Correlation Between Aluminium Alloys Plasticity and Heat Treating Technology

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This paper presents studies regarding the behaviour at heat treating of an AlCu4Mg1 aluminum alloy. The experiments were made on laboratory conditions and can be applied in industry. The proposed methodology can be resumed in: adopting the heat treating technology for the proposed alloy; choosing the necessary working installations in order to realize the heat treating for the specified alloy; choosing the tools and the machines used for studying the chemical and mechanical characteristics; programming the experiment and analytical interpretation of the results. For experiments, was used a study charge (9 treated parts) and a test part (a non treated part). Every part from the study charge had a particularly final heat treating technology. Test part is not treated and the mechanical characteristics are determined in this situation. As a conclusion, the paper presents the algorithm for applying the optimum heat treating in order to obtain the necessary properties for the working parts.

Keywords: aluminum, plasticity behaviour, heat treating, chemical composition, elasticity

Heat treating [1-5], among other chemical and electrochemical processes [6-8], on its broadest sense refers to any of the heating and cooling operations that are performed for the purpose of changing the mechanical properties, the metallurgical structure, or the residual stress state of a metal product.

Heat treating to increase strength of aluminum alloys is a two - step process: quenching heat treating; ageing (age hardening) heat treating [2].

Quality-assurance criteria that heat-treated materials must meet always include minimum tensile properties and, for certain alloys and tempers, adequate fracture toughness and resistance to detrimental forms of corrosion (such as intergranular or exfoliation attack) or to stress-corrosion cracking. All processing steps through heat treatment must be carefully controlled to ensure high and reliable performance.

In general, the relatively constant relationships among various properties allow the use of tensile properties alone as acceptance criteria. The minimum guaranteed strength is ordinarily that value above which it has been statistically pre-dicted with 95% probability that 99% or more of the material will pass. Testing provides a check for evidence of conformance; process capability and process control are the foundations for guaranteed values.

Published minimum guaranteed values are applicable only to specimens cut from a specific location in the product, with their axes oriented at a specific angle to the direction of working as defined in the applicable procurement specification. In thick plate, for example, the guaranteed values apply to specimens taken from a plane midway between the center and the surface, and their axes parallel to the width dimension (long transverse). Different properties should be expected in specimens taken from other locations, or in specimens whose axes were parallel to thickness dimension (small transverse) [3]. However, the specified "referee" locations and orientations do provide a useful basis for lot-to-lot comparisons, and constitute a valuable adjunct to other process-control measures.

Tensile tests can be used to evaluate the effects of changes in the process, provide specimens are carefully selected. A variation in process that produces above-minimum properties on test specimens, is not necessarily satisfactory-acceptability can be judged only by comparing the resulting properties with those developed by the standard process on similarly located specimens. Finally, variations in heat-treating procedure are likely to affect the relationships among tensile properties and other mechanical properties. In applications where other properties are more important than tensile properties, the other properties should be checked also [4, 7, 8].

Elasticity tests are less valuable for acceptance and rejection of heat-treated aluminum alloys than they are for steel. Nevertheless, elasticity tests have some utility for process control [9, 10, 11].

This paper presents a cast aluminum alloy, AlCu4Mg1 that is used for aeronautical parts. This alloy is heat treated in order to establish the optimum mechanical properties, and is referring especially to elasticity. So, were took 10 parts, of identical measures, from this alloy were taken and the final heat treating was applied. At the end, it was studied the elasticity, in order to establish the optimum technology.

Experimental part

The proposed methodology for studying the improvement of heat treating technology of AlCu4Mg1 aluminum alloy can be resumed in:

- adopting the heat treating technology for the proposed alloy;
- choosing the necessary hot working installation, in order to realize the heat treating for the aluminium alloy;
- choosing the tools and the machines used for the mechanical characteristics;
- programming the experiment and interpretation of the results.

For the experiments, was used a study charge (9 parts) and a test part. Every part had a particularly final heat technology that consists of a quenching heat treating and

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Table 1
CHEMICAL COMPOSITION EXPERIMENTAL DETERMINATIONS

	part	Chemical composition, %										
		Mg	Cu	Fe	Ni	Si	Sn	Mn	Zn	Ti	Cr	Pb
AlCu4Mg1	1	1,23	3,84	0,31	0,01	0,16	0,01	0,68	0,07	0,03	0,01	0,02
	2	1,18	3,61	0,30	0,01	0,14	0,02	0,77	0,05	0,03	0,01	0,03
	average	1,21	3,73	0,31	0,01	0,15	0,02	0,73	0,06	0,03	0,01	0,02

artificial aging heat treating that are in standard conditions. Test part is not treated and the mechanical characteristics are determined in this situation.

The charge is from aluminum alloy AlCu4Mg1 and the chemical composition for this alloy, determined in laboratory conditions, is illustrated in table 1. The parts design and dimensions are specific for mechanical stress experiments according to standards.

For a mechanical characterization of the considered charge, in order to describe exactly the behavior of each aluminum alloy part after final heat treating experiments were made in order to:

-determine the exact chemical composition of the used AlCu4Mg1 alloy, shown in table 1, in order to establish the right heat treating technology;

-study the mechanical parameters for each part from the studied charge, in order to establish the right technology for this alloy;

-establish the elasticity modulus variation with heating temperatures;

-connect the elasticity modulus with heat treating technology.

In order to realize this study, it was done a process optimization by establishing some various heating temperatures in standard limits and were determined the mechanical properties obtained in every case. Experimental methodology is presented in table 2.

Experiments were made in the same conditions for furnace preheating, and was used the same equipments for every experimental determination.

Final heat treating parameters, from aluminum standards, are:

- for quenching heat treating, the heating temperatures are 485 - 505°C, for all types of parts. The maintaining time at the heating temperature depends on the dimensions of the working parts. The cooling is at air speed<

- for artificial aging heat treating, the standards for AlCu4Mg1 recommend a 185 -205°C heating temperature, maintained for 6 - 15h.

Results and discussions

In order to perform the technology we had in view, a modern device was used; it was computer assisted in order to control the process and to reduce energy consumption, especially at heating for quenching and artificial aging. This is an electrical furnace with forced air circulation. Temperature control and command for the heating mechanism is automatically performed, with high precision, of 3°C. Temperature control is accomplished at the maximum working temperature.

For experimental tests regarding heat treatment a SUPERTHERM Furnace, manufactured by Nabertherm Industries was chosen. This equipment is for laboratory

Table 2
EXPERIMENTAL PROCEDURE

Experiment	Part code	Quenching temperature, T_c, °C	Artificial aging temperature, $T_î$, °C	Variation factor, x_1	Variation factor, x_2
0.	N	-	-	-	-
1.	1.1.1.	485	185	-1	-1
2.	1.1.2.	485	195	-1	0
3.	1.2.2.	485	205	-1	+1
4.	2.2.1.	495	185	0	-1
5.	2.1.1.	495	195	0	0
6.	2.2.2.	495	205	0	+1
7.	3.2.1.	505	185	+1	-1
8.	3.1.2.	505	195	+1	0
9.	3.2.2.	505	205	+1	+1

Table 3
EXPERIMENTAL RESULTS, AFTER HEAT TREATMENT

Part code	Maximum applied strength	Elasticity Modulus
	kN	MPa
3.1.2.	32.093	69151.0
3.2.1.	45.779	67464.2
3.2.2.	37.751	69027.2
2.1.2.	37.217	65933.8
2.2.1.	50.385	69385.2
2.2.2.	41.373	69364.7
1.1.1.	43.108	65044.9
1.1.2.	26.202	64849.2
1.2.2.	37.150	69758.5
N	31.109	20686.9

use and can obtain any proposed heating diagrams. The maximum temperature is 1800°C.

The elasticity modulus curves and values were obtained on a servo – hydraulically controlled MTS 824.10 Test Star II machine, with a computer Test Star System, soft, digital controller and a force unit.

The mathematical interpretation is based on a programmed experiment [7 - 9] that consists in:

-establishing the working conditions for the final heat treating of the AlCu4Mg1 studied alloy;

-establishing the necessary and sufficient number of experiments for the studied aluminum alloy;

-establishing the regression equation which represents the model of the process;

-establishing the conditions to obtain a maximum value of the process performance;

-measuring the regression equation that describes final heat treating of the AlCu4Mg1 alloy.

The regression equation for final heat treating technology consists in establishing the minimum number of experiments that are necessary for a correct process description. In this case, using the 3^k factorial experiment model [8, 10], a number of 9 experiments (k = 2 for two variables: artificial aging heat treating temperature and quenching heat treating temperature) were performed. Therefore, for each process variable, a base level and a variation range for a correct description of the heat treating technology will be formulated.

In order to obtain the proposed equation, experiments were performed; they are illustrated in Table 2, with a base level of 495°C for the quenching temperature and 195°C for the artificial aging temperature. The variation range for the two established base levels is ±10°C. During the experiment, every part had its own particular code.

Experiments were made in the same conditions, if they refer to the maintained time at maximum temperature, cooling speed and medium. Experimental results are shown in table 3.

Diagrams were also obtained, facilitating the elasticity modulus determination at a specific heat treatment technology.

The regression, which describes the process, is:

$$M = 67097{,}162 + 998{,}3x_1 + 1042{,}683x_2 - \\ - 787{,}65x_1x_2 - 678{,}727x_1^2 + 1696{,}1x_2^2 \qquad (1)$$

In this equation, x_1 and x_2 are the factors that describe the variation of quenching heat treating temperature and artificial aging heat treating temperature. For the two parameters, the values are:

- x_1 describes the variation of quenching heat treating temperature and can be determined by means of the relation:

$$T_c = T_{c0} + DT_c\, x_1, \qquad (2)$$

where:

T_{c0} is the base level for the quenching temperature (495°C) ;

ΔT_c is the proposed variation range (10°C);

- x_2 describes the variation of artificial aging heat treating temperature and can be determined using the following relation:

$$T_i = T_{i0} + \Delta T_i\, x_2, \qquad (3)$$

where:

T_{i0} is the base level for the artificial aging temperature (195°C);

ΔT_i is the proposed variation range (10°C).

- M describes the variation of the elasticity modulus.

The regression is graphically illustrated in figure 1, which represents a three-dimensional variation of elasticity modulus with heat treatment parameters.

Analyzing the determined mathematical model conclusion about the existing area for mechanical characteristics, after final heat treating, has been revealed:

- for elasticity modulus, AlCu4Mg1 alloy has a maximum value of 69758.50 MPa;

- for elasticity modulus, AlCu4Mg1 alloy has an optimum value of 67436,35 MPa, graphically obtained. This value is reached through Grapher 2.0 for Windows computer program.

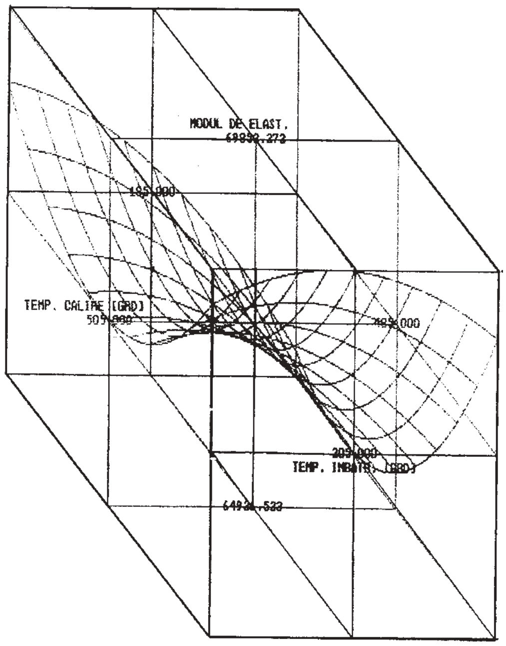

Fig. 1. Three-dimensional variation of elasticity modulus with the heat treatment parameters

Conclusions

Analyzing the presented results, are developing the following conclusions are concluded:

- the maximum value for elasticity modulus for a treated part is obtained for part 1.2.2.;
- the minimum value for elasticity modulus for a treated part is obtained for part 1.1.2.;
- the non-treated part had the minimum value, compared to any treated one.

Nevertheless, a maximum increase for the elasticity modulus is obtained by applying the following technologies:

- for quenching heat treating, the heating temperature is 485 °C. The maintaining time at the heating temperature depends on the dimensions of the working parts. The cooling is at air speed.
- for artificial aging heat treating, a 205°C heating temperature, is maintained for 6 - 15h.

In these conditions was obtained a 237. 21 % increasing value for elasticity modulus.

Based on these conclusions, a better plasticity for studied alloy in conditions of heat treatment, according to results presented in table 3 is noticed.

Nomenclature

M describes the variation of the elasticity modulus
T_c is the quenching temperature
T_i is the artificial aging temperature
T_{c0} is the base level for the quenching temperature (495°C)
T_{i0} is the base level for the artificial aging temperature (185°C)
ΔT is the proposed variation area (10°C)
x_1 describes the variation of quenching heat treating temperature
x_2 describes the variation of artificial aging heat treating temperature

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