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EXPERIMENTAL AND THEORETICAL INVESTIGATION OF STRESS VARIATION IN ALCU4MG1 ALUMINUM ALLOY

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Introduction

The heat treatment in its broad sense refers to any heating and cooling operations performed with the aim to change mechanical properties, the metallurgical structure or the residual stress state of a metal product. The general methods of heat treatment of aluminum alloys include the use of molten salt baths, air chamber furnaces and induction heaters [1, 2]. Air furnaces are used on a wider scale because they permit greater flexibility in the range of operating temperatures. Air furnaces are also more cost effective in the case of a small-scale production; it is far more expensive to maintain the temperature of a large volume of salt waiting parts than to heat an equal volume of air. At the same time, induction methods can provide high heating rates, which affect the transformations. A good temperature control and uniformity throughout the furnace and load are required for all kinds of heat treatment. Materials subjected to a heat treatment should always meet specific quality criteria that include tensile properties and, for certain alloys, adequate durability. All processing steps during the heat treatment should be carefully controlled to ensure a high and reliable performance [3, 4].

The methodology has been proposed to study improvements in AlCu4Mg1 aluminum alloy in the process of heat treatment, which included the following steps:

– adopting the heat treatment technology for the specified alloy;

– choosing the necessary heat treatment installations to perform the heat treatment of the specified alloy;

– choosing tools and machines used to study mechanical characteristics;

– planning the experiment and analytical interpretation of the results.

The aim of this paper was to study the behavior of an AlCu4Mg1 aluminum alloy at final heat treatment. In order to carry out this study, we have done the process optimization by variation of heating temperatures in standard limits. After we fulfilled the planned experiments, we determined the mechanical stress. For the experiments, we used a set of parts, which included nine items, and a test part. Every part had a specific final heat treatment technology, which consisted of quenching and artificial aging by heat treatment in standard limits. The test part was not subjected to the heat treatment and its mechanical characteristics were determined in this situation. Every part was assigned a particular code during the experiment.

Table 1. Experimental results

Code no.	T_c, °C	T, °C	Stress, Rm
1.1.1.	485	185	276.36
1.1.2.	485	195	392.42
1.2.2.	485	205	331.17
2.2.1.	495	185	329.24
2.1.1.	495	195	436.32
2.2.2.	495	205	355.31
3.2.1.	505	185	367.85
3.1.2.	505	195	224.19
3.2.2.	505	205	316.42

In order to apply the proposed technology, we used an electric furnace with forced air circulation and we made experiments in the same conditions of the furnace preheating. The process optimization of the final heat treatment envisaged to determine the minimum number of experiments needed for the correct process description. In this case, when the 3^k factorial experiment model was used, it was enough to perform 9 experiments (k = 2 for two variables: artificial aging temperature and quenching temperature). Therefore, for each process variable a base level could be established and the variation area should be determined for a correct description of the heat treatment technology; the experimental results are summarized in Table 1.

1. Experimental

This paper presents the results of experimental and theoretical studies regarding the improvement of heating processes, which determine a better heat treatment technology for aluminum alloys and low energy consumption. To perform the mechanical characterization of the studied set of parts and to describe exactly the behavior of each aluminum alloy part after the final heat treatment, experiments were carried out with the aim to:

- determine the exact chemical composition of the used $AlCu_4Mg_1$ alloy in order to establish the proper heat treatment technology;
- study mechanical parameters for each part from the studied set of parts in order to establish the proper technology for this alloy;
- establish the yield strength variation with heating temperature;
- find the yield strength variation with the heat treatment technology.

The final heat treatment for this alloy included quenching and artificial aging in the process of heat treatment. The following parameters were used, according the standards for aluminum alloys [1]:

- for quenching, the heating temperatures were of 480-505 °C for all types of the parts. The time of exposure at the heating temperature depended on the type and dimensions of working parts. The cooling was performed with a very high rate [6].
- for artificial aging, the standards for AlCu4Mg1 alloy recommend to maintain the heating temperatures of 185 – 210°C for 6 – 15 hours [6]. At the end of the process, the variation of yield strength was studied and the results were compared with the parameters of the test part.

The tridimensional variation of hardness and stress, depending on heating temperatures, was obtained using the results illustrated in Table 1, 3^k factorial experiment model and a specific computer program. Furthermore, the regression equation, which describes the process was derived:

$$R = 286.88 + 71.927x_1 + 96.02x_2 + 6.71x_1x_2 - 10.693x_1^2 - 31.276x_2^2$$

The experimental matrix for obtaining the regression dependence is presented in Table 2.

Table 2. The experimental matrix for k=2

Exp. no.	*Quenching temp., T_c, °C*	*Variation, x_1*	*Aging temp., T, °C*	*Variation, x_2*
1	485	-1	185	-1
2	485	-1	195	0
3	485	-1	205	+1
4	495	0	185	-1
5	495	0	195	0
6	495	0	205	+1
7	505	+1	185	-1
8	505	+1	195	0
9	505	+1	205	+1

On the basis of these experiments and the obtained regression equation we carried out a theoretical study with the aim to determine the heating parameters for quenching and aging in order to obtain a specified stress needed for application of this alloy.

2. Rezults and discussion

For this theoretical study we considered two cases [7, 8]: the stress and quenching temperature were fixed and we determined the aging temperature; the stress and aging temperature were fixed and we determined the quenching temperature.

Case I: the quenching temperature T_c was known and we obtained the variation of the aging temperature T` with the stress R_m,

x_1 = -1, T_c = 485°C; $T = 196.65 \pm \sqrt{-267 + 1.1R_m}$

This equation has a restriction: R_m > 242.73 MPa.

x_1 = 0, T_c = 495°C; $T = 196.79 \pm \sqrt{-345 + 1.1R_m}$

This equation has a restriction: R_m > 313.89 MPa.

x_1 = 1, T_c = 505°C; $T = 196.93 \pm \sqrt{-299.9 + 1.1R_m}$

This equation has a restriction: R_m > 272.704 MPa.

The relations are shown graphically in Fig. 1. and demonstrate the variation of the tensile stress of AlCu4Mg1 alloy vs. the aging temperature.

Case II: the aging temperature T_t was known and we obtained the variation of the quenching temperature T_c with the stress R_m,

x_2 = -1, T = 185°C; $T_c = 496.59 \pm \sqrt{787., -1.8R_m}$

This equation has a restriction: R_m < 437.299 MPa.

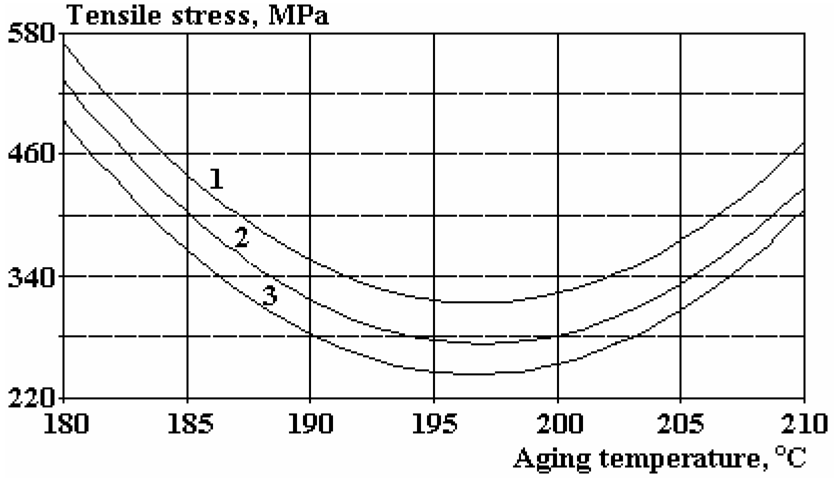

Fig. 1. Graphical determination of the aging temperature for AlCu4Mg1 alloy. 1 – T_c = 495 °C; 2 – T_c = 505 °C; 3 – T_c = 485 °C

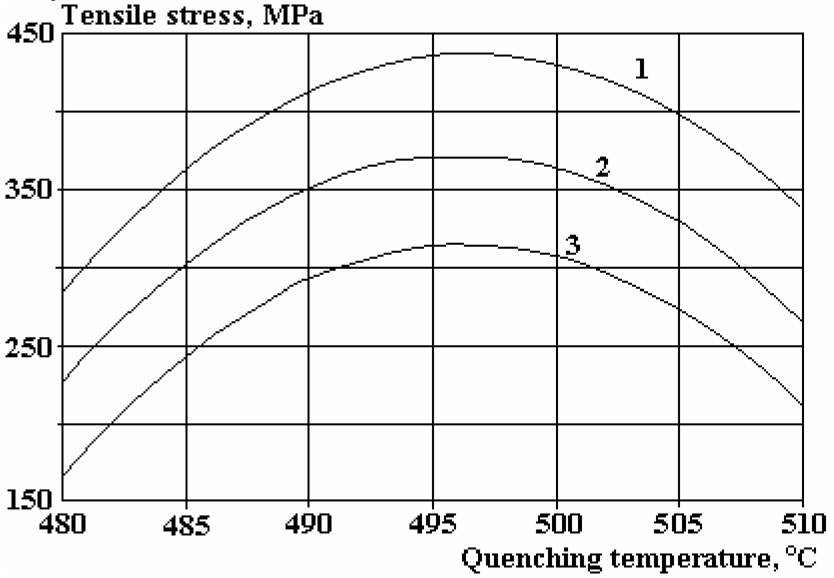

Fig. 2. Graphical determination for the quenching temperature for AlCu4Mg1 alloy. 1 – T_c = 185 °C; 2 – 195 °C; 3 – 205 °C

x_2 = 0, T = 195°C; $T_c = 496.37 \pm \sqrt{566.3 - 1.8R_m}$

This equation has a restriction: R_m < 314.657 MPa.

x_2 = 1, T = 205°C; $T_c = 496.15 \pm \sqrt{669.7 - 1.8R_m}$

This equation has a restriction: R_m < 372.069 MPa.

The relations are shown graphically in Fig. 2 and demonstrate the variation of the tensile stress of AlCu4Mg1 alloy with the quenching temperature.

Conclusions

This paper describes how the tensile strength varies with aging and quenching temperatures. Also, we obtained the equations for theoretical determination of some properties in the standard or special conditions of heat treatment. Using the determined equations, we assumed some characteristics, which the final working parts should possess and calculated parameters of quenching and artificial aging by the heat treatment. Also, in some given conditions of final heat treatment, it was possible to predict the mechanical characteristics of the treated parts; namely, their mechanical stress and hardness. This is a very important problem, because in practice it is absolutely necessary to predict the behavior of working parts, which can influence the reliability of a machine or a mechanism.

We should mention that the calculated temperatures must be between the standard limits for the studied alloy. In the case, when the calculated temperature is not in the standard limits, we cannot impose some characteristics and must use the functions of only one variable. The chosen research methodology allowed to perform the experiments that revealed the following improvements in the final heat treatment technology of AlCu4Mg1 aluminum alloy:

– the correct calculation of parameters of the final heat treatment technology for the studied alloy;

– the selection of an up-to-date furnace and an air chamber furnace with controlled heating;

– the use of the up-to-date equipment for testing the final heat treated parts, particularly of their yield strength;

– the correct planned experiments and interpretations.

In conclusion, the paper presents the algorithm for applying the proper heat treatment technology in order to obtain the necessary properties for the working parts.

REFERENCES

[1]. ASTM Handbook: Alloy and temper designation systems for aluminum. 2004.
[2]. *Banno T.* Heat Treatment Technology - Present Status and Challenges, Heat Treatment of Metals. 1994.
[3]. *Sheppard T.* Mater. Sci. Technol. 1988. Vol. 4. 636 P.
[4]. Manzini S.G., Influence of deformation before artificial aging on properties of Al-Cu-Mg aluminum alloy, Scripta, Met. Et Materialia, 1994. 31, P. 1127 – 1130.
[5]. *Abis S., Massazza M., Mengucci P., Riontino G.* Early ageing mechanisms in a high-copper AlCuMg alloy, Scripta Materialia, 2001 45, P. 685–691.
[6]. ASTM Standards for aluminum and magnesium alloys. 2005 02.02.
[7]. *Taloi D., Florian E.* Optimizarea proceselor metalurgice, Ed. Tehnica, Bucuresti. 1998.
[8]. *Minea A.A., Minea O., Dumitrash P.* Properties of AlCu2Mg1.5Ni behavior at heat treatment, Elektronnaya obrabotka materialov, 2003, no. 6, P. 82–84.

Received 18.01.08

Summary

This paper presents the results of experimental and theoretical studies regarding the behavior of AlCu4Mg1 aluminum alloy after a heat treatment. The methodology has been proposed to study improvements in AlCu4Mg1 aluminum alloy in the process of heat treatment, which included the following steps: 1) adopting the heat treatment technology for the specified alloy; 2) choosing the necessary heat treatment installations to perform the heat treatment of the specified alloy; 3) choosing tools and machines used to study mechanical characteristics; 4) planning the experiment and analytical interpretation of the results. On the basis of these experiments and the obtained regression equation we made a theoretical study with the aim to determine the heating parameters for quenching and aging in order to obtain a specified stress needed for application of this alloy. We considered two cases for this theoretical study: 1) the stress and quenching temperatures were fixed and we determined the aging temperature; 2) the stress and aging temperatures were fixed and we determined the quenching temperature. Using the determined equations, we assumed definite characteristics needed for the working part after treatment and calculated parameters for quenching and artificial aging in the process of heat treatment. Note, that the calculated temperatures should be in the standard limits for the studied alloy. In conclusion, the algorithm was proposed for the process of the optimum heat treatment in order to obtain the necessary properties of working parts.