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EFFECT OF THE TYPE OF AGING AFTER SUPERSATURATING ON HARDNESS AND AW-7020 STOP STRUCTURE

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Abstract

Aluminum alloy AW-7020 is characterized by high fatigue strength. It is used primarily in welded constructions, which should be characterized by high strength and resistance to cyclically variable operational loads. They have found wide application in light welded ship constructions, bridge-carrying elements, cranes, hoists, vehicles, roof beams in roof constructions, and security barriers. The paper attempts to determine the influence of selected types of applied heat treatment on the structure and hardness of the AW-7020 alloy used in the shipbuilding industry. Heat treatment processes have been described in the aspect of improving the mechanical and strength properties of the tested alloy and its impact on ductility. Several supersaturation and aging sequences were used in the course of the study. The results of hardness tests of aluminum alloy after its earlier supersaturation and aging (natural and artificial) have been presented. Photographs of internal structures in individual sequences were taken. The obtained hardness measurement results and analysis of structures in individual states were compared with the delivery condition. To illustrate selected heat treatment processes, transient tests were also performed to accurately verify the effect of aging after saturation on hardness and changes occurring in the material structures. The results of the material tests showed that the type of heat treatment after saturation is of significant importance for the hardness and structures of the AW-7020 alloy. As a result of the research, it was proved that the tested alloy obtained in the artificial aging process more favourable strength properties, in a shorter period, compared to the use of the natural aging process.

***Keywords**: AW 7020 alloy, natural aging, artificial aging, saturation, hardness, ductility, internal structure*

1. Introduction

The technological development enabling the emergence of new, more advanced constructions requires, from constructors from many industries, to search for and use new types of materials, alloys with combined mechanical and physical-chemical properties, i.e.: lightness and durability, good flexibility, ease of processing, corrosion resistance, easy surface treatment, ease of forming and joining, non-toxic and non-flammable, good electrical conductivity and processability as a secondary raw material [1].

Considering the above parameters, it is not surprising that the range of aluminum and its alloys is a very wide and growing range as a perfect alternative to steel, but the relatively low mechanical properties of pure aluminum have significantly limited its use as a structural material for many years. A series of technological advances in the aluminum manufacturing process, the development of new alloy compositions by introducing further combinations of alloy additives and the use of heat and plastic treatment allows to optimize the manufactured components, adapting them to the assumed design needs. Due to the types of modifications and application, these alloys can be divided into casting alloys, usually multicomponent with a concentration of alloy elements at the level of 5-25% mainly Cu, Mg, Si, the most widely used group of these alloys are silills with extremely good castability enabling the elements to be made with complex shapes and relatively thin walls while maintaining good strength properties. The next group are alloys for plastic forming which after heating have a single-phase structure of a solid solution and show good plastic properties, they contain Cu, Mg, Si, Fe, Ni, Cr, Zn, Ti as the main alloying components, however the content of individual additives is lower from their solubility in Al. The basic alloys of this type can include duralumin with high strength after heat treatment, but low corrosion resistance and hydronalium with good corrosion resistance, especially in seawater. Aluminum alloys can also be divided into precipitation-hardening, which can be subjected to strengthening plastic processing (ie supersaturation and natural or artificial aging) and unpolluted alloys, whose strength can be increased by plastic deformation, cold deformation.

Subsequent research on new types of alloy joints and various types of plastic processing clearly show that changes that increase one parameter often have a significant impact on reducing other beneficial properties. On the example of a batch of samples made of aluminum alloy with the AlZn5Mg2CrZr marking, it has been proved that the addition of Cr, Zr and Ti additives to the original material AlZn5Mg1 improves the strength properties but decreases the plastic properties of the material. At the same time, it was shown that the type of heat treatment, i.e. variable cooling rate after supersaturation, does not affect the fatigue and corrosion properties of the tested material [4].

Supersaturation and aging is a way to strengthen aluminum by using the phenomenon of decreasing solubility of one component in the other when lowering the temperature. This process can be divided into two successive stages. The first stage is supersaturation consisting in heating the batch at a high temperature, above the solubility temperature limit of a single-phase solid solution, this process ends with a rapid cooling allowing the well-dissolved substance and allowing its release from the solution. The material subjected to this process will exhibit low strength and hardness as well as high ductility. The next step after this treatment will be aging during which the solution of the supersaturating component is released. This component is characterized by a form with small phases and a defined degree of dispersion. Considering the method of aging, we distinguish between natural aging that spontaneously occurs in the ambient temperature (close to room temperature) and artificial aging (accelerated) that overheat the material for a certain time at a given temperature. Depending on the chemical composition of the alloys and the components of the equilibrium systems formed by their components, we can obtain a wide range of strengthening by matching the appropriate parameters. The phenomena described above are often called precipitation strengthening (dispersion). When using the processes in question, we can obtain far-reaching benefits consisting in the optimization of parameters in order to achieve the assumed properties, for eg increased resistance of the material to corrosion at the expense of strength or vice versa.

The purpose of the conducted research was to determine the influence of plastic forming (rolling), supersaturation and aging (natural and artificial) of samples made of metal plate with the symbol AW-7020 in several assumed time and temperature intervals for structural changes of the material and changes in its physical properties, hardness tests for of tested samples in all accepted states. At the same time, reference was made to parallel tests of strength and results from a tensile test performed on samples given processes with identical temperature parameters, while maintaining the same time intervals for tests.

2. Characteristics of the material tested and research methodology.

Samples for testing were made of rolled metal plate 7020 F35 made according to EN-AW 7020, whose chemical composition (according to declaration of conformity HP-Stal No. KJ / 2014/09192 of

19.09.2014) is shown in Tab. 1. This type of alloy was chosen due to the alloy addition used in it, and especially on the Ti content, which ensures the fine graining of the alloy structure by reducing the grain size and the contribution of large secondary phases in the grain matrix and their boundaries [9, 4].

Tab. 1. The chemical composition of the AW-7020 alloy quality plate

Material type	Content of alloys [%]										Number of heat	Standarts
	Zn	Mg	Cr	Zr	Ti	Fe	Si	Cu	Mn	Al		
AW 7020 F35	4.53	1.22	0.19	0.13	0.03	0.24	0.10	0.14	0.24	rest	1-12-9007	EN AW 7020 EN 10204:2004

In the research in question, the process of thermal rotation in the form of precipitation strengthening was used. Effective precipitation strengthening of aluminum alloys consists in introducing foreign atoms and dislocations into the basic metal network and creating a corresponding number of very strong and stable precipitates of intermetallic phases, preferably in the form of uniformly distributed and fine particles. In order to obtain such a structure in the dispersion reinforcement process, the content of the Ti alloy [6, 1] was added to the selected material.

The analysis of the results of the previous tests of 7XXX alloys clearly shows that in addition to the phase composition (relative volume, morphology, dispersion and distribution of intermetallic phases), heat treatment and, in particular, crack resistance, have a decisive influence on strength properties, plasticity and precipitation strengthenin. The fatigue strength and fatigue and corrosion resistance of artificially aged alloys from group 7XXX depends on the cooling rate after supersaturation. The increase in the cooling rate (tb21) increases fatigue strength, but radically reduces fatigue and corrosion resistance. On the other hand, reducing the cooling rate after supersaturation increases fatigue and corrosion resistance [5, 6].

Samples for testing were made in such a way as to enable further processing related to the metallographic defect (etching, grinding and flooding of the mould with resin) as well as leaving some of them to perform a hardness test. At the same time, it was taken into account that the tested alloy achieves maximum strength properties in the cooling process after supersaturation of 0.5°C/s. Cooling of this alloy should be carried out in the air stream or with the use of immersion in water at ambient temperature [8]. The list of parameters related to heat treatment of the samples is presented in Tab. 2, the plastic working was made using a laboratory furnace with a ceramic-resistance insert from SNOL, model 8.2 / 1100, while metallographic examinations were made using a STRUES matalographic grinder of the Labotom 5 type using 4 grinding phases (variable abrasive granulation, variable process times with a total time of deflection of 17 minutes), and then the samples were subjected to etching in 1% HF solution.

Fig. 1. The sample aging process in the SNOL furnace model 8,2 / 1100

Fig. 2. The process of preparation of metallographic sections using a STRUES type Labotom 5 grinder

Tab. 2. List of plastic forming parameters

<table>
<tr><th rowspan="3">Material type</th><th rowspan="3">Destignation of the sample</th><th colspan="3">Parameters of heat treatment</th><th rowspan="3">Destignation of heat treatment</th></tr>
<tr><th colspan="2">Supersaturation</th><th rowspan="2">Aging</th></tr>
<tr><th>Temperature/time</th><th>The cooling method after supersaturation</th></tr>
<tr><td>AW-7020 F35</td><td>0</td><td>---</td><td>---</td><td>---</td><td>as-fabricated state</td></tr>
<tr><td>AW-7020 F35</td><td>1</td><td>450°C/1.5 hours</td><td>water at temp. 20°C</td><td>air at temp 20°C for 6 days</td><td>intermediate state</td></tr>
<tr><td>AW-7020 F35</td><td>2</td><td>450°C/1.5 hours</td><td>powietrze o temp. 20°C</td><td>air at temp 20°C for 90 days</td><td>ta</td></tr>
<tr><td>AW-7020 F35</td><td>3</td><td>450°C/1.5 hours</td><td>water at temp. 20°C</td><td>air at temp 20°C for 6 days, then heating at temp. 95°C for 15 hours and at temp.150°C for 10 hours.</td><td>tb21</td></tr>
</table>

Prepared metallographic sections were tested on a metallographic stand presented below using ZEISS type Axio Obserwer D1 Mat, a metallographed microscope, allowing observation of metallographic specimens in reflected light using an adapted computer station. The structures analyzed for particular, assumed states (Tab. 2) are shown in the pictures (5a, 5b, 5c, 5d).

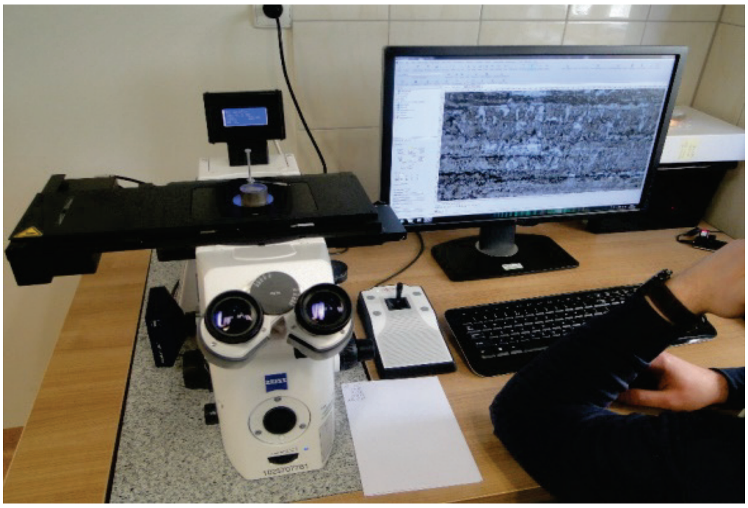

Fig. 3. Condition for metallographic research using the ZEISS microscope model Axio Obserwer D1 MAT

In the next stage of the conducted tests for samples corresponding to the assumed conditions (Tab. 2), the hardness was measured using the Qness Q250M hardness tester shown on Fig. 4 with Qpix t12 software. The study was carried out in parallel with two attached measurement methods (Vickers and Brinell), a summary of the measurement results is presented in Tab. 3 (mean values from three measurements for each measurement position).

At the same time, the comparative analysis was based on the results of the tensile tests performed on the samples made in accordance with the recommendations of PN-EN ISO 6892-1: 2010, [9] and the same processes of plastic forming (summary Tab. 2, picture 1), the average measurement results obtained in the implementation of static tensile tests on the Zwick & Roell strength machine MPMD P10B using the Zwick & Roell software XpertII test for the samples in question are presented in Tab. 3 (mean values of three measurements for each measurement position).

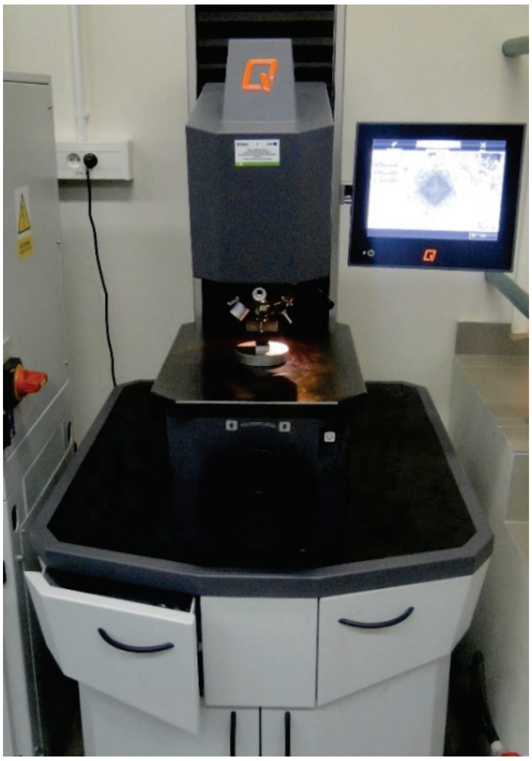

Fig. 4. Hardness test stand, Qness Q250M hardness tester, QPix T12 software

Tab. 3. List of test results for all samples [3]

Destignation of the sample	**m_E** [GPa]	**$R_{p0.2}$** [MPa]	**R_m** [MPa]	**F_m** [kN]	**A_{50}** [%]	L_c [mm]	L_0 [mm]	d_0 [mm]	S_0 [mm²]	**Z** [%]
0	70.59	294.42	379.50	19.09	12.11	60	50	8.00	50.31	18.39
1	72.52	221.34	354.01	17.74	13.92	60	50	7.99	50.10	22.59
2	71.38	247.83	393.34	19.87	14.45	60	50	8.02	50.52	19.63
3	72.03	360.68	414.97	20.84	13.09	60	50	8.00	50.22	46.60

3. Discussing research results.

The selection of heat treatment parameters of Al alloys largely regulates the process of separation of transition and equilibrium phases, as well as the structure of the matrix and the degree of coherence of precipitates with the matrix. The magnitude of these precipitates regulated by the aging process usually grows, which leads to the development of deformations (HB growth) associated with their confusion in the structure. Under certain conditions associated with these deformations, the cyclic strain energy exceeds the boundary level of the coherent interface between the precipitates and the matrix, and the secretion becomes nicoherent. This is accompanied by changes in the interaction between secretions and dislocations from the impact of creating dislocation loops or bypassing precipitates. The direct effect of these changes seems to be changes in the slope of the strength curves in the cooling rate function [4].

Effect of heat treatment on the structure of the AW-7020 alloy material with chemical composition (according to the declaration of conformity HP-Stal No. KJ / 2014/09192 of 19.09.2014, Tab. 1) in four assumed design states by plastic forming processes (Tab. 2), are shown in pictures 5a, 5b, 5c, 5d.

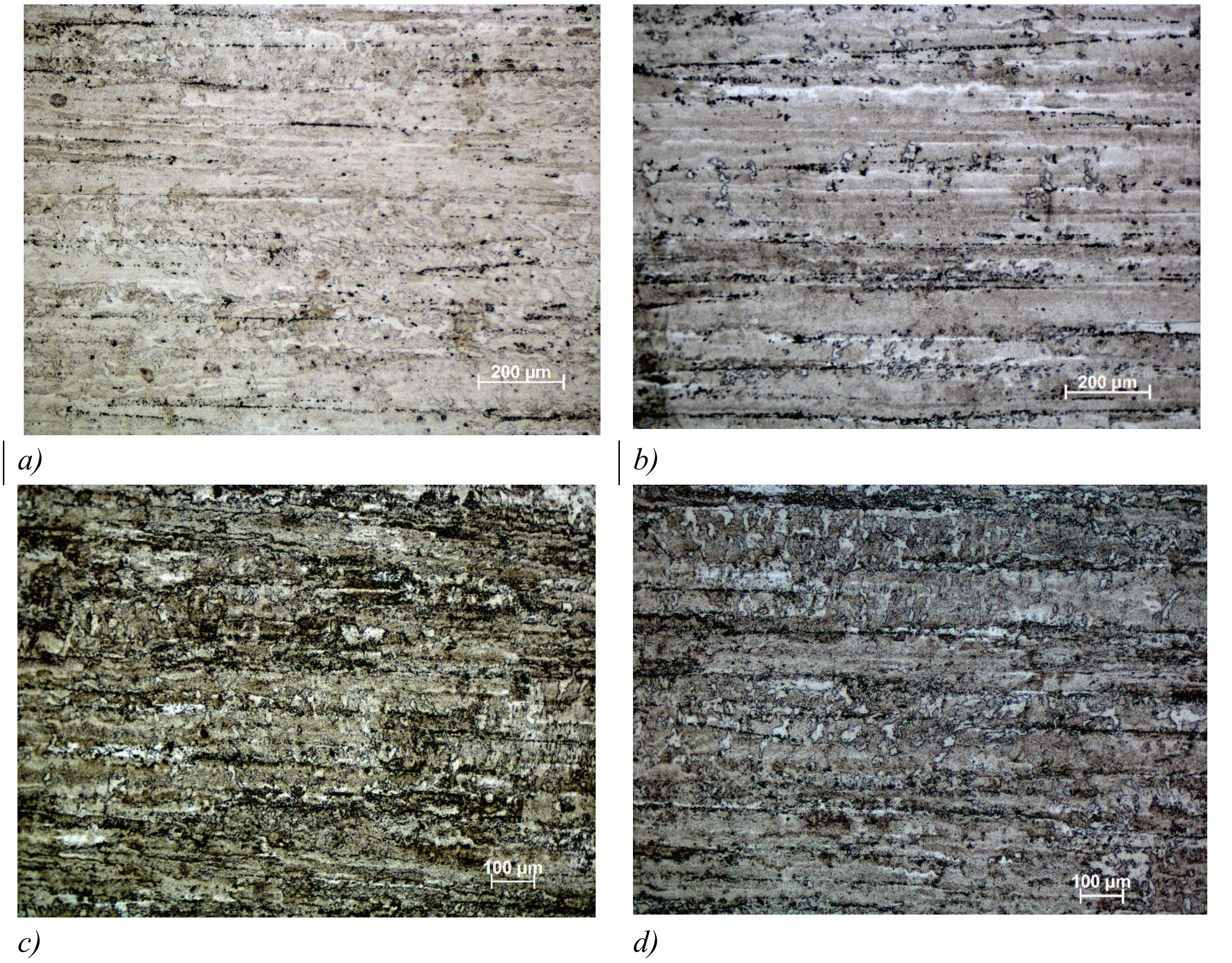

Fig. 5. a) Sample 0, as fabricated state,(parameters: Tab. 2, position 1), rolled surface. Magnification 100x b) Sample 1, intermediate state, (parameters: Tab. 2, position 2), supersaturation 450°C, aging 6 days, rolled surface Magnification 100x; c) Sample 2, state ta, (parameters: Tab. 2, position 3) supersaturating 450°C, aging 90 days rolled surface. Magnification 100x; d) Sample 3, state tb21, (parameters: Tab. 2, position 4), supersaturating 450°C aging 6 days and 1 hour in variable temperatures, rolled surface. Magnification 100x

The hardness tests carried out showed that the properties of the material were subject to significant changes in particular assumed states of the precipitation process (Tab. 2). The hardness of samples supersaturated and artificial-aged (state 3, tb$_{21}$) 105 HV was 7% higher than the initial state (delivery status), for which the parameter was accordingly 105 HV. At the same time, the averaged results obtained from the static tensile test carried out on samples from the same material being in the same state of the precipitation process (state 3, tb$_{21}$) were respectively: for the strength limit, the value of Rm was 414.97 MPa, which constituted 9.35% increase to the state the initial one for which Rm amounted to 379.50 MPa with a simultaneous increase in plasticity, the extension of A_{50} from the initial level of 12.11% to the level of 13.09%.

Tab. 4. A summary of the measurement results for samples corresponding to the machining conditions shown in

No. of sample/ state Tab. 2	*Vickers measurement [HV]*	*Brinell measurement, ball ϕ 1, load 5 kg [HBW]*
0	105	100
1	98	92
2	109	102
3	125	116

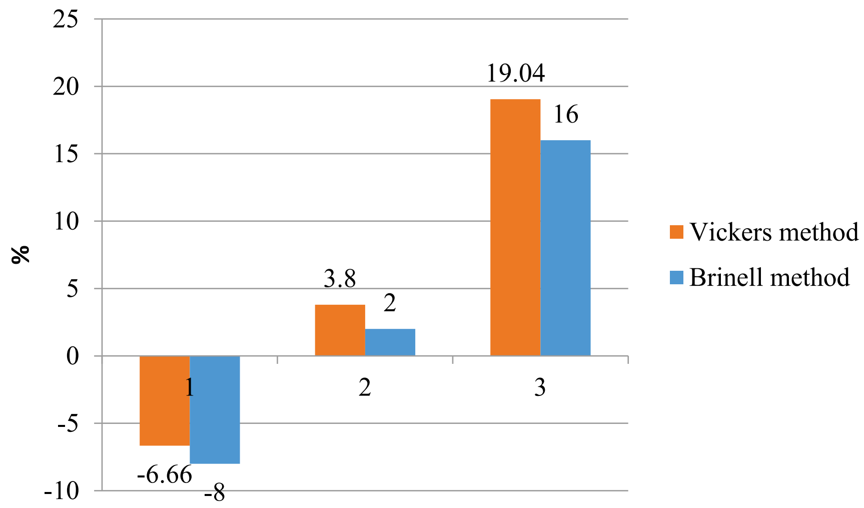

Fig. 6. Comparison of percentages of increase and decrease in hardness (by Brinell HBW method and Vickers HV method), in relation to the state of the sample 0

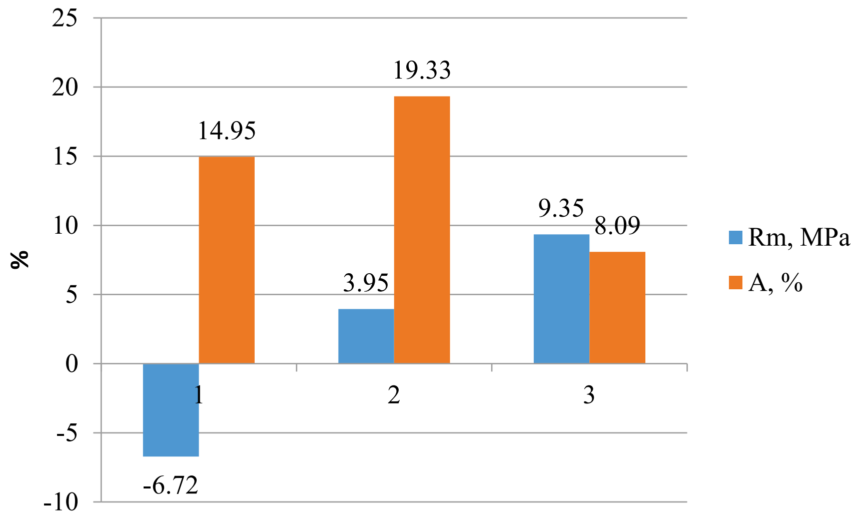

Fig. 7. Percentage increase and decrease of the tensile strength limit (mean values) and percent elongation (mean values) in relation to the 0 sample

The hardness of samples supersaturated and aged naturally (state 2, ta) was 109 HV and was 3.8% higher than the initial state. At the same time, the averaged results obtained from the static tensile test carried out on samples from the same material being in the same state of the precipitation process (state 3, tb_{21}) amounted respectively to the limit of resistance Rm, the value was 399.34 MPa, which was 3.95% increase to the state the initial one for which Rm amounted to 379.50 MPa with the simultaneous increase in plasticity, the elongation of A_{50} from the initial level of 12.11% to the level of 14.45% (Fig. 6, 7, Tab. 3).

Intermediate state (state 1) for samples subjected to supersaturation at 450°C / 1.5 hours. and then natural aging at 20°C, the duration of 6 days, was at the level of 98 HV, which was a 7% reduction in the parameter value, Rm was 354.01, which was 6.71% decrease compared to the initial state, and the endless plasticity slight improvement to 13.92% (Fig. 6,7, Tab. 3).

4. Conclusions

1. The conducted research clearly showed that the adopted plastic forming algorithms shape the precipitation processes in the tested AW 7020 alloy and significantly affect its structural shape,

and consequently the physical properties (strength, hardness, ductility).

2. Appropriate selection of the parameters of plastic forming (supersaturation and aging), related to the alloy's chemical composition, allow for adjusting its properties (in certain ranges) to the assumed needs.
3. Artificial aging in many aspects allows to obtain higher parameters, properties (higher strength, higher hardness), however, it can be done at the expense of other parameters (deterioration of plasticity, reduction of fatigue and corrosion resistance).
4. The modification of AlZnMg alloy structure with alloy elements such as Cr, Zr, Tr improves the strength properties by about 15%, but lowers the plastic properties as a result of the strengthening of hard AlMg phases, the distribution of which depends on the cooling rate after supersaturation [4].
5. Artificial aging allows to obtain a material with more favorable properties in many ranges (strength, hardness) in a much shorter period of time than material aged naturally.

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