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**HIGH-STRENGTH, HEAT-RESISTANT AND
STRUCTURAL ALLOYS OF ALUMINUM WITH
LITHIUM**

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ABSTRACT: This is chapter 7 of a book entitled Aluminum Alloys. Industrial, Deformable, Sintered and Cast Aluminum Alloys. These alloys are broken down into groups depending on their properties, use and chemical composition. This chapter deals with aluminum alloys alloyed with lithium with lithium and cadmium and with lithium and magnesium. Research on proportions, alloying procedures, and the resulting properties of alloys (VAD23 and 01420 alloys in particular) are discussed in detail. Data on mechanical properties at various temperatures and physical and corrosion properties of the alloys are included.

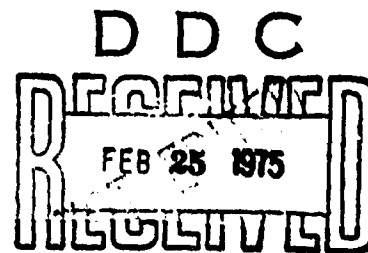
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CHAPTER 7

1. High-strength and Heat-resistant Structural Alloy with Lithium, VAD23¹

Alloying aluminum alloys with lithium results in a considerable decrease in specific weight and an increase in the modulus of elasticity; these characteristics often are of decisive importance when designing aircraft equipment. The introduction of lithium along with cadmium in alloy system Al--Cu--Mn causes a significant improvement in strength characteristics. The study of such compositions resulted in the creation of VAD23 alloy. The high strength of this alloy at room temperature is combined with high heat resistance at temperatures up to 225° C. Its specific weight is lower by 3--5% and its modulus of elasticity higher by 5--8% than alloys of the D16 and V95 type.

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VAD23 alloy belongs to the Al--Cu--Li system. The Al--Li binary system has been studied comparatively recently [1; 2, p. 51. p. 231; 3; 4].

In equilibrium with aluminum solid solution in ternary system Al--Cu--Li, according to data [5, p. 423, 6], one finds the following six intermetallic compounds:

- 1) θ -CuAl₂--tetragonal structure ($a = 6.06$; $c = 4.89$ Å);
- 2) T_B --LiCu₄Al_{7.5} (54.9% Cu and 1.5% Li¹), cubic structure of CaF₂ type ($a = 5.825^{+5}$ --5.8328 Å);
- 3) T_1 --Li₃CuAl₆ (53.8% Cu and 5.4% Li), hexagonal structure ($a = 4.96$; $c = 9.35$ Å);
- 4) T_2 --Li₃CuAl₆ (26.9% Cu and 8.8% Li);
- 5) δ -AlLi, cubic structure ($a = 6.37$ Å);
- 6) R --Li₃CuAl₅, cubic structure ($a = 13.92$ Å [7]).

In a USA patent² and work [5, p. 429] a significant increase in the effect of aging of ternary alloys which contain about 4.5% Cu and 1% Li from the introduction of 1% Ag; 0.1% Cd and 0.05% In is described.

Research on surplus phases showed that cadmium in VAD23 alloy, apparently, does not form intermetallic compounds [8, 9]. Being predominantly in a solid state at hardening temperature, this element with subsequent artificial aging facilitates intense work hardening [9--11]. According to data of metallographic analysis, manganese in Al--Cu--Li--Cd system alloy does not form compounds either with lithium [12], or with cadmium [13], but compounds are observed with aluminum, copper and sometimes with iron and silicon.

¹The content of elements is presented in % (of mass).

²Lo Baron, USA, patent No. 2381219, 1945.

An analysis of mechanical properties of ternary alloys¹ of the Al--Cu--Li system with 0.5% Li, after hardening² and aging showed that the increase in content of copper from 3 to 6% increases the tensile strength to approximately the same value as in binary alloys without lithium ($\approx 17 \text{ kgf/mm}^2$) [14]. With higher contents of lithium (1--4%) the difference in tensile strength in alloys with 3 and 6% Cu decreases from 5 to 0 kgf/mm^2 .

An increase in content of lithium from 0.5 to 2.0% in an alloy with 3.0% Cu results in work hardening at 20 kgf/mm^2 , and in an alloy with 6% Cu--only at 7 kgf/mm^2 . Relative elongation with an increase in concentration of lithium to 1.2% is decreased by 2--3 times.

The ternary alloys studied with 0.5% Li are located at 350° C in a two-phase field (Al + T') of the compound diagram (Figure 93). According to Silcock's data [9], after aging at 165° C for 16 hr one observes in these alloys a single work hardening phase θ' (Figure 94) in quantities which are approximately the same as those for alloys without lithium (apparently, this explains their uniform strength). Alloys with 1% lithium are located in the field (Al + T_B + T₁) and after the aging mentioned above these alloys, except θ' , segregate phase T₁ whose formation mainly can explain the changes observed in strength and ductility. Alloys with 2--2.5% Li are found in fields (Al + T₁) or (Al + T₁ + T₂) and are characterized by maximum strength. The decrease in strength of alloys with three or more percent lithium, apparently, is caused by conversion in the field (Al + T₂ + δ).

¹The study of properties of ternary and more complex alloys was done on pressed springs with diameter 10--18 mm of laboratory manufacture.

²All of the alloys studied were quenched in water at 525--530° C.

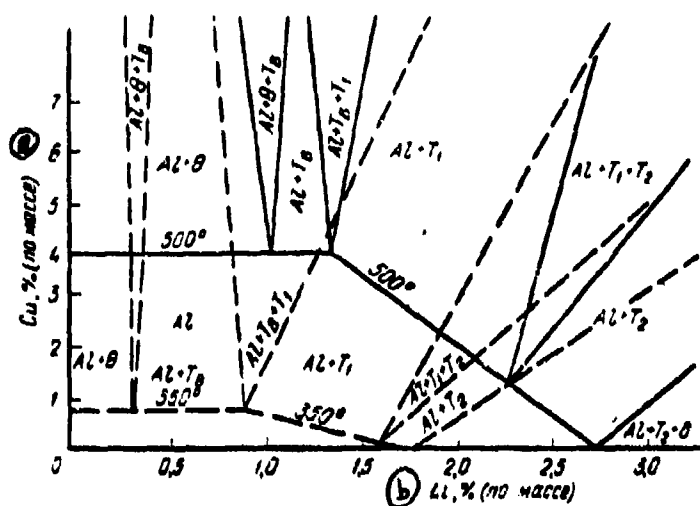


Figure 93. Distribution of Phase Fields in the Al--Cu--Li System at 500 and 350° C [5, p. 423]

Key: a. Cu, % (of mass) b. Li % (of mass)

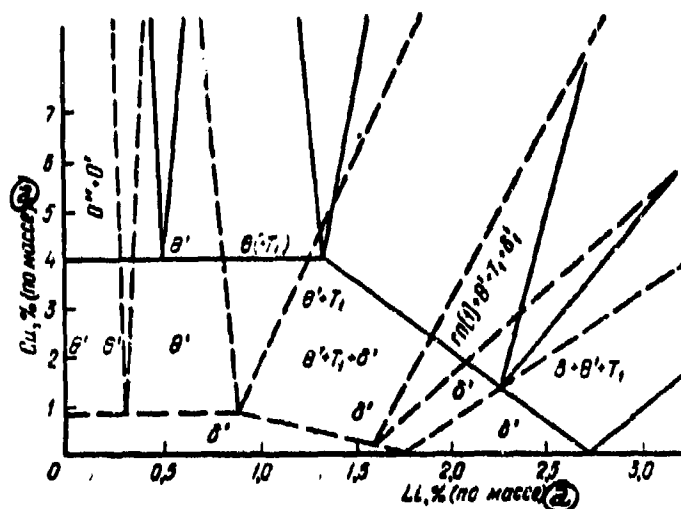


Figure 94. Segregation Which is Formed in the Alloys of the System After Aging at 165°, 16 hr [9]

Key: a. (of mass)

Quaternary alloys alloyed with 0.7% Mn, 1.4% Li (first group) and 7% Mn, 0.1% Cd (second group) were studied in freshly quenched, naturally aged (7 days) and artificially aged (at 190° C, 16 hr) states.

The strength of alloys of the first group increases with an increase in the content of copper as a result of improving the hardening effect. The maximum tensile strength (of an alloy with 6% Cu) amounts to 53.5 kgf/mm² with relative elongation 5.0%.

Alloys of the second group are located in the Al + θ phase field (see Figure 93). The effect of hardening of these alloys also increases with an increase in the content of copper from 2 to 6% (from 3.5 to 12 kgf/mm²), and ductility at the same time decreases by 8--10%. Work hardening after natural aging is weak (0.8--1.5 kgf/mm²), and the size of relative elongation remains large (25--33%).

The effect of artificial aging increases up to 17 kg/mm² with an increase in the content of copper to 6%. Relative elongation at the same time is decreased by approximately 2.5 times ($\delta = 10\%$). The principle of change of mechanical properties due to the content of copper in alloys of the Al--Cu--Mn--Cd system is similar to the relationship in binary Al--Cu alloys [15].

With a content of 4--6% Cu, the introduction of 0.1% Cd less effectively increases the strength of alloys of Al--Cu--Mn system than does the addition of 1.4% Li. The strength of alloys with cadmium is 6--8 kgf/mm² lower than alloys of the Al--Cu--Li--Mn system with the same content of copper. However, ductility of alloys with cadmium is higher: if there is insignificant difference with 4--5% Cu, then with 6% Cu the ductility of alloys with 0.1% cadmium is approximately two times as high as alloys with 1.4% Li (5 and 10%, respectively).

The combined effect of the addition of lithium (0.7--2.8%) and cadmium (0.1%) on the effect of thermal treatment was studied for alloys of the Al--Cu--Mn system which contain 0.6% Mn and 2--6% Cu (Figures 95--96).

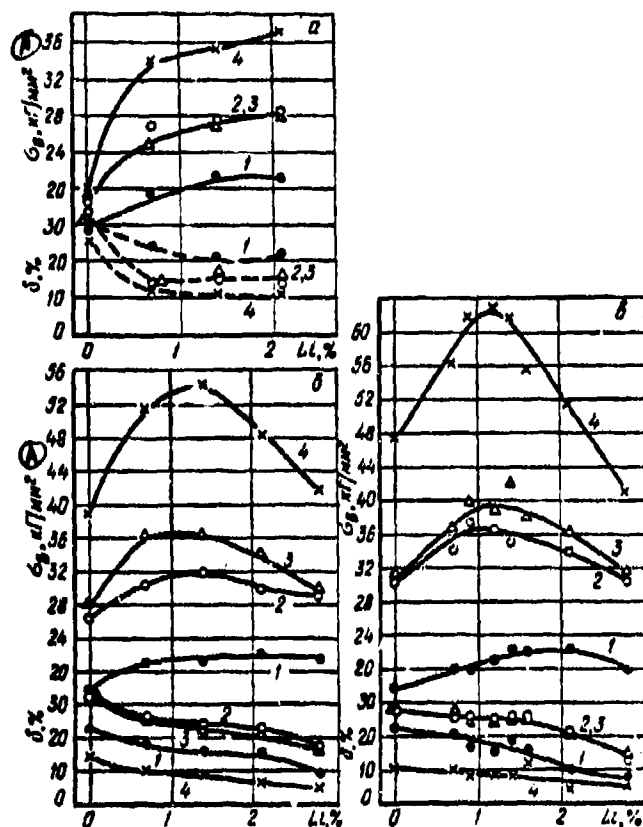


Figure 95. The Effect of the Content of Li on Mechanical Properties of Alloys of the Al--Cu--Mn--Cd System:

a--2% Cu; b--4% Cu; c--6% Cu; 1--Annealed state; 2--Hardened; 3--Naturally aged; 4--artificially aged

Key: A. kgf/mm²

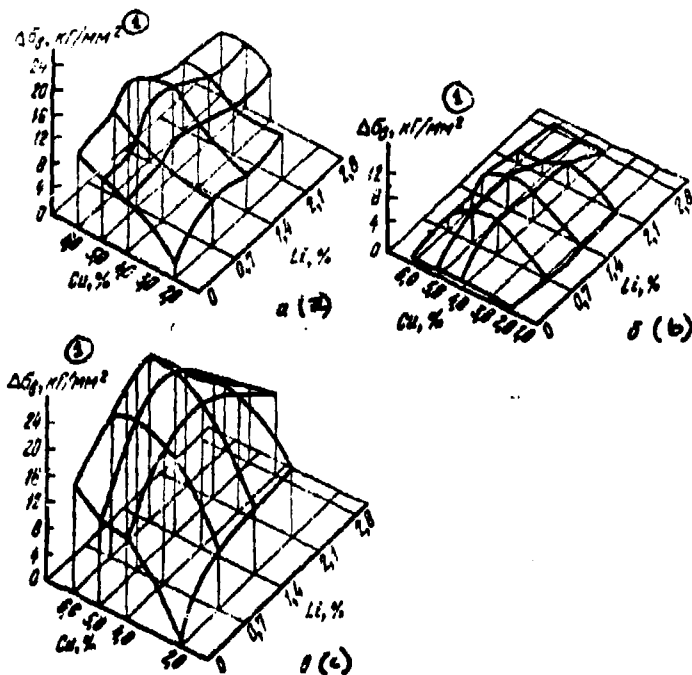


Figure 96. Effects of Thermal Treatment $\Delta\sigma_0$ of Alloys of the Al--Cu--Li--Mn--Cd System

a--Effect of hardening; b--Effect of natural aging;
c--Effect of artificial aging

Key: 1. kgf/mm²

The effect of hardening of alloys located in a solid state field increases according to the increase in concentration of solid solution both for lithium and for copper (Figure 96, a). Heterogeneous alloys with 6% Cu and 0.7--1.4% Li show the maximum effect of hardening (14--17 kgf/mm²). With an increase in content of copper from 2 to 4% the hardened alloys with lithium located in a solid state field increase somewhat both in strength and in ductility. With a further increase in the concentration of copper (transition in a heterogeneous field) strength increases somewhat and elongation does not change.

Strength of alloys in a hardened state with constant content of copper with a change in the concentration of lithium from 0 to 2.8% changes along the curve with a small maximum both in homogeneous and in heterogeneous alloys. With an increase in concentration of copper, the maximum tensile strength shifts to the side of lower contents of lithium (see Figure 95). Ductility of alloys with all contents of copper decreases when introducing even 0.7% Li. However, all the alloys studied which contain less than 2.1% Li have relative elongation greater than 20%.

In all the alloys of the Al--Cu--Li--Mn--Cd system studied the effect of natural aging (7 days) is insignificant, less than 5 kgf/mm² in tensile strength (Figure 96, b). Ductility of naturally aged alloys is practically the same as that of freshly quenched. The effect of artificial aging of alloys¹ located with a quenching temperature in a single-phase field increases with an increase in the content of both copper and lithium. With transition to a heterogeneous field this effect either is unchanged or decreases. Maximum work hardening is observed in alloys with 4--6% Cu and 1--1.4% Li (25 kgf/mm²).

In alloys aged at 165--170° C of the Al--Cu--Li system with additions of cadmium and manganese which contain 0.8--1.5% Li and 4--6% Cu, according to data of work [9] (see Figure 94) and the authors of this section, besides segregating θ' by $\{100\}_{Al}$, one discovers laminar phase T_1 by $\{111\}_{Al}$. The intermediate structure which precedes deformation of T_1 was not observed.

With a change in phase composition of the alloy from $(\alpha + \theta')$ to $(\alpha + \theta' + T_1)$ the character of decomposition changes: from a predominant segregation of θ' -phase along the grain and the appearance of separate compact particles along the boundary before segregation along the grain of phase

¹All alloys were aged at 165° C for 16 hr.

T_1 and θ' and the formation of ductile particles T_1 along a large section of high-angle boundaries. Segregation of T_B in the process of aging at 165--200° C was not observed. A certain change in the forms of reflexes of the θ' phase (the appearance of asymmetrical tails) on the X-rays of monocrystals of a number of alloys Al--Cu--Li--Cd was evaluated in work [9] as a tendency toward transition of θ' to T_B . Segregation in the alloys with similar diffraction patterns was called θ'_B . An increase in strength properties with an increase in the content of lithium from 0.3 to 1.5% in ternary and more complex alloys with 4--5% Cu, apparently, is explained by the increase in quantity and certain breaking up of the θ' particles by possible springy distortions of the matrices which cause transition of θ' to T_B and the formation of T_1 [25].

The introduction of up to 2.1% Li in alloys of the Al--Cu--Mn--Cd system with 2% Cu continuously increases strength (Figure 95). Tensile strength increases particularly noticeably (by 14 kgf/mm²) from the addition of 0.7% Li. Relative elongation also decreases by two times when adding 0.7% Li. Further increase in the concentration results in a small decrease in ductility.

Testing at 125--250° C showed that maximum tensile strength at all temperatures and aging is observed at the same concentrations of lithium and copper as at 20° C in an artificially aged state. Analogous principles were obtained when studying long-term strength with these alloys [10, 11].

Alloys of the Al--Cu--Li--Mn--Cd system with a content of 4--6% Cu and 0.7--1.4% Li combine high strength at room temperature with high heat resistance. The general corrosion resistance of these alloys does not depend on the content of copper (in limits 4--6%) and lithium (in a range 0--2%). Alloys

aged at 165° C for 16 hr are not inclined toward corrosion under stress or inter-crystalline corrosion.

The introduction of manganese into the alloy of an Al--Cu--Li--Cd system with all conditions of thermal treatment, except annealed, results in a simultaneous increase of strength and ductility (Figure 97). The maximum tensile strength in an artificially aged state is attained at 0.8--1.0% Mn, in freshly quenched and naturally aged states--at 1.2--1.5% Mn. Maximum ductility is attained in all three states with a concentration of 0.3--0.6% Mn. The principle of change of mechanical properties at 20° C of alloys of the system with varying content of manganese is close to the principle of change of the properties of alloys of type D20 of the Al--Cu--Mn system [16].



Figure 97. The Effect of the Content of Mn on the Mechanical Properties of Alloys of the Al--Cu--Li--Cd System:

1--Annealed state; 2--Quenched; 3--Naturally aged; 4--Artificially aged

Key: σ. kgf/mm²

¹Average composition of alloys: 5.2% Cu; 1.2% Li; 0.15% Cd.

As in many aluminum alloys when casting alloys of an Al--Cu--Li--Mn--Cd system, manganese forms supersaturated solid solutions. The decomposition of a solid solution during homogenization, heating under hardening or before deformation and in the process of deformation results in the appearance of fine manganese phases with dimensions in tenths of a micron. The presence of manganese in an alloy slows down recrystallization. Therefore, semi-manufactured products from alloys with manganese have a finer grain.

The addition of 0.2--1.5% Mn in alloys of an Al--Cu--Li system hardly affects heat resistance during short-term tests. However long-term strength at 200° C increases sharply due to the addition of 0.7--0.8% Mn which involves apparently, not only the change in the size of the grain, but also an increase in heterogenization of the structure as a result of the formation of dispersed manganese particles.

An addition of 0.05--0.20% Cd, as in alloys of an Al--Cu--Mn system¹ sharply increases strength as a result of an increase in the effect of artificial aging, somewhat decreasing ductility of the alloy (Figure 98). The effect of natural aging drops noticeably. This is explained by the fact that the addition of cadmium decreases the dimensions and increases the number of segregations during artificial aging and slows down the formation of the GP [Geksagonal'naya' plotnoupakovannaya (reshyetka), Hexagonal close-packed (lattice)] during natural aging [9]. The introduction of 0.08--0.3% Cd in alloys of an Al--Cu--Li--Mn system increases their heat resistance and then the lower the testing temperature the greater is the effect of the addition of cadmium [17].

The introduction of up to 0.3% Ti in alloys of an Al--Cu--Li--Mn--Cd system does not affect the mechanical properties at room and increased

¹Average composition of alloys: 5.2% Cu; 1.2% Li; 0.6% Mn.

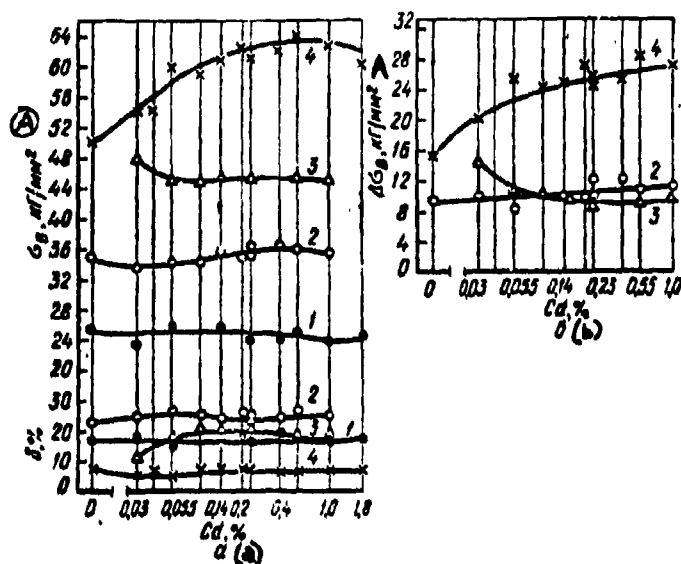


Figure 98. The Effect of the Cd Content on Mechanical Properties (a) and the Effects of Thermal Processing (b) of Alloys of an Al--Cu--Li--Mn System:

1--Annealed state; 2--Quenched; 3--Naturally aged; 4--Artificially aged

Key: A. kgf/mm²

temperatures for short-term elongation, but noticeably increases long-term strength; the maximum is attained at 0.1--0.2% Ti. The presence of silicon in alloys of this system (both separately and in combination in quantities greater than 0.3% each) decreases strength characteristics at room and increased temperature [17].

VAD23 alloy (AMTU [Aviatsionnyye metallurgicheskiye tekhnicheskiye usloviya, Aviation metallurgical technical specifications] 506--69) has the following composition: 4.8--5.8% Cu; 0.9--1.4% Li; 0.4--0.8% Mn; 0.1--0.25% Cd; admixtures (not more than): 0.15% Ti; 0.3% Fe; 0.3% Si; 0.1% Zn; 0.05% Mg.

The alloy is quenched at $520 \pm 5^\circ \text{C}$ in water (hot spot temperature is higher than 530°C). Holding during heating under quenching of pressed semimanufactured products must be cut down by 1.5--2 times in comparison with instructions for series alloys, in order to avoid recrystallization and grain growth. One should keep in mind that articles with fine elements can oxidize during heating. This results in a decrease both in strength and in ductility. The time for transfer from the furnace to the quenching tank must not exceed 40 s. An increase in temperature of the quenching water to 70°C does not affect the mechanical and corrosion properties of the alloy. Quenching in hotter water or in liquid nitrogen decreases both strength and ductility of the alloy.

The effect of natural aging on the alloy is small. The effect of the length of time of the aging on mechanical properties of clad sheets is presented in Table 59.

TABLE 59 MECHANICAL PROPERTIES OF SHEETS OF VAD23 ALLOY IN VARIOUS STATES

а. Состояние материала	$\sigma_{0.2}$ кг/мм ²	$\sigma_{0.5}$ кг/мм ²	δ , %
1. Отожженное	22	10	20
2. Естественно состаренное в течение:			
3. 2 ч	33	14	20
4. 2 месяцев	36	18	18
5. 1 года	37	23	17
6. 7 лет	38	25	15
7. Искусственно состаренное по режиму 160°--10 ч	54	49	5

Key:

- | | |
|--------------------------|---|
| а. State of the material | 5. 1 year |
| 1. Annealed | 6. 7 years |
| 2. Naturally aged for: | 7. Artificially aged according to the procedure 160°--10 hr |
| 3. 2 hr | 8. kgf/mm ² |
| 4. 2 months | |

The kinetics of aging of various semimanufactured products of VAD23 alloy

are practically uniform (Figure 99).

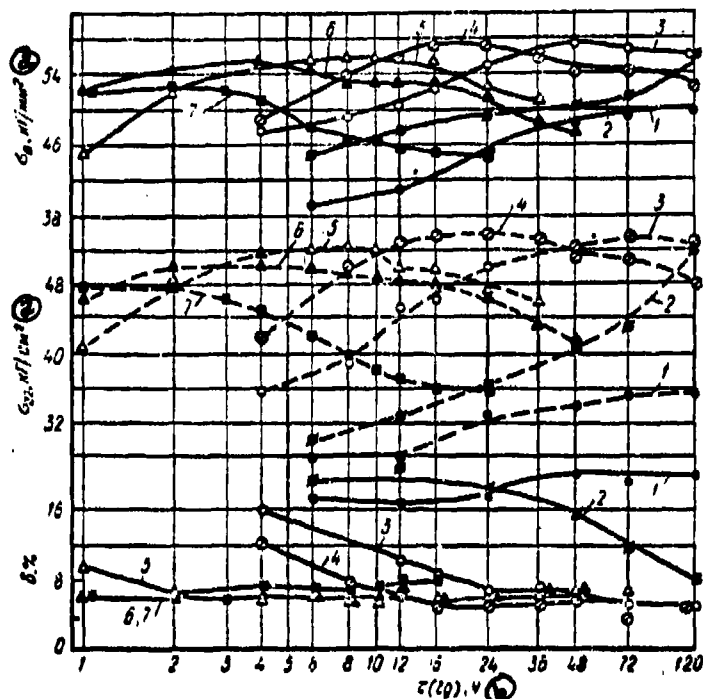


Figure 99. The Effect of Procedures of Artificial Aging (Temperature and Holding Time τ) on the Mechanical Properties of VAD23 Alloy:

1--100° C; 2--130° C; 3--150° C; 4--160° C;
5--170° C; 6--180° C; 7--200° C

Key: a. kgf/mm² b. hr.

At 100° C, the processes of work hardening of the alloy occur very slowly. After 120 hr the tensile strength increases to 50 kgf/mm² and the yield point--to 36 kgf/mm², not reaching maximum value; ductility is practically unchanged and remains at a high level (δ = 16--20%). The relationship $\sigma_{0.2}/\sigma_b$ is also practically unchanged and equals 0.71--0.72. At this temperature, in the time intervals studied in the alloy, apparently, there is a zone stage of aging.

At temperatures of 130--140° C the processes of work hardening accelerate somewhat: after 120 hr tensile strength increases to 54--60 kgf/mm², and the yield point--to 51 kgf/mm². The relationship of $\sigma_{0.2}/\sigma_B \leq 0.7$ with holding up to 12 hr, with greater length of holding (18--30 hr) $\sigma_{0.2}/\sigma_B = 0.73$ --74, a further increase in holding results in a sharper growth in the relationship $\sigma_{0.2}/\sigma_B$ and after 120 hr it reaches a value of 0.9--0.93. In semimanufactured products aged at 140° C for 18--30 hr, one observes a tendency toward corrosion under stress. The ductility of alloys during long-term aging up to 30 hr is high ($\delta = 14$ --20%; $\psi = 30\%$) and is practically unchanged with an increase in holding time. The work size of breakdown of samples with cracks with impact bending is also large ($a_{ty} = 1.2$ --1.5 kgf m/cm²).

If aging time exceeds 30 hr, the characteristics of ductility decrease sharply--by 1.5--2 times. Electric resistance at 140° C with holding less than 12 hr increases somewhat, but when the length of time of aging is increased up to 30 hr it decreases below the initial level and does not change with further increase in holding time up to 96 hr. By comparing the data obtained with the general principles of change of properties during aging of aluminum alloys [18, p. 316] one can come to the conclusion that at temperatures 130--140° C up to holding of 12 hr processes primarily occur which correspond to the zone, with holding 14--30 hr--mixed, and with longer holding times--primarily a phase stage of aging. However, even after aging for 120 hr, maximum strength is not attained.

With higher temperatures of 150--200° C work hardening of the alloy is accelerated even more; maximums appear on the kinetic curves of aging (see Figure 99). With an increase in temperature the time for reaching maximum strength is cut down. The time for attaining maximum tensile strength and

maximum yield point are the same. Minimum ductility for each temperature is attained in a shorter time than is maximum strength. The higher the aging temperature the lower are the maximum strength characteristics of the alloy, the relationship $\sigma_{0.2}/\sigma_B$ and the higher the minimum values of ductility.

After aging at a temperature of 220° C and holding for 0.5 hr and more one observes only recrystallization by process annealing.

Thus, zone aging at a temperature of 160° C is short term (1 hr), and at 170° C it occurs even more quickly.

During holding times studied this stage apparently was not observed. The aging stage of pressed semimanufactured products of VAD23 alloy are presented in the form of a diagram in Figure 100.

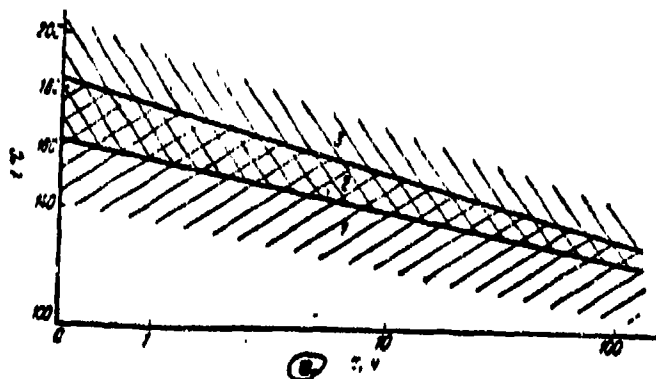


Figure 100. Temperature-time Fields of Aging for VAD23 Alloy:

1--Zone aging; 2--Mixed; 3--Principally phase

Key: a. hr.

Phase aging of VAD23 alloy before attaining maximum strength causes uniform decomposition of the solid solution with the formation of ductile segregations θ' and T_1 with diameter 600--900 Å (Figure 101). Along most



Figure 101. The Microstructure
of Sheel VAD23 Alloy After Aging
at 160° C for 16 hr X 21500

boundaries there are segregations in the form of dotted lines. A zone forms on the boundaries which is depleted of alloying components and therefore is free of segregations. An increase in aging temperature from 160 to 200° C, and also the application of additional long term heating results in embrittlement of particles, a decrease in their number per unit of volume and expansion of the free zone. This facilitates relaxation of stresses and somewhat increases ductility with a decrease in strength.

Depending on operating conditions for the articles made from VAD23 alloy it is recommended that one use three aging procedures. The first procedure (140° C, 18--24 hr) provides increased ductility and is intended for articles which operate at room temperature. The second procedure (160° C, 10--16 hr) give maximum characteristics of strength with somewhat lower ductility and is recommended for articles for short term operation at room temperature or increased temperatures. The third procedure (200--220° C, 6--15 hr) leads to relative stabilisation of the structure and properties of the alloy and is recommended for articles for long term operation at increased temperatures. The mechanical properties of aged semimanufactured products are presented in Table 60.

TABLE 60 MECHANICAL PROPERTIES OF SEMIMANUFACTURED PRODUCTS OF VAD23 ALLOY AT ROOM TEMPERATURE AFTER VARIOUS AGING PROCEDURES

① Вид полуфабриката	② Режим старения		③ $\sigma_{\text{вд}}$ кг/мм ²	④ $\sigma_{\text{поп}}$ кг/мм ²	⑤ δ , %
	темпера- тура, °C	время, ч			
① Профили прессованные тон- кие *	140	18	48—52	38—42	8—12
	160	10	52—60	45—55	4—8
	200	7	49—52	40—45	5—7
② Профили прессованные круп- ногабаритные *	140	18	50—57	40—48	10—15
	160	10	55—66	54—60	5—9
	200	7	49—57	42—51	7—9
③ Листы неплакированные **	140	18	48—52	37—44	10—18
	160	10	55—60	48—53	3—6
	200	7	49—52	40—45	4—7

Key;

- | | |
|--------------------------------------|----------------------------------|
| a. Type of semimanufactured products | 1. Pressed thin sections* |
| b. Aging procedure | 2. Pressed large scale sections* |
| c. Temperature, °C | 3. Unclad sheet** |
| d. Time, hr | |
| e. kgf | |

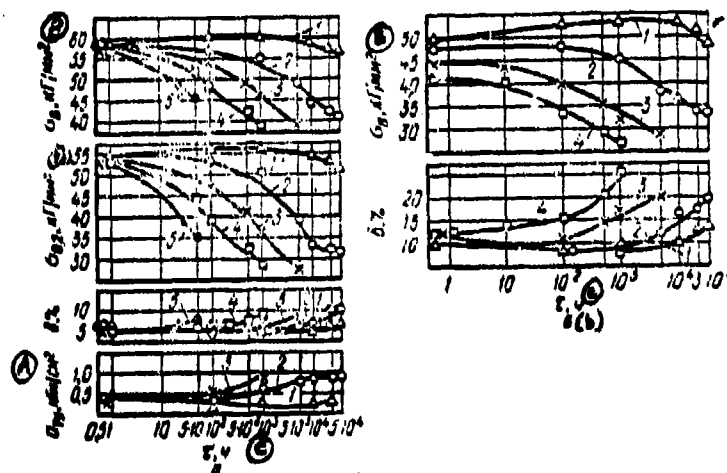
Notation. Semimanufactured products aged by the second and third procedures do not have a tendency toward corrosion cracking or intercrystalline corrosion.

*Lengthwise direction
**Crosswise direction

Long term heating (up to 5000 hr at 50° C) of pressed semimanufactured products aged at 140° C for 18 hr does not result in a decrease in the ductility the alloy. Strength characteristics increase by 4--5 kgf/mm². Heating at 70° C for up to 1000 hr gives the same results and for a greater length of time (3000 and 5000 hr) relative elongation decreases approximately by two times.

For articles which operate at increased temperatures it is important to take into account the effect of operational heating on the mechanical properties of the material.

Experimental data obtained showed that both reduced strength and strength at 125° C of pressed semimanufactured products from VAD23 alloy which are treated by two aging procedures (160° C, 10 hr and 200° C, 7 hr) are practically unchanged after heating at 125° C for 20000 hr (Figure 102).



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Figure 102. The Effect of Heating on Mechanical Properties of Thin Pressed Sections Aged at 160° C for 10 hr:

a--Testing at 20° C; b--Testing at heating temperature: 1--125° C; 2--150° C; 3--175° C; 4--195° C; 5--225° C

Key: A. kgf/cm² B. kgf/mm²
C. hr

Sections aged at 160° C have an advantage in strength characteristics. However their relative elongation and work breakdown of samples with cracks in a range of 1000--10000 hr is decreased. In sections aged at 200° C, the

decrease in ductility is not observed.

Heating at higher temperatures (150--200° C) results in a certain recrystallization by process annealing.

It is necessary to note the more intense decrease in strength after heating semimanufactured products aged according to the procedure: 200° C, 7--10 hr. Tensile strength of the sections after heating 1000 hr at temperatures 150 and 175° C decreases by 2--4 and 15%, and semimanufactured products aged according to a procedure of 160° C for 10 hr by 8 and 28%, respectively.

Pressed semimanufactured products made from VAD23 alloy are distinguished by high long-term strength and resistance to creep. Unclad sheet in heat resistance is close to pressed semimanufactured products. However, clad sheet has lower characteristics of heat resistance both in short-term and in long term tests.

Corrosion resistance of unclad semimanufactured products of VAD23 alloy is the same as for unclad semimanufactured products of D16 alloy. It is necessary to protect the alloys from corrosion by anodizing with an application of paint or varnish coatings.

VAD23 alloy deforms well in a hot state. And from it one can make all types of pressed, rolled and forged semimanufactured products.

The characteristics of deformation capability of the alloy in annealed and naturally aged states differ very little from each other. In an annealed state the alloy in properties is close to D16M alloy. The alloy aged at 140° C for 18 hr has a much greater ductility than after aging at 160 and 200° C. VAD23 alloy is satisfactorily welded in spot and seam welding.

2. Structural Alloy 01420¹

Aluminum, deformable, thermally work-hardened alloy 01420 belongs to the Al--Mg--Li system. The introduction of magnesium and lithium in the aluminum permitted obtaining a material with a specific weight decreased by 11% in comparison with D16 alloy and ϵ modulus of elasticity increased by 4%. In specific strength at room temperature alloy 01420 is better than D16T alloy and in corrosion resistance is close to AMg6M alloy. Pressed and rolled semimanufactured products are made from it.

Alloys of the Al--Mg--Li system were studied in detail in 1952 by F.I. Shamray [19]. He established that alloying Al--Mg system alloys with lithium has little effect on their mechanical properties and does not result in the appearance of effects of thermal treatment. The author came to the conclusion that developing new industrial compositions on this bases was not promising.

As a result of a research on series binary Al--Li and certain ternary Al--Mg--Li alloys with a low content of magnesium done in 1959 [20] noticeable work hardening was observed during artificial aging. However, strength properties of these alloys even after thermal treatment remained very low.

In 1965 I.N. Fridlyander, V.F. Shamray and M.V. Shiryayeva [21] discovered a large concentrated field of alloys of the Al--Mg--Li system which were distinguished by a considerable effect of work hardening after artificial aging and adequately high strength properties. However, the ternary alloys had low corrosion resistance. An increase in corrosion resistance was

¹Authors: I.N. Fridlyander, M.V. Shiryayeva, B.V. Tyurin, V.S. Sandler.

attained by the additional introduction of manganese, zirconium and silicon. This resulted in the creation of industrial alloy 01420, patented in a number of countries.

In equilibrium with aluminum solid solution in an Al--Mg--Li system [19, 21, 22] there are the following phases:

- 1) Mg_2Al_3 (β) cubic ($a = 28.2 \text{ \AA}$);
- 2) $Mg_{17}Al_{12}$ (γ) cubic type α -Mn ($a = 10.52 \text{ \AA}$);
- 3) $MgLiAl_2$ (δ) cubic ($a = 20.2 \text{ \AA}$);
- 4) $AlLi$ (δ) cubic, B 32 ($a = 6.37 \text{ \AA}$).

In work [21] the phase field ($\alpha + Mg_{17}Al_{12}$) did not fall into a number of studies with the temperatures and concentrations taken.

The figurative field of alloy 01420 in concentrations of magnesium and lithium on isothermal cross sections of the Al--Mg--Li diagram at quenching and at aging temperatures lies in phase fields where, with a solid solution, phases β and $Mg_{17}Al_{12}$ can coexist.

The phase composition of alloys of the Al--Mg--Li system has a strong effect on their mechanical properties (Table 61, Figure 103).

Alloys which are located in fields belonging to a binary Al--Mg system (fields α and $\alpha + \beta$) at the quenching temperature are not work hardened by thermal processing and have a tensile strength not greater than alloys of the magnalium type. Alloys, which at quenching temperature are located in fields ($\alpha + \delta$) and ($\alpha + \delta$), are thermally work hardened and have strength on the order of 45 kgf/mm^2 . The effect of thermal treatment amounts to $10\text{--}13 \text{ kgf/mm}^2$.

Work hardening in the aging process at temperatures $50\text{--}200^\circ \text{C}$ of binary low-alloy alloys of aluminum with lithium [20; 9], ternary alloys which contain $3\text{--}6\%$ Mg and more than 1.6% Li [23, 24], is determined by the segregation of spherical particles of δ' -phase with a dimension of several hundredths of

TABLE 61 THE MECHANICAL PROPERTIES OF ALLOYS OF THE Al-Mg-Li SYSTEM STUDIED

Содержание элементов, % (по массе)	Фазы	Отожженное состояние		Порядочно-выявленное состояние		Свежекатаное после ок.		Искусственно состаренное состояние после закалки		Эффект термической обработки после охлаждения			
		σ _{0.2} , кг/мм ²		σ _{0.2} , кг/мм ²		σ _{0.2} , кг/мм ²		σ _{0.2} , кг/мм ²		σ _{0.2} , кг/мм ²		σ _{0.2} , кг/мм ²	
		σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²	σ _{0.2} , кг/мм ²
Mg	Li												
6.52	—	32.1	14.0	36.9	32.7	15.3	37.0	—	—	—	—	—	—
6.67	0.50	32.8	14.1	27.1	32.5	15.4	31.3	—	—	—	—	—	—
6.73	0.75	30.0	14.0	20.8	32.0	17.2	15.7	—	—	—	—	—	—
6.67	1.00	30.0	14.5	23.2	30.0	16.9	10.5	—	—	—	—	—	—
6.48	1.45	37.1	17.5	22.4	40.8	23.2	21.0	35.7	16.2	30.0	—	—	—
6.76	2.30	36.7	19.0	15.2	42.5	29.0	14.1	43.8	23.1	16.3	—	—	—
5.70	—	29.6	13.0	32.0	29.3	12.9	37.3	—	—	—	—	—	—
5.82	0.30	29.9	13.6	37.5	30.2	13.2	36.0	—	—	—	—	—	—
5.70	0.50	30.5	13.7	33.2	33.9	13.0	24.0	—	—	—	—	—	—
6.06	0.74	31.0	14.0	29.1	30.4	13.5	31.7	—	—	—	—	—	—
5.76	0.99	31.8	13.1	34.6	31.0	13.7	31.0	—	—	—	—	—	—
5.76	1.46	33.3	14.2	30.6	34.6	16.2	30.0	33.1	14.5	33.1	—	—	—
5.76	1.95	36.3	15.0	21.3	31.9	15.3	29.1	34.3	15.1	29.6	—	—	—
5.70	2.13	33.6	17.0	19.0	35.0	19.0	23.5	42.6	22.8	18.4	—	—	—
5.90	2.96	29.8	18.0	14.0	38.0	19.6	15.7	42.0	24.0	9.2	—	—	—
4.60	—	24.4	9.7	34.6	25.3	9.6	34.0	—	—	—	—	—	—
4.65	0.50	26.0	11.2	32.4	27.7	12.6	32.3	—	—	—	—	—	—
4.90	0.98	28.9	12.4	30.7	28.7	13.2	29.3	—	—	—	—	—	—
4.60	1.49	28.8	12.1	29.8	28.9	12.9	25.2	—	—	—	—	—	—
4.85	1.86	31.3	13.0	25.9	31.5	13.4	26.0	30.0	11.9	27.3	—	—	—
4.42	2.26	32.0	13.2	16.5	36.2	17.4	24.7	36.3	17.2	25.9	—	—	—
4.86	2.73	30.0	12.5	12.6	35.7	19.5	16.7	37.6	20.7	15.1	—	—	—
1.66	0.53	15.9	5.4	29.3	20.1	9.6	23.8	—	—	—	—	—	—
3.44	1.07	24.0	9.3	32.4	26.0	10.9	28.0	—	—	—	—	—	—
1.66	3.64	25.8	14.3	13.1	31.0	20.5	9.6	29.7	15.3	17.9	—	—	—

Key:

a. Content of elements, % (by mass)

b. Phases

c. Annealed state

d. Hot-pressed state

e. Freshly quenched state after cooling

f. In air

g. In water

h. Artificially aged state after quenching

i. Effect of thermal processing after

cooling

j. kgf/mm²

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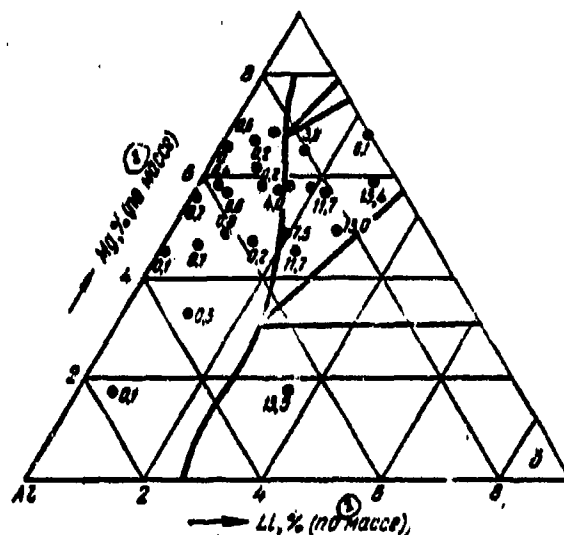
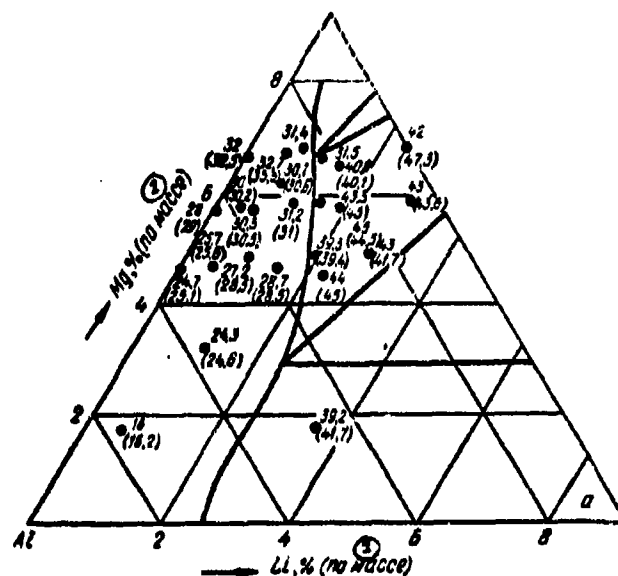


Figure 103. The Distribution of Phase Fields at 440° C, Tensile Strength (a), Effects of Aging (b) ($\Delta\sigma_s$) of Pressed Rods Made from Alloys of the Al-Mg-Li System After Quenching at 450° C in Air (in parentheses), in Water and Aging for 16 hr at 170° C

Key: 1. By mass

Angströms. This superstructure type Cu_3Au on a base g. ts. k. [Granetsentrirovannaya kubicheskaya (reshyetka), Face-centered cubic (lattice)] of aluminum lattice primarily of the composition Al_3Li is detected as an intermediate structure in the aging of alloy Al--2.2% Li. A decrease in the effects of thermal treatment with a decrease in the content of lithium in ternary alloys of the system is explained by the absence or lower intensity of segregation of the δ' -phase.

Alloys of the Al--Mg--Li system are not work hardened by natural aging. Corrosion resistance of alloys located in the field ($\alpha + \delta$) after quenching and artificial aging is very low: the loss of strength of alloys after testing over 3 months in a 3% solution of NaCl with the addition of 0.1% H_2O_2 after quenching in water and artificial aging approach 90--95%, after quenching in air after artificial aging--less than 25% and corrosion disintegration under stress occurs after 8--15 days.

The addition of manganese, zirconium and titanium increases strength characteristics of sheet and pressed semimanufactured products made from Al--Mg--Li alloys and also improves their corrosion resistance (Table 62, 63). Additions of manganese and zirconium improve mechanical properties of semimanufactured products to a considerably greater degree than does titanium.

The introduction of manganese (0.4--0.8%) in the alloy Al--5.5% Mg--2% Li results in the formation of surplus manganese intermetallic compounds of complex composition. Moreover, with the use of an electronic microscope one observes uniformly distributed fine manganese phases with dimensions 0.1--0.2 microns. (Their quantity amounts to several volumetric percents of the alloy). They form as a result of decomposition of the solid solution of super-saturated manganese after crystallization of the ingots.

TABLE 62 THE EFFECT OF MANGANESE, ZIRCONIUM AND TITANIUM ON MECHANICAL PROPERTIES OF PRESSED STRIP MADE FROM ALLOYS OF THE Al--Mg--Li SYSTEM QUENCHED AT 450° C AND AGED AT 170° C FOR 16 HR

a. Химический состав, % (по массе)					b. Закалка в воде			в. Закалка на воздухе		
Mg	Li	Mn	Zr	Ti	$\sigma_{0.2}$, кг/мм ²	$\sigma_{0.5}$, кг/мм ²	δ , %	$\sigma_{0.2}$, кг/мм ²	$\sigma_{0.5}$, кг/мм ²	δ , %
5,7	2,13	—	—	—	45,0	30,0	16,6	44,5	29,5	14,1
5,87	2,15	0,7	—	—	52,3	39,0	6,0	52,5	40,0	5,1
5,64	2,16	—	0,17	—	51,7	38,0	9,3	52,0	37,7	8,0
5,52	2,13	—	—	0,12	48,0	31,0	12,0	47,2	30,0	13,0
5,55	2,12	0,65	—	0,17	53,5	38,0	8,0	50,0	38,0	9,5

Key

- a. Chemical composition, % (by mass) c. Quenching in air
b. Quenching in water d. kgf

TABLE 63. THE EFFECT OF MANGANESE, ZIRCONIUM AND TITANIUM ON CORROSION RESISTANCE OF PRESSED STRIP MADE FROM ALLOYS OF THE Al--Mg--Li SYSTEM QUENCHED AT 450° C AND AGED AT 170° C, 16 HR

a. Химический состав					b. Вид закалки	в. Потери, %		г. Среднее время до разрушения, сут.
Mg	Li	Mn	Zr	Ti		σ_1	δ	
5,7	2,13	—	—	—	1. На воздухе	24,0	—	20
					2. В воде	95,8	—	14
5,87	2,15	0,7	—	—	1. На воздухе	10	25	87
					2. В воде	0	0	>90
5,64	2,16	—	0,17	—	1. На воздухе	0	0	70
					2. В воде	0	0	>90
5,52	2,13	—	—	0,12	1. На воздухе	1,6	43	72
					2. В воде	0	35	>90

Key:

- a. Chemical composition d. Average time before disintegration, days**
b. Type of quenching 1. In air
c. Loss, %* 2. In water

* Testing in a solution of 3% NaCl + 0.1% H₂O₂.

** Testing for the tendency to corrode under stress (stress 0.9 $\sigma_{0.2}$) in a 3% solution of NaCl with periodic submersion.

The addition of up to 0.15% Zr in a ternary alloy close to the composition described above decreases solubility of magnesium and lithium in aluminum. Therefore in distinction from a composition with manganese, after quenching at 450° C the large quantity of undissolved particles in the structure of the semimanufactured products is decreased, apparently, of equilibrium compounds of aluminum with magnesium and lithium with dimensions 0.1--0.3 microns. Dissolving of the particles occurs at 500--540° C.

The introduction of manganese, zirconium and also chromium (less than 0.15%) each separately or in combination slows down recrystallization. Strength properties of semimanufactured products then essentially improve and relative elongation drops. Corrosion resistance is improved considerably. The nature of work hardening in the process of thermal treatment of these complex alloy compositions is analogously described in literature for ternary alloys.

The results of research on the effect of magnesium (in ranges 5.0--6.0%) and lithium (1.6--2.3%) with 0.11% Zr show that with one and the same content of lithium the change of concentration of magnesium has very little effect on the mechanical properties of semimanufactured products of alloys from an Al--Li--Mg--Cr system in an artificially aged state. An increase in content of lithium from 1.5 to 2.4% sharply changes the mechanical properties: tensile strength and yield point increase by 10--14 kgf/mm², relative elongation is decreased by 12% (Table 64).

Research on the effect of lithium and magnesium on corrosion resistance showed that Al--Li--Mg--Zr alloys with a content of up to 1.8% Li have low resistance to corrosion under stress. When the content of lithium is 1.9% higher, the Al--Li--Mg--Zr alloys are not inclined to corrosion cracking. An addition of magnesium in ranges 5.0--6.0% does not affect resistance to

TABLE 64 THE EFFECT OF LITHIUM AND MAGNESIUM ON THE MECHANICAL PROPERTIES OF PRESSED STRIP MADE FROM ALLOYS OF THE Al--Mg--Li--Cr SYSTEM QUENCHED AT 450° C AND AGED AT 170° C, 16 HR

a. Содержание % (по массе)			b. Закалка в воде			c. Закалка на воздухе		
Mg	Li	Zr	$\sigma_{0.2}$ кг/мм ²	$\sigma_{0.2}$ кг/мм ²	δ %	$\sigma_{0.2}$ кг/мм ²	$\sigma_{0.2}$ кг/мм ²	δ %
5,05	1,61	0,11	42,0	24,0	15,0	43,5	23,6	15,6
5,05	1,94	0,10	53,2	35,4	6,0	53,2	37,4	6,1
5,04	2,26	0,12	55,8	42,0	4,5	55,7	41,0	4,0
5,91	1,58	0,11	43,0	20,0	14,8	44,9	25,0	15,3
5,95	1,83	0,10	55,5	35,5	4,8	56,9	37,7	4,5
5,95	1,9	0,11	57,9	39,5	3,8	57,3	39,0	4,3

Key:

- a. Content % (by mass)
b. Quenching in water

- c. Quenching in air
d. kgf/mm²

corrosion under stress (Table 65).

TABLE 65 RESISTANCE TO CORROSION UNDER STRESS OF PRESSED STRIP MADE FROM ALLOYS OF THE Al--Mg--Li--Zr SYSTEM IN A 3% SOLUTION OF NaCl WITH PERIODIC SUBMERSION (QUENCHING AT 450° C AND AGING AT 170° C, 16 HR)

a. Содержание, % (по массе)			b. Вид закалки	c. Среднее время до разрушения, сутки	a. Содержание, % (по массе)			b. Вид закалки	c. Среднее время до разрушения, сутки
Mg	Li	Zr			Mg	Li	Zr		
5,05	1,61	0,11	1. На воздухе 2. В воде	16 5	5,95	1,83	0,10	1. На воздухе 2. В воде	45 10
5,04	2,26	0,12	1. На воздухе 2. В воде	>90 80	5,95	1,9	0,11	1. На воздухе 2. В воде	>90 75
5,91	1,58	0,11	1. На воздухе 2. В воде	8 1	5,98	2,31	0,10	1. На воздухе 2. В воде	>90 >90

Key:

- a. Content, % (by mass)
b. Type of quenching
c. Average time before breakdown, days

1. In air
2. In water

When manufacturing aluminum alloys there is an inevitable accompaniment of admixtures of iron, silicon and sodium which have a considerable effect on technological strength and corrosion properties of materials. The results of

research on the effect of iron showed that up to 0.7% Fe does not change the mechanical properties, does not worsen corrosion under stress, but strongly decreases corrosion resistance. Silicon in quantities less than 0.3% does not affect tensile strength of Al--Li--Mg--Zr alloys, increases the yield point by 4 kgf/mm² and decreases relative elongation by 5%. For obtaining satisfactory corrosion strength of Al--Li--Mg--Zr alloys they must contain no less than 0.1% S.

Research on the effect of sodium in ranges 0.005 and 0.01% in a temperature range of 20--475° C on the properties of an alloy which contains 5% Mg, 1.9% Li, 0.11% Zr, showed that this element sharply decreases relative elongation and tensile strength of the alloy. Obviously, in this case sodium acts as it does in alloys of the Al--Mg system in which it also has an extremely unsuitable effect on ductility in the temperature range of deformation. The presence of sodium in alloys with lithium causes their embrittlement: during quenching cracks appear; thermal treatment does not have an effect on the alloy.

On the basis of research done the optimum chemical composition of alloy 01420 was established: base Al, 5.0--6.0% Mg; 1.9--2.3% Li; 0.09--0.15% Zr; 0.1--0.3% Si; admixtures not more than: 0.3% Fe, 0.1% Ti, 0.3% Mn, 0.005% Na [18, p. 42, p. 335; 25--27].

No change was observed in mechanical properties with alloy 01420 in the process of aging at room temperature. At temperatures 50--160° C the curves of strength properties increased monotonically up to a holding time of 100 hr, and at 180--300° C after maximum approached recrystallization by a process of annealing (Figure 104).

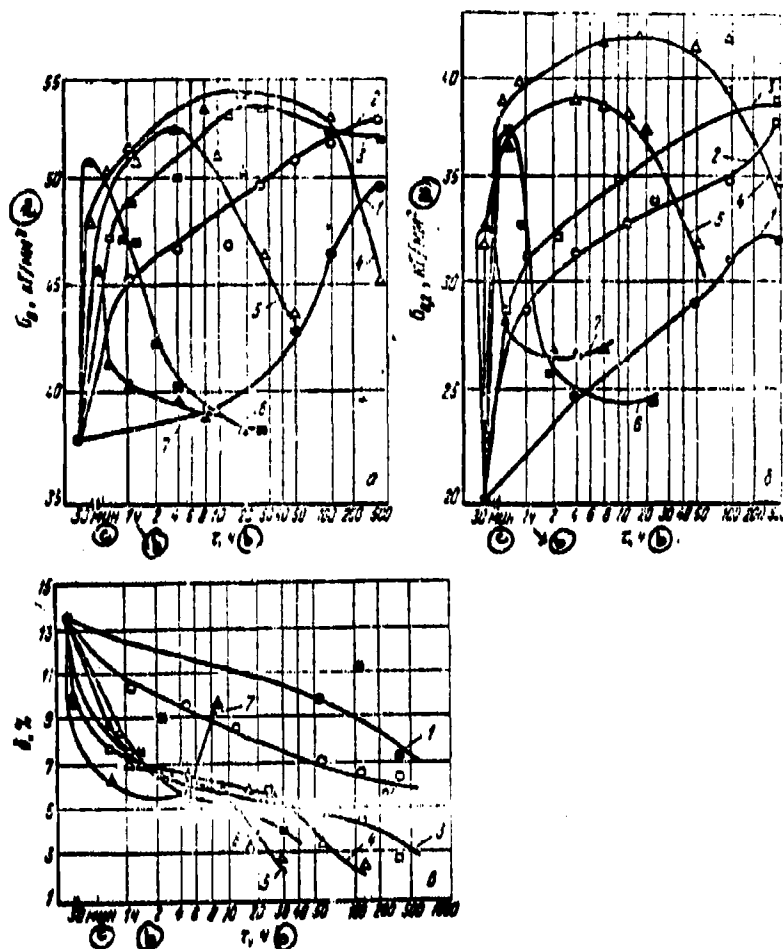


Figure 104. The Change in Tensile Strength (a), Yield Point (b) and Relative Elongation (c) in the Process of Aging Sections Made from Alloy 01420:

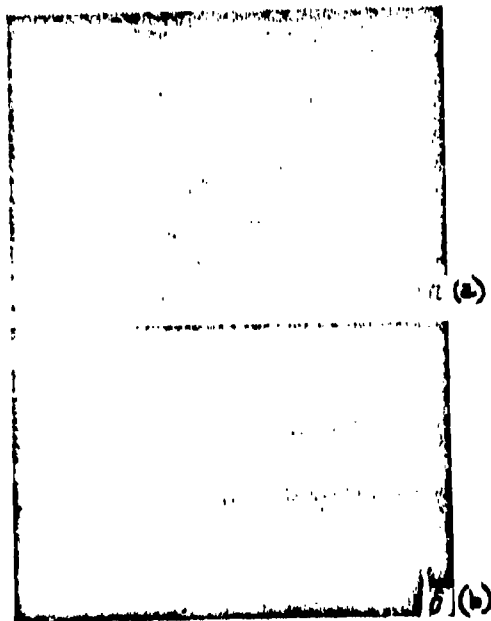
1--70; 2--120; 3--140; 4--170;
5--190; 6--250; 7--300°C

Key: a. kgf/mm^2 b. τ , hr. c. min.

Relative elongation drops corresponding to an increase in strength properties. Aging at 170° C for 8--24 hr results in obtaining maximum strength properties, and at 120° C for 12--48 hours one obtains improved ductility with a certain decrease in strength.

Work hardening of an alloy, apparently, is connected to an increase in the quantity and dimensions (within specific limits) of particles of the δ' -phase (Figure 105). Thus, if after 16 hr of aging the diameter of the particles is 50--150 Å, then after 100 hr, 100--300 Å. During decomposition of the solid solution, besides the δ' -phase, there form and increase thin segregations along the boundaries and compact crystal face particles, apparently, equilibrium phase or phase. In alloy 01420 with magnesium, without zirconium, these phases are formed mainly along inter-phase boundaries of manganese particles (Figure 105). Recrystallization by process annealing during aging is connected to enlargement and mainly to dissolving of the δ' -phase which occurs because of depletion of the solid solution during intensive formation and growth of stable segregations which contain lithium. In the process of aging, monotonic decrease in electric resistance occurs (Figure 107).

Figure 105. Dark-filled Microphotography (a) and Electronogram (b) of a sheet of 01420 Alloy with Magnesium Aged at 170° C for 100 hr X 35000



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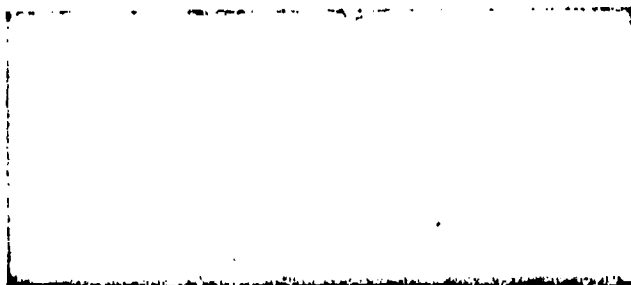


Figure 106. The Microstructure of a Sheet of 01420 Alloy with Manganese Quenched at 450° C in Water and Aged at 170° C for 100 hr (Oxide Replica). X 14500

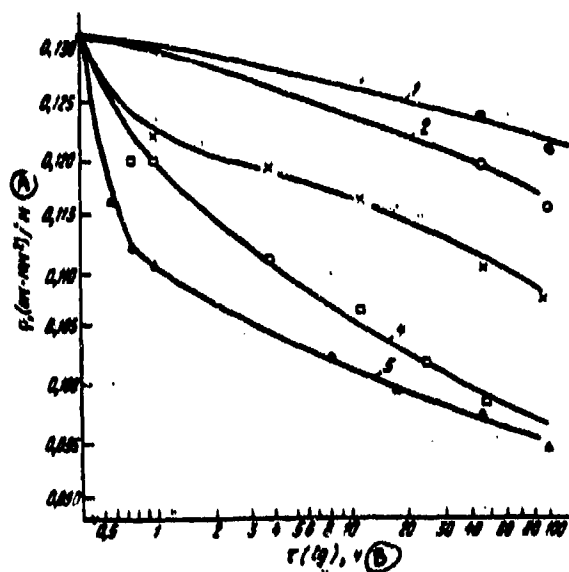


Figure 107. A Change in Electrical Resistance of Alloy 01420 (Pressed Section) Quenched from 450° C in Water, in the Process of Aging at temperatures:

1--70; 2--90; 3--120; 4--140; 5--170°C

Key: A. ohm·mm²

B. hr.

Alloy 01420 has an increased modulus of elasticity 7500 kgf/mm². It is known that the modulus of elasticity of alloys changes usually approximately additively depending on the size of the modulus of elasticity of the components and their content in the alloy. The size of the modulus of elasticity of aluminum, magnesium and lithium respectively is 7100, 4300 and 500 kgf/mm². Aluminum-magnesium alloys have a modulus of elasticity which decreases to 6900 kgf/mm². Alloys in the Al--Mg--Li system in spite of an extremely low corresponding characteristic for lithium have a modulus of elasticity considerably higher; consequently, these alloys have an anomalously high modulus of elasticity.

The typical mechanical properties of semimanufactured products made from alloy 01420 manufactured under industrial conditions are presented in Tables 66 and 67.

TABLE 66 TYPICAL MECHANICAL PROPERTIES OF SEMIMANUFACTURED PRODUCTS QUENCHED IN AIR AND AGED AT 120° C, 24--12 HR

② Полуфабрикаты	а $\sigma_{0.2}$ кг/мм ²	б $\sigma_{0.2}$ кг/мм ²	в $\sigma_{0.2}$ кг/мм ²	д, %	е $\sigma_{0.2}$ кг/мм ²	ж $\sigma_{0.2}$ кг/мм ²
① Штампованная вафельная панель (полотно, продольное направление)	23	28	45	12	1,2--1,4	0,8--0,9
② Прессованный профиль	22	31	47	10	—	0,3--0,5
③ Лист (поперечное направление)	20	27	44	10	—	0,2--0,4

Key:

- | | |
|-----------------------------------|--------------------------------|
| а. Semimanufactured products | lengthwise direction) |
| б. kfg | 2. Pressed section |
| 1. Stamped waffled panel (barrel, | 3. Sheet (crosswise direction) |

TABLE 67 SENSITIVITY TO CONCENTRATIONS OF STRESS* OF SEMIMANUFACTURED PRODUCTS
QUENCHED IN AIR AND AGED AT 120° C FOR 24 HR
(S.I. Kishkina, T.K. Ponarina)

② Полуфабрикаты	σ_B , кг/мм ²	σ_B^H ($\alpha_K=2.5$) кг/мм ²	σ_B^H/σ_B
① Штампованная вафельная панель (по- лотно)	42,0—44,5	34,0—37,0	0,82—0,84
② Прессованный профиль (толщина пол- ки 1,5—3,0 мм)	47,5—49,5	43,0—44,0	0,89—0,90
③ Лист толщиной 1,5—2,0 мм	45,0	36,0—37,0	0,80—0,82

* Концентратор — отверстие диаметром 3 мм, отношение ширины рабочей части образца к диаметру отверстия $b/a = 5$.

Key:

- | | |
|-----------------------------------|--------------------------------------|
| a. Semimanufactured products | 2. Pressed section (thickness of the |
| b. kgf/mm ² | rack 1.5--3.0 mm) |
| 1. Stamped waffled panel (barrel) | 3. Sheet thickness 1.5--2.0 mm |

Sheets of alloy 01420 with a thickness 2.5 mm during testing for compression and warping have the following characteristics:

$$E_{сж} = 7700 \text{ кг/мм}^2; \sigma_{-пл} = 20 \text{ кг/мм}^2; \sigma_{-0.2} = 28,5 \text{ кг/мм}^2; \sigma_{0.2 \text{ см}} = 35 \text{ кг/мм}^2.$$

Waffled panel during testing for twisting and shear strength have the following properties:

$$G = 2850 \text{ кг/мм}^2; \mu = 0,31; \tau_{пл} = 13 \text{ кг/мм}^2; \tau_s = 37 \text{ кг/мм}^2; \tau_{ср} = 27 \text{ кг/мм}^2.$$

Figure 108 shows the curves of fatigue and static strength of semimanufactured products made from alloy 01420.

Corrosion resistance of the alloy in a T1 state is the same as for alloy AMG6M. In quenched relatively homogeneous material, anticorrosion properties are considerably greater. After aging in semimanufactured products with a

*Concentrator--aperture diameter 3 mm, ratio of the width of the working part of the sample to the diameter of the aperture $b/a = 5$.

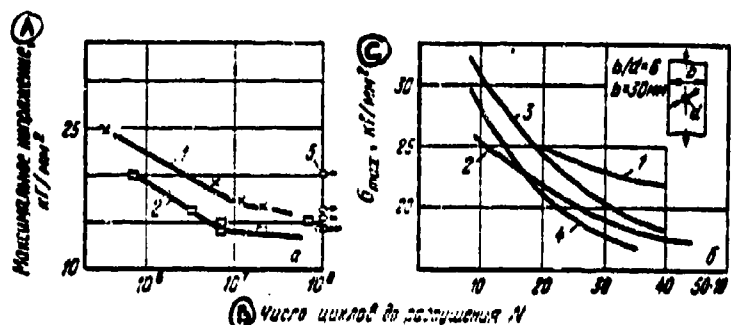


Figure 108. Curves of Fatigue (a) (Pure Bending During Rotation of Circular Samples) and Static Strength (b) (Flat Samples with Apertures) of Pressed Semimanufactured Products Made from Alloy 01420 in Comparison with Other Alloys; According to the Data of the Authors and S.I. Kishkina and Co-workers:

1--Alloy D16 ($\sigma_B = 44$ kgf/mm²); 2--01420 ($\sigma_B = 50$ kgf/mm²);
 3--VAD23 ($\sigma_B = 58$ kgf/mm²); 4--V95 ($\sigma_B = 60$ kgf/mm²);
 5--01420, reinforced with vibration cold hardening

Key: A. Maximum stress, kgf/mm² B. Number of cycles before disintegration N C. σ_{max} , kgf/mm²

recrystallized structure the intercrystalline corrosion grows, often in a type of delamination. This process is controlled by segregation in the form of dotted lines or sublayers along the boundaries. A decrease in the rate of quenching (for example in hot media, in air) slows down the boundary decomposition and increases resistance to the corrosion under stress. Semimanufactured products with partially recrystallized structure are subject to intercrystalline corrosion to a lesser degree because one does not observe formation of thin dotted line segregation along the sub-boundaries.

Research on the technological properties of alloy 01420 during the manufacture of parts from sheets and sections showed that pressed sections in a quenched state are characterized by high technological properties for bending,

cutting, levelling. One can manufacture fairly complex parts from sections. Sheets made of alloy 01420 in a quenched state have technological characteristics which are lower than those of D16T alloy. One can make parts from sheets of alloy 01420 with a smaller degree of deformation for one transition. The manufacture of complex parts by stamping, sheathing with double curves stretched on the press or knock-out parts must be produced in several passes using interoperational quenching. For obtaining maximum ductility it is recommended that one quench in water. For final thermal processing of parts made from alloy 01420 for obtaining satisfactory corrosion resistance quenching in air is desirable.

The use of alloy 01420 in structures showed that articles of equal value from alloy 01420 are 10--15% lighter than those from alloy D16. The decrease in weight is attained as a result of decreasing the specific weight of alloy 01420 while retaining the strength level of alloy D16. An analogous decrease in weight of structures when using high-strength alloys with increased specific weight is fairly complex to attain because a number of technological and design limitations exist for minimum thickness of parts. Moreover, one has to take into account the fact that, by far, not all the elements of the structure will have maximum load.

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