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RESEARCH ON THE IMPROVEMENT OF THE MECHANICAL PROPERTIES OF ALUMINUM ALLOYS OF THE SERIES Al-Zn-Mg-Cu BY HEAT PROCESSING

Marian-Iulian NEACȘU
“Dunarea de Jos” University of Galati, Romania
e-mail: mneacsu@ugal.ro

ABSTRACT

The paper presents the results of the research carried out on an Al alloy from the 7000 series. The material was subjected to several variants of thermal and thermomechanical processing. Research has been conducted on various artificial aging temperatures of the material in combination with various aging time values. Some samples were also subjected to plastic deformation, between quenching and artificial aging, in order to determine the influence of this deformation on the values of the final mechanical properties.

KEYWORDS: aluminum alloy, solution hardening, artificial aging, plastic deformation

1. Introduction

The high mechanical properties, which characterize the Al-Zn-Mg-Cu system alloys, are obtained by plastic deformation and hardening thermal treatment, the last operation being performed under conditions similar to those applied to the other light alloys that can be hardened by precipitation, respectively putting in solution, quenching in water and artificial aging [1].

Establishing the technological elements that determine the heat treatment of Al-Zn-Mg-Cu type alloys required a large volume of experiments, the working conditions having a direct influence on the material's resistance to stress cracking corrosion [2].

In parallel with the classical processes, the application possibilities of thermo-mechanical treatment, isothermal treatment and thermal treatment in steps to these alloys were studied, on the one hand, and on the other hand, the mechanical properties that could be obtained in each case.

During the thermal treatment of aluminum alloys, supersaturation of the solid solution (putting in solution), maintenance of the supersaturated solid solution at ambient temperature (quenching), precipitation, in the mass of the supersaturated solid solution, of the excess phases, in the form of fine and uniformly distributed particles (aging), which ensure the hardening of the alloy [2].

The solution temperature Ts must be close to the melting temperature Tt of the alloy; practically it is accepted: Ts = Tt - 30 °C. The duration of the operation is variable depending on the type of alloy, the casting conditions, the geometry of the part and the thickness of its walls. During the solvation operation there is a substantial increase in the number of vacancies (from 10^{-4} to 10^{-3}), due to the rise in temperature [3].

The effect of quenching depends on the type of alloy and the rate of quenching; the last parameter is conditioned by the thickness of the part walls and the cooling medium used. Tempering allows, at normal temperature, to maintain the number of vacancies from the solution temperature.

Since the transition of the alloy from the hardened state to the aged state is not instantaneous, intermediate, metastable states appear in the material during the operation.

If the temperature does not exceed the ambient one, in the hardened material there is a monophasic, sub microscopic separation of atoms of the phase dissolved in excess in the form of coherent precipitates, which are deposited in the material of the basic solid solution recipe, as agglomerations; sites enriched in separate atoms form the GUINIER-PRESTON zones [4, 5].

The changes that occur because of this in the arrangement of the atoms in the network of the basic solid solution produce a hardening of it called cold hardening.

At slightly higher temperatures, metastable precipitates of an intermediate phase appear, which differ, from the point of view of the crystalline recipe, both from that of the basic solid solution and from that of the stable precipitation phase [6, 7].

Along with the appearance of this precipitation process, a significant increase in hardness is also manifested, called hot hardening.

If the temperature continues to rise, the stable precipitation phase is finally reached. The decrease in hardness, which is often found at the end of this process, is known as over aging.

Cold hardening can take place either before or simultaneously with heat hardening.

There are aluminum alloys, such as those of the Al-Cu-Mg type, in which the introduction of dislocations, through the cold plastic deformation of the hardened material, increases the aging speed and ensures obtaining higher quality figures than those in which it would have arrived through aging, under similar conditions of the undeformed witness; the phenomenon is explained by the nucleating action of dislocations on the hardening phases.

In other types of alloys, including those in the Al-Zn-Mg-Cu group, the effect of the cold deformation of the hardened material, on the mechanical properties obtained after aging, is practically nil or even negative [4, 8].

The explanation of this different behavior lies in the fact that the hardening of the alloys is essentially due to the formation of the Guinier-Preston zones during the artificial aging heat treatment and not due to the reduction of dislocation mobility.

2. Experimental conditions

The samples subjected to research were made from the alloy of chemical composition presented in Table 1.

Table 1. *Chemical composition of the studied alloy*

The chemical element	**Zn**	**Mg**	**Cu**	**Mn**	**Cr**	**Ti**	**Fe**	**Si**	**Al**
%	6	2	1	0.15	0.5	0.10	0.4	0.4	rest

The minimum mechanical properties of the material, which had to be obtained after heat treatment, are those shown in Table 2.

Table 2. *The imposed mechanical properties*

Rm, MPa	**$R_{p0,2}$, MPa**	**HB, MPa**	**A_5, %**
500	400	160	8

The alloy was developed in electric furnaces. The alloying was done in induction furnaces, casting in metal shells or by the semi-continuous method, and the homogenization of the cast bars in electrically heated furnaces, part of the semi-continuously cast bars were extruded from Φ135 mm to Φ 80 mm.

The heat treatment of the samples and parts was done in electric resistance furnaces with temperature regulation between the limits: ±10 °C at around 550 °C and ±2 °C at around 170 °C.

Due to the large number of alloying elements, it contains, the investigated alloy has a complex structure, which from the point of view of the way of presentation in the microscopic examination depends on its condition. The phases that can be found at ambient temperature in Al-Zn-Mg-Cu type alloys can be synthesized as follows:

- complex solid solution α of Zn, Mg and Cu in Al and solid solution β (Zn-Mg);
- defined binary or ternary compounds: Al_2Cu, Al_3Fe and $T(Al_2Mg_3Zn_3)$;
- binary eutectic: (α + Al_2Cu), (α + T) and (α + Al_3Fe).

Figure 1 shows the microstructure, at room temperature, of a sample taken from a semi-continuously cast bar.

If the cast raw alloy is heated to about 460 °C, so close to its melting point, only Al, α solid solution and β compound (Zn Mg) exist in its structure.

In the specialized literature, the prescriptions for the heat treatment of Al-Zn-Mg-Cu type alloys are as follows [4, 5]:

- the solution temperature is in the range of 450-470 °C;
- the heating duration, which depends on the geometry and size of the piece, must be chosen so that the entire metal mass has a uniform temperature;
- the tempering of the piece must be done within 15 s maximum after leaving the mouth of the furnace; in practice, sheets and profiles are quenched in water at room temperature, while forged parts are quenched in warm water (50-70 °C), in order to reduce the stresses generated by too energetic cooling. Before artificial aging, the hardened parts are left to rest for about 16 h; if this term is not respected, the parts hardened by heat treatment have about 10% lower mechanical properties;

- working parameters, in the case of artificial aging, depend on the chemical composition of the alloy; generally, the temperature varies between 105 °C and 200 °C, and the duration between 4 and 24 h;
- in order to reduce the duration of the artificial aging process, step aging is sometimes applied.

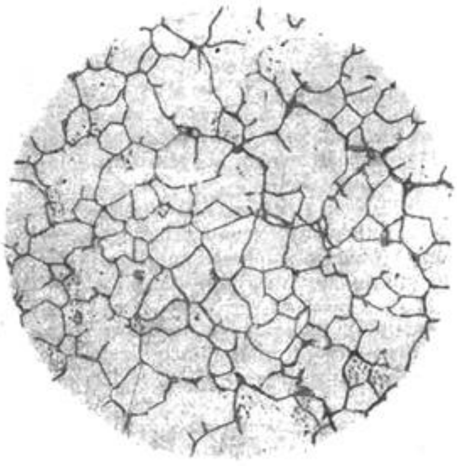

Fig. 1. *Microstructure of a cast bar; Magnification x250, Attack: 0.5 HF* [4]

Figures 2, 3 and 4 show diagrams given in the literature regarding the variation of the mechanical properties of some semi-finished products from Al-Zn-Mg-Cu type alloys used in the USA and Switzerland, depending on heat treatment parameters.

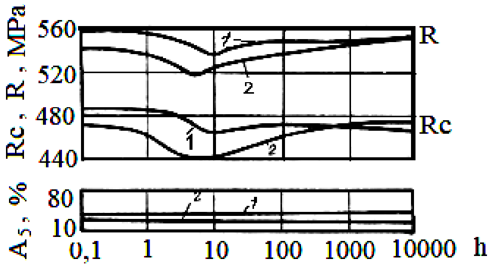

Fig. 2. *The influence of time between solution quenching and artificial aging of 7075 alloy sheets, on the mechanical properties aged at 120 ºC/24 hours (curves 1) and at 135 ºC/12 hours (curves 2)* [4]

For the thermal treatment of the studied alloy, furnaces with electric resistances were used, equipped with devices for automatic temperature regulation and internal air recirculation and with tempering tanks that allow the water to be heated to about 50 °C.

In the framework of the research, samples taken from extruded bars with cores 4 and 8 were used; the chemical composition of the alloy being within the prescribed limits.

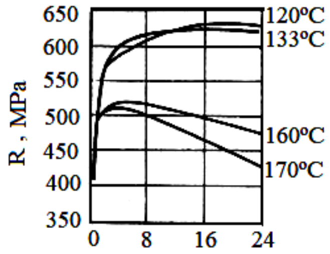

Fig. 3. *The influence of artificial aging parameters on mechanical strength for the Swiss alloy PERUNAL* [4]

The experimental researches were carried out after 6 variants of thermal processing according to the schemes in Figures 4, 5, 6, and 7. In all cases, the placing in the solution was carried out at 460 ± 5 °C/8 h, and the final cooling in the open air.

Within the six variants studied, the artificial aging was done in classical conditions (I_A and I_B), isothermal (II), in two stages (III and IV) and in three stages (V).

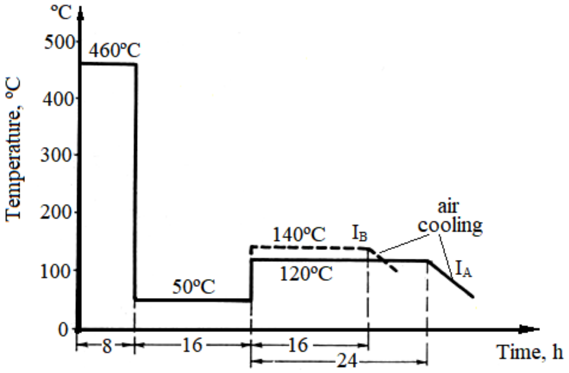

Fig. 4. *Treatment scheme according to variants I_A and I_B*

Treatment parameters for variants I_A and I_B were:

- putting in solution at 460 °C/8 hours;
- quenching in water at a temperature of 50 °C;
- artificial aging at 120 °C/24 hours (I_A);
- artificial aging at 140 °C/16 hours (I_B);
- air cooling.

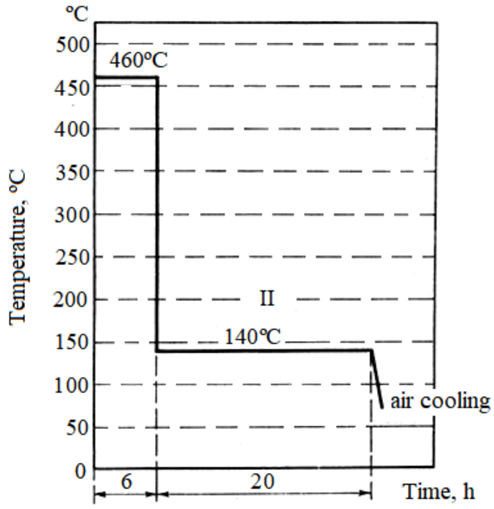

***Fig. 5.** Isothermal treatment scheme according to variant II*

Treatment technological parameters for variant II were:

- putting in solution at 460 °C;
- quenching in water at a temperature of 50 °C;
- artificial aging at 140 °C/20 hours;
- cooling in the air.

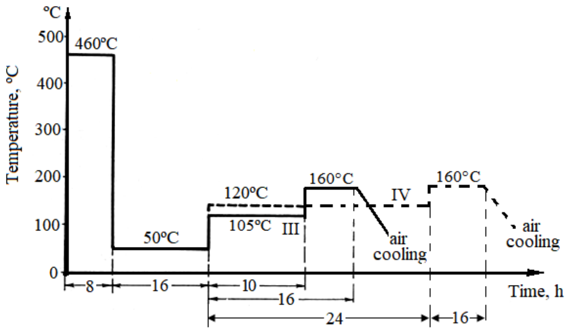

***Fig. 6.** Stepwise treatment scheme according to variants III and IV*

For variants III and IV, the research consisted of the following:

- putting in solution at 460 °C/8 hours;
-quenching in water at a temperature of 50 °C;
-artificial aging at 120 °C/24 hours (I_A);
-artificial aging at 140 °C/16 hours (I_B);
- air cooling.

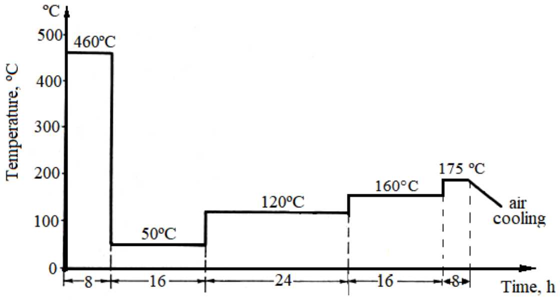

***Fig. 7.** The two-stage treatment scheme according to the V variant*

Variant of treatment consisted of the following sequence of specific technological operations:

- placing in solution 460 ± 5 °C/8 hours;
- water quenching at 50 °C;
- artificial aging 120 °C/24 hours +160 °C/16 hours + 175 °C/6 hours;
- air cooling.

The results obtained following the application of these treatment variants are illustrated in Figures 8 for Mechanical Strength and Yield Strength, 9 for Brinell hardness and 10 for Elongation at break.

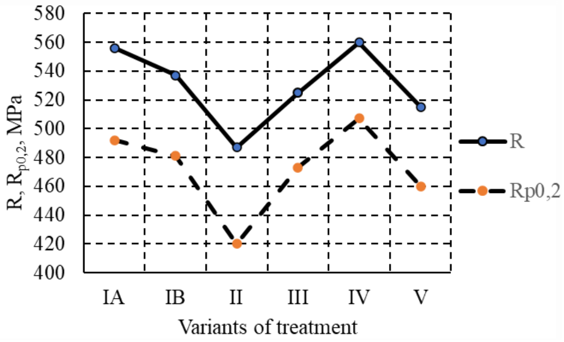

***Fig. 8.** Variation of mechanical strength and yield strength depending on the treatment option adopted*

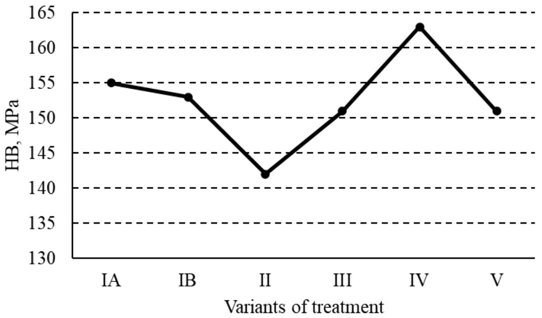

***Fig. 9.** Brinell hardness variation depending on the treatment option adopted*

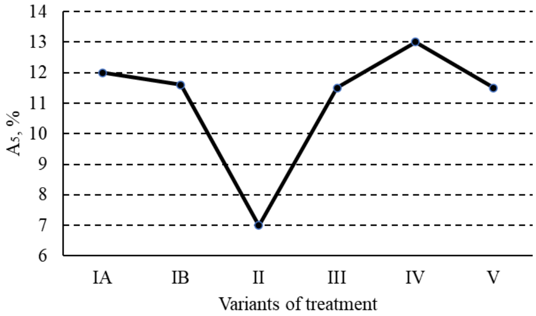

Fig. 10. *The variation of elongation at break depending on the treatment option adopted*

From these images it can be seen that the best properties are obtained in the case of thermal processing according to variants IA and IV.

During the tests, the influence of the cold plastic deformation of the hardened alloy, as well as the amount of time between the end of the quenching operation and the start of the aging process, on the mechanical properties of the artificially aged material was also monitored.

In the samples that in the hardened state had been cold forged (plastically deformed) at cores 4 and 8, mechanical properties were obtained, after artificial aging, about 10% lower compared to those found in the samples that did not undergo this deformation intermediate plastic.

It was thus practically verified that the hardening by heat treatment of Al-Zn-Mg-Cu type alloys is mainly due to the formation of Guinier-Preston zones.

A similar reduction in the mechanical properties of the artificially aged material is also found in the case when the duration of keeping the material in the hardened state is less than 16 h.

3. Conclusions

The factors that condition the obtaining of high mechanical properties of the studied Al-Zn-Mg-Cu alloy, after the thermal hardening treatment, can be concretized as follows:

- strict compliance with the prescribed heating temperatures and durations, a tempering carried out in max. 15 s from removing the part from the oven and starting the artificial aging only after the time interval indicated above (16 h);
- the use of precise furnaces in terms of working temperature tolerances.

In the case of the studied alloy, the optimal heat treatment parameters resulting from the tests performed are:

- solution tempering at a temperature of 460 °C with a holding time of 8 h;
- cooling (quenching) in hot water at 50 °C;
- artificial aging in stages: the first stage was carried out at a temperature of 105 °C with a holding time of 10 h followed by a second stage at a temperature of 160 °C and an aging time of 6 h.

Cold plastic deformation of Al-Zn-Mg-Cu quenched alloy was found not to improve the mechanical properties after artificial aging.

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