The paper presents the results of experimental research with a view to optimizing the thermo mechanical treatment process that has been applied to AlZn5Mg3Cu alloy used in the aviation industry. The research led to the conclusion that, for the alloy studied, the highest mechanical strength values were obtained for an artificial aging time of 16 hours at a temperature of 120 °C, while the lowest resistance values were obtained for an artificial aging time of 8 hours at 160 °C.

Keywords: AlZnMgCu-alloy, thermo mechanical treatments, energy, mechanical properties

INTRODUCTION

The alloy studied is part of the AlZnMgCu, series 7000. Due to their superior mechanical characteristics obtained through thermal and / or thermo mechanical processing, they are used with very good results in the aviation industry and machinery industry. These mechanical characteristics are obtained by controlling the precipitation hardening process [1, 2].

Thermo mechanical processing for AlZnMgCu alloys involves a combination of plastic deformation and artificial aging. Cold flow accelerates and intensifies the age-hardening process. This acceleration is closely related to the degree of plastic deformation. The experimental data presented in the literature reveal that the acceleration of the precipitation process is mainly determined by an accumulation of dislocations up to saturation during plastic deformation. This increases the efficiency of diffusion phenomena in artificial aging, subsequent to plastic deformation [3, 4].

By using modern techniques of investigating materials such as atomic probe, tomography researchers systematically managed to see the microstructure of the precipitates resulted (obtained) after applying some regimes of heat treatment (aging or artificial re-aging) and thermo mechanical treatments for AlZnMgCu alloys.

The parameters of the thermo mechanical treatment regime influence the achievement and evolution mechanisms of the precipitates during the recovery and re-aging stages [5].

The AlZn5Mg3Cu alloy is deformable and hardenable and after the application of some heat treatment and / or thermo mechanical treatments, the values obtained in the mechanical characteristics recommend it to be used in the aviation industry. The technical and economic performances of a metallurgical process depend on the process parameters and on the conditions and mode of operating the system as a whole. [6, 7].

Determining the optimal solution is made by determining the values of the independent variables so as to obtain the best value for the objective -function (the optimized function). In the case of optimizing the thermo mechanical processing parameters of the alloy studied, the objective function is represented by the consumption of energy "Q = f (T, τ, ε)", where T and τ are the temperature, respectively the time for the final artificial aging, in this case, and ε is the degree of plastic deformation, given the restrictions on the values of the mechanical properties investigated.

In this work, the mathematical model is given by the equations for calculating the energy Q consumed with heat treatment furnace and the mini rolling mill where the plastic deformation of the studied alloy samples was performed.

The model equations express the relationships between the process parameters and are deducted either by theoretical analysis or based on experimental observations (empirical) [8].

MATERIALS AND METHODS

The materials for experimental research are samples made of AlZn5Mg3Cu aluminum alloy whose chemical composition is shown in Table 1, and which fall within the requirements of EN 573-3-2013.
- cold plastic deformation with three degrees of deformation $\varepsilon_1 = 10\%$, $\varepsilon_2 = 20\%$ and $\varepsilon_3 = 30\%$ to achieve the set dimensions;
- after having performed these deformations, a final artificial aging heat treatment is made at the following temperatures: $T_1 = 120^\circ\text{C}$, $T_2 = 140^\circ\text{C}$, $T_3 = 160^\circ\text{C}$ with the holding time: $t_1 = 8\text{ hour}$, $t_2 = 12\text{ hour}$, $t_3 = 16\text{ hour}$ for each temperature.

At the end of the thermo-mechanical processing, the dimensions of the samples are: length $L = 200\text{ mm}$, width $l = 60\text{ mm}$, thickness $h = 5\text{ mm}$.

RESULTS AND DISCUSSIONS

After the thermo mechanical treatment, the samples were subjected to mechanical tests, after which the values of $R_m$, $R_{p0.2}$, $A_5$, HB properties were determined as shown in Tables 3. The values listed in the Tables represent the average of 5 measurements.

The mechanical properties were considered as functions of three variables of the thermo mechanical treatment, namely: $R_m = R_m(T, \tau, \varepsilon)$, $R_{p0.2} = R_{p0.2}(T, \tau, \varepsilon)$, $A_5 = A_5(T, \tau, \varepsilon)$, $HB = HB(T, \tau, \varepsilon)$.

The optimization of the thermo-mechanical treatment was carried out by calculating the total energy consumption $Q_{\text{total}}$ and choosing the mechanical treatment variant for which $Q_{\text{total}}$ is minimal in terms of obtaining values in accordance with EN-485-2-2013 for the mechanical characteristics studied.

These calculations were performed using the following relationship:

$$Q_{\text{total}} = Q_{\text{total oven}} + Q_{\text{lam}} \quad [11]$$

where: $Q_{\text{total oven}}$ - the amount of heat necessary to attain and maintain the treatment temperature throughout performing the heat treatment;
$Q_{\text{lam}}$ - the amount of energy consumed for rolling samples.

Table 1  Chemical composition of the AlZn5Mg3Cu research / mas. % / [9]

<table>
<thead>
<tr>
<th>Zn</th>
<th>Mg</th>
<th>Cu</th>
<th>Si</th>
<th>Fe</th>
<th>Cr</th>
<th>Mn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3</td>
<td>0.75</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
<td>0.25</td>
<td>Remainder</td>
</tr>
</tbody>
</table>

Table 2  Mechanical properties of AlZn5Mg3Cu / [10]

<table>
<thead>
<tr>
<th>$R_m$ / MPa</th>
<th>$R_{p0.2}$ / MPa</th>
<th>$A_5$ / %</th>
<th>HB</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td>370</td>
<td>8</td>
<td>133</td>
</tr>
</tbody>
</table>

According to EN 485-2-2013[10] after thermo mechanical processing, the values obtained for the main mechanical characteristics must be at least equal to those shown in Table 2.

Figure 1 shows schematically thermo mechanical processing that the samples studied have undergone.

The thermo mechanical processing consisted of the following technology sequence:
- solution quenching at 500 $^\circ\text{C}$ for 2 hours;
- preliminary artificial aging at a temperature of 100 $^\circ\text{C}$ for 1 hour to stabilize the structure of the material;
- cold plastic deformation with three degrees of deformation $\varepsilon_1 = 10\%$, $\varepsilon_2 = 20\%$ and $\varepsilon_3 = 30\%$ to achieve the set dimensions;
- after having performed these deformations, a final artificial aging heat treatment is made at the following temperatures: $T_1 = 120^\circ\text{C}$, $T_2 = 140^\circ\text{C}$, $T_3 = 160^\circ\text{C}$ with the holding time: $t_1 = 8\text{ hour}$, $t_2 = 12\text{ hour}$, $t_3 = 16\text{ hour}$ for each temperature.

At the end of the thermo-mechanical processing, the dimensions of the samples are: length $L = 200\text{ mm}$, width $l = 60\text{ mm}$, thickness $h = 5\text{ mm}$.

RESULTS AND DISCUSSIONS

Table 1  Chemical composition of the AlZn5Mg3Cu research / mas. % / [9]...
Using the software package MATLAB interpolation functions of three variables and heat balance equation (1), was performed a graphical interface that allows viewing (simulation) by calculation of $Q_{\text{total}}$ minimum.

An example of such a simulation is shown in Figure 2.

CONCLUSIONS

After conducting the research described in this paper, the following conclusions were drawn:
- the thermo mechanical processing carried highlighted the dependence of the level of resistance mechanical properties values on the degree of cold plastic deformation preceding the final artificial aging;
- the resistance mechanical properties values are directly proportional to the values of aging time and inversely proportional to the heat treatment temperature;
- the mechanical strength of the alloy processed has the highest values during artificial aging of 16 hours and a temperature of 120 °C, and the lowest resistance values in the case of thermal processing are for the aging time of 8 hours and the temperature of 160 °C;
- the value of the alloy elongation at break is decreasing with increasing final aging time and decreasing final artificial aging temperature, as well as with increasing plastic deformation degree;
- the graphic interface created using MATLAB enables simulation and identification based on mathematical calculation, of the minimum amount of $Q_{\text{total}}$ which means finding the optimum of the thermo mechanical processing;
- with the help of the graphical user interfaces, there can be distinguished, in tabular form, the values of the thermo mechanical processing parameters for those situations where it is desired to obtain a particular value of one or more properties of the studied ones.

REFERENCES


Note: The responsible translator for English language is Bujor Cornelia, official English and French interpreter and translator under license no. 23-306/2008 issued by the Romanian Ministry of Justice, Romania