INFLUENCE OF THERMOMECHANICAL PROCESSING PARAMETERS ON THE MECHANICAL PROPERTIES OF AN ALUMINUM ALLOY USED IN CUTTING-EDGE TECHNIQUE

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ABSTRACT

Special aluminum alloys are mainly used in the aeronautical and machine-building industries, areas of technique where materials must possess superior mechanical properties. These properties are obtained as a result of special methods of elaboration and subsequent processing. The special properties of these alloys are also influenced by the alloying elements present in their chemical composition. In this paper it is studied the way in which the parameters of the thermomechanical treatment process applied to an aluminum alloy influence the mechanical properties of the studied alloys. Thermomechanical processing consists of solution hardening, cold plastic deformation and artificial ageing at different temperatures and various times of maintenance at these temperatures.

KEYWORDS: aluminum alloy, thermomechanical processing, mechanical properties

1. Introduction

In this work it has been experimentally researched the influence of thermomechanical treatments on mechanical properties for an alloy belonging to the Al-Zn-Mg-Cu system. This aluminum alloy belongs to the category of special alloys. Special aluminum alloys (those used in cutting-edge technique) have a design technology with specific peculiarities presented in the field literature [1, 2], which are determined on the one hand by the variation of their physico-mechanical properties and on the other hand by some conditions that they must meet, either in moulded state or in a deformed plastic state.

The elaboration of aluminum alloys in induction electric ovens and vacuum atmosphere has a wide spread worldwide. Vacuum induction melting plants can work both in advanced vacuum conditions, 10^{-4}-10^{-5} Pa and in inert gas atmosphere [3]. Copper concentration in duralumin alloys does not generally exceed 5%. The increase in copper content leads to increased mechanical resistance, but continuously decreases the plasticity and corrosion resistance of the alloy. Plasticity decreases as a result of the fragility of the $CuAl_2$ compound.

Another element of hardening of aluminum alloys by the formation of the Al_2Mg_3 compound is the magnesium that also has the role to increase the corrosion resistance, and in the presence of the silicone forms the Mg_2Si compound. Magnesium concentration in deformable aluminum alloys is limited to 2.5% because over this value the plasticity of alloys decreases greatly. At higher concentrations 0.5...1.2% S, the mechanical properties of alloys do not increase significantly, but plasticity decreases greatly. Zinc is one of the main hardenable elements in special aluminum alloys, with high mechanical strength, by forming the Al_2Zn_3 compound that has a higher hardening effect than other compounds [4].

The fact that they benefit from good corrosion resistance and are easily processed by cutting, the Al-Zn alloys are increasingly used in foundries. Between Al and Zn the solid α solution has a very wide range and therefore, in the structure of industrial alloys do not appear separate phases, rich in zinc. At 382 °C, the solubility of zinc in aluminum is 84% and it decreases with temperature decrease, reaching the value of 2% at ambient temperature. In the limit of concentrations of 31.62...77.72%, a non-scibility domain appears between two solutions, α1 and α2, with different zinc content [5].

Zinc, due to its high solubility, influences in a considerable degree the improvement of mechanical properties. For this reason, the Al-Zn and Al-Zn-Si alloys are characterized by good casting properties, as

well as appropriate mechanical properties, without the application of heat treatment.

Zinc is added as a basic element for increasing resistance of Al-Zn-Cu alloys, which were used among the first aluminum-based metallic materials, both for casting and for plastic deformation. In these alloys, copper is introduced for hardness, improved casting properties and corrosion resistance under load. The silicon introduced into these alloys increases fluidity and eases casting, but decreases plasticity. Iron, zirconium, nickel, chromium and manganese decrease sensitivity at high temperatures, but the last two elements improve corrosion resistance properties under load [4].

Magnesium increases resistance, but decreases plasticity; the properties of casting and processing by cutting and antifriction are improved by calcium, lead and tin. The structure of the alloys is of solid solution for small quantities of zinc and copper, or the AlCuZn compound is formed which diffuses to the border of the grain. When the copper content exceeds 2% and that of silicon is greater than 0.5%, ternary eutectic Al-Al$_2$Cu-Si is formed. Iron, silicon and manganese present in these alloys form Fe$_2$SiAl$_8$, when they do not contain Mn, and when they also have in composition Mn, they form FeMn$_3$Si$_2$Al$_{15}$. Nickel strongly influences the properties in the presence of copper by forming the compound of AlCuNi or Al$_3$FeCuNi. Magnesium forms the Mg$_2$Si compound and a large amount is dissolved in the solid solution, but by segregation can lead to the occurrence of the Mg$_2$Zn$_{11}$ compound [5].

Phase transformations in solid state, if allowed in the alloy balance diagram, are an essential condition for carrying out a heat treatment by quenching in solution and artificial ageing on an aluminum alloy. An alloy of this type is the one that can withstand an order-clutter reaction; the hardening process accompanying this process (similar to the hardness by precipitation) is determined by the order-hardening reaction. The conditions for this form of hardening are quite stringent so that the most important methods, often used for alloys, are based on precipitation from a solid oversaturated solution and by eutectoid decomposition [6-8].

Heat-treated by hardening and ageing, aluminum alloys acquire a higher mechanical resistance. This is due to interactions between precipitation and matrix dislocations, interactions that decrease the mobility of the deployations. Thus, there are three causes of increased mechanical resistance in alloys hardened by precipitation [8, 9]:
• Hardening by internal tension;
• Chemical hardening (produced when dislocations cross precipitation);
• Dispersion hardening (produced when dislocations bypass precipitation).

The emergence of Guinier-Preston areas or precipitation of compound in the structure of the alloy determines in their vicinity a number of structural, chemical, energy-related discontinuity, etc. [10]. Depending on the nature of the discontinuity, there may be several mechanisms that affect the mobility of these dislocations leading to the production of aluminum alloys hardness [8, 11].

The superficial energy value of the interfaces decides the form of precipitation. Depending on the deformation energy ΔUe for the elastic accommodation of the two networks, the form of precipitation can be spherical or acicular.

The emergence of Guinier-Preston areas and consistent or semi-consistent precipitations create fields of elastic tension surrounding these precipitations. These tensions have the value directly proportional to the concentration of solid C solution and the difference between the network parameters of the matrix and the Guinier-Preston area considered [20].

If the precipitation has spherical shape, the average tension will be [5]:

$$\Delta = 2G \cdot \varepsilon \cdot c \qquad (1)$$

where: G = Matrix elasticity module; ε = is a concentration function C.

At the interaction of dislocations with a surge of tensions characterized by a mean internal tension T, occurs the curvature of the deployations whose radius is calculated with the relationship [8, 12]:

$$2R = \frac{G \cdot b}{\sigma} \qquad (2)$$

where b is the Burger vector of the dislocation, being the order of the interatomic distance.

2. Experimental conditions

In order to study the influence of thermal and thermomechanical treatments applicable to deformable alloys with aluminum base on physico-mechanical properties, it was necessary to adopt a methodology capable of simultaneously ensuring microstructural changes and the study of the variation of the main mechanical properties, in order to determine the technological variants of optimum thermal and thermomechanical treatments. The alloy studied, due to its chemical composition, allows the phenomenon of structural hardening by heat treatment, because zinc, magnesium and copper, form intermetallic phases with aluminum, phases with variable solubility in solid state (MgZn$_2$, with Al$_2$Mg$_2$Si, Al$_2$MgCu, etc.). Therefore, the work aims

to investigate the influence of the final thermomechanical treatments on the properties of cold-rolled semi-product aluminum alloys.

The material intended for experimental research is an aluminum alloy from the Al-Zn-Mg-Cu system, with the chemical composition shown in Table 1.

Table 1. Chemical composition of the research-subject alloy

Element / The alloy	Zn	Mg	Cu	Cr	Mn	Al
Al6Zn2,5Mg2	6	2.5	0.6	0.2	0.25	rest

Table 2. Alloy Properties According to EN 485-2-2007 [12]

Property / The alloy	Rm, [Mpa]	$Rp_{0,2}$ [Mpa]	A_5 [%]	HB
AlZn6Mg2,5Cu	540	470	7	161

The mechanical properties of the studied alloy, according to EN 485-2-2007, are shown in Table 2.

These alloys were developed, molded into ingots and homogenized at S.C. ALRO S.A. Slatina.

The manufacture of the test tubes was carried out by cutting from homogenized ingots. The mechanical test tubes were made according to specifications given by SR EN 10 002-1/1995 for traction tests.

Figure 1 shows the geometry of a sample at the end of thermomechanical processing.

The sequence of thermomechanical treatment operations according to the chosen variant is presented in Table 3.
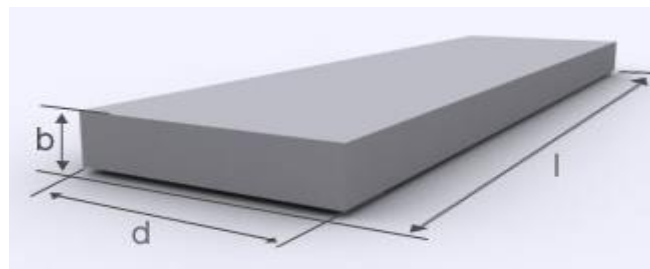

Fig. 1. The shape and dimensions of a sample at the end of experiments B = 3 mm; D = 60 mm; L = 150 mm

Table 3. Experimental variant

Experimental variant	Description of experimental variant
Chosen variant	1. Homogenization at a temperature of 480 °C for 24 hours of poured bullion; 2. The cooling of the bullion with the furnace; 3. The flow of samples in order to carry out the experiments; 4. Heating up to a temperature of 435 °C for hot lamination; 5. Hot lamination with the degree of plastic deformation: ε = 25%; 6. Cooling in the air up to ambient temperature; 7. Heating for the commissioning of the solution at a temperature of 500 °C for 2 hours; 8. Cooling in water; 9. Artificial ageing at a temperature of 100 °C with a maintenance time of 1 hour; 10. Cold plastic deformation with a deformation degree: ε = 30%; 11. Artificial ageing having several experimental variants in turn.

As shown in Table 3, after quenching in solution, a slight artificial ageing was performed at 100 °C with a maintenance time of one hour. This first artificial ageing achieves structural stability of the material because, in the hardened state, after approximately 3-5 hours, the natural ageing process is

initiated, which is not an advantage for subsequent deformable alloys. The increase in mechanical characteristics occurs on account of complex interactions between base matrix dislocations and precipitated particles occurring in the structure of alloys following ageing. As a result of the formation of the $CuAl_2$ compound, copper is the main element of hardening of special aluminum alloys.

The cold plastic deformation process, resulting in the final dimensions of the investigated material was made between two artificial ageing processes.

The cold lamination of aluminum alloys resulted in increased density of structural defects and their uniform distribution, which has the effect of intensifying the phenomena of uniform decomposition of the supersaturated solid solution.

The smoother structure, with evenly distributed precipitation obtained in aluminum-based alloys after the application of thermo mechanical treatments leads to an optimum association of properties of resistance and plasticity, the high increase of resilience and elongation at breakage with maintaining at roughly the same level of resistance to breaking the alloy.

3. Experimental results

Putting into practice the technological operations according to the processing variant of the investigated alloy, we obtained a series of values of mechanical properties according to the parameters of thermomechanical processing, shown in Figures 2-5.
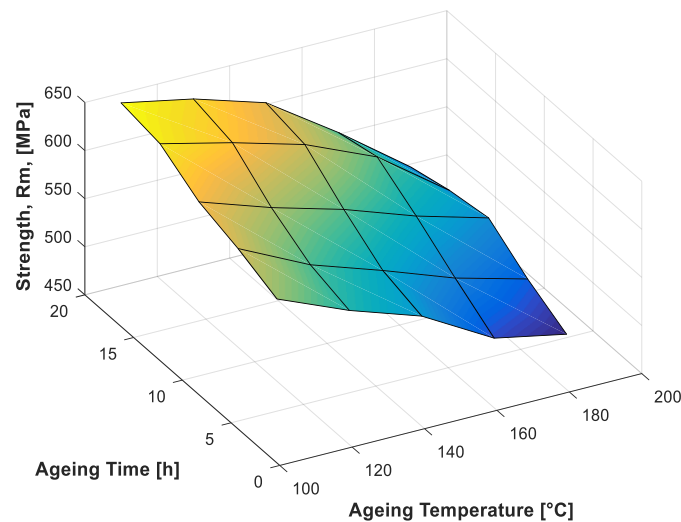

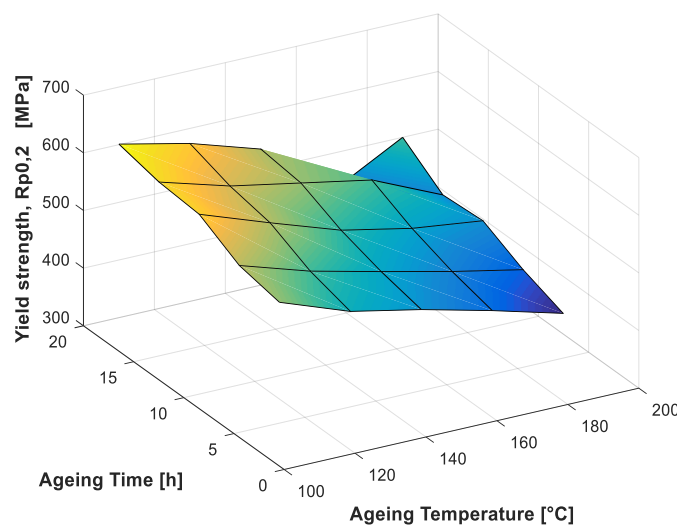**Fig. 2.** *Variability in breaking resistance of studied alloy with aging time and temperature for ε = 30%*

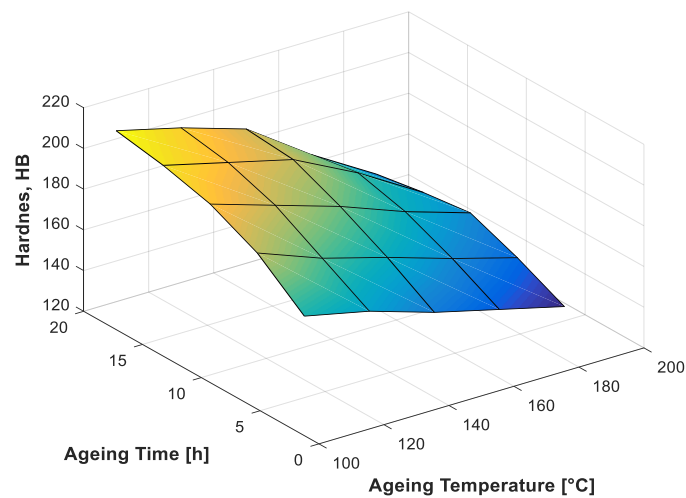**Fig. 3.** *Variability in flow resistance of studied alloy with time and temperature of aging for ε = 30%*

Fig. 4. *The variation of the HB hardness of the studied alloy with aging time and temperature for ε = 30%*
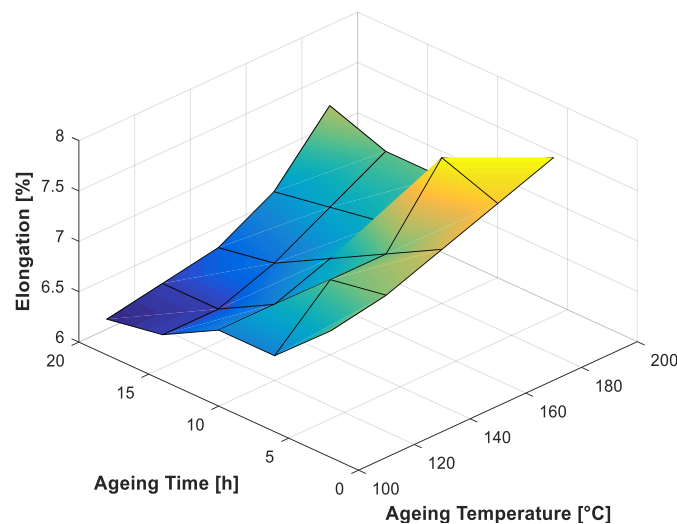

Fig. 5. *Variation of elongation at breaking A_5 of the alloy studied with aging time and temperature for ε = 30%*

4. Conclusions

Analyzing the curves of the variation of properties in the above graphs obtained by statistical processing of experimental data, it can be observed that the mechanical properties of resistance (mechanical strength, flow limit and the hardness of HB) increase with increasing aging time and decrease as the ageing temperature grows.

Elongation at breakage increases as the ageing time increases and decreases as the ageing temperature increases.

The literature offers relatively little information about the combination of thermal treatments and plastic deformation carried out in the order and at the parameters described in this variant, although the results obtained are at a fairly high level, which should give this variant of unconventional treatment an application in practice.

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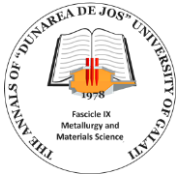
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