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Investigation of the effect of aging modes on the hardness of aluminum alloy

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ABSTRACT
Aluminum alloys are in demand in various industries, including the aircraft and automotive industries. Today, with the increase in the pace of life and the development of scientific and technological progress, the issue of increasing the strength of aluminum alloys is becoming increasingly relevant. Hardening as a result of the aging process is of great importance in the development of the aluminum industry. The process of isolating excess mass from a supersaturated solid solution is called aging. Aging occurs as a result of the appearance of non-metallic compounds due to elements introduced into aluminum. The article presents the experience of studying the effect of natural aging on the mechanical properties of corrosion resistant alloy sheets. As a result of the study, the effect of a break between hardening and aging on the mechanical properties of the alloy was established.

Key words: aluminum alloys, aging conditions of aluminum alloys, specific strength, heat treatment, natural aging.

1. INTRODUCTION

Aluminum alloys are in demand in various industries, including the aircraft and automotive industries. In the automotive industry, aluminum displaces steel and there is an objective need for its hardening. If the natural aging alloy is turned over for several seconds or minutes to the influence of high temperatures (up to 230-270 ° C) and rapid cooling, then the hardening is removed and the properties of the freshly quenched state are returned. The magnitude of the hardening depends on the nature of the hardener phase and the particle distribution. The greatest hardening of the alloys is achieved due to $MgZn_2$, Mg_2Si and the S phase (Al_2CuMg), which have a complex structure and composition different from the α-solid solution[1].

«Aluminum alloy 1913 can be attributed to the group of low-alloy alloys 1915, 1925 and 1935 of the A-Khp-M system, in which the total content of zinc and magnesium does not exceed -6.0%. These alloys are characterized by a high level of mechanical properties, good corrosion resistance, are well welded by all types of welding [2]. Alloy 1913 differs from these alloys by additional alloying with copper in a small amount (-0.5%)» [18].

The duration of natural aging after quenching has a certain effect on the mechanical properties in an artificially aged state. For a number of aluminum alloys, the interval between hardening and artificial aging is limited.

2. THEORETICAL FRAMEWORK

Before starting to consider the effect of aging on aluminum, it is necessary to consider the most characteristic properties of pure aluminum [3]. First of all, it should be noted its low density (2.7) and low melting point (660 ° C) [4]. Aluminum, unlike iron, has an almost three times lower density, so this metal and its alloys are used where low density and high strength are of high importance [5].

The processing technology of aluminum and its alloys is significantly different from the processing of iron [6]. Aluminum crystallizes in a face-centered lattice, does not have allotropic modifications, conducts heat well, has a high level of thermal conductivity and high latent heat of fusion. Aluminum undergoes little corrosion on air and in some other environments [7]. The more it is free from impurities, the higher its resistance to corrosion processes [8]. Among the areas of application of industrial aluminum are:

- stamping, rolling to a small thickness;
- electrical goals;
- transportation and storage of food [9].

The main alloying element for aluminum alloys is copper.

In figure 1, presented by A.K. Vershina depicts the Al-Cu state diagram [10].

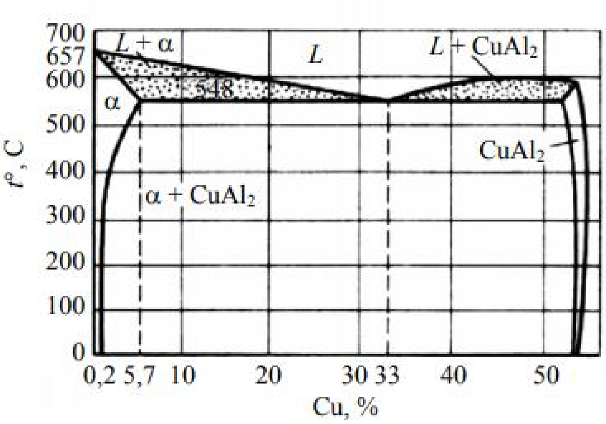

Figure 1: State diagram of the alloy Al–Cu

The course of the curve during hardening of the metal during aging is shown in figure 2.

Figure 2: Curve during hardening of metal during aging

The period that is characterized by weak hardening is called the incubation period [10].

The incubation period is of great importance, since for this period of time the alloy has the greatest ductility. And hardened parts can be deformed. The ability to deform begins to decline sharply after 2-3 hours. In case of artificial aging, the speed strongly depends on temperature (Fig. 3):

- increasing temperature increases the speed of processes;
- the higher the aging temperature, the lower the maximum strength obtained.

Figure 3 shows (according to A.K. Vershina) aging curves of duralumin [10].

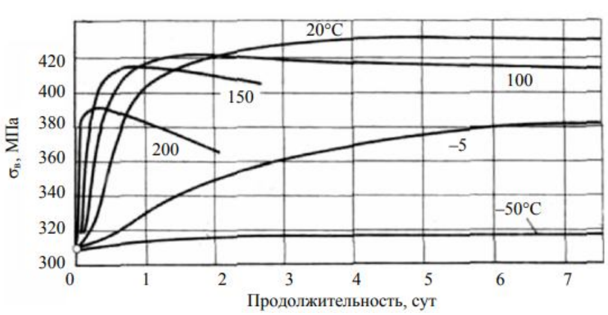

Figure 3: Duralumin aging curves at various temperatures (duration: day)

Aluminum alloys gain hardness when a controlled precipitation of alloy elements is established (due to decay of the supersaturation of the solution necessary for effective solidification), and so that the formed precipitate is connected (bonded) or partially connected with the lattice of the microstructure of the base metal.

The kinetics of precipitation of a supersaturated solid solution is a function, i.e. chemical composition. For example, for alloy 2024, aging is achieved naturally, while for alloy 7075, the kinetics of precipitation in a solid solution occurs only at +100 - 200 ° C. Alloys subjected to natural aging can be artificially aged [11].

But the best resistance to intergranular corrosion is achieved artificially. In natural aging, resistance characteristics and greater resistance to the propagation of fatigue cracks are preferred [11].

With different aging parameters, the same results can be achieved. For example, alloy 6060, the same conditions are achieved for 5 hours at 185 ° C and for 11 hours at 170 ° C.

In insufficiently aged parts, a decrease in the level of mechanical properties during subsequent processing may be observed [12].

Overcrowding can occur due to plastic deformation performed after quenching before aging (by rolling, molding, rolling, rolling, etc.)

These operations accelerate the kinetics of precipitation, proportional to the degree of deformation, in cases of homogeneous processing (such as stretching, compression, rolling, rolling) [13].

In General, the combinations are such as to bring the alloy to the maximum hardness of T6 [14]. T7 – more aging, rather overcooking, with a partial reduction in mechanical characteristics [14]. With such processing, it is possible to increase the stability of the product size, which allows the product to be used for work at high temperatures [15]. You can also develop greater resistance to surface corrosion or exfoliative corrosion (exfoliation) [16].

Products that will work at high temperatures, for example, motor parts can only achieve good dimensional stability when artificially aged, T5 processing is very rarely used in these cases, the material aged during natural aging. (T1) [17].

Alloys with a small amount of alloying substances, such as 6060, should age until the maximum hardness of T6 is reached [18].

Different processing cycles are used for products that require high accuracy (dimensions). Within 1-2 hours at 175-200C after pre-treatment (grinding), after machine processing and during intermediary phases [19].

At the first stage of isothermal aging cycles. For example, 6 hours at 100°C, up to 3 hours at 120°C. In the second stage, the temperature and time must be controlled, because it can cause changes in the physical properties of the part. The temperature in the oven must be uniform .

Undesirable effects of overcooking parts can be caused by a long process caused by a low heating rate caused by overloading the furnace.

The time between quenching (cooling) and aging does not affect the aging of the profile. However, it should be remembered that in some 6060 series alloys, the mechanical properties will be slightly higher if aging is performed immediately after quenching. While other alloys require exposure to ambient temperature before aging for better mechanical properties.

Table 1: The maximum interval allowed between the dissolution of substances and quenching (quenching delay).

Nominal thickness (mm)	Maximum time (seconds)
Before 0,3	4
0,3-0,8	6
0,7-2,3	9
over 2,3	14

Table 2: Hardening agent

Quenching agent	t °C	relative speed of the quenching agent and-product (m/s)	coefficient of thermal compliance
water	27	0,00	3,55
		0,25	4,78
		0,50	5,14
water	38	0,00	3,28
		0,25	4
		0,50	4,91
water	100	0,50	0,13
		0,00	0,13
		0,25	0,13

Deformable thermally strengthened aluminum alloys include, for example, duralumins (D1, D16, etc.), forging (AK4, AK6, etc.) and other alloys.

To justify the choice of the quenching temperature, as well as to explain the transformations that occur in alloys during heat treatment, we use the diagram of the state of Al–si, shown in fig. 4.

The alloy becomes single-phase. With rapid cooling, the intermetallic θ-phase does not have time to separate from the solid solution, which results in the structure of a homogeneous supersaturated solid solution of copper in aluminum at room temperature. Alloy state diagram proposed by G.V. Klevtsov is shown in figure 4 [17].

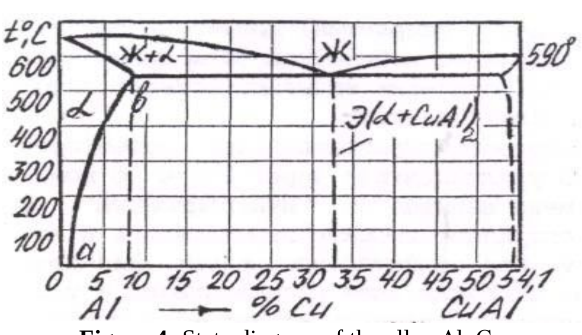

Figure 4: State diagram of the alloy Al–Cu

Underheating leads to the fact that the secondary θ-phase does not completely pass into the solid solution, which worsens the mechanical properties. Within the guignier – Preston zones, atoms are rearranged «and new intermediate θ′ ($CuAl_2$) и θ′′ ($CuAl_2$) phases. hey have a strongly distorted crystal lattice compared to the θ ($CuAl_2$) phase. Fine particles of θ′′ и θ′ – phase partially "coherent or coherent with the main solid solution» [18] (fig. 5 a, b) strengthen the alloys (3), creating barriers to moving dislocations. According to G.V. The Klevtsov interface between the selections and the matrix is as follows.

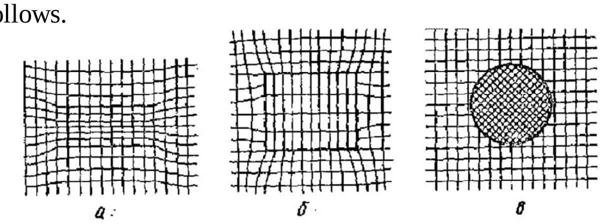

Figure 5: Fully coherent (a) and partially coherent (b) incoherent and (b) the interface between the precipitates and the matrix

Increasing the duration of artificial aging leads to the transition of theθ′ (CuAl2) phase to a stable θ ($CuAl_2$) phase that does not have a coherent connection with the solid solution (fig. 6 in). The formation of an «incoherent θ- phase and its enlargement lead to a decrease in distortion from the duration of aging of the solid solution crystal lattice and the softening of the alloy» [18] (fig. 6) (.According to G.V. Klevtsov) [17].

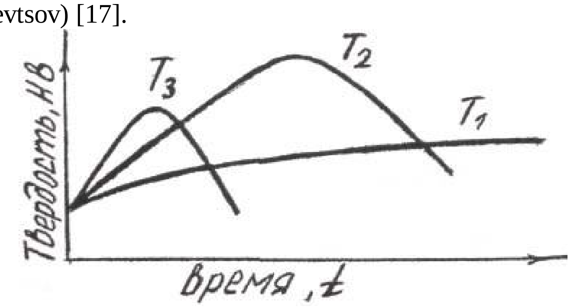

Figure 6: Diagram of the dependence of the hardness of hardened duralumin on the aging time at different aging temperatures ($T_1 < T_2 < T_3$)

Thus, the sequence of structural changes during artificial aging of Cu–Al alloys can be represented as a GP scheme→ θ′′ → θ′ → θ ($CuAl_2$).

As can be seen from fig. 5, with artificial aging of duralumin (curves T_1, T_2 и T_3) its hardness first increases, reaches a maximum and then decreases.

3. RESULTS AND DISCUSSION

Instruments, materials and tools for conducting research:

- muffle oven, pliers;
- quenching tank with water;
- Brinell hardness tester;
- magnifying glass for fingerprint measurement;
- aluminum alloy samples;
- calliper;
- abrasive paper.

«Based on the results of research on the DSK curves of alloy 1913 and the influence of quenching parameters, the heating temperature for quenching was selected: 470°C. Samples from the sheets were quenched in water at room temperature» [18]. Determination of mechanical properties «under tension was performed at room temperature in accordance with GOST 1497-84 on a universal servo-hydraulic testing machine MTS (USA)» [18].

Tests for delaminating corrosion were carried out according to GOST 9.904-82. Flat samples of 60x40 mm size were used for testing. Before the test, the samples were etched in a 10% solution of caustic soda at a solution temperature of 60°C for 5 minutes and clarified in a 30% solution of nitric acid, after which they were again washed and dried in air. The tests were performed when the samples were completely immersed in solution No. 4 for 7 days at a temperature of 18-25°C.

The maximum strength growth in alloys of Al-Zn-M and Al-Zn-M-Cu systems is observed in the first three months, and then-slows down, but a slight increase in strength is observed after three years of exposure. «The regularities of changes in mechanical properties during prolonged natural aging up to 3500 hours of sheets made of alloy 1913 are established. The strength and yield limits increase to 465 and 325 MPa, respectively, with a slight reduction in elongation from 26.5 to 24%. The break between quenching and artificial aging up to 4 months practically does not affect the strength limit, while slightly reducing the yield strength (by 30 MPa) and maintaining high corrosion resistance» [18].

4. CONCLUSION

When the alloy reaches maximum strength, there is no excess phase and hardening is not associated with the decomposition of the solid solution.

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