of suitable alloy AL9 on content of cryolite in different groups of covering flux.

1—30% NaCl + 70% KCl, 2—20% NaCl + 70% KCl + 10% NaF, 3—30% NaCl + 60% KCl + 10% NaF, 4—40% NaCl + 50% KCl + 10% NaF, 5—50% NaCl + 40% KCl + 10% NaF.

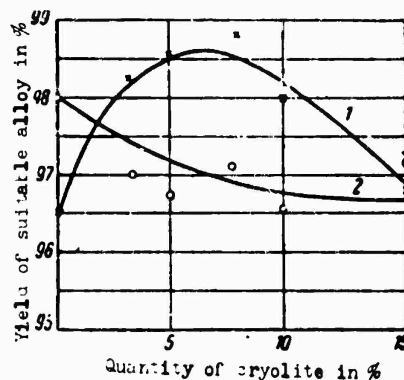


Fig. 2. Dependence of yield of suitable alloy AL9 on content of cryolite in different groups of covering-refining flux. 1 — 75% NaCl + 25% NaF; 2 — 40% NaF + 45% NaCl + 15% KCl.

Introduction of small quantities of fluoride salts to fluxes of groups I-V (up to 10% NaF or 15%  $\text{Na}_3\text{AlF}_6$ ) is useful, since they make the film of melted flux more dense, make it less permeable to gases.

Further increase of the content of fluorides not only does not strengthen, but even lowers the protective action of fluxes (Fig. 2). However, inasmuch as fluoride salts are necessary

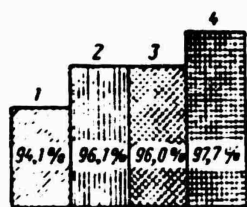


Fig. 3. Yield of suitable alloy AL9 (melt with a weight of 10 kg, average data from three melts). 1 - melt in hearth (without flux); 2 - melt in electric furnace (without flux); 3 - melt in hearth (under flux); 4 - melt in electric furnace (under flux).

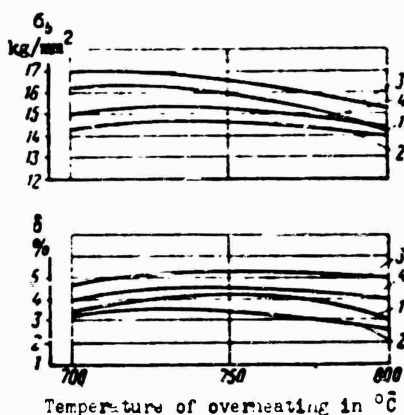


Fig. 4. Change of mechanical properties depending on technology of preparation of alloy AL9. 1 - melt in electric furnace without flux; 2 - melt in gas furnace without flux; 3 - melt in electric furnace under flux; 4 - melt in gas furnace under flux.

for giving fluxes refining and modifying properties, it is necessary to allow a certain decrease of surface activity of fluxes, increasing the content of fluorides.

It is necessary to note that the degree of contamination of alloy by nonmetallic inclusions is influenced also by the type of furnaces in which melts are conducted, and the application of fluxes during melt. Data of balanced melts conducted in a gas furnace and in an electric furnace without flux and under a flux (we used a flux consisting of 45% NaCl; 40% NaF; 15% KCl), show (see Fig. 3) that in the gas furnace the melt is subjected to action of fuel gases, in consequence of which yield of the suitable alloy drops. At the same time it is clear that application of a flux, independently of the type of furnace, increases yield of the suitable alloy.

Purification of an alloy from gas pockets promotes an increase of its strength properties. As the graphs of Fig. 4 show, mechanical properties of alloy AL9 depend on the technology of its preparation: they are higher in the case of use of an electric furnace and application of flux during melt of the alloy than in a gas or electric furnace. Losses of magnesium during melt under a flux (45% NaCl; 40% NaF; 15% KCl) were determined for alloy AL9. Results of the chemical analysis are given in Table 2.

These data show considerable losses of magnesium during melt of alloy AL9 under a flux. The influence of quantity of a flux on losses of magnesium should be explained by the direct relationship between concentration of interacting components of the reaction  $\text{Mg} + \text{NaCl} \rightarrow \text{MgCl} + \text{Na}$ .



Table 2. Influence of Quantity of Flux on Content of Magnesium in Alloy AL9

% Flux	% magnesium in alloy	Time of sampling
Without flux	0.29	Immediately after reaching a temperature of 750°
Without flux	0.29	
0.5	0.29	After standing one h at 750°
1.0	0.24	
2.0	0.21	
3.0	0.20	
5.0	0.17	
10.0	0.09	

#### Refining Action of Fluxes

A series of works shows that fluxes to a larger degree refine a melt from nonmetallic inclusions (gas and oxide) than do chlorous salts.

Fluxes used at present for treatment of a melt made from aluminum alloys can be divided into two groups:

- 1) fluxes for refining and protection of a melt from oxidation;
- 2) fluxes for refining and simultaneously for modification of casting alloys based on system Al-Si. \

Representative of a group of refining fluxes is a flux of the following composition: 47% KCl; 30% NaCl; 23%  $\text{Na}_3\text{AlF}_6$ . This flux, with a specific gravity in liquid state of  $1.6 \text{ g/cm}^3$  and melting point  $700^\circ$  dissolves up to 0.66% (weight) and adsorbs up to 10% (weight) aluminum oxide. The flux is used in for stock casting. Its degasifying ability does not yield to the degasifying ability of chlorine.

The group of refining-modifying fluxes includes:

- a) Flux consisting of 60% NaF; 25% NaCl; 15%  $\text{Na}_3\text{AlF}_6$ . The specific gravity of the flux in liquid state is  $1.8 \text{ g/cm}^3$ , melting point  $850^\circ$ . The flux dissolves up to 1.7% (weight) and adsorbs up to 8% (weight) aluminum oxide.

This flux is intended for alloys with a high content of silicon, such as AL2, and also for other alloys of this system, when a high casting temperature is necessary.

b) Flux consisting of 30% NaF; 50% NaCl; 10% KCl; 10%  $\text{Na}_3\text{AlF}_6$ .

The specific gravity of the flux in liquid state is  $1.689 \text{ g/cm}^3$ . The melting point is  $715^\circ$ . The flux dissolves up to 1.3% (weight) and adsorbs up to 8-10% (weight) aluminum oxide. The flux is recommended for alloys Al-Si, when parts are poured at low temperatures.

The degasifying properties of both fluxes are considerably higher than for chlorous salts.

Considering the good protective and refining properties of fluxes, and also the fact that replacement of chlorine by fluxes improves working conditions, in plant conditions we conducted a comparative investigation of the influence of fluxes and chlorine on the quality of castings from alloys AL1, AL2, AL3, AL4, AL5 and AL9.

Quality was checked on parts poured in plant conditions in terms of mechanical properties, X-ray control, macro- and microstructure and tests for fracture of parts, and technological tests for oxide scales.

The method of technological tests for oxide scales is based on the fact that during deformation in height, 75-80% of small ingots have a concentration of scales dispersed over the section of an ingot. Concentration of scales on a comparatively small section facilitates their detection, and by fracture of such a sample it is possible to judge about contamination of alloy by oxides.

Alloys AL2, AL4 and AL9. For refining alloys AL2, AL4, AL9 we used chlorine and a flux consisting of 60% NaF; 25% NaCl; 15%  $\text{Na}_3\text{AlF}_6$ . The flux simultaneously served a modifier for these alloys.

Results of the investigation of macro- and microstructure of alloys are represented in Table 3.

In terms of X-ray control, macro- and microstructure, and tests for fracture, no parts poured from alloys AL2, AL4 and AL9 refined by flux yield in terms of quality to parts poured from these alloys refined by chlorine with subsequent modification by a double modifier. Mechanical properties of separately poured samples of alloys AL2, AL4 and AL9 with different technology of treatment of melt are given in Table 4.

As these data show, mechanical properties of separately poured samples of alloys AL2, AL4 and AL9, smelted with application of a flux containing 60% NaF; 25% NaCl; 15%  $\text{Na}_3\text{AlF}_6$ , correspond to All-Union Government Standard 2685-53. Technological samples testified to the fact that treatment of alloys of system Al-Si with fluxes to a larger degree than chlorous salts and chlorine refines the alloy from oxide inclusions.

Table 3. Change of Macro- and Microstructure of Samples Made from Alloys AL2, AL4 and AL9 Depending on Treatment of Melt

Refining and modifying means	AL2		AL4 <sup>1</sup>		AL9	
	standard porosity	state of micro-structure	standard porosity	state of micro-structure	standard porosity	state of micro-structure
Chlorine and double	1-3	Modified	1	Modified	1-2	Modified
Flux	1-3	Modified	1	Modified	1-2	Modified

<sup>1</sup>Parts and samples were cast in an autoclave.

Alloys AL1, AL3 and AL5. For refining alloys AL1, AL3 and AL5 we used chlorine and a flux consisting of 47% KCl; 30% NaCl; 23% Na<sub>3</sub>AlF<sub>6</sub>. Results of the investigation of macro- and microstructure of alloys are represented in Table 5.

Table 4. Mechanical Properties of Separately Poured Samples from Alloys AL2, AL4 and AL9 Depending on Technology of Treatment of Melt

Refining and modifying means	AL2, cast		AL4, heat treatment by regime T6		AL9, cast	
	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %
Chlorine and double modifier	15,2	6,9	25,9	4,1	—	—
Flux	16,6	7,9	25,7	4,8	17,4	2,8
According to All-Union Government standard 2685-53	15,0	4,0	23,0	3,0	16,0	2,0

In terms of X-ray control, macro- and microstructure, and tests for fracture, all parts poured in sand and chill mold from alloys AL1, AL3 and AL5 refined by flux completely meet requirements.

Mechanical properties of samples made from alloys AL1, AL3, AL5, poured with application of a flux of composition 47% KCl, 30% NaCl; 23% Na<sub>3</sub>AlF<sub>6</sub> exceed the requirements of All-Union Government Standard 2685-53 (see Table 6).

Selection of metal from the distributing furnace during casting in a chill mold occurs for 2-3 hours. Therefore we took before control melts AL1 and AL3 immediately after refining, in 1 h, 2 and 3 h, and also castings made from these alloys. A noticeable impairment of casting quality and an increase of porosity of parts during standing of the melt for 3 h does not occur.

Table 5. Change of Macro- and Microstructure of Alloys AL1, AL3 and AL5 Depending on Technology of Treatment of Melt

Refining means	AL1 <sup>1</sup>		AL3		AL5	
	standard porosity	state of micro-structure	standard porosity	state of micro-structure	standard porosity	state of micro-structure
Chlorine	2	Normal	1-2	Normal	1-2	Normal
Flux	2	Normal	1-2	Normal	1-2	Normal

<sup>1</sup>Parts were poured in chill mold.

<sup>2</sup>Porosity not revealed.

On this group of alloys fluxes the refining action from oxide inclusions is better than chlorous salts ( $ZnCl_2$ ) and chlorine.

Table 6. Change of Mechanical Properties of Separately Poured Samples of Alloys AL1, AL3 and AL5 Depending on Technology of Treatment of Melt

Refining means	AL1, heat treatment by conditions T5		AL3, heat treatment by conditions				AL5, heat treatment by conditions T5	
			T1		T5			
	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %	$\sigma$ kg/mm <sup>2</sup>	$\delta$ %
Chlorine	32,7	0,9	18,8	0,8	24,0	0,6	23,4	1,2
Flux	31,7	0,9	18,2	1,2	24,5	1,2	24,1	1,4
According to All-Union Government standard 2-85-53	20,0	0,5	17,0	1,0	21,0	—	20,0	—

<sup>1</sup>Samples poured in chill mold.

### Conclusions

1. The protective action of fluxes (the investigation was conducted on alloy AL9) is ensured by chlorides which improve the wetting ability of fluxes, and fluorides which increase strength of the flux film.

Melt under fluxes increases yield of the suitable alloy by 2-6%.

2. Melt under fluxes made from fluoride and chloride salts leads to burning out of magnesium in alloys containing small quantities of this component (AL4, AL9).

3. Treatment of alloys AL1, AL2, AL3, AL4, AL5 and AL9 by fluxes permits obtaining a melt of the same quality as during treatment with chlorine.

Castings made from the prementioned alloys, in terms of contamination with nonmetallic impurities (gaseous and solid) completely meet technical specifications, and in terms of mechanical properties, macro- and microstructure they completely fulfill All-Union Government Standard 2685-53.

## DEGASSING OF ALUMINUM AND ITS ALLOYS BY ULTRASONIC OSCILLATIONS

M. B. Al'tman, V. I. Slotin, N. P. Stromskaya,  
G. I. Eskin and L. I. Loktionova

During passage of elastic oscillations through a liquid medium (melt) a phenomenon of cavitation is observed, leading to fracture of continuity in the liquid phase with formation of cavities to which gas dissolved in the liquid (melt) rushes. Due to this elastic oscillations of sound, and especially of ultrasonic frequency, promote formation of embryo blowholes, stimulate their further growth in the liquid phase and their coalescence to dimensions which ensure active liberation of gas from the liquid (melt).

Krüger<sup>1</sup> used elastic oscillations, obtained with the aid of a magnetostrictive radiator with a frequency of 8-10 kHz for degassing optical glass, and Rummel, Esmarch and Beuter<sup>2</sup> treated with sound and ultrasonics alloys Al-Mg with a content of magnesium from 5 to 7%. In these investigations a method was offered of degassing melts by imposition of a permanent magnet field on the high-frequency field of the induction furnace in which the melt was carried out. With such a method of treatment, in the melt intense oscillations appeared on account of electrodynamic forces, ensuring full degassing of the melt in 30-60 minutes. Eckhardt and Eden<sup>3</sup> used the same method for degassing high-quality optical glass.

In literature, however, there is very little data on investigation of the influence of elastic oscillations on the degree of degassing of aluminum melts.

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<sup>1</sup> F. Krüger, *Glastechnik*, 1938, B. 16, S. 233.

<sup>2</sup> Th. Rummel, W. Esmarch, K. Beuter, *Metallwirtschaft*, 1940, B. 19, S. 1929.

<sup>3</sup> A. Eckardt, C. Eden, *Glass und Hochvakuumtechnik*, 1952, № 2, S. 15.

A search of the most effective methods of refining, in particular, methods whose application excludes water touching the melt, brought us to an investigation of the influence of elastic oscillations on the process of separation of hydrogen from certain aluminum alloys.

Simultaneously we studied the change of structure and properties of these alloys under the influence of ultrasonics.<sup>1</sup> The work generalizes earlier investigations by the authors and is their continuation.

For production of elastic oscillations of ultrasonic frequency the magnetostrictive method was used. As a source of high-frequency oscillations a generator of self-excitation type [UZG-10] (УЗГ-10) was used. For conversion of electromagnetic oscillations into mechanical we used a magnetostrictive converter of type [PMS-7] (ПМС-7) made from stamped annealed plates of permendur of make [K50F2] (K50Ф2) 0.2 mm thick. In Fig. 1 is represented the scheme of the installation for transmission of elastic oscillations to the melt.

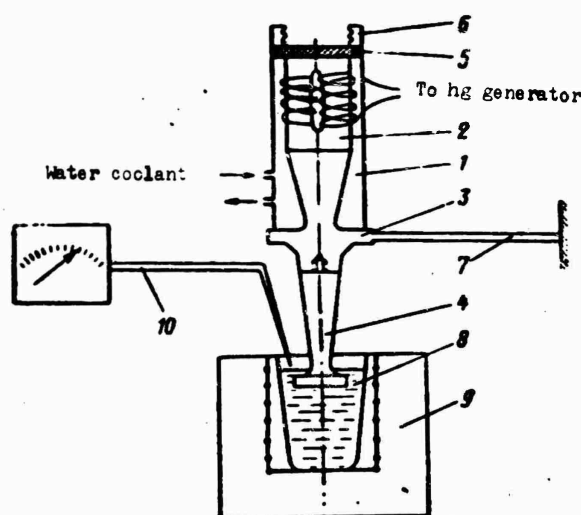


Fig. 1. Scheme of introduction of elastic oscillations into a melt. 1 - housing; 2 - magnetostrictive converter with winding; 3 - concentrator; 4 - waveguide with thread bracing; 5 - resin shock absorber; 6 - bellows; 7 - bracing of oscillation subassembly support; 8 - crucible with melt; 9 - electrical resistance furnace; 10 - thermocouple.

<sup>1</sup>M. B. Al'tman, V. I. Slotin, D. V. Vinogradov and G. I. Eskin. Izv. AN SSSR, OTN, 1958, No 9.

M. B. Al'tman, V. I. Slotin, N. P. Stromskaya and G. I. Eskin. Izv. AN SSSR, OTN, 1959, No 3.

During transmission through the vibrator winding of alternating current from the hf generator and constant magnetizing current from the rectifier, the vibrator changes its linear dimensions in tune with the high-frequency current variations.

Bellows introduced in the construction press the rubber washer to the nonoperating end of the vibrator, which through a rubber washer borders with air. In these conditions oscillation damping of the nonworking end of the vibrator occurs. Thus a large part of the elastic energy produced in the vibrator is usefully used for treatment of the melt by elastic oscillations. From Fig. 1 it is clear that the working face of vibrator is soldered to the concentrator and all the system of housing, vibrator, and concentrator is energetically cooled with water.

Direct transmission of elastic oscillations to the melt was carried out through a waveguide which was assembled in the concentrator with the aid of a thread connection.

Great difficulties were met during selection of material for the waveguide. It is necessary to underline the heavy work conditions of waveguides in the liquid melt at a refining temperature ( $720-730^{\circ}$ ) and the great power of ultrasonic radiation.

The effect of cavitation in the liquid phase around the fluctuating waveguide leads to local pressure jumps and microexplosions caused by erosion of the waveguide and its destruction. Two groups of waveguides were tested. The first group were steel waveguides, quartz waveguides, steel waveguides with ends made from copper and titanium alloy [VT1] (BT1) and, finally, waveguides made from titanium alloy of the same make. The second group of waveguides were compound waveguides made from titanium rods with caps made from refractory metals.

The form of the waveguide was selected so as to ensure a sufficient oscillation front.

Experiments showed that of the first group of waveguides the best stability was possessed by the waveguide made from titanium alloy, although it is subject to erosion, in consequence of which the alloy was saturated with titanium: after 15 minutes of treatment the content of titanium in the alloy was increased from 0.1 to 0.2%, and after 23 minutes of influence of ultrasonic oscillations the quantity of titanium in the alloy was increased to 0.3%.

Application of quartz and especially steel waveguides turned out to be inexpedient due to their rapid destruction. After even 7 minutes of ultrasonic treatment the content of iron in the alloy was increased from 1.23 to 1.7%, and after 17 minutes it reached 2.0%.

Therefore the basic experiments were conducted with application of the waveguide made from alloy VT1. We simultaneously searched for materials of a waveguide from refractory metals which would be stable at temperatures of degassing of aluminum alloys (waveguides



of the second group).

Compound waveguides were made in the form of a titanium rod with a cap made from molybdenum, niobium, chromium, tungsten. Waveguides of this group were preliminarily tested in water. Caps made from molybdenum and niobium during testing in water showed good results. Caps made from chromium and tungsten in view of raised brittleness were broken, and therefore were not used for treatment of the melt.

Investigation of waveguides with caps made from molybdenum and niobium were conducted on aluminum of make A1. The action of ultrasonics on metal was checked with the aid of vacuum tests, and the change of composition of the alloy due to dissolution of the waveguide was checked by chemical analysis.

Experiments with application of a waveguide made from alloy VT1 were conducted in the following way: the metal prepared in graphite a crucible in an electric furnace. After melting and bringing the temperature of the melt to  $720-730^{\circ}$ , into the crucible with the metal we lowered the waveguide until it contacted the surface of the melt. After heating the working end of the waveguide the generator was switched on.

Treatment with ultrasonic oscillations was given to pure aluminum of make A00, an alloy of average strength with good casting properties [AL9] (AL9) (Al-Si-Mg), and highly durable casting alloy AL20 (Al-Si-Cu-Mg).

From the melt treated by ultrasonic oscillations we poured in sand molds rupture test samples with a diameter of 10 mm and parts. From the heads of test samples we prepared samples with a diameter of 10 mm and length 15 mm for measurement of specific gravity by the method of hydrostatic weighing.

Parts were subjected to X-ray radiography and hydrotests under a pressure of 10 at. Some of the parts were poured by the method of exact casting in smelting patterns. From parts we cut Gagarin samples for determination of mechanical properties and prepared micro- and macrographs.

Results of every separate experiment were compared with control data obtained on material without the influence of ultrasonics.

Before treatment the melted metal was specially saturated with moisture by means of introduction of wet asbestos, which permitted us more clearly to observe the action of ultrasonics on degassing of a melt.

The degree of purification of metal from gas pockets was checked by vacuum tests. In terms of intensity of separation of bubbles at the time of crystallization under vacuum there was composed a scale of points. Intense liberation of gas over the surface of a sample with its strong distending corresponds to 5 points; liberation of more than 20 bubbles, 4 points; liberation of less

Table 1. Properties of Aluminum and Alloys AL9 and AL20 Before and After Treatment of the Melt by Ultrasonic Oscillations

Make of alloy	Content of Ti %	Technology		Mechanical properties found							Point porosity	Specific gravity g/cm <sup>3</sup>
		+ treat- ment of melt	casting of parts <sup>1</sup>	: for separately poured samples			for samples cut from parts					
				σ <sub>0.2</sub> kg/mm <sup>2</sup>	δ %	HB kg/mm <sup>2</sup>	σ <sub>0.2</sub> kg/mm <sup>2</sup>	σ <sub>0.2</sub> kg/mm <sup>2</sup>	δ %			
A/10	—	untreated	3	5,0	44	16,4	—	—	—	2	—	
	0,53	treated	3	6,9	37	18,5	—	—	—	1	—	
A/19	0,04	untreated	—	22,7	2,4	82,1	15,6	18,8	1,7	5	2,698	
	0,09	treated	—	23,5	5,0	67,9	15,5	20,2	1,8	1	2,763	
	0,13	untreated	3	31,3	1,3	121	24,0	27,8	0	5	2,771	
A/20	0,20	treated	3	32,9	1,2	122	26,0	29,1	0,4	1	2,785	
	0,20	treated	B. M.	—	—	—	29,1	30,1	1,0	—	—	

<sup>1</sup>V. M. — casting in smelting patterns, Z — casting in sand molds.

Designations: 3 = Z

than 20 bubbles, 3 points; up to 5 bubbles, 2 points and crystallization without liberation of gases 1 point. Furthermore vacuum samples were cut in half, and on vertical cuts we made slides which were etched with a 10% solution of NaOH for exposure of the macrostructure.

For melt with weight 8 kg conditions were worked out for introduction of ultrasonics into the melt, allowing fuller degassing of the melt. The duration of ultrasonic degassing, ensuring lowering of gas saturation of the alloy from 5 points to 1 point was 8 minutes. It was established that subsequent standing for 4-5 minutes of alloy treated by ultrasonics in turn decreases gas saturation since, obviously, blow lies on the bottom of the crucible succeed to rise to the surface. The shown conditions of treatment were accepted for all subsequent experiments.

Table 1 gives properties of pure aluminum of make A00 and alloys AL9, AL20, and the content of titanium before and after treatment of their melt by ultrasonic oscillations during use of a waveguide made from alloy VT1.

Removal of gas pockets from the melt renders a direct influence on increase of density: specific gravity of alloys after treatment by ultrasonics is increased in the second decimal place.

Ultrasonic oscillations remove from the melt not only gas pockets visible to the eye but also microscopic blowholes, where action of the oscillation field is not limited to separate sections, but spreads over the whole volume.

As was already noted, a waveguide made from an alloy on the basis of titanium, lowered in the bath with liquid aluminum at a temperature of  $720-730^{\circ}$ , is gradually destroyed and, being dissolved, passes into the melt.

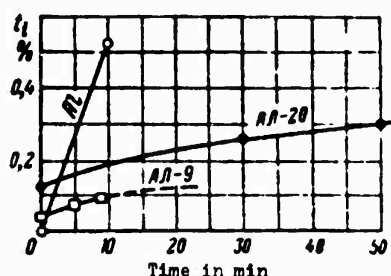


Fig. 2. Change in the content of titanium in aluminum and its alloys during the use of waveguides of VT1 alloy, depending on the duration of treatment of melts by ultrasound.

This occurs due to cavitation destruction, and also the action of diffusion. Data represented in Fig. 2 show the change of content of titanium in aluminum and alloys AL9 and AL20 depending on time of ultrasonic treatment. If the process of destruction on account of forces of cavitation can be recognized as independent of the composition of the melt, connected only with power and frequency of radiation of ultrasonics, then the diffusion rate of titanium in aluminum alloys depends on the temperature of the liquid metal and its composition. This peculiarity of action of ultrasonic

treatment on melts should be considered in order to avoid excess saturation of alloys with the material of the waveguide.

On the other hand, it is known that the character of distribution and physical-chemical properties of impurities render considerable influence on the process of crystallization. In particular, impurities of refractory metals (Ti, Cr and others) are modifiers, since particles of the refractory phase constitute ready surfaces which serve as centers of crystallization. It is natural to consider therefore that introduction in a melt of aluminum of a considerable number of particles of destroyed titanium waveguide promotes formation of a very dispersed structure. Such a property of ultrasonic oscillations presents considerable interest, since it permits alloying and modification of alloys by refractory components. These experimental facts are well substantiated with data of roentgenographic analysis.<sup>1</sup>

Comparing X-ray photographs of samples cast from aluminum A00 (Fig. 3), treated and untreated by ultrasonics, it is possible to see that dimensions of the greater part of grains decrease after treatment. Furthermore, actual grains consist of a somewhat layer quantity of block fragments.

The same was observed for alloy AL20 (Fig. 4), possessing as compared to A00 a more fine-grained structure.

Apparently, the increase in mechanical properties is caused by crushing of grain fragments and by its enrichment.

During ultrasonic oscillation treatment of pure aluminum, an increase of its mechanical properties occurs: tensile strength after 10 minutes of treatment increases 37% from 5.0 to 6.9 kg/mm<sup>2</sup>, while lengthening drops only 15%. This hardening of pure aluminum, obviously, is connected with a change of chemical composition and formation of system Al-Ti (content of titanium reaches 0.5%). In heterophase alloys an increase of the content of titanium, and also strength, occurs less intensively. Thus, for alloy AL9 five minutes of treatment by ultrasonic oscillations increases tensile strength 7.5% from 18.8 to 20.2 kg/mm<sup>2</sup>; yield point does not change.

A greater effect is revealed for alloy AL20. Tensile strength on samples cut from parts poured in sand forms is increased to 29.1 kg/mm<sup>2</sup>, and yield point to 28 kg/mm<sup>2</sup>, with lengthening 0.5%. Technical conditions for alloy AL20 during casting of separately poured samples in sand forms gives the following mechanical properties: tensile strength 23 kg/mm<sup>2</sup>, yield point 24 kg/mm<sup>2</sup>, lengthening 1%. Deserving of attention is an interesting peculiarity

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<sup>1</sup>Roentgenographic investigation was conducted by G. V. Zhevakinoy and the late G. M. Rovenskiy.

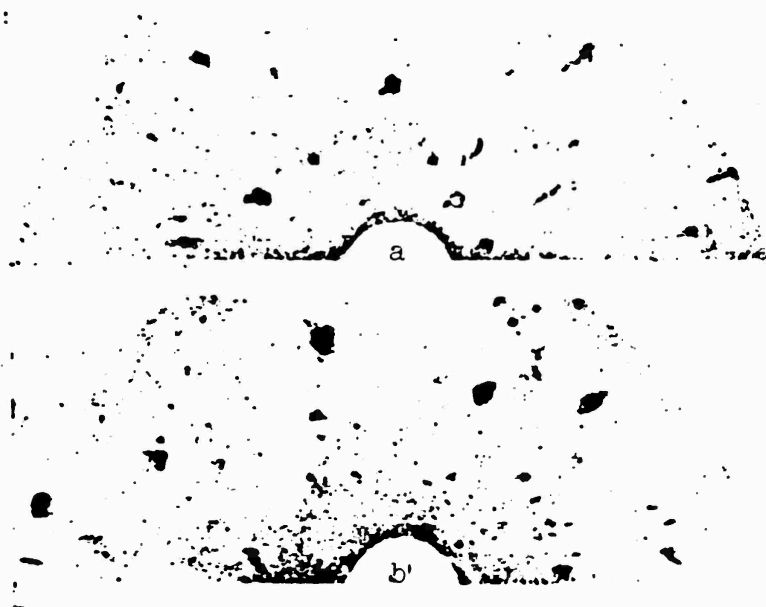


Fig. 3. X-ray photographs of aluminum.  
a) before treatment by ultrasonics, b)  
after treatment by ultrasonics.

**GRAPHIC NOT  
REPRODUCIBLE**

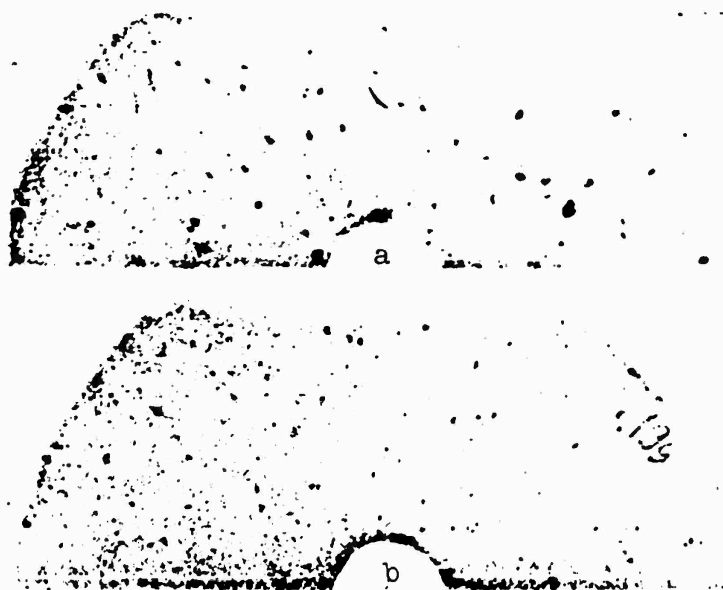


Fig. 4. X-ray photographs of alloy 0.  
a) before treatment by ultrasonics, b)  
after treatment by ultrasonics.

of ultrasonic treatment of alloy AL20. During exact casting of parts from this alloy in smelting patterns the crystallization rate is considerably delayed, in connection with delayed heat removal, and mechanical properties usually drop 10-15%. Ultrasonic treatment of melt AL20 before pouring permits increasing mechanical properties: tensile strength  $30.0 \text{ kg/mm}^2$ , yield point  $29 \text{ kg/mm}^2$  and lengthening to 1.0%. This hardening, obviously, is connected with a more effective influence of titanium, forming in the melt additional centers of crystallization under conditions of delayed cooling.

Results of research in ultrasonic oscillation treatment of aluminum melts with a capacity of up to 8 kg show that optimum conditions of treatment to a small degree differ from earlier utilized conditions of treatment of a 2 kg melt. With the same intensity of ultrasonic flow and the same dimensions of working surface of the waveguide, time of treatment of a melt strongly contaminated by gas was increased in all from 5 to 8 min, and with less contamination, even less than 5-6 min.

Table 2. Change of Properties of Aluminum Depending on Time of Ultrasonic Degassing and Material of Waveguide

Cap material	Time of treatment, minutes	Gas saturation, points	Specific gravity, $\text{g/cm}^3$	Content in aluminum of cap material 1: 6	
				Mo	Nb
Molybdenum	—	5	2,507	Saturated by wet asbestos	
	3	2	2,707	—	—
	9	2	2,707	0.06	—
	20	1	2,710	0.25	—
Niobium	—	5	2,507	Saturated by wet asbestos	
	3	1	—	—	not revealed
	9	1	2,711	—	
	20	1	2,711	—	

Testing of compound waveguides with caps made from refractory metals permitted selecting sufficiently stable materials, and thus made it possible to avoid saturation of the melt by inclusions which in certain cases can be undesirable.

The change of chemical composition, density, gas saturation of vacuum tests depending on time of ultrasonic degassing and material of the waveguide are given in Table 2.

It was determined that aluminum is not saturated by niobium even during treatment for 30 min; degassing of the melt occurs actively. During treatment of aluminum by waveguides with a cap made from molybdenum the melt is saturated by molybdenum.

High stability of niobium is possibly explained by its greater viscosity as compared to other investigated metals.

### Conclusions

1. Treatment of a melt of aluminum and its alloys by ultrasonic oscillations is an effective method of degassing.

2. Treatment of melt, before pouring in forms, by ultrasonic oscillations increases density and mechanical properties of castings.

3. During treatment of melt by ultrasonics there occurs saturation of the melt by the material of certain vibrators as a result of their dispersion under the influence of elastic oscillations and temperatures. This phenomenon can be used for direct modification and alloying of alloys.

4. It was determined that of tested materials for waveguides the most stable is niobium, which it is possible to recommend for manufacture of waveguides.

## REFINING OF CAST ALUMINUM ALLOYS BY BORON CHLORIDE

M. B. Al'tman, N. P. Stromskaya, L. T. Baykova  
and L. M. Korol'kova

One of basic forms of rejects of aluminum casting is rejects with gaseous and solid nonmetallic inclusions. Gaseous inclusions mainly consist of hydrogen. Solid inclusions constitute, mainly, oxides of aluminum and other metals in aluminum alloys.

For struggle with these defects different methods of refining are used: treatment of melt by gaseous chlorine and nitrogen, treatment by chlorous salts  $ZnCl_2$ ,  $MnCl_2$ ,  $AlCl_3$ . Recently they have started to use refining fluxes. All these materials have one inherent common deficiency: in a greater or smaller quantity they contain water which during refining gets into the melt. As it is known, water is a basic source of gas porosity of aluminum alloys. Consequently, effectiveness of refining drops. Best results can be obtained by treatment of a melt with substances which do not contain moisture. As such a refining substance we tested boron chloride with a low temperature of vaporization ( $18^\circ$ ).

Boron chloride at room temperature is kept in a bottle in the form of two phases, liquid and gaseous. When opening a valve from the bottle under excess pressure gaseous boron chloride is given off. Thus, boron chloride has two advantages: it does not contain moisture and it can be introduced into a melt in a gaseous, i.e., most reactive state. Blowing is carried out by means of submersion of an iron tube in the melt, connected with the bottle with the aid of a rubber tube. Refining by boron chloride ( $BCl_3$ ) should be conducted under a hood, as also refining by chlorine.

### Method of Investigation

The influence of treatment of a melt by boron chloride was checked on alloys of systems Al-Si (alloy [AL4] (АЛ4)), Al-Cu (alloys [AL10-V] (АЛ10-В) and AL1) and Al-Mg (alloy AL8).



Alloys AL4, AL10-V and AL1 were prepared in gas furnaces with a capacity 1-2 tons, then they were poured into distributing crucibles with a capacity of 100 kg, from melts technological samples were poured (hemisphere), after which they were treated with boron chloride at  $710^{\circ}$  for 7-8 min. Alloy AL8 was prepared in a steel crucible by gas heating with a capacity of 250-300 kg and at  $700-710^{\circ}$  ventilated by boron chloride.

After termination of refining slag was taken from the surface of the melt and the metal was heated to casting temperature, but alloy AL4 to temperature of modification. Standing of alloys after refining lasted 7-10 min and not more than 30 min taking into account time of preheating and modification.

After standing, technological samples and experimental parts were cast. For comparison the same parts were poured from alloys AL4, AL10-V, AL1 and AL8, prepared without refining. The quality of parts was checked by external inspection, X-ray radioscopy, investigation of macro- and microstructure, and test of mechanical properties on samples cut from parts.

#### Refining of Alloy AL4

The effect of refining of alloy AL4 by boron chloride was checked on sand poured parts No. 1 with a rough weight of 25 kg and No. 2 with a rough weight of 35 kg. For every designation two parts each were cast from the alloys refined by boron and chloride and modified by ternary flux, and from the alloy prepared without refining but also modified by a ternary flux. During external inspection of parts defects of a metallurgical character are not revealed; after X-ray radioscopy they are suitably recognizable.

After heat treatment conditions T6 from parts we cut macrographs and turned samples for determination of mechanical properties. Mechanical properties of samples cut from parts cast from the alloys refined by boron chloride are as follows: part No. 1 -  $\sigma_b = 22.1 \text{ kg/mm}^2$ ;  $\delta = 2.0\%$ ; part No. 2 -  $\sigma_b = 23.2 \text{ kg/mm}^2$ ;  $\delta = 1.8\%$ . By density parts correspond to 1 and 2 points.

Parts poured from the alloys prepared without refining, have the following mechanical properties: part No. 1 -  $\sigma_b = 18.8 \text{ kg/mm}^2$ ;  $\delta = 1.3\%$ ; part No. 2 -  $\sigma_b = 22.8 \text{ kg/mm}^2$ ;  $\delta = 1.5\%$ . By density parts correspond to the third point.

Alloys in all cases have the usual structure of modified Silumin.

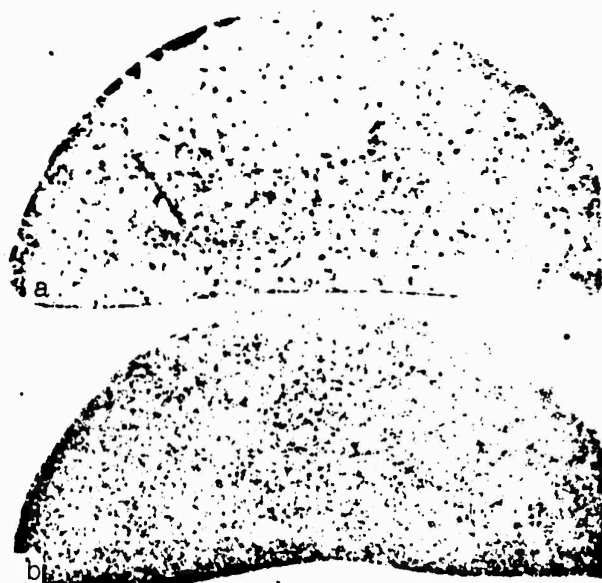
#### Refining of Alloy AL10-V

Refining of alloy AL10-V by boron chloride was checked for part No. 3, poured in a chill mold. The rough weight of the casting was

25 kg. For the given part high airtightness is required. The casting passes the hydrostatic test at 4 atm water pressure.

From the alloy refined by boron chloride three experimental parts were cast. Technological samples were poured before and after treatment of the melt by boron chloride.

Of three experimental parts, on one there is revealed a noncast lateral wall the two others externally and by hydrostatic tests were suitable. For checking of density macrographs were made from technological samples on three directions from the part. On macrographs from experimental parts there is revealed porosity on the order of 1-2 points. On macrographs of parts poured from the alloy not refined by boron chloride there is revealed porosity on the order of 3 points.



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Fig. 1. Macrographs from technological samples of alloy AL10-V. a) before treatment by boron, chloride; b) after treatment by boron chloride.

Technological samples showed considerable packing of the metal after blowing by boron chloride. While samples poured from nonrefined alloy had great porosity all over the section corresponding to 4-5 points, in those cast by refined alloy the metal was dense (porosity corresponding to 2 points); shrinkage porosity was revealed (Fig. 1a, b).

Mechanical properties of samples cut from experimental parts satisfy requirements of technical conditions.

### Refining of Alloy AL1

Refining of alloy AL1 by boron chloride was conducted for the purpose of checking the possibility of eliminating the autoclave for parts of average complexity.

From the alloys treated by boron chloride cast part No. 4 was poured with a rough weight 80 kg without application of the autoclave; separately poured samples and technological samples were poured both before treatment and after treatment of the melt by boron chloride. During external inspection of experimental parts defects were not revealed.

On macrographs of an experimental part poured at atmospheric pressure, porosity was 1-2 points and locally 3 points (in bottom part of casting). On macrographs of a part poured with application of the autoclave, porosity is 2 points. Macrographs of technological tests testified to considerable packing of the metal after blowing by boron chloride: samples poured from the nonrefined alloy had great porosity all over the section, corresponding to 5 points; in tests, poured with refined alloy, the metal was dense with porosity not more than 1-2 points.

Results of the investigation (see Table) showed that in terms of density and mechanical properties the experimental part completely satisfies requirements of technical conditions and does not yield to a part poured with application of crystallization in the autoclave.

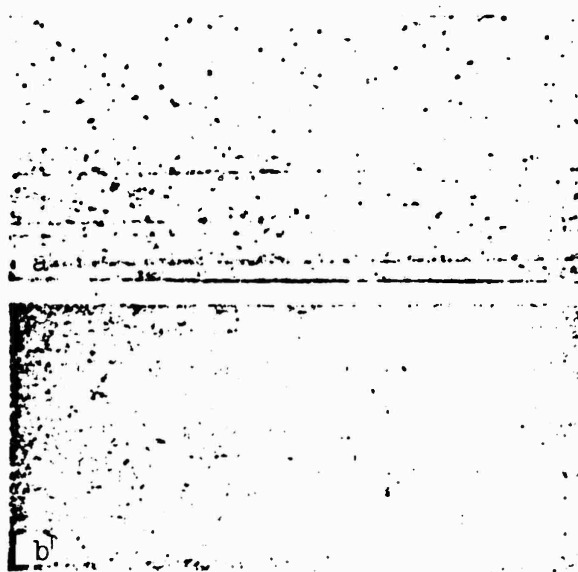
**Mechanical Properties of Parts and Samples Made from Alloy AL1 Depending on Technology of Treatment of Melt and Pouring of Parts**

Technology		Place of cutting samples	Mechanical properties		
treatment of melt	pouring of parts		$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>
Series	In autoclave	I zone	15.6	0.5	80.4
		II zone	18.5	0.7	80.4
Experimental	Without autoclave	I zone	15.3	0.7	80.4
		II zone	22.0	1.2	89.7
Series	The same	Separately poured samples	19.25	0.6	84.9
Experimental	The same		20.8	0.6	89.7
According to specs. [TY = TU]		for parts	14	—	70
		for samples	16	—	70

### Refining of Alloy AL8

The effect of refining alloy AL8 by boron chloride was checked on part No. 5 with a rough weight of 120 kg.

On macrographs made from technological samples and parts poured from the alloy without treatment by boron chloride porosity 3-4 points. On macrographs made from samples and parts poured from the alloy treated by boron chloride porosity is not higher than 1-2 points. Thus, density of alloy AL8 after treatment of the melt by boron chloride is increased by 2-3 points (Fig. 2).



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Fig. 2. Macrographs cut from casting of alloy AL8. a) without treatment by boron chloride; b) after treatment by boron chloride.

Mechanical properties of samples and parts poured from the alloy treated by boron chloride ( $\sigma_b = 21.2 \text{ kg/mm}^2$ ,  $\delta = 7.6\%$ ) are higher than mechanical properties of samples and parts poured from the alloy not treated by boron chloride ( $\sigma_b = 17 \text{ kg/mm}^2$ ,  $\delta = 3.2\%$ ).

### Conclusions

1. Refining by boron chloride of alloys AL4, AL10-V, AL1 and AL8 rendered a positive influence on density and mechanical properties of castings.
2. Parts cast from alloys AL4, AL10-V, AL8, refined by boron chloride by density exceed series parts by 1-2 points. Parts with a rough weight near 80 kg poured from alloy AL1 refined by

boron chloride, by density and mechanical properties do not yield to similar castings poured with application of the autoclave.

3. The method of refining by boron chloride can be recommended for increasing density of castings made from alloys AL4, AL10-V, AL1 and AL8, and in separate cases in exchange for autoclave when casting parts requiring a density of 2-3 points.

## REFINING OF ALUMINUM ALLOYS IN A VACUUM<sup>1</sup>

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Alloys on the basis of aluminum possess raised chemical activity.

In process of storage, casting and especially during melt aluminum alloys interact with gases of the surrounding atmosphere. If products of reaction get into the melt, but from the melt into a casting, then their strength and density decrease.

For removal from aluminum alloys of gaseous and solid nonmetallic inclusions chlorination, treatment by chlorous salts, fluxes, blowing by inert gases and so forth are used. This is connected with defined difficulties: chlorine and to a smaller degree chlorous and fluoride salts are toxic; the used materials require preliminary treatment (drying, grinding and so forth). Moreover, all these means in the world of growing requirements for shaped castings made from aluminum alloys are not very effective.

As a rule, for production of dense large thick-walled parts it is necessary as a supplement to refining to get crystallization under pressure in an autoclave.

Refining promotes removal of solid and gaseous inclusions, and an autoclave ensures raised density of articles. The combination of refining with crystallization in an autoclave considerably complicates the technological process and raises the price of production.

We have investigated a new method of refining aluminum melts in a vacuum.

The basis of this method is the following considerations.

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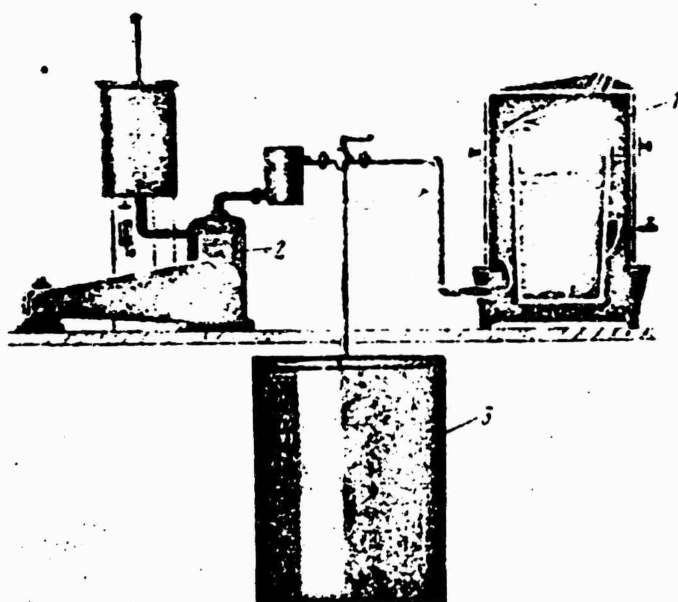
<sup>1</sup>In the work participated A. P. Shulenin, I. S. Kuznetsov, D. S. Chervyakov, A. I. Komendat.

Nonmetallic inclusions in aluminum melts consist of hydrogen and oxides, mainly aluminum oxide. Hydrogen carries a positive charge ( $H^{1+}$ ), oxide of aluminum is charged negatively ( $O^{2-}$ ). In view of this hydrogen chiefly is adsorbed on particles of aluminum oxide. During imposition of a vacuum, bubbles of hydrogen being separated from melt attract hard nonmetallic inclusions.

If on the surface of the melt one puts a little flux which adsorbs oxide of aluminum, then the process of degassing flows more actively.

An advantage of the given method is also the possibility of control of the degree of degassing by means of a change of the power of the vacuum pump.

Investigations were conducted on alloys [AL4] (AJ4) and AL9 in a specially designed installation (see Fig. 1).



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Fig. 1. Diagram of vacuum installation.

The volume of the vacuum chamber 1 is  $1.5 \text{ m}^3$ , which permits placing in it a crucible with a capacity of up to 300 kg. For creation of a lowered pressure on the order of 0.1 mm Hg pump 2 of make [VN-6G] (BH-6P) was used. Acceleration of creation of the vacuum was attained with the aid of receiver 3 whose volume was twice larger than the volume of the vacuum chamber. Necessary rarefaction in the vacuum chamber is created in 45 s.

### Selection of Conditions of Vacuum Evaporation

Selection of the time of evacuation depending on the weight of the melt was conducted on alloy AL9. The alloy was prepared in a gas furnace with a capacity of 1.5 tons, then portions of 80, 160 and 250 kg each were poured in steel crucibles with a capacity of 250 kg and were vacuum evaporated for 2, 4 and 6 minutes. For every holding of alloy under vacuum a new portion of alloy was selected.

Before vacuum evaporation the alloy in the crucible was overheated to  $780^{\circ}$ . On the surface the melt was covered with a double modifier (0.2% of weight of alloy). The modifier remained on the surface of the melt up to the end of vacuum evaporation. From the treated alloy at a temperature of  $700^{\circ}$  there were poured in dry sand molds technological samples of variable section (Fig. 2).

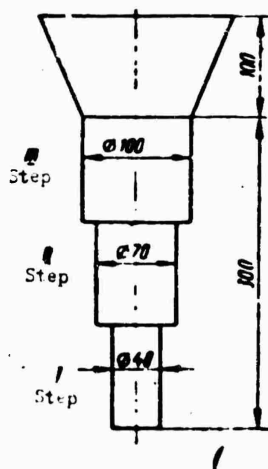


Fig. 2. Technological test of variable section.

It is necessary to note that temperature of the alloy in the crucible during the time of installation of the crucible and vacuum treatment descended from  $780$  to  $720^{\circ}$ . Samples were investigated for content of magnesium and for density in terms of porosity and specific gravity.

Chemical analysis of the alloy before and after vacuum treatment for 2, 4 and 6 minutes showed that the content of magnesium remains constant when the weight of metal in the crucible is 80 kg as well as when the weight is 160 kg.

In Table 1 an appraisal is given of porosity of these samples on a 5 point scale of porosity.

From these data, and also from the graph in Fig. 3, it follows that as a result of vacuum treatment there is an increase in density of alloy AL9. An increase of time of vacuum treatment from 2 to 6 minutes lowers porosity approximately one point. The influence of flux on results of vacuum treatment was checked on a melt with a



Table 1. Porosity of Alloy AL9 Before and After Vacuum Treatment

Weight of treated alloy, kg	Points, porosity <sup>1</sup>			
	initial alloy	after treatment in minutes		
		2	4	6
80	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{4}$	$\frac{2}{3}$
160	$\frac{4}{5}$	$\frac{3}{4}$	--	$\frac{2}{4}$

<sup>1</sup>The upper figure refers to a step II sample, the lower - to a step III sample.

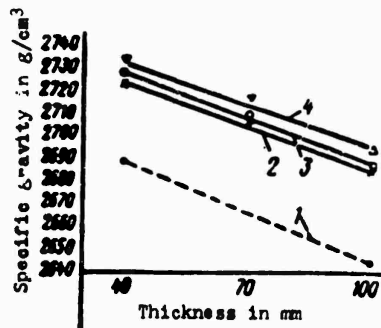


Fig. 3. Change of specific gravity of samples depending on thickness of section of casting and time of holding under vacuum. 1 - initial alloy, 2 - vacuum 2 minutes, 3 - the same, 4 minutes, 4 - the same, 6 minutes.

weight of 100 kg. The alloy was vacuum treated for 10 minutes without flux and with 0.20% flux (ternary modifier).

Porosity of technological samples (in II and III steps) in points was as follows:

	Points of porosity
Initial alloy. . . . .	4/5
After vacuum treatment for 10 min. . . . .	2/3
After vacuum treatment for 10 min with 0.2% flux . . . . .	1/2

From these data and photographs of macrostructures (Fig. 4) it is clear that small additions of flux covering the surface of the melt promote best degassing during vacuum treatment; porosity drops from 4-5 points to 1-2 points.

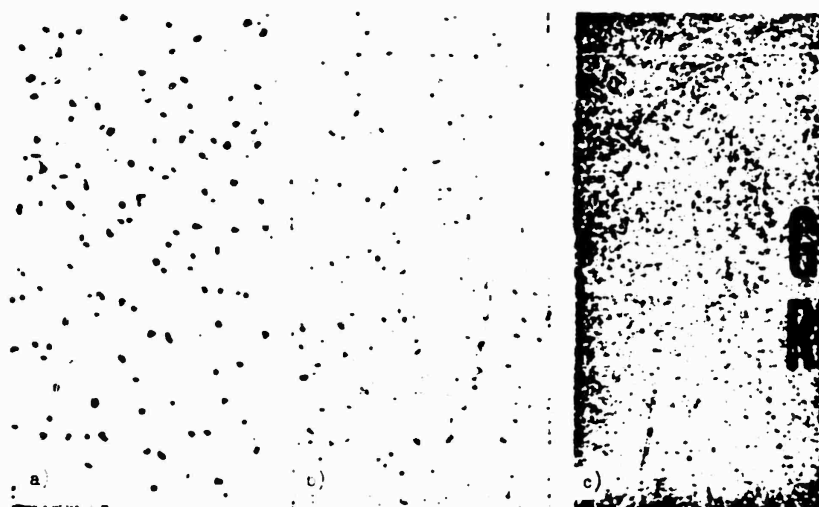


Fig. 4. Macrostructures of Alloy AL9. a) in initial state, b) vacuum 10 minutes, c) vacuum 10 minutes with addition of 0.2% double modifier.

The same is confirmed by results of determination of specific gravity of samples (Fig. 5).

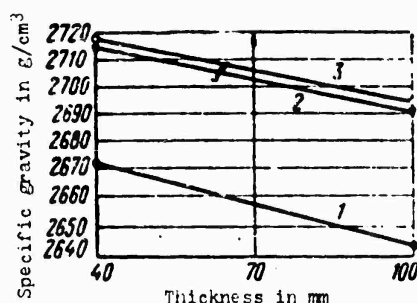


Fig. 5. Specific gravity of samples depending on conditions of vacuum treatment. 1 - initial alloy, 2 - after treatment without flux, 3 - the same with 0.2% flux.

In order to set the optimum (minimum) time of treatment depending on weight of the melt in the crucible there were conducted special experiments on parts with weight 30-110 kg. Moreover we considered that the time of vacuum treatment in industrial conditions is limited by a lowering of temperature towards the end of treatment by 30-50°.

Alloys were prepared in a gas furnace with a capacity of 2 tons, after which they were poured in distributing crucibles in portions of 50-150 kg each. Then the melt was modified by a binary flux at a temperature of 780-790° and immediately vacuumed after the surface of the melt was covered by the binary modifier in an amount of 0.2%. Results of these experiments are represented in Table 2.

Table 2. Optimum Time of Vacuum Treatment of Alloy AL9 Depending on Its Weight in Crucible

Weight of metal in kg	Time of vacuum treatment in min.
50--100	3
100--150	5
150--250	7-9

Investigation of Parts Poured From Alloys AL4 and AL9 with Application of Vacuum Treatment

The quality of the alloy was checked on parts for density, mechanical properties and fracture in accordance with operational technical conditions.

Table 3. Influence of Vacuum Treatment on Properties of Parts Made From Alloy AL9

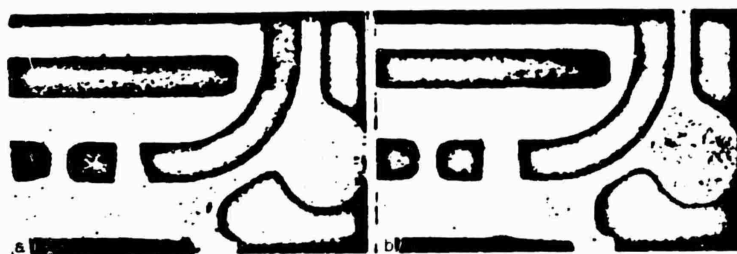
No. of part	Treatment by vacuum	Mechanical properties after heat treatment by conditions T5			Point, porosity	Specific gravity g/cm <sup>3</sup>
		$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>		
1	Without treatment	16,0	1,0	84,9	3-4	2,687
2	Vacuum treatment for 4 min	17,8	1,5	76,3	1-2	2,71
3	The same	20,8	1,8	80,4	2-3	—
4	Without treatment	19,8	1,0	80,4	4-5	—
	According to technical specs.	15,0	1,0	60		—

As can be seen on macrographs (see Fig. 6 and Table 3) the part poured without treatment has a porosity of 3-4 points, but the one poured from a treated alloy, 1-2 points. Both parts are poured from one melt without subsequent crystallization under pressure.

Mechanical properties of samples cut from parts poured with application of a vacuum before pouring exceed properties of parts obtained without treatment in a vacuum.

Microstructures and fractures of alloys refined with application of a vacuum and nonrefined alloys have no essential distinctions.

We also investigated parts of other configurations with a weight of 60 and 100 kg with wall section 10-15 mm (the alloy was



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Fig. 6. Macrostructure of parts made from alloy AL9. a – without vacuum treatment, b – after vacuum treatment.

modified by a binary flux). On macrographs of parts there is revealed a porosity of 2-3 points (see Table 4). In fractures of

Table 4. Properties of Parts Made From Alloy AL9, Subjected to Vacuum Treatment

Weight of part kg	Mechanical properties			Point, porosity
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>	
60	20,2	1,9	84	2-3
100	22	2,8	76,3	2-3
According to technical specs..	15,0	1,0	60	3-4

parts defects are not revealed. Mechanical properties found on samples cut from these parts are considerably higher than technical requirements.

#### Alloy AL4

We poured parts with a weight of 110 kg, section 10-25 mm, and with a weight of 110 kg, section up to 100 mm from vacuum treated and untreated alloy (in all cases modification by a binary modifier).

Table 5. Properties of Parts Made From Alloy AL4, Subjected to Vacuum Treatment

Treatment by vacuum	Mechanical properties after heat treatment by conditions T6			Point, porosity	Characteristic of fracture
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>		
Without treatment	16,8	2,0	62,3	4-5	Pure
Treatment by vacuum	19,6	2,6	75,4	2-3	Pure
According to technical specs.	17,0	1,0	60	3-4	

A comparison of the quality of parts made from untreated and treated alloy (see Table 5) shows that treatment in a vacuum essentially increases the density and mechanical properties of parts.

### Conclusions

1. We developed a method for refining aluminum alloys with application of a vacuum and flux, and we designed and mastered in production a vacuum installation for aluminum alloys, allowing one to refine a melt with a weight of up to 300 kilograms.

2. Refining with the aid of a vacuum lowers porosity of aluminum alloys by 2 points on a 5-point scale of porosity and increases mechanical properties by 10-15%, which permits in a number of cases elimination of crystallization of poured parts in an autoclave.

3. Application of double refining: vacuum with addition of a small quantity of flux (0.20% of the weight of the alloy) increases effectiveness of degassing of aluminum alloys as compared to vacuum treatment without flux.

## PROPERTIES OF ALUMINUM ALLOYS DURING DIFFERENT METHODS OF CASTING

O. B. Lotareva, N. S. Postnikov, and  
L. I. Loktionova

New methods of casting of aluminum alloys in investment patterns, in shell and plaster forms have as yet been studied little.

The speed of cooling of a metal in various forms is different, which is reflected in properties of castings. Therefore we determined the properties of the most widely used standard aluminum alloys [AL2] (AL2), AL3, AL4, AL5, AL7, AL8, AL9, and also new alloys AL19 and AL21 during casting by the new methods.

### Casting With Application of Investment Patterns (Lost Wax Process)<sup>1</sup>

During casting in investment patterns mechanical properties are determined on Gagarin samples 6 mm in diameter, since by this method there are poured mainly small and thin-walled parts. Furthermore, we poured so-called "wobblers" (Fig. 1), from which breaking samples 8 mm in diameter were turned.

Investment patterns were prepared from a mixture of 50% paraffin and 50% stearin. We connected patterns of 16 samples each to one riser. The ceramic coating consisted of 30% hydrolysed ethylsilicate and 70% marshalite. Ethylsilicate was prepared from an esteraldehyde fraction.

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<sup>1</sup>I. Ye. Shub, "Founding," 1953, No. 1.

N. S. Kreshchanovskiy, M. L. Khenkin, N. K. Levin,  
M. N. Zimmering, "Founding," 1954, No. 2.

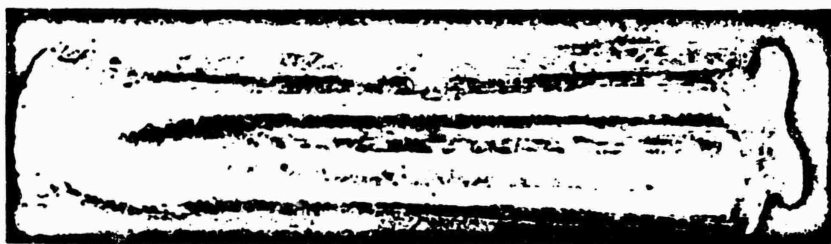


Fig. 1. "Wobbler" casting for manufacture of samples.

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On investment patterns there were deposited three layers of ceramic plastering, after which the obtained forms were placed in mold-boxes made from stainless steel covered with dry heated sand and placed in a drying cabinet for melting the pattern material. Then we heated forms at  $900^{\circ}$  for 2 hours, cooled them to 20, 100, 200, 300 and  $350^{\circ}$  and poured samples. Forms were not cooled to higher temperatures since for aluminum alloys delayed crystallization is undesirable due to formation of a macrocrystalline structure. Temperature of the melt was equal to  $700^{\circ}$ . "Wobblers" were poured in cold forms at melt temperature  $680^{\circ}$ .

Table 1. Influence of Temperature of Form on Mechanical Properties of Aluminum Alloys During Casting by Investment Patterns

Alloy	Temperature of form $^{\circ}\text{C}$	$\sigma_b$ $\text{kg/mm}^2$	$\delta$ %	State of alloy
AJ2	20	19,2	9,1	Modified, without heat treatment
	100	18,5	10,6	
	200	17,5	10,8	
	20	12,4	2,3	The same (samples are cut from Wobblers)
AJ3	20	35,4	0,8	Hardened by conditions T5
	100	33,4	0,6	
	180	33,4	0,4	
	200	31,9	0,4	
	300	31,5	0,6	
	350	30,4	0,5	
AJ3	20	27,5	0,4	Hardened by conditions T5 (samples are cut from wobblers)

Table 1 (cont). Influence of Temperature of Form on Mechanical Properties of Aluminum Alloys During Casting by Investment Patterns.

Alloy	Temperature of form °C	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	State of alloy
A.14	20	25,8	5,2	Modified, hardened by conditions T6
	100	26,3	4,8	
	200	26,8	4,6	
	300	25,4	3,3	
	320	24,2	2,2	
A.15	20	31,5	1,9	Hardened by conditions T5
	100	31,2	2,0	
	200	31,2	1,5	
	300	30,3	1,5	
	320	30,6	1,0	
	20	26,0	0,5	The same (samples are cut from wobblers)
A.17 (without addition of silicon)	20	30,1	—	Hardened by conditions T4
	200	31,5	6,5	
	300	29,0	4,0	
	360	25,5	4,0	
A.17 (with addition of 2% silicon)	20	27,7	4,3	The same
	100	27,3	3,4	
	200	28,4	4,5	
	300	22,5	1,5	
	20	19,2	1,6	The same (samples are cut from wobblers)
A.18	20	30,7	9,8	Hardened by conditions T4
	100	28,2	7,3	
	200	26,7	6,1	
A.19	20	20,2	8,1	Hardened by conditions T4
	100	21,4	10,1	
	200	21,2	9,7	
	300	19,1	6,2	
	20	14,8	2,2	The same (samples are cut from wobblers)



From the data of Table 1 it is clear that for all investigated alloys the highest properties are obtained during filling in cold forms. According to an increase of temperature of forms, properties of alloys in greater or lesser degree descend. The most noticeable lowering of properties is at a temperature of forms higher than 200°, when the structure of alloys is considerably enlarged. Mechanical properties of samples cut from "wobblers," are lower than properties of separately poured Gagarin samples, explained by the large section of this casting. In general, properties of alloys during casting by investment patterns satisfy requirements of All-Union Government Standard 2685-53 and in a number of cases even exceed them.

For determination of the ability of alloys to fill a form during casting by investment patterns, we determined fluidity of alloy AL7 in comparison with casting in sand. We determined fluidity over the length of a spiral. A spiral model was turned from aluminum alloy and mounted on a metallic plate with pushers so that it was possible to use it for shell forms. For the obtained investment pattern we prepared a split press-form from highly durable gypsum in which the pattern material was pressed.

It was determined that during casting by investment patterns fluidity of alloy AL7 is somewhat higher than during casting in sand: during casting by investment patterns the length of the spiral was 666 mm, and during casting in sand, 500 mm.

#### Casting in Shell Molds<sup>1</sup>

Mechanical properties during casting in shell forms was determined on samples 12 mm in diameter, since by this method are usually poured parts of larger dimensions than by investment patterns. The method of pouring samples was the same, as during casting in sand. By this method on pattern plates with pushers there were mounted metallic models of samples with the flow gate system (Fig. 2), by which we prepared shell half-molds. The molding sand consisted of quartz sand and 5% pulverized bakelite. As lubrication we used a 5% water emulsion of liquid No. 5. Shell half-molds before filling were fastened by clamps, placed on a sand pad and covered by sand.

We determined mechanical properties of alloys AL2, AL3, AL4, AL7, AL8 and AL9, poured simultaneously in shell and earthen forms. Results of tests showed that mechanical properties of alloys AL2, AL3, AL4, AL9, obtained on samples, poured in shell and earthen forms, are practically identical. Properties of alloys AL7 and AL8 during casting in shell forms were somewhat higher (Table 2).

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<sup>1</sup>B. A. Alekseyev, P. S. Pershin, "Founding," 1953, No. 2.

Table 2. Mechanical Properties of Aluminum Alloys During Casting in Shell and Earthen Forms

Alloy	Method of casting	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	State of alloy	Remarks
A.12 modified	Earthen form	15.9	5.0	Without heat treatment	Separately poured samples
	Shell form	15.5	4.7	The same	The same
A.13	Earthen form	23.6	0.4	Heat treated by conditions T5	The same
	Shell form	23.7	0.2		
A.14 modified	Earthen form	26.0	2.2	Heat treated by conditions T6	The same
	Shell form	25.3	1.5		
A.17	Earthen form	27.4	5.2	Heat treated by conditions T4	The same
	Shell form	28.5	7.4		
		21.5	4.1	The same	Samples cut from part
A.18	Earthen form	32.2	13.0	Heat treated by conditions T4	Separately poured samples
	Shell form	34.0	12.5		
		22.2	4.0	The same	Samples cut from part
A.19 modified	Earthen form	21.5	9.8	Heat treated by conditions T4	Separately poured samples
	Shell form	21.8	10.2		
		15.3	2.8	The same	Samples cut from part

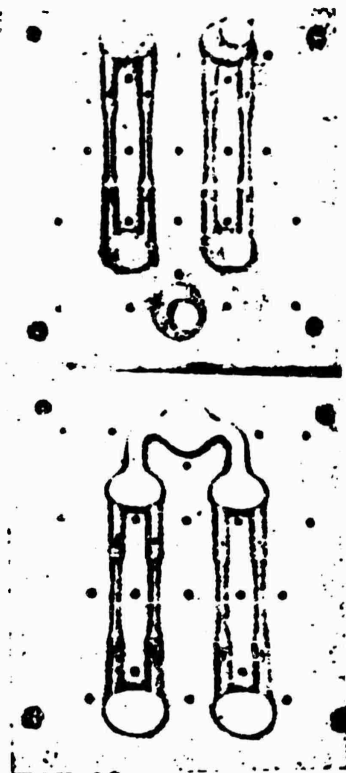


Fig. 2. Pattern plate with samples for determination of mechanical properties during casting in shell forms.

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Mechanical properties of samples cut from parts were lower than properties of separately poured samples, but correspond to set requirements (75%  $\sigma_b$  and 50%  $\delta$  of separately poured samples). A change of structure of alloys during casting in shell forms as compared to casting in sand is not observed. Density of the casting is sufficiently good.

Table 3. Fluidity of Alloys AL7, AL8 and AL9 During Casting in Shell and Earthen Forms

Alloy	Method of casting	Length of spiral in mm
AL7	Shell mold	575
	Earthen mold	508
AL8	Shell mold	633
	Earthen mold	650
AL9	Shell mold	727
	Earthen mold	683

We determined fluidity of alloys AL7, AL8 and AL9. Alloys AL7 and AL9 were poured at 750°, alloy AL8 at 700°. During casting in shell forms, just as three castings by investment patterns, fluidity was obtained somewhat higher than during casting in sand (see Table 3). An exception is alloy AL8.

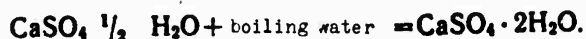
### Casting in Gypsum Molds<sup>1</sup>

Gypsum molds<sup>2</sup> are expediently used when castings have high requirements for cleanness of surface and other methods of pouring such castings can not be used. When casting in gypsum forms we used liquid forming material which exactly reproduced the configuration of the pattern.

A hardened and heated gypsum mass has the lowest thermal conductivity of all mold materials used at present. This property of a gypsum mass permits filling a mold with less speed, which decreases capture of air and consumption of metal on the flow gate system.

However, small thermal conduction of gypsum and, consequently, raised (as compared to earthen forms) time of crystallization is reflected in mechanical properties.

During development of the technological process of casting in gypsum forms, the basic difficulty was that the gypsum mass cracked at 700-800°. Furthermore, pure gypsum is almost completely gastight. It was established that by steaming gypsum forms in autoclave under a vapor pressure 1.3-1.4 atm leads to recrystallization of the gypsum mass and a change of the form of crystals of gypsum, which in dimensions become the same as a grain of sand. Besides, gas permeability is sharply increased. The chemical process consists in transformation of a semihydrate of gypsum into a dihydrate by the reaction:



This transformation occurs not only in pure gypsum, but also in mixture with other components of the forming mass. The process of recrystallization of gypsum lasts nearly 6-12 hours depending on dimensions of the mold. For decrease of shrinkage and an increase of gas permeability sand is added to the mass.

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<sup>1</sup>Technology of manufacture of forms was developed by engineer V. G. Baradan'yants who participated in the present work.

<sup>2</sup>H. Brown, Foundry, 1950, January, p. 74. Light Metals, 1952, November, p. 365; Foundry, 1956, September, p. 104.

On the composition of the gypsum mass and the make of gypsum depends the quality of the mold, and consequently also the casting; therefore, in the process of mastery of casting in gypsum molds and selection of the composition of the mold mass we tested mixtures whose compositions and properties are given in Table 4.

Table 4. Composition and Property of Gypsum Mixtures

Mixture ratio	Quantity of water %	Tensile strength during compression in kg/mm <sup>2</sup>		Coefficient of gas permeability cm <sup>3</sup> /m h, mm water col		Coefficient of thermal conduction in kcal/m deg h
		heat treatment at 600°, 3 h	steaming and drying at 350° 24 h	heat treatment at 600°, 3 h	steaming and drying at 350°, 3 h	
80% kuybyshev gypsum, 20% asbestos	60	25,2	16,0	0,169	8,0	0,289
40% gypsum, 50% sand, 10% asbestos	33	17,0	8,8	0,0818	1,835	0,201
30% gypsum, 67% sand, 3% asbestos	25	18,0	11,25	0,069	1,669	—

An 80/20 mixture of gypsum and asbestos possesses the greatest gas permeability and strength. Furthermore, the mixture hardens slowly (5-7 minutes) which permits using it without retarders. A mixture of gypsum, sand and asbestos 40/50/10 somewhat yields in strength and gas-permeability to the preceding mixture, but is still fully satisfactory. Thermal conduction of this mixture is 1.5 times greater, which is important for crystallization of castings.

The dry gypsum mass was prepared from sifted gypsum and asbestos by mixing in a drum for 8-12 minutes. To the mixture was added a corresponding quantity of water, then it was mixed and poured in the mold-box. In 15-20 minutes, when the gypsum mass was hardened, the pattern was removed from the form and the gypsum form was subjected to heat treatment. Heat treatment of forms can be produced in furnaces of type [PN-30] (ИП-30) or PN-75 at 600° for 8-10 hours. Such conditions of heat treatment completely exclude boiling of the poured metal, and the small thermal conduction of a gypsum mold permits lowering the temperature of the poured metal.

For determination of mechanical and technological properties we tested alloys with different character of crystallization: AL9, AL19 and AL21, which were cast in forms prepared from a gypsum mass of composition: 40% gypsum, 50% sand and 10% asbestos. Alloy AL9 is a hypoeutectic silumin with a small interval of crystallization. Alloy AL19 is related to system Al-Cu-Mn-Ti, alloy AL21 to system Al-Mg-Zn. Both these alloys have a wide interval of crystallization (Table 5).

To ensure uniform chemical composition, work was conducted on preliminarily prepared alloys. The prepared alloy was loaded in a

Table 5. Interval of Crystallization and Pouring Temperature of Investigated Alloys

Alloy	Temperature of crystallization °C	Pouring temperature °C	Conditions of heat treatment
AL9	610—575	720	T5
AL19	650—548	690	T5
AL21	609—440	680	T4

graphite crucible and melted in an electric resistance furnace. Alloy AL9 before pouring was subjected to modification, and alloys AL19 and AL21 to refining. The ready alloy at a corresponding temperature (see Table 5) was poured into molds which had a temperature from 20 to 250°.

In parallel with gypsum molds earthen molds were filled. Specimens were of different diameters (5 mm, 8 mm, 12 mm) in accordance with the most widely used sections of castings. As the curves in Fig. 3 show, mechanical properties of samples with a diameter of 8 and 12 mm made from alloys AL19 and AL21 descend during casting in gypsum forms even at a mold temperature of 20° and according to an increase of temperature they continue to drop. This

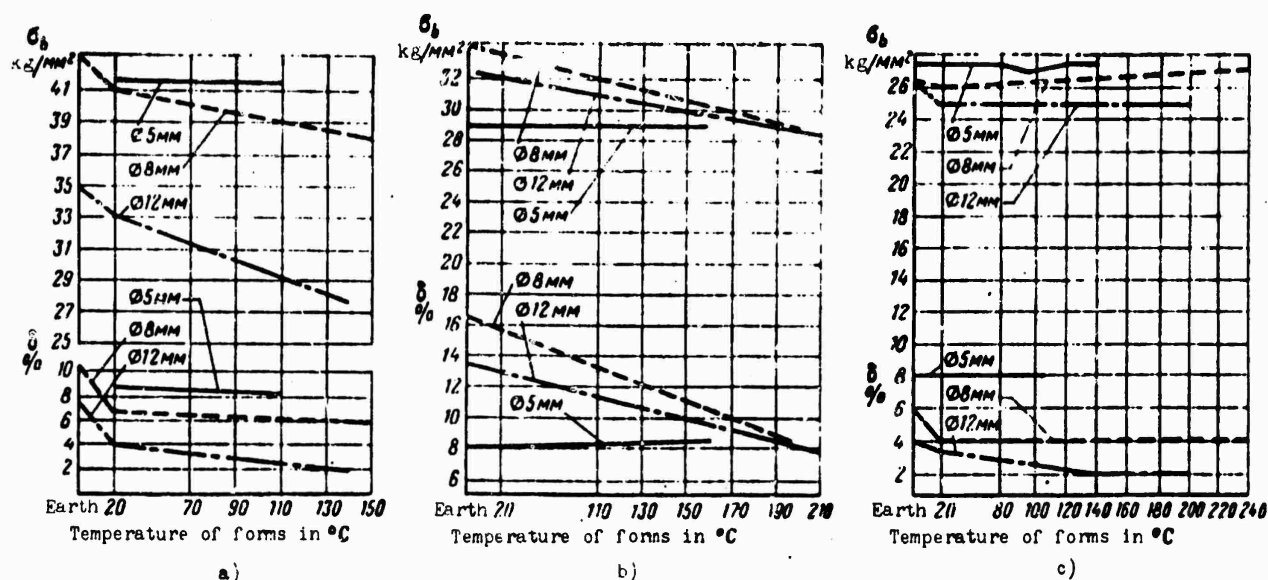


Fig. 3. Influence of temperature of mold on mechanical properties of aluminum alloys. a) alloy AL19, b) alloy AL21, c) alloy AL9.

is explained by the wide interval of crystallization of alloys, which promotes growth of the grain and consequently a lowering of

mechanical properties. Furthermore, thermal conduction of gypsum molds also increases time of crystallization of castings, which additionally worsens their mechanical properties.

In samples 5 mm in diameter a fall of mechanical properties with an increase of temperature of the mold is not observed, since in this case crystallization goes considerably faster due to the small section of the casting.

Pouring alloy AL9 in a gypsum mold at 20° somewhat lowers mechanical properties as compared to casting in sand. But by heating gypsum molds the mechanical properties are practically not changed.

As can be seen from Table 6, fluidity of alloys during casting in cold gypsum forms is 2-3 times greater than during casting in earthen molds. Heated to 200°, gypsum molds were filled completely with melt, i.e., fluidity of alloys turned out to be higher than provided for by maximum length of the spiral (1500 mm).

Table 6. Fluidity of Alloys AL9, AL19 and AL21

Alloy	Mold	Length of spiral in mm at mold temperature		
		20°	100°	200°
AL9	Gypsum	1500	—	1500
	Earthen	550	—	—
AL19	Gypsum	900	1050	1500
	Earthen	300	—	—
AL21	Gypsum	1000	1200	1500
	Earthen	400	—	—

High fluidity during casting in gypsum molds is caused by their considerably lower thermal conduction (which increases as compared to an earthen mold the time before the beginning of crystallization), and also by the smoother surface of the actual mold.

For production of exact data about time of crystallization and heat transfer of molds we recorded curves of cooling of castings and molds. The most convenient for this purpose was a two-hole frame (Fig. 4). Recording was conducted by instrument [EPP-09] (ЭПП-09) which fixes simultaneously 12 points.

Shell molds and molds made by investment patterns were covered by dry sand. Thermocouples were set in the center of the middle rod of the frame. For determination of heat transfer of molds, thermocouples were attached to their external surface. The thickness of the shell mold and the mold obtained by investment pattern was approximately 6 mm, and thickness of the gypsum form was 8 mm. To set a thermocouple in an earthen form of thickness 6-8 mm was not



Fig. 4. Two-hole frame.

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possible, therefore there is no data on heating of an earthen mold. Recording of curves was produced during casting of alloy AL2, which has a site of crystallization of eutectic. Before filling, the alloy was modified with universal flux [VI-45] (BM-45) at  $740^{\circ}$ .

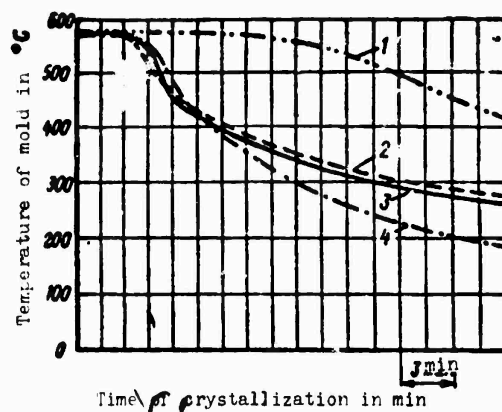


Fig. 5. Curves of cooling of alloy AL2 in molds: 1) gypsum, 2) with investment pattern, 3) earthen, 4) shell.

Cooling curves (Fig. 5) showed that the fastest crystallization occurs in an earthen mold and in a mold obtained by investment patterns; then the shell mold and finally the gypsum mold (Table 7).

Curves of heating of molds, characterizing ability of molds to remove heat from castings, are shown in Fig. 6. The fastest removal of heat is in the ethylsilicate mold, then in the shell mold; the least heat-conducting is the gypsum mold. This explains lower mechanical properties during casting in gypsum forms and practically identical properties obtained during casting in earthen shell and ethylsilicate form.



Table 7. Crystallization Rate of Frames Made From Alloy AL2 During Filling in Earthen, Shell, Gypsum and Ethylsilicate Molds

Form	Time of crystallization
Earthen	3 min 52 s
Shell covered by dry sand	5 min 1 s
Ethylsilicate covered by dry sand	4 min 06 s
Gypsum	13 min 21 s

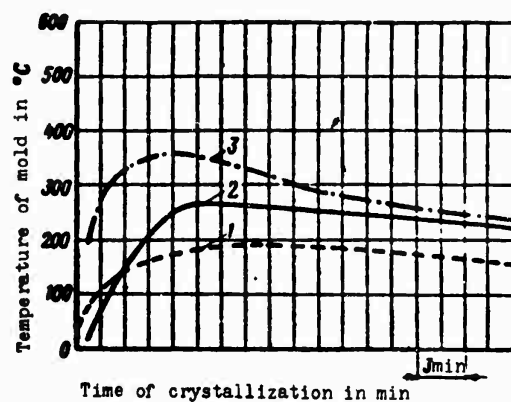


Fig. 6. Temperature of molds (pouring of alloy AL2). 1) gypsum, 2) shell, 3) with investment pattern.

### Conclusions

1. Mechanical properties of alloys AL2, AL3, AL4, AL5, AL7, AL8 and AL9, obtained during casting in ethylsilicate molds, by investment patterns and in shell molds, satisfy requirements of All-Union Government Standard 2685-53.
2. Temperature of molds up to 200° comparatively little affects mechanical properties of investigated alloys. At higher temperatures of molds a lowering of mechanical properties is observed.
3. Fluidity of alloys during casting in shell and ethylsilicate molds is somewhat higher than in earthen molds.
4. Mechanical properties of samples 5 mm in diameter made from alloy AL9 during casting in gypsum molds do not differ from properties of this alloy poured in earthen molds. On samples with a diameter of 8 mm and 12 mm a small lowering of mechanical properties is noted.

5. Mechanical properties of alloys AL19 and AL21 decrease during casting in gypsum forms by nearly 10-15%.

Heating of gypsum molds lowers mechanical properties of 8 mm and especially 12 mm samples made from these alloys; properties of samples with a diameter of 5 mm are not changed.

6. Fluidity of aluminum alloys during casting in gypsum (cold and heated) molds a few times exceeds the fluidity during casting in earthen molds.

## METHODS OF INCREASE OF QUALITY OF A PRECISION CASTING MADE FROM ALUMINUM ALLOYS

V. I. Slotin and G. I. Eksin

The effectiveness of turborefrigerating units grows with an increase of the  $r/\text{min}$  of rotor disks, since one can decrease diametrical dimensions of a turbine and its weight. Centrifugal forces appearing during high speeds of rotation force the material of castings to be plastically deformed, leading to jamming of turbines and their breakdown. Therefore, the value of the ratio of yield point to specific gravity determines selection of the most durable alloy.

Profiles of rotor disks of aviation turborefrigerators, and also their constructive forms are complicated, making it necessary to manufacture disks by the method of precision casting in gypsum mold and by investment patterns.

Application of these methods of casting permits using, for disks of a turbine rotor, twisted blades of aerodynamic profile, whereas milling gives the possibility of obtaining blades of only simplified profile, lowering effectiveness of work of the unit. Regarding economic considerations, casting of disks of a turbine rotor is approximately 2 times cheaper than milling. Therefore there is great value in selection of a correct technology of exact casting, allowing one to combine in such important parts as turbine discs, high quality of metal (strength and density) with precision of dimensions and form.

The appearance of castings of a rotor disk of a turborefrigerator, obtained by the method of precision casting in gypsum mold, is shown in Fig. 1. In this work are illuminated questions of technological conditions of melt and casting of aluminum casting alloys with the use of vacuum and ultrasonic techniques for production of castings of rotor disks of high quality. In Table 1 are given typical mechanical properties of casting aluminum alloys used in the production of turbine rotor disks.

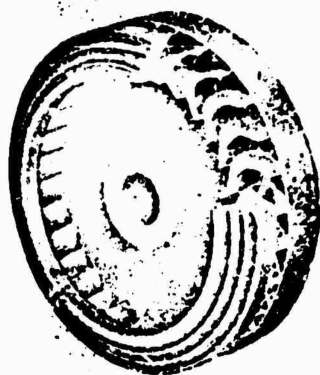


Fig. 1. External view of casting of rotor disk of turborefrigerator in gypsum mold.

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Table 1. Typical Mechanical Properties<sup>1</sup> at Room and Raised Temperatures of Casting Aluminum Alloys (Casting in Sand)

Make of alloy	$\rho$ g/cm <sup>3</sup>	Mechanical properties at 20°			$\sigma_{0.2}/\rho$	Mechanical properties at 300°	
		$\sigma_b$ kg/mm <sup>2</sup>	$\sigma_{0.2}$ kg/mm <sup>2</sup>	$\delta$ %		$\sigma_{100}$ kg/mm <sup>2</sup>	$\sigma_b$ kg/mm <sup>2</sup>
АЛ9	2,66	22	11	3,0	4,1	2,8	9,0
АЛ19	2,78	37	22	5,0	7,9	7,0	12,0
АЛ20	2,83	32	25	2,0	8,8	3,5	15,0

<sup>1</sup>After heat treatment by condition T5.

Alloy [AL9] (АЛ9) is very convenient in casting, however it requires thorough degassing due to an inclination to absorption of hydrogen during melt. Furthermore, low mechanical properties, in particular yield point, do not permit using alloy AL9 for especially high-speed disks.

Alloy AL19 is a highly durable and heat-durable alloy. Casting of the alloy is produced at a temperature of ~750° which during a wide interval of crystallization sometimes leads to microporosity; therefore good feeding of castings is required. Alloying components in the alloy called AL20 (its composition: 0.8-2.0% Cu; 0.5-1.5 Ni; 2.0-3.0% Si; 0.3-0.8% Mg; 0.8-1.4% Fe; 0.15-0.3% Ti; up to 0.3% Mn, remaining Al) condition a good combination of relatively high strength at room and raised temperature. The presence of silicon gives the alloy good fluidity and filling properties for a complex profile. From the point of view of production it is convenient that iron is an alloying component connected in a chemical compound of type Al-Fe-Si-Mn, in consequence of which the alloy even during prolonged melt in cast-iron crucibles does not become brittle.

### Degassing of Alloys

The conditions of work of turbine rotor disks present high requirements for density of a casting; in connection with this a thorough degassing of the liquid metal before pouring in mold is necessary.

Refining with the aid of volatile chlorides ( $\text{AlCl}_3$ ,  $\text{ZnCl}_2$ ) in this case does not ensure the necessary degree of degassing. With respect to contamination of the metal by moisture, the method of degassing in a vacuum<sup>1</sup> is safe.

On Fig. 2 is shown a general view of the vacuum decontaminator developed by the authors on the basis of a laboratory furnace [TG-5] (TF-5). The decontaminator constitutes a detachable vacuum cap which is set on an intermediate plate with special rubber

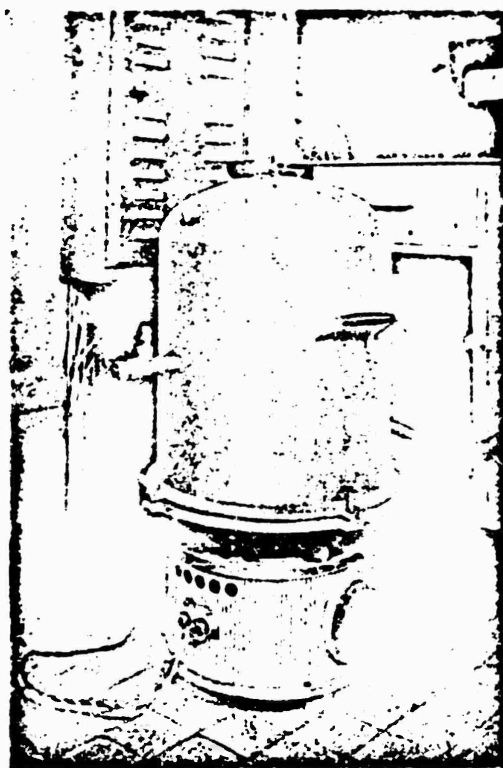


Fig. 2. Vacuum decontaminator.

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packing. In the vacuum cap is a viewing window for observation of the process of degassing. The vacuum is created by pump [GNV-20] (THB-20) and is measured exactly by instrument [UTV-49] (YTB-49) or more roughly by a mercury differential manometer. This laboratory

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<sup>1</sup>DePierre, Foundry, 1956, v. 84, No. 12.

vacuum decontaminator, in spite of simplicity, turned out to be convenient in work and allowed us to obtain a residual pressure near 1.0 mm Hg. In the course of experiments it was found to be convenient to conduct degassing in the vacuum starting from the moment of melting (600-620°) and finishing by holding for 20 minutes at temperatures 20-40° higher than the temperature of casting. In view of the slag inclusions emerging on the surface of the melt, it turned out to be useful to repeat the process of degassing for 10-15 minutes after purification of the surface.

X-radiation radioscopy, and also macrostructures of cut castings showed good density after vacuum degassing (Fig. 3).

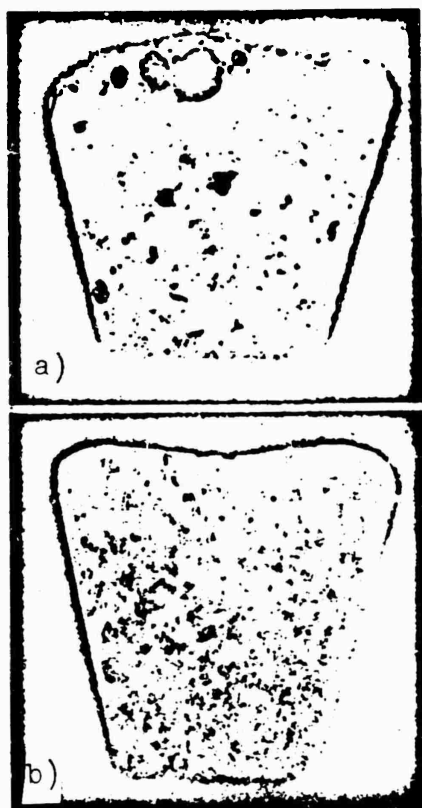


Fig. 3. Macrostructures of vacuum samples of alloy AL20. a) before degassing in vacuum, b) after degassing in vacuum.

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Investigations of the process of degassing by ultrasonics in laboratory conditions confirmed its indubitable merits.<sup>1</sup> In further work we used both of these methods.

### Technology of Casting

As a forming material for manufacture of molds we used highly durable gypsum in a mixture with asbestos. The combination of casting in gypsum molds with the method of vacuum suction permitted a considerable expansion of the possibility of manufacture of thin-walled castings of any complexity.

Operational experience showed that by casting aluminum alloys AL9, AL20, AL19 in gypsum molds with application of vacuum suction there can be obtained very thin rotor disk blades which are impossible to prepare by any other method. The profile of blades poured by this method preserves with precision the form with which the model rotor disk was made. During vacuum suction there is carried out closed pouring of the liquid metal, which excludes the possibility of capture of air, mechanical mixing of the oxide film in the stream of metal, and hit of aluminum oxide in the casting.

Of great value also is mixing of the liquid alloy and its motion during hardening. During slow cooling, comparatively low temperature of casting and mixing there can be obtained a fine crystalline structure and raised mechanical properties.<sup>2</sup> These conditions were created by introduction of ultrasonic oscillations in aluminum melt which is crystallized in the gypsum mold.

Our investigations showed that application of ultrasonic treatment of alloy AL20 at frequencies of 800 kHz and intensity  $7-8 \text{ W/cm}^2$  accelerates the process of hardening and promotes formation of a very fine macro- and microstructure (Fig. 4).<sup>3</sup> Experiments on small ingots and castings bear witness that as a result of ultrasonic influence it is possible to strengthen an

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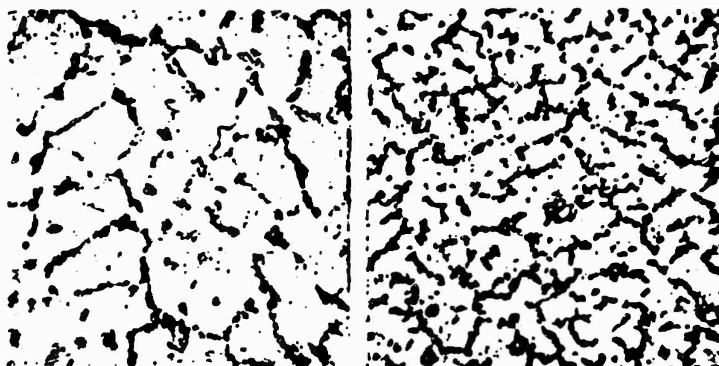
<sup>1</sup>M. B. Al'tman, D. V. Vinogradov, V. I. Slotin, G. I. Eskin, Izvestia of Academy of Sciences of USSR, OTN, 1958, No. 9.

M. B. Al'tman, V. I. Slotin, N. P. Stromskaya, G. I. Eskin, Izvestiya of Academy of Sciences of USSR, OTN, 1959, No. 3.

See also the article of M. B. Al'tman, G. I. Eskin, N. P. Stromskaya, V. I. Slotin and L. N. Loktionovaya in the present collection on p. 137.

<sup>2</sup>A. A. Bochvar, Metal science, Metallurgy Publishing House, 1956.

<sup>3</sup>V. I. Slotin, G. I. Eskin, Izvestiya of Academy of Sciences of USSR, OTN, 1957, No. 9.



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Fig. 4. Fig. 4. Microstructure of alloy AL20. a) before treatment by ultrasonic oscillations, b) after treatment by ultrasonic oscillations.

Table 2. Mechanical Properties of Samples Cut from Parts Poured from Alloy AL20 by Different Techniques

Method of casting	Mechanical properties					
	before heat treatment			after heat treatment		
	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>	$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>
Casting in gypsum molds under vacuum without influence of ultrasonics	15—16	2—3	62—63	24	1.0	100
Casting in gypsum molds with influence of ultrasonics	20—23	4—6	69—76	32—33	4—6	101

Table 3. Mechanical Properties of Samples Made from Alloy AL9 Cut from Parts After Casting on UMVO (poured state).

Method of casting	Method of degassing	Number of grains on 1 cm <sup>2</sup>	Mechanical properties		
			$\sigma_b$ kg/mm <sup>2</sup>	$\delta$ %	HB kg/mm <sup>2</sup>
UMVO, without ultrasonics	Refining by zinc chloride	5	12—14	7—8	50
UMVO, with crystallization in ultrasonic field	Refining by zinc chloride	40	15,5—6	8—10	50
UMVO, with crystallization in ultrasonic field	Degassing with the aid of ultrasonics	More than 100	16—17	12—16	50

alloy, where strength properties are increased to a larger degree than plasticity (Tables 2 and 3). Using the technique of treatment of a melt by ultrasonics with a piezocrystal vibrator and combining it with the method of vacuum suction, it was possible to carry out



exact casting in gypsum molds of rotor disks of high mechanical strength.

However application of such a vibrator is hampered by a series of limitations, connected mainly with the difficulty of obtaining quartz of large dimensions. Therefore we conducted research in treatment of castings of greater weight with the use of ultrasonic influence at a frequency of 18-19 kHz and intensities of 40 and 100 W/cm<sup>2</sup>, obtained with the aid of magnetic constriction.<sup>1</sup> Casting was conducted in gypsum casting molds with introduction of elastic oscillations of ultrasonics from below. As can be seen on the photographs of Fig. 5, ultrasonics crushes the micrograin. This confirms our notions about the mechanism of ultrasonic influence, which consists of an increase of the number of centers crystallization

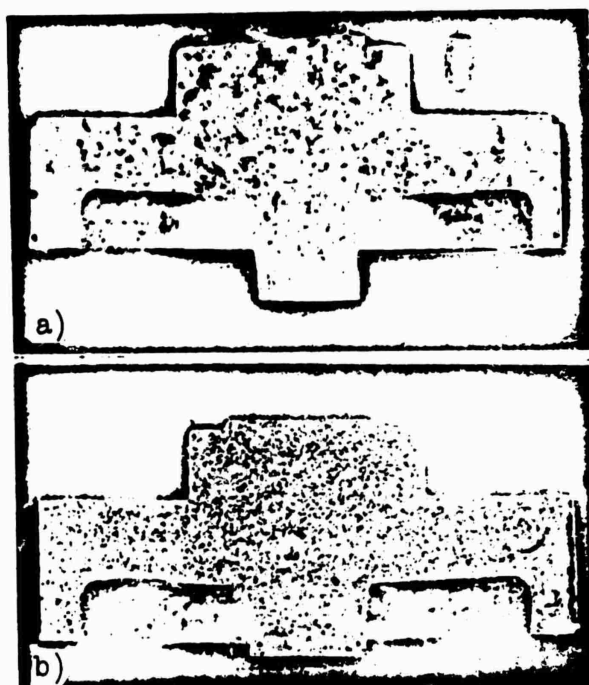


Fig. 5. Macrostructure of castings of disks in gypsum molds. a) before treatment by ultrasonics in process of crystallization, b) after treatment by ultrasonics in process of crystallization.

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in the volume of the melt and dispersion of already formed crystals and their subsequent delivery all over the volume of the alloy as

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<sup>1</sup>Authors conducted work in Institute of Metal Science and Physics [TsNIICHERMETa] (ЦНИИЧЕРМЕТА) jointly with I. I. Teumin, M. P. Usikov and O. N. Gusevaya.

a result of agitation.<sup>1</sup>

It is necessary to note, however that insufficient preliminary degassing of the melt can lead to porosity if castings from alloy AL20 are subsequently crystallized in gypsum molds in an ultrasonic field. Also obtained are blowholes with a diameter of up to tenth fractions of a millimeter evenly distributed all over the volume of the casting.

Porosity is caused by an incomplete process of degassing in the ultrasonic field. Blowholes formed in cavitation recesses under the influence of hydrodynamic mixing spread all over the volume of the casting setting stuck in shaped transitions and coagulate, and the gradual increase of viscosity of the melt according to crystallization prevents their getting to the surface. Thus, for use of ultrasonics at a frequency of 20 kHz for increasing mechanical properties of precision casting one should preliminarily degas the melt.

On the basis of initial experiments on treatment of castings (hardening in gypsum molds) by ultrasonic oscillations there was designed and built an installation for combined casting with vacuum suction with treatment by ultrasonics in the process of crystallization. The ultrasonic magnetostrictive vacuum mold-box [UMVO] (YMB0) was designed for casting turbine rotor disks from alloy AL9.

The UMVO combines the processes of vacuum suction and ultrasonic treatment, it permits under conditions of closed pouring of liquid metal to produce a casting in molds of any thermal conductivity. Such a mold can be a metallic chill mold and gypsum mold and a combination of both forms, i.e., gypsum mold with coolers.

A schematic diagram of the installation is shown in Fig. 6. Form 6 is placed under vacuum cap 5, united through receiver (storage unit of vacuum) and a cock with the vacuum pump. From above in the cap is a hermetically built-in ultrasonic converter 1, fed from ultrasonic generator [UZG-10] (Y3Г-10).

The vacuum mold-box with secured mold is lowered into the melt; from the difference of pressures liquid metal enters the form, where thanks to contact with the ultrasonic waveguide there is ultrasonic treatment up to actual hardening.<sup>2</sup> In assembled form the appearance of the UMVO is shown in Fig. 7.

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<sup>1</sup>V. I. Leont'yev, Collection "Problems of metal science and the physics of metals," Metallurgy Publishing House, 1959.

<sup>2</sup>For prevention of seizure of the waveguide with the casting the surface of the waveguide was covered by chalky plaster. Furthermore, with the help of special measures succeeded in lifting the face of the waveguide somewhat above the casting after 1 minute of treatment, when the metal was still in a solid-liquid state.

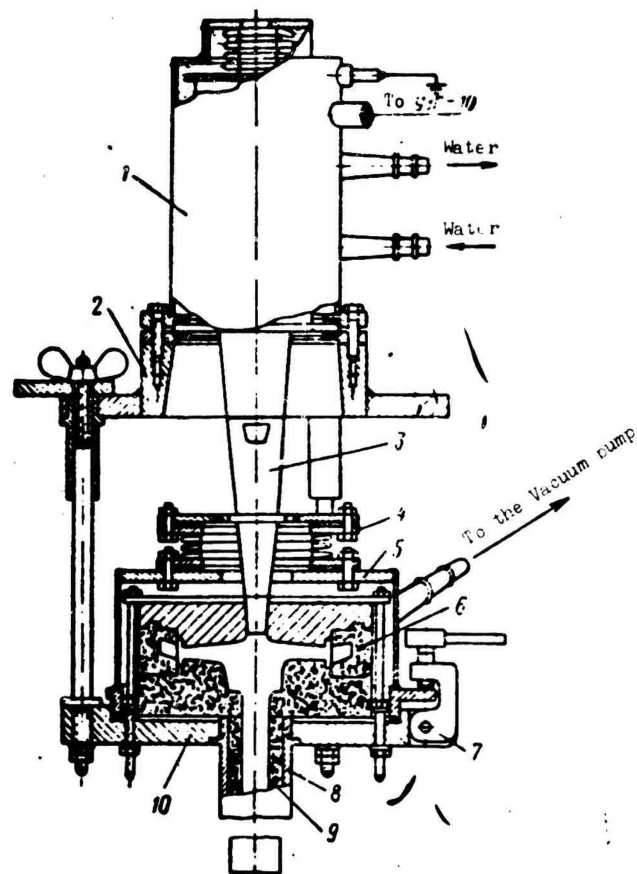


Fig. 6. Diagram of installation for combined ultrasonic treatment with vacuum suction. 1 - ultrasonic converter, 2 - upper base, 3 - ultrasonic waveguide, 4 - bellows, 5 - vacuum cap, 6 - mold, 7 - binding screw, 8 - metallic flow gate, 9 - gypsum flow gate, 10 - base of UMVO.

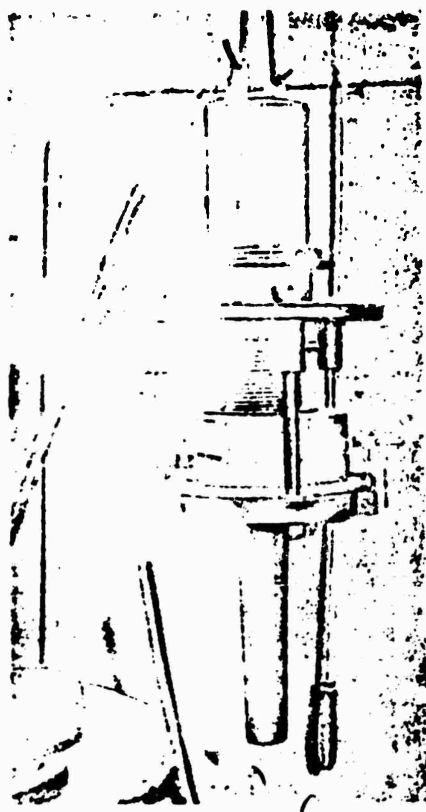


Fig. 7. External view of UMVO.

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Conditions of casting of turbine rotor disks on the UMVO was selected as follows. The alloy was prepared in a graphite crucible with a capacity of 4 kg, after melting it was degasified by zinc chloride and ultrasonics. At  $700 \pm 10^\circ$  we switched on the vacuum and produced sucking of the metal in the mold-box with simultaneous treatment by ultrasonics for 1-1.5 minutes at a frequency of 19-20 kHz and intensity  $40 \text{ W/cm}^2$  (diameter of waveguide 15 mm). In Table 3 are given results of crushing of grain and mechanical properties in poured state of disks cast with application of ultrasonic treatment in the process of crystallization and without treatment. Microstructure of metal treated by ultrasonics had crushed plates of silicon and was close to the structure of alloy AL9 which had undergone the operation of modification. This coincides with data obtained by other authors.<sup>1</sup>

#### Conclusions

1. The method of casting turbine rotor disks in gypsum molds permits the most exact reproduction of aerodynamics of profile.

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<sup>1</sup>N. N. Sirota, Ye. A. Lekhtblyau, E. M. Smolyarenko, "Physics of metals and metal science," 1959, t. VII, issue 6.

2. During melt of aluminum alloys intended for manufacture of castings of important assignment, ultrasonic degassing turns out to be the most effective method.

3. Ultrasonic treatment in the process of hardening increases mechanical properties and improves the structure of castings.

## FORMING AND AUXILIARY MATERIALS USED DURING CASTING IN SHELL FORMS

B. A. Arbuzov and V. A. Kurakina

The method of casting in shell forms is even more frequently used at plants. During a comparison of the technological process with casting in usual sand forms one sees the considerable effectiveness of the new process, expressed in a considerable increase of the utilization factor of the metal, lowering of labor-input in casting and in mechanical workshops, increase of quality and sharp lowering of reject of castings.

At the same time mastery and introduction of the method of casting in shell forms showed that technical economic results of the new process depend on forming and auxiliary materials. Basic forming materials for manufacture of shell forms or cores are quartz sands with grains of different value and thermosetting resins. Quartz sand serves as filler and thermosetting resins as binding material.

During selection of optimum compositions of sand-resin mixtures for production of shell forms and cores we investigated quartz sand of different deposits, distinguished among themselves by content of clay components and in terms of value of grains. During investigation of seepage depth of metal depending on grain composition of mixtures (used for shell forms and cores it was established that the best surface is obtained during use of sand with grains 0.06-0.15 mm in diameter and with minimum gas-forming ability of mixtures.

Consequently, for production of quality castings it is important to use a form with a minimum content of binding materials and sands of defined granularity. Shown requirements coincide with the necessity to obtain quality shell forms with minimum content of binder. To ensure these conditions we studied in detail different technological factors which affect quality of forms and castings. Data given in Table 1 show that application of sands washed from clay permits increasing strength properties of shell forms by 30 to 40%, i.e., lowering consumption of scarce binding materials by 30 to 40%.

Table 1. Influence of Content of Clay Substances on Strength of Shell Forms and Cores

Composition of mixtures in parts by weight	Content of clay component in %	Tensile strength kg/mm <sup>2</sup>	
		during fracture	during bend
Sand 1K010A-100,0; pulverized bakelite - 5,0	1,2	33,0	82,0
The same mixture with washed sand	0,1	49,0	118,0
Sand 1K0063A-100,0; pulverized bakelite - 5,0	3,4	26,0	81,0
The same mixture with washed sand	0,1	34,0	101,0

Table 2. Influence of Grain Structure of Sands on Physical and Mechanical Properties of Shell Forms

Composition of mixtures in parts by weight <sup>1</sup>	Tensile strength kg/mm <sup>2</sup>		Yield of mixture through $\varnothing 7$ mm s	Porosity in %	Volume weight g/cm <sup>3</sup>	Specific gravity g/cm <sup>3</sup>	permeability
	during fracture	during bend					
Sand 1K025E - 100,0 Pulverized bakelite - 5,0 Kerosene - 0,3	29,5	61,5	45	45	1,39	2,53	300
Sand 1K010E - 100,0 Pulverized bakelite - 5,0 Kerosene - 0,3	32,0	65,0	59	49,2	1,28	2,52	146
Sand: 1K0063A - 100,0 Pulverized bakelite - 5,0 Kerosene - 0,3	28,0	65,0	75	50,6	1,26	2,50	102
Sand 1K010/E - 70,0 Sand 1K0063A - 30,0 Pulverized bakelite - 5,0 Kerosene - 0,3	36,5	66,5	66	49,9	1,26	2,51	108
Sand: 1K010E - 30,0 Sand: 1K0063A - 70,0 Pulverized bakelite - 5,0 Kerosene - 0,3	33,0	70,0	74	50,0	1,24	2,48	90

<sup>1</sup>For data of experiments we used sand preliminarily washed of clay.

Strength characteristics of shell forms and cores are rendered a negative influence not only by clay components in utilized sands, but also by all possible sand grain surface precipitations in the form of crusts. These precipitations constitute a complex of different mineral and organic compounds.<sup>1</sup> Their negative influence can be considerably decreased if before use sand is subjected to heat treatment at 800-1000°. The influence of sands with different grain structure on strength of shell forms is given in Table 2.

These data show that maximum strength properties of forms are attained during use of sands of brands 1K010A and 1K0063A, taken in the ratio 7:3.

Certain researchers indicate that the smaller the granularity and, consequently, the larger the specific surface of quartz sand used, the bigger is the requirement to introduce in the sand-resin mixture binding material, for example pulverized bakelite.

However, as is shown in Tables 1 and 2, this opinion is not confirmed during application of sands preliminarily washed from clay substances. Presence of clay and different oxides in sands distorts results of analyses and leads to inaccurate conclusions. In connection with this, for clarification of the mechanism of hardening of shell forms and cores we conducted experiments on the influence of the value of the specific surface of used fillers and the degree of packing of the mixture on strength characteristics of obtained shell forms and cores. Results of these experiments, given in Tables 3 and 4, permit making the following conclusions (see Tables 3 and 4 below):

1) strength of shell forms and cores is decisively influenced by density of packing of grains of filler. Density or the coefficient of packing, defined as the ratio of weight of mineral particles-sand grains in a unit of volume of a mold to true specific gravity of sand:

$$K = \frac{PM}{\gamma},$$

where PM — weight of 1 cm<sup>3</sup> of sand grains;  $\gamma$  — specific gravity of sand;

2) the more heterogeneous the grain structure of sand and the less it contains of clay substances, the denser the grains of sand and the higher the strength of properties of shell molds and cores;

3) use of sands of corresponding structure with minimum content of clay permits obtaining quality shell cores and molds with minimum possible content of binding material.

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<sup>1</sup>P. I. Fadeyev, Sands of USSR, Publishing house of Moscow State University, 1951.



Table 3. Influence of Change of Value of Specific Surface of Sands and Their Mixtures on Strength Properties of Shell Forms and Cores<sup>1</sup>

Designation of sand and its make	Specific surface in cm <sup>2</sup> /g	Tensile strength kg/cm <sup>2</sup>	
		fracture	bend
Lyuberetskiy 1K025A	466.0	29.5	61.5
Lyuberetskiy 1K016A	605.0	—	—
Alexinskiy 1K010A	705.0	—	—
Gremyacheskiy 1K01B	710.0	32.0	65.0
Tul'skiy 1K0063A (experimental)	1,470.0	28.0	—
Gremyacheskiy 1K010B 70% + Tul'skiy 1K0063A 30%	925.0	36.5	70.0
Gremyacheskiy 1K010B 30% Tul'skiy 1K0063A 70%	1,170	33.0	65.0
Pulverized bakelite	12,300	—	—
Dust-like quartz (Bolotov deposit)	14,200	—	—

<sup>1</sup>Every mixture contained 5% pulverized bakelite.

Table 4. Influence of Packing on Strength of Shell Molds and Cores

Composition of mixtures in parts by weight	Tensile strength, kg/cm <sup>2</sup>		Increase of strength in %
	for samples obtained by free filling	for samples obtained with packing	
Sand 1K0063A — 100.0 Pulverized bakelite — 5.0 Kerosene — 0.3	29.0	38.0	31.0
Sand 1K010A — 70.0 Sand 1K0063A — 30.0 Pulverized bakelite — 5.0 Kerosene — 0.3	31.4	38.0	21.0
Sand 1K025A — 40.0 Sand 1K010A — 30.0 Sand 1K0063A — 30.0 Pulverized bakelite — 5.0 Kerosene — 0.3	39.0	42.0	7.1

### Binding Materials

As binding materials during manufacture of shell forms we use synthetic thermosetting resins, which during heating pass to an infusible and insoluble state, a resite stage. Transition of resins to a resite stage occurs on account of formation of three-dimensional molecules, which ensures high strength indices and raised thermal stability of the sand-resinous mixtures.

Related to thermosetting resins which can be used in shell castings are phenolformaldehyde, cresolformaldehyde, urea-formaldehyde (carbamide) and melamineformaldehyde resins. Most often used for this purpose was phenolformaldehyde B-stage resins, so-called resitol, constituting a mixture resoflax resin, hydroxybenzyl alcohols and free phenol, partially soluble in alcohol and acetone.<sup>1</sup> Resitol is fairly brittle, which makes it possible to obtain the resin in powdery form.

Abroad they use phenolformaldehyde resins of make resinox and urea-formaldehyde resins, Mosantos rezimin.<sup>2</sup>

In domestic industry for shell casting there is used pulverized bakelite, constituting a mixture of novolacs phenolformaldehyde resin with urotropine, dear and critical product. Shell forms, prepared from pulverized bakelite for thin-walled castings made from light alloys, have high residual strength which hampers shrinkage, and also removal of forms and cores, but during casting of steel parts and other refractory metals the heat resistance of pulverized bakelite is insufficient. Therefore at present as we have, so also abroad work has been done on search of substitutes of pulverized bakelite and obtaining other thermosetting resins useful for manufacture of shell forms and cores.

The State Scientific Research Institute for Casting Machining and Technology jointly with the State Scientific Research Institute of Plastics established the possibility of obtaining resins close in terms of their characteristics to pulverized bakelite, based on lignite phenol, technical xylenol and schistose phenol.

Application of urea-formaldehyde and melamineformaldehyde resins in shell forms during casting of nonferrous alloys is expedient because speed of polymerization and temperature of decomposition of these resins are considerably lower than phenolformaldehyde. This last circumstance is a positive quality, since at a low temperature of decomposition of resins compliance of forms is increased and knockout is facilitated.

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<sup>1</sup>I. P. Losev, G. S. Petrov, Chemistry of synthetic resins, State Chemistry Publishing House, 1951.

<sup>2</sup>N. A. Sokolov, Casting in shell molds (survey of the foreign press), Mashgiz, 1956.

However a check of commercial urea-formaldehyde resins of binder type "M" and resin [MF-17] (MF-17) for shell casting did not give positive results. Strength characteristics of a mixture with urea-formaldehyde resins did not differ from a mixture with pulverized bakelite, but the surface strength of samples made from mixtures with pulverized bakelite was higher than for samples with urea-formaldehyde resin. The ratio of bending strength to tensile strength in the mixture with pulverized bakelite was larger than in the mixture with urea-formaldehyde resin. Furthermore, the mixture with pulverized bakelite possessed considerably smaller hygroscopicity than the mixture with urea-formaldehyde resin.

At present during manufacture of shells for steel parts at the plants pulverized bakelite is used, but shell cores are prepared with a mixture of novolacs oxidized phenol-formaldehyde resin No. 180.

#### Separator Compounds

During manufacture of shell molds, for preventing adhesion of the mold mixture to the pattern a separating compound is used.

Separating compounds have to ensure the following conditions: ease of removal of mold, cleanness of surface of pattern after removal of mold, precision of contours of edges of mold and its smoothness, the biggest number of removals for every covering. All these requirements can be carried out if separating compounds can sustain the high temperatures at which they remain inert, and are stable, and have low surface tension, promoting separation of contacting surfaces.

From source material it is known that as separating compounds it is possible to use paraffin wax, polyethylene products, but stearate, siloxane compositions and others.<sup>1</sup>

Operational experience here and abroad has shown that the most suitable materials for separating compounds are silicoorganic compounds polysiloxane, neutral with respect to pattern and mold possessing high thermal stability and good lubricating ability.

Of polysiloxane liquids liquid No. 5 has found application used for separation in the form of a water emulsion, the emulsifier in which was soap. However this emulsion was not stable. At present liquid No. 5 and a water emulsion of liquid No. 5 are not used at the plants.

We used an emulsion of liquid No. 5 with polyvinyl alcohol according to the following prescription in weight: liquid No. 5 - 5; polyvinyl alcohol 1.5; water 93.5%.

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<sup>1</sup>Ya. G. Polyakov, Founding abroad, Mashgiz, 1958.

The emulsion is prepared in the following way. Polyvinyl alcohol is dissolved in a small quantity of water and stirred to full solution. After that a small portion is put in liquid No. 5, everything is thoroughly mixed to obtaining an absolutely uniform mass, which is then diluted by water according to the necessary concentration. Mixing continues for 2.5 hours. The emulsion based on polyvinyl alcohol possesses good lubricating ability and is stabler than the emulsion based on soap.

Better results are obtained with other silicoorganic liquids: methylpolysilicone oil [SKT-3] (CKT-3) and SKT-2 which are still residues during pyrolysis and rectification of highest methylsilicone polymers. However application of these liquids has a limited character due to scarcity.

For the purpose of reduction of consumption of shown compounds SKT-3 and SKT-2 can also be used in the form of 5% water emulsions. Emulsification of SKT-3 and SKT-2 is conducted in water heated to 40-50°.

All available separating liquids and emulsions obtained on their basis were tested in laboratory conditions by development method on Michaels instrument with a reverser. A special pattern consisting of a plate, split ring and pusher, was heated to 200°, then lubricated by the separating liquid, covered by the tested mixture.

After filling the mixture the ring was unclapsed and removed. The plate with the shell was placed in the furnace for 5-10 minutes at 200-250° for further hardening of the shell. Then the plate was placed in a special attachment and inserted on the lower base of the reverser of the Michaels instrument, after which the lock from which the fraction is poured was opened. At the time of unfastening the shell from the plate the influx of the fraction ceased. The fraction was weighed on scales. The force necessary for breakaway of the shell from the plate is determined by the formula:

$$R = \frac{g}{F \cdot 1000} \cdot a.$$

where  $g$  — weight of fraction in grams;

$F$  — area of section of sample in  $\text{cm}^2$ ;

$a$  — gear ratio for arms, equal to 50;

1000 — conversion of grams into kilograms.

Shells were prepared from a mixture based on pulverized bakelite and urea-formaldehyde resin. From the results of tests, given in Table 5, it is clear that the best separating lubrication is liquid SKT-3.

Table 5. Characteristic of Oils

Lubrication	Shell made with pulverized bakelite		Shell made with urea-formaldehyde resin	
	number of removals	force $k_L/cm^2$	number of removals	force $k_L/cm^2$
CKT-2; CKT-3	From 1 to 25	Without force	From 1 to 30	Without force
	26	1.2	31	0.5
	27	1.5	32	1.0
	30	1.6	—	—
5% polysiloxane emulsion with polyvinyl alcohol	From 1 to 9	Without force	—	—
	10	1.5	—	—
	12	1.7	—	—
	14	1.8	—	—
Polyxyloxan liquid No. 5	From 1 to 5	Without force	From 1 to 12	Without force
	6	1.2	13	1.2
	7	1.5	14	1.4
	8	2	—	—
10% polysiloxane emulsion	From 1 to 2	Without force	From 1 to 9	Without force
	3	0.9	10	0.94
	4	1.4	11	1.1
	6	2	13	1.8
Ceresin	1	Without force	—	—
	2	1.2	—	—
	3	1.5	—	—
	5	2	—	—
Paraffin	1	Without force	—	—
	2	2.4	—	—
	4	2.7	—	—
	7	2.8	—	—

Tests showed that the mixture with pulverized bakelite adheres to the pattern faster than the mixture with urea-formaldehyde resin during use of the same lubrication. This phenomenon is observed for all lubricators tested.

Liquids SKT-3 and SKT-2 were also tested in industrial conditions on a section of a casting in a chill mold with application of cores made from plated sands. Lubrication SKT-3 ensures not less than 10-12 removals of rods after one covering, not leaving deposits on the patterns.

In industrial conditions we tested the emulsion and separating liquid SKT. Liquid SKT-3 in industrial conditions ensures removal of 15-20 shells after one covering of the pattern plate.<sup>1</sup>

### Wetter

During preparation of resin-sand mixtures for shell castings, in mixers of various kinds is observed formation of dust; furthermore, in process of filling of molding sand on a pattern, stratification of the mixture occurs, caused by difference of specific gravity and dimensions of particles of binding and loose materials. For removal of this phenomenon it is necessary to use wet additions since the sand-resinous mixtures have to be uniform. Local accumulations of resin in mixture lead also to unnecessary gas formation during filling.

As wetter additions, we use furfural, this is a product of processing vegetable raw material; esteraldehyde fraction (a byproduct of alcohol production); white spirit; a solution of paraffin in white spirit; bakelite varnish; lubricating oils (avtol).

By a whole series of experiments it was established that best wetter additions are an esteraldehyde fraction and furfural in quantities of from 0.5 to 1% of the weight of the mixture.

### Glues

Shell molds consists of two or several half molds, which are connected and are fastened together with the aid of clamps, bolts, and in series production by means of gluing. Gluing ensures a tighter connection of parts of a shell mold and guarantees obtaining the most precise castings. At present for gluing of shell forms inorganic and organic glues are used.

One inorganic glue is a glue with water glass of composition: clay of brands [FV-1] ( $\Phi$ B-1), [FO-1-24%] ( $\Phi$ O-1-24%); electrocorundum (powder): 6%; water glass: 70%. The glue is deposited on the cold half of the mold and is glued with the hot half of the mold just taken from the pattern plate. Furthermore, it is possible to use glue consisting of 50% clay or dust-like quartz and 50% water glass.

Of organic glues there are used glues on the basis of urea-formaldehyde and phenolfurfural resins. Most had the following compositions of glue:

- 1) resin MF-17 (technical spec: [MKhP] (MXII) 2538-55): 75-85%;

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<sup>1</sup>The Scientific Research Institute of the Automobile Industry used as a separating lubrication a 5% solution of synthetic thermo-resistant rubber in white alcohol. According to their data during application of this lubrication it is possible to remove up to 40 shells.

dextrin: 25-15%; orthophosphoric acid (20% solution): 6% over 100;

2) resin MF-17: 40%; dust-like quartz: 60%; chlorous ammonium or oxalic acid (above 100%): 1-1.5%;

3) resin MF-1 (Plastics Institute Technical Specs): 40%; dust-like quartz: 60%; Petrov kerosene contact (above 100%): 3-4%.

### Conclusions

1. As forming materials for production of quality castings one should use sands washed of clay or sands subjected to heat treatment at a temperature of 800-1000°.

Maximum strength properties are attained during the use of sands of brands 1K01A and 1K0063A, in the ratio of 7:3.

2. As binding material for shell forms and cores best results are obtained with the use of drying oil oxidized phenol-formaldehyde resin No. 180.

3. As separating compounds it is possible to recommend methylsilicone oil SKT-3 and SKT-2, still residues during pyrolysis and rectification of methylsilicone polymers. (

4. Best wetter additions are an esteraldehyde fraction and furfural in amount of 0.5-1% of the weight of the mixture.

5. The best composition of glue used for gluing shells is as follows:

resin MF-17 (technical specs MKhP 2538-55) 75-85%;

dextrin 25-15%;

orthophosphoric acid (20% solution), 6% over 100%.

## METHODS OF CONTROL AND INVESTIGATION OF SAND-RESIN MIXTURES FOR CASTING IN SHELL MOLDS

B. A. Arbuzov, N. M. Stepanova and N. L. Soboleva

Methods of test and control of mixtures used for casting in shell molds differ from standard methods of control of usual molding mixtures. At present it is necessary to unify methods of control of technological properties of shell molds, since indices obtained in institutes and at plants are very contradictory. This does not allow correct estimates of those or other technological measures.

Research data and industrial experience of application of shell molds show that the quality of forms and castings, just as during casting in sand molds, depends on properties of the forming materials and obtained mixtures.

In this connection, for establishing optimum proportions and maintaining constant properties of mixtures for shell molds and cores, instruments and attachments for investigation and control of the following parameters of sand-resin mixtures were developed; tensile and bending strength, yield, degree of compliance and yield, gas permeability, crumbling, degree of polymerization, gas-burning ability, porosity, speed of formation and hardening of the sand-resin mixture.

### Preparation of Samples

For manufacture of samples in standard conditions a laboratory hopper with detachable attachments was designed for tensile tests and bend tests (Fig. 1). It is a box of rectangular section 60 x 250 mm, depth 300 mm with a bottom of cylindrical form. The hopper with the aid of journals welded to its side walls sits in bearings of hard carbon steel on a stand. From above along walls of the hopper is welded an angular iron, to which is riveted an iron box 100 x 150 x 31 cm, serving as a bed for the core box during manufacture of samples.



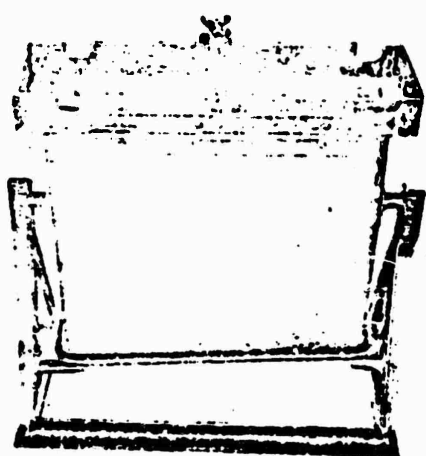


Fig. 1. Laboratory hopper.

**GRAPHIC NOT  
REPRODUCIBLE**

From above the iron box has a stop and clamp, with the aid of which the pan with core box is secured. The hopper during rotation on journals can be easily turned over and with the aid of a rod inserted in the clamp of the hopper and in the stand, it occupies its initial position.

The split core boxes (Fig. 2) are three-cell for samples "eights" and single bar made of steel, their surface polished. Core boxes



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REPRODUCIBLE**

Fig. 2. Core box for "eights."

due to their conicity and conicity of the internal cavity of the pan are securely held in the latter and do not fall. The capacity of the hopper is calculated for loading 3-4 kg of molding sand.

For cut of surplus mixture in the process of manufacture of samples in the upper part of the hopper between hopper and plate is set a special knife. In overturned position of the hopper the knife is put through a cut in the frame separating the form from the higher column of mixture. The knife will cut the mixture in a loose state directly in the hopper immediately after filling a form. Samples are obtained with an even smooth surface and sharp edges.

Eight samples and bars are prepared in the following way. The pan from the demountable form is set in the furnace and heated to a defined temperature, which is checked by a contact thermocouple. After achievement of the needed pan temperature, equal to  $180^{\circ}$ , in its grooves are pushed lateral parts of the form, generators of configuration "eights" or bar. The internal surface of the form is lubricated by a separating lubrication and is secured to the bottom on the hopper with the mixture. Then we turn the hopper  $180^{\circ}$ , keep it in such a position for 45 seconds, and return it to initial position.

The form is taken from the hopper and placed in a furnace for polymerization of samples. Polymerization is produced at  $350^{\circ}$  and holding 8 minutes. Then the form with samples is removed from the furnace, samples are extracted from the form and cooled to room temperature. The form is cleaned from adhering sand grains, lateral parts of it are cooled under a cock in running water, again we measure the temperature of the pan with the aid of a contact thermocouple and begin to manufacture samples as described above.

We conducted a test of a series of samples of one and the same composition during identical conditions for determination of the limit of deflections in indices.

By test we established that deflection from the arithmetic mean are permissible and are within limits of  $\pm 4\%$ .

The following stage of check of correspondence of the proposed method to peculiarities of shell molding in workshop conditions was determination of the specific work of packing which was set by calculation. Thus, specific work of packing on a 4-position machine of the All-Union Industrial Technological Institute of Heavy Machinery Construction during use of  $300 \times 400$  mm plate equals  $0.62-0.65 \text{ kg/cm}^2$ . For a monoposition machine of the Brake plant with plate dimension  $400 \times 500$  mm specific work of packing is equal to  $0.62-0.70 \text{ kg/cm}^2$ .

It was determined that the value of specific work of packing on a laboratory hopper closely coincides with average workshop indices and is characterized by the value  $0.58-0.60 \text{ kg/cm}^2$ .

As a basic index of degree of packing of samples we took the characteristic of porosity. Determination of porosity in workshop samples showed that it is characterized by the value  $45.5-46.8\%$ , i.e., values of the same order as of experimental samples obtained by us (porosity of laboratory samples made by the method of free filling, is within limits of  $45\%$ ).

#### Determination of Fracture Strength

Fracture strength is determined by a test of eights-samples of standard dimension with thickness 12 mm on a Schopper machine, [UP-1] (УП-1) on another rupture-test machine and is set by the formula:

$$\sigma_0 = \frac{P}{F},$$

where  $\sigma_0$  - tensile strength in kg/cm<sup>2</sup>,

P - load in kg;

F - area of cross-section of samples in cm<sup>2</sup>.

#### Determination of Bend Strength

For determination of bend strength we used special samples - bars 170 x 20 x 20 mm. Samples for bend were prepared just as eight-samples. They were tested on a Schopper or Fischer machine. During the test on instrument 051 samples were prepared 70 x 15 x 6 mm in three-cell form.

Calculation of bending strength is done by the formula:  $\sigma_{\text{изг}} = \frac{3Pl}{2bh^2}$ ,

where  $\sigma_{\text{изг}}$  - bend strength limit in kg/cm<sup>2</sup>;

P - load in kg;

l - length between supports in cm (14 cm);

b - width of sample in cm (2 cm);

h - height of sample in cm (2 cm).

#### Determination of Collapsibility

Collapsibility is determined by loss in weight of standard cylindrical sample 50 mm in diameter and 50 mm in height. Samples for determination of collapsibility were prepared in individual split cylinders during conditions: temperature of pan 180°, temperature of polymerization 350°, time of polymerization 20 minutes. After cooling samples were placed in a net-like drum of instrument [FG-4] (ФГ-4) of the Usmanskiy plant, where during rotation of the drum it is subjected to abrasion for 2 minutes. Collapsibility is expressed in percent weight of sample.

#### Determination of Porosity

Porosity is determined according to the method of Sharfshtein and Heifetz, modified in reference to shell forms. For determination of porosity it is necessary to know the volume and specific gravity of the material.

Volume weight is determined in the following way. A sample made from a sand-resin mixture 50 mm in height, diameter 30 mm is preliminarily weighed on technical scales with a precision of 0.01 g, then heated for 20 minutes in a drying cabinet at 180-200°, after which it is rapidly transferred to a porcelain glass of 1 liter capacity with cold distilled water. This creates a vacuum in pores, which promotes fairly rapid saturation of the sample with water.

Further the sample in the glass is boiled 30 minutes; after cooling to room temperature it is wiped with a wet towel and weighed on technical scales with an accuracy of 0.01 g. Thus is determined weight of the saturated sample in air.

For calculation of volume of the sample, furthermore, it is necessary to determine the weight of the saturated sample in water. With this goal we use hydrostatic weight according to All Union Government Standard 2400-53 on usual scales. The left suspension with cup is removed and replaced by a suspension having instead of a cup a net-like platform with a loose wire grid. The net-like platform is put in the vessel with water. The level of the liquid when weighing is kept constant, for which the vessel is provided with a siphon.

Scales before weighing are put in equilibrium with the net-like platform immersed in liquid, and when filling the vessel to the level of the overflow pipe.

Volume weight  $\delta$  is calculated by the formula:

$$\delta = \frac{P_1}{v},$$

where  $P_1$  - weight of sample before test in g;

$v$  - volume of sample, equal to  $P_2 - P_3$ , in  $\text{cm}^3$ ;

where  $P_2$  - weight of sample in air before saturation by water;

$P_3$  - weight of sample saturated by water, in water.

Consequently: 
$$\delta = \frac{P_1}{P_2 - P_3}.$$

Specific gravity is determined by the method accepted for determination of specific gravity of sands. A dried pycnometer is weighed on analytic scales. Then in it is poured a 10-20 g sample, triturated in a porcelain mortar and sifted through sieve No. 70, after which we determine the weight of the pycnometer with the sample. Further, the pycnometer is half filled with distilled water and the contents boiled in a water tank for 30 minutes (until cessation of liberation of bubbles of air). After cooling to room temperature the pycnometer is filled with distilled water up to the measuring line and weighed. Then the contents of the pycnometer are poured out, the pycnometer is thoroughly washed, filled to the line with distilled water and again weighed. Specific gravity  $\gamma$  is calculated by the formula:

$$\gamma = \frac{g_2 - g_1}{g_2 - g_1 + g_4 - g_3},$$

where  $g_1$  - weight of dry pycnometer in g;

$g_2$  - weight of pycnometer with sample in g;

$g_3$  - weight of pycnometer with water and sample in g;

$g_4$  - weight of pycnometer with water in g.

True porosity  $A$  is calculated by the formula:

$$A = \frac{1 - \frac{\rho}{\rho_s}}{\gamma} \cdot 100$$

or

$$A = \left[ 1 - \frac{P_1}{\gamma(P_2 - P_1)} \right] \cdot 100.$$

### Determination of Gas-Permeability

Sand-resin mixtures are tested for gas-permeability on an instrument of type 042 of the Usmanskii plant on samples of two types: standard cylindrical and disk 70 mm in diameter and 10 mm thick.

Samples are prepared just as for determination of collapsibility; for disks the duration of polymerization is 8-10 minutes.

A diagram of the test of samples for gas-permeability is shown in Fig. 3. For a test of cylindrical samples in the lower gate of

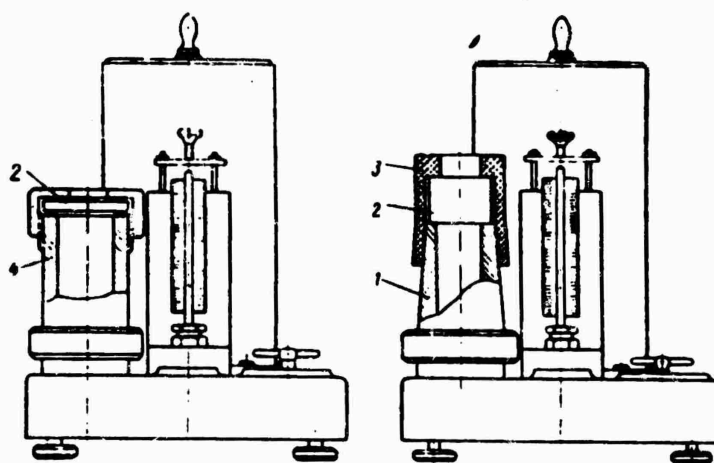


Fig. 3. Diagram of test of samples for gas-permeability.

the instrument set tube 1 (Fig. 4), on which is placed sample 2. On the lateral surface of the sample an elastic rubber 3 is placed for hermetic sealing.

During the test of disk samples we use a special tube 4, which ensures a proper clamp and hermetic sealing of the sample. Gas-permeability is calculated by the formula:

$$K = \frac{Vh}{F P t},$$

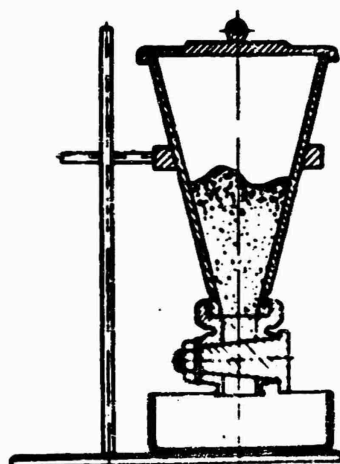


Fig. 4. Funnel for determination of yield of sand-resin mixtures.

where  $v$  — volume of air, equal to  $2000 \text{ cm}^3$ , which passed through sample;  
 $h$  — height of thickness of sample in cm;  
 $t$  — time of flow of  $2000 \text{ cm}^3$  air in minutes;  
 $P$  — counterpressure in mm of a water column;  
 $F$  — cross section of sample in  $\text{cm}^2$ .

#### Determination of Yield of a Sand-Resin Mixture

Yield of the mixture is set by the time of outflow of a defined volume of mixture from a special funnel (Fig. 4), supplied with a detachable cock with holes 10 and 15 mm in diameter.

We determine yield by formula:

$$v_{\text{exp. acet}} = \frac{v}{t} \text{ B cm/s,}$$

where  $v$  — volume of funnel in  $\text{cm}^3$ ;  
 $f$  — area of hole in  $\text{cm}^2$ ;  
 $t$  — time of outflow in s.

#### Determination of Degree of Polymerization of a Shell

The weighed portion of a shell 3-4 g in weight is weighed on analytical scales and preliminarily triturated in a porcelain mortar and placed in the extractor of a Sokslet instrument. Through the extractor acetone is poured in a quantity approximately 1.5 times exceeding the volume of the extraction part of the instrument. The retort of the instrument is heated in a water bath for 6 hours and upon expiration of the shown period the acetone in portions is poured in a calibrated retort 100 ml in capacity and driven off with the aid of a Libikh refrigerator. The retort with the remainder is dried to constant weight at  $80^\circ$ .

The degree of polymerization  $X$  is calculated by the formula:

$$X = 100 - \frac{a \cdot 100}{g},$$

where  $X$  - degree of polymerization in %;  
 $a$  - weight of extracted resin in g;  
 $g$  - weight of resin in given weighed portion of shell in g.

#### Determination of the Degree of Compliance of the Mixture

The degree of compliance of the mixture is set by the value of residual compressive strength of the sample, a cylinder with a diameter of 30 mm and height 50 mm heated to different temperature.

Residual strength is determined by the formula:

$$\sigma_{cx} = \frac{P}{F},$$

where  $\sigma_{cx}$  - compression strength in  $\text{kg}/\text{cm}^2$ ;  
 $P$  - load in kg;  
 $F$  - area of cross section in  $\text{cm}^2$ .

#### Determination of Time of Polymerization of Resins

For the test we prepared a mixture of resin and urotropine. For resols we took 1% (by weight) urotropine, for novolacs, 14%. The mixture was triturated in a porcelain mortar.

The time of polymerization was determined on a steel plate 160 x 160 mm and 15 mm thick, having in its lateral face a hole for a thermometer reaching to the center of the plate. In the hole we inserted the thermometer and with the aid of a rheostat set the temperature at  $150-160 \pm 2^\circ$ .

A weighed portion of the mixture (1.0 g) was deposited on the central part of the surface of the plate. Resin was evenly distributed by a small stick on the plate. Just as the resin started to melt we fixed the time by a stop watch and started to mix the resin with the small stick from left to right and back. During mixing one should maintain an equal distribution of the resin within limits of the limited area, about 2-3 cm in diameter.

When the resin starts to thicken, the small stick, not stopping mixing, for an instant is raised above the surface of the plate. The thickening resin during rise of the small stick stretches, forming a thread.

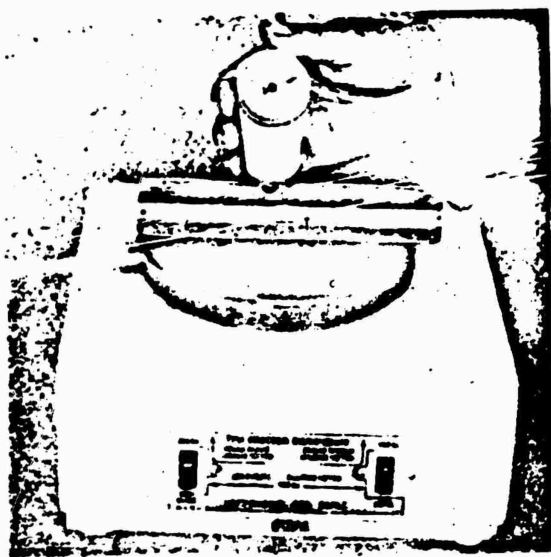
Upon further heating these threads start to be broken. At this instant the stop watch is stopped. The time in seconds, from the moment of melting of the resin on the plate before the beginning of

breaking threads is noted as the time of polymerization. The test was conducted on two parallel weighed portions.

#### Determination of Speed of Formation and Setting of Sand-Resin Mixtures

In industrial conditions the necessity was revealed of determination of speed of formation and setting of sand-resin mixtures before starting work.

For this purpose we developed a method of control of this parameter, founded on the change of hardness of a sample in the process of its hardening during heating. Determination of the speed of formation and setting of the mixture is produced on a special instrument (Fig. 5), which consists of an electric heater plate



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REPRODUCIBLE**

Fig. 5. Instrument for determination of speed of formation and setting of sand-resin mixtures.

(All Union Government Standard 306-56), metallic plate with a diameter of 150 mm, demountable form, hardness gage [TNSH-1] (ТНШ-1), 350° thermometer.

On the electric heater plate we set the metallic plate, in the lateral hole of the plate the thermometer was inserted with the aid of which we measured the temperature of the metallic plate. The demountable form is placed on the metallic plate and the electric heater plate is switched on.



The electric heater plate is switched on in three conditions: low, medium, and high. Depending on the necessary temperature we switch to one or another heat. Upon achievement by the metallic plate of a temperature of  $280^{\circ}$ , and demountable form to  $200^{\circ}$  the split form is removed, filled with the mixture, placed on the plate and at the same time the stop watch is started. Through each 0.5 minutes we measure hardness with a hardness gage. The interval of time from the first measurement until obtaining a constant value of hardness determines speed of formation of the mixture.

After determination of speed of formation the demountable form is taken from the plate and from it is extracted a sample. The form is cleaned, placed for 5-10 minutes on the metallic plate for preheating to  $200^{\circ}$  and readied for the next experiment.

#### Determination of Gas-Forming Ability

The gas-forming ability is determined by means of heat treatment of samples in a tubular furnace of Mars type at  $700-750^{\circ}$  for forms utilized during nonferrous casting, and  $1000^{\circ}$  for cast-iron and steel casting. For investigation we weigh a 1 g tested mixture, which is placed in the forming boat and loaded in the tubular furnace. A general view of the apparatus is schematically depicted in Fig. 6.

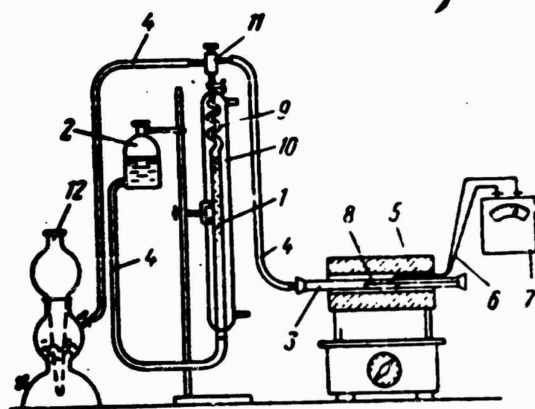


Fig. 6. Instrument for determination of gas-forming ability of mixtures: 1 - measuring burette, 2 - equalizing vessel, 3 - quartz tube, 4 - rubber tube, 5 - tubular furnace, 6 - thermocouple, 7 - galvanometer, 8 - boat with tested mixture, 9 - cooler, 10 - water jacket, 11 - cock, three-way, 12 - Kipp apparatus.

At the time of installation of the sample in the porcelain boat in the furnace the stop watch is started and a reading of liberated gases by indices of a graduated measuring phial is made in which at the time of reading the level of water is levelled with its level

in the jar. A reading of the quantity of gases is produced every 30 s.

#### Conclusion

~ The developed methods of control constitute a whole complex of determinations of the quality of shell forms and can be recommended for use in workshop practice.

At present these methods of control and investigation of sand-resin mixtures have found application at a series of plants.

# U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

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

\* ye initially, after vowels, and after ъ, б; e elsewhere.  
 When written as ѣ in Russian, transliterate as yѣ or ѣ.  
 The use of diacritical marks is preferred, but such marks  
 may be omitted when expediency dictates.