

<sup>1</sup>Olimpia PANDIA, <sup>2</sup>Ion SARACIN, <sup>3</sup>Marian NEACSU,  
<sup>4</sup>Ioan GANEA-CHRISTU, <sup>2</sup>Diana Loredana RĂDULESCU

## THERMO-MECHANICAL TREATMENT PROCESS OF AlZn5Mg3Cu ALLOY AND OPTIMIZATION OF TECHNOLOGICAL PARAMETERS

<sup>1</sup>University of Agricultural Sciences and Veterinary Medicine Bucharest, ROMANIA

<sup>2</sup>University of Craiova, Faculty of Agriculture, ROMANIA

<sup>3</sup>University of Dunarea de Jos, Galati, ROMANIA

<sup>4</sup>INMA Bucharest, ROMANIA

**Abstract:** The paper presents the results of experimental researches aimed to optimize the thermo-mechanical treatment process applied to AlZn5Mg3Cu alloy used in aviation industry. The optimal solution is determined by finding some values of independent variables, so that to obtain the best value for objective-function. Objective function in the case of optimizing thermo-mechanical treatment regime studied is represented by the energy consumption " $Q=f(T, \tau, \epsilon)$ " under certain restrictions regarding mechanical properties values researched. Researches were based on an experimental program of thermo-mechanical processing applied to aluminium alloy studied in order to obtain the required values of mechanical properties with minimal cost.

**Keywords:** optimization, aluminium alloy, thermo-mechanical treatments

### 1. INTRODUCTION

The alloy studied is part of the system AlZnMgCu, series 7000. Due to their superior mechanical characteristics obtained through thermal and / or thermo mechanical processing, this alloy is used with very good results in the aviation industry and machinery industry. These mechanical characteristics are obtained by controlling the precipitation hardening process [7, 5].

Thermo mechanical processing for AlZnMgCu alloys involves a combination of plastic deformation and artificial aging. Cold flow deformation 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 have revealed that the acceleration of the precipitation process is mainly determined by an accumulation of dislocations up to oversaturation during plastic deformation. This increases the efficiency of diffusion phenomena in artificial aging, subsequent to plastic deformation [1, 3].

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 [6]. The AlZn5Mg3Cu alloy is deformable and hardenable and after the application of some heat treatment and / or thermo mechanical treatments, the mechanical characteristics values obtained 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 of the system as a whole. [4].

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 " $Q = f(T, \tau, \epsilon)$ ", where  $T$  and  $\tau$  are the temperature, respectively the time for the final artificial aging, in this case, and  $\epsilon$  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 deduced either by theoretical analysis or based on experimental observations (empirical) [8].

## 2. MATERIAL AND METHOD

The materials for experimental research are samples made of AlZn5Mg3Cu aluminium alloy whose chemical composition is shown in Table 1, and which fall within the requirements of EN 573-3-2013.

Table 1. Chemical composition of the AlZn5Mg3Cu alloy researched / mas. %

Alloy	Zn	Mg	Cu	Si	Fe	Cr	Mn	Al
AlZn5Mg3Cu	5	3	0,75	0,5	0,5	0,2	0,25	remainder

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.

Table 2. Mechanical properties of AlZn5Mg3Cu alloy

Property	R <sub>m</sub> / [MPa]	R <sub>p0.2</sub> / [MPa]	A <sub>5</sub> / [%]	HB
AlZn5Mg3Cu	450	370	8	133

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

The thermo mechanical processing consisted of the following technology sequences:

- » solution quenching at 500°C for 2 hours;
- » preliminary artificial aging at a temperature of 100°C for 1 hour to stabilize the structure of the material;
- » cold plastic deformation with three degrees of deformation  $\epsilon_1 = 10\%$ ,  $\epsilon_2 = 20\%$  and  $\epsilon_3 = 30\%$  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:  $\tau_1 = 8$  hour,  $\tau_2 = 12$  hour,  $\tau_3 = 16$  hour for each temperature.

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

## 3. RESULTS

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

Thermo-mechanical processing researched revealed that not for all combinations of processing thermo mechanical parameters considered (time, temperature, degree of plastic deformation) were obtained the values of mechanical properties studied that fit the requirements of specific norms in force. The mechanical properties were considered as depending on the three parameters of the thermo-mechanical treatment regime, the mechanic features were considered as depending on three variables of thermo-mechanic treatment, namely:  $R_m = R_m(T, \tau, \epsilon)$ ,  $R_{p0.2} = R_{p0.2}(T, \tau, \epsilon)$ ,  $A_5 = A_5(T, \tau, \epsilon)$ ,  $HB = HB(T, \tau, \epsilon)$ .

Table 3. The values of the mechanical properties after applying thermo-mechanical treatment with high plastic deformation degree  $\epsilon = 10$  / %

The time for the artificial aging/hours	Artificial aging temperature / °C											
	120				140				160			
	R <sub>m</sub> / MPa	R <sub>p0.2</sub> / MPa	HB	A <sub>5</sub> / %	R <sub>m</sub> / MPa	R <sub>p0.2</sub> / MPa	HB	A <sub>5</sub> / %	R <sub>m</sub> / MPa	R <sub>p0.2</sub> / MPa	HB	A <sub>5</sub> / %
8	402	316	123	9.2	394	318	118	10	364	305	115	10.4
12	424	345	131	8.8	412	329	129	9.7	380	325	121	10.3
16	461	371	148	8.6	441	367	137	9.1	394	341	132	9.5

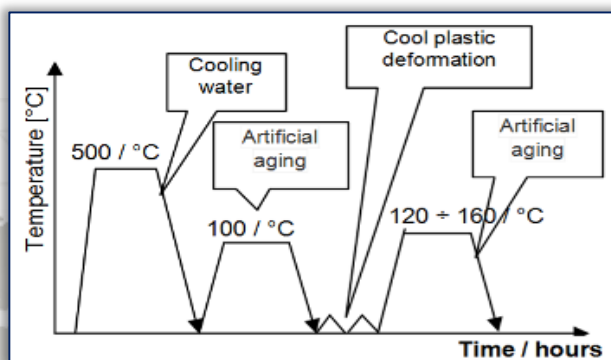


Figure 1 - Schematic representation of thermo-mechanical processing





Table 4. The values of the mechanical properties after applying thermo-mechanical treatment with high plastic deformation degree  $\epsilon = 20 / \%$

The time for the artificial aging/hours	Artificial aging temperature / °C											
	120				140				160			
	Rm / MPa	Rp02 / MPa	HB	A5 / %	Rm / MPa	Rp02 / MPa	HB	A5 / %	Rm / MPa	Rp02 / MPa	HB	A5 / %
8	466	429	134	8,6	433	391	130	9	426	374	119	9.2
12	481	436	147	8	462	398	143	8.7	456	385	135	9
16	492	453	159	7.6	477	416	153	8.2	465	403	142	8.5

Table 5. The values of the mechanical properties after applying thermo mechanical treatment with high plastic deformation degree  $\epsilon = 30 / \%$

The time for the artificial aging/hours	Artificial aging temperature / °C											
	120				140				160			
	Rm / MPa	Rp02 / MPa	HB	A5 / %	Rm / MPa	Rp02 / MPa	HB	A5 / %	Rm / MPa	Rp02 / MPa	HB	A5 / %
8	485	430	153	8.3	454	392	141	8.6	429	363	132	8.7
12	498	450	164	8.1	473	420	154	8.4	462	385	144	8.5
16	523	465	170	8.0	505	440	162	8.1	484	417	155	8.3

With the help of MATLAB software package was performed the functions interpolation with three variables, using a specific function namely interp3.

It was performed sequentially interpolation for all four mechanical characteristics studied based on the three parameters: T – artificial aging final temperature  $\tau$  – artificial aging final time and  $\epsilon$  – degree of cold plastic deformation preceding the final artificial aging.

Because aluminium alloys are "sensitive" to small variations of the temperature of the heat treatment, a variation of five by five degrees was set, resulting in a number of 9 interpolated values of temperature, between 120 /°C and 160 /°C. Artificial aging time from 8 hours up to 16 hours has been discretized with one hour interval, resulting in 9 interpolation values.

For the degree of plastic deformation in the range of 10–30/% was set of a number of 21 increasing values with 1/% interval which was interpolated.

After interpolation, a volume of 1701 interpolated values for each property resulted.

Under these conditions, the thermo-mechanical optimization process has meant in the first stage finding among these 1701, data corresponding to each property, only those which meet all the restrictions imposed by EN\_485-2-2013, and in the second stage was calculated the energy consumption necessary for thermo-mechanical processing for all situations identified in the first stage and the selection of the variant for which the energy Q is minimal.

In order to calculate energy consumption as heat (thermal energy) was calculated total energy  $Q_{total}$ , consumed by heat treatment furnace in which is made the final artificial aging according to Figure 1 and at the rolling mill used for plastic deformation. These calculations were performed using the following relationship:

$$Q_{total} = Q_{total\ oven} + Q_{lam}, [2], \quad (1)$$

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

$$Q_{total\ oven} = Q_A + Q_B, [2], \quad (2)$$

where:  $Q_A$  – the amount of heat (energy) consumed during the furnace heating;  $Q_B$  – the quantity of heat (energy) consumed in the maintaining the temperature of heat treatment during the whole treatment period;

$$Q_{lam} = U \cdot t_{lam} \cdot I / kWh [2], \quad (3)$$

where:  $Q_{lam}$  – energy consumed for cold plastic deformation; U – electric voltage of supply for rolling mill motor ( $U = 380 / V$ );  $t_{lam}$  – rolling time of a sample / hours; I – electrical current intensity used at rolling / A.

The program drafted in MATLAB by using the tool interp3 and heat balance equations (1)–(3), shows that for any value imposed of the total 1701, for any of the four properties, was obtained a number of possible variants which may be determined by optimum calculation in terms of the total energy consumption. Based on these data (information) was carried out a graphical interface with the help of the program, graphical interface that allows viewing (simulation) of those possible situations and the choice of a large number of possible values for any of the four properties, as an example of such simulation in Figure 2.





## CONCLUSIONS

After conducting the research described in this paper, the following conclusions were drawn:

- » the thermo-mechanical processing carried has 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 for artificial aging of 16 hours and a temperature of 120°C, and the lowest resistance values in this thermal processing are for the aging time of 8 hours and the temperature of 160°C;
- » the value of the alloy elongation at breaking is decreasing with increasing the final artificial time and final artificial aging temperature decreasing, 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  $Q_{total}$ , which means finding the optimum of the thermo-mechanical processing;
- » with the help of the graphical interface, 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.

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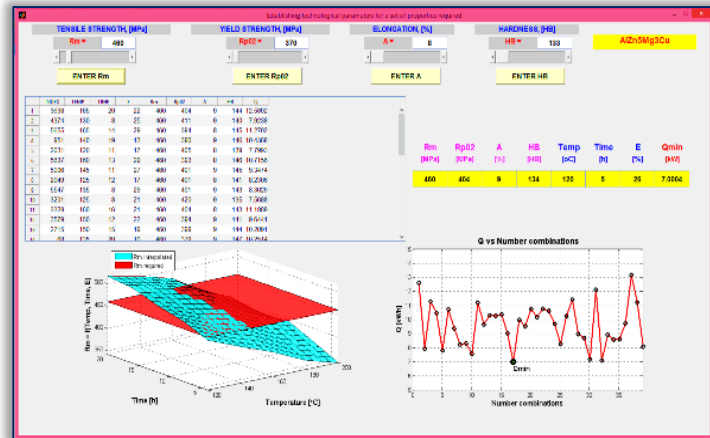


Figure 2 - Values of thermo-mechanical treatment parameters to achieve  $R_m = 460$  MPa

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