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ISSN 0543-5846
METABK 53(1) 63-66 (2014)
UDC – UDK 669.715:621.35.001.43:620.17=111

THE EFFECT OF THE T6 HEAT TREATMENT ON HARDNESS AND MICROSTRUCTURE OF THE EN AC-AlSi12CuNiMg ALLOY

Received – Prispjelo: 2013-03-18
Receiver – Prihvaćeno: 2013-05-25
Preliminary Note – Prethodno priopćenje

Presented work discusses research results concerning the effect of the T6 heat treatment process, including soaking of the alloy near the solidus temperature, holding in this temperature and next cooling in cold water (20 °C), as well as exposing to the artificial ageing to check the change in HB hardness and microstructure of the EN AC-AlSi12Cu-NiMg (EN AC-48000) alloy modified with strontium and cast into metal moulds. The temperature range of solutioning and ageing treatments was selected on the basis of crystallization curves recorded with the use of thermal-derivative method. Performed investigations enabled to determine the optimal parameters (temperature and time) of solutioning and ageing heat treatments and their effect on the change in alloy's hardness.

Key words: aluminum alloys, modification, thermal analysis, heat treatment, hardness

INTRODUCTION

The Al-Si alloys, commonly named as silumins, pertain to the most popular aluminum casting alloys. Mechanical and technological properties of castings made from these alloys depend on the correctly performed process of melting and pouring, the structure of the casting and the mould, as well as their heat treatment.

Current investigations connected with the improvement of mechanical properties of aluminum alloys pertain mostly to the advancement in selection of alloy additions methods, using contemporary acquired knowledge of the synthesis of alloys, the improvement in selection of complex modifiers, the reduction of quantities of the hydrogen and gaseous porosity, the reduction of non-metallic impurities, the development and the implementation of modern heat treatment technology [1-5].

A standard heat treatment consists in solutioning (holding the alloy in temperature below temperature of the eutectic reaction in order to dissolve the precipitations of Mg_2Si, homogenize the chemical elements concentration on the cross-section of dendrites of the α phase and the change in the silicon con precipitations morphology), and ageing (soaking of the supersaturated alloy to separate strengthening phases from the supersaturated solid solution – in case of the silumins comprising magnesium or copper only, the precipitation strengthening is obtained as a result of the phases precipitation of Mg_2Si, Al_2CuMg and Al_2Cu) [6-8]. Holding the castings in constant temperatures during predetermined period of time results in the improvement of the mechanical properties such as: R_m tensile strength and HB hardness; and in simultaneous worsening of plasticity (A_5, KCV). Due to the fact that the growth of alloy's strength after heat treatment is very often accompanied with the reduction of the plasticity, their optimal relation should be selected depending on a given application of the alloy.

A remedy in such case could be the implementation of new methods of heat treatment, like for instance the thermo-cyclic heat treatment (TCO) consisting in multiple heating and cooling of products [9], the silicon spheroidization treatment [10] or the usage of optimization methods to select the process' parameters (temperature and duration of solutioning and ageing treatments), basing on the analysis of their effect on the change of mechanical and technological properties of the alloys [11-14]. Another very important issue connected with heat treatment of the silumins is the selection of temperature and the duration of solutioning and ageing treatments. It is connected with the necessity to obtain the optimal results, for instance the improvement of mechanical properties of processed alloy, as well as with the economical aspect of heat treatment operations.

EXPERIMENTAL METHOD

In the course of investigations the eutectic EN AC-48000 (AlSi12CuNiMg) alloy was used, which was melted in an electric resistance furnace. After melting the alloy was refined with Rafal 1 preparation in quantity of 0,4 % of the mass charge, in temperature 730 °C and next, after 60 minutes, the oxides and the slag from the metal-level were removed and the modification treatment with strontium was performed, using AlSr10 master alloy in quantity of 0,4 % of the mass charge (0,04 % Sr).

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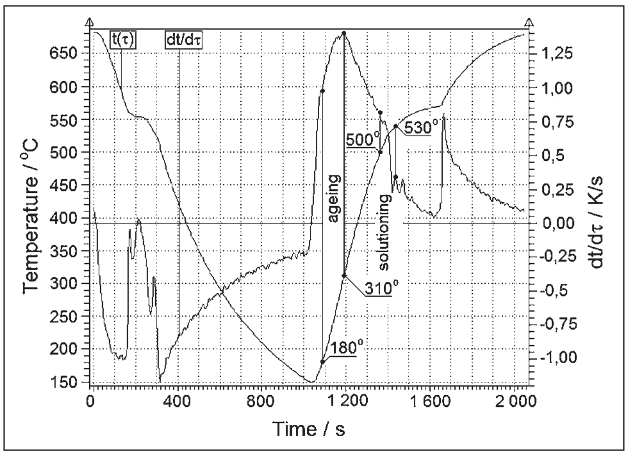

Figure 1 Curves of the ATD method

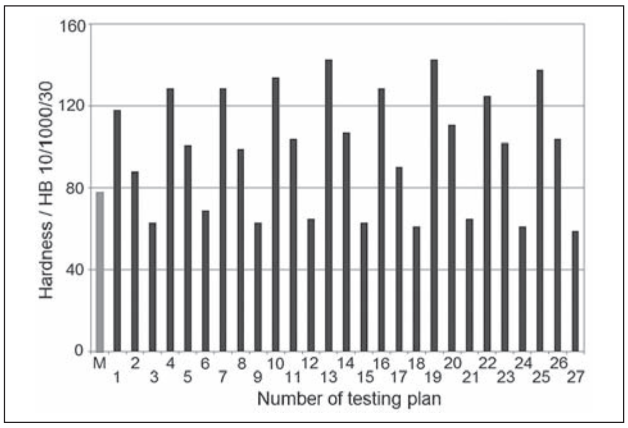

Figure 2 The HB hardness change of the EN AB-48000 alloy for individual systems of the testing plan

The process of solidification and soaking (melting) was recorded with the use of the thermal derivative method (ATD method), using the automatic Crystaldimat analyzer. Figure 1 shows the recorded curves from the ATD method with temperature range of solutioning and ageing treatments marked.

Test pieces used in the hardness test were cast in metal mould heated to the temperature of 250 °C. Cast test pieces from the investigated material underwent solutioning and artificial ageing treatments. After performing the heat treatment, hardness of the alloy was measured with the use Brinell hardness tester of the PRL 82 type, with ø 10 steel ball, at 9800 N load sustained for 30 seconds.

The chemical composition of the investigated alloy is shown in Table 1.

Table 1 **Chemical composition /mas. %**

Chemical composition / mass %				
Si	Cu	Zn	Fe	Mg
11,0	1,15	0,15	0,50	1,10
Ti	Mn	Ni	Cr	Al
0,05	0,35	1,35	0,09	rest

The analysis of the chemical composition was performed with the use of the emission spectroscopy (an emission spectrometer type GDS 850A with glow-discharge).

The temperature range of solutioning heat treatments of the investigated alloy (500 - 530 °C) and the range of ageing temperatures (180 - 310 °C) are marked on the thermal curve (Figure 1). Solutioning time amounted from 0,5 to 3 hours, while ageing time was within the interval between 2 to 8 hours.

To determine temperatures and durations of solutioning and ageing treatments aimed at improvement of HB hardness of the investigated alloy, one implemented three-stage fraction plan of the investigations with four variables, three blocks and 27 systems.

Photos of metallographic structures were made with the use of Neophot 32 microscope and the computer picture analysis system - MultiScan.

RESULTS

Hardness of the alloy after refinement amounted to 75 HB 10/1000/30. The modification did not result in any visible growth of hardness of the alloy, which amounted to 77 HB 10/1000/30.

After performing heat treatment, obtained hardness of the alloy amounted to HB 10/1000/30, and was in the range from 59 to 143.

Figure 2 shows the average values of HB hardness of the EN AB-48000 alloy after heat treatment in relation to the alloy without heat treatment for 27 systems of assumed testing plan (with symbol “M” is marked the test piece from modified alloy, without heat treatment).

The comparison of the obtained average parameters taken from the investigations of the alloy after heat treatment and without heat treatment, shows the highest growth of HB hardness in case of the system no. 13 (solutioning temperature - 520 °C; solutioning time - 1,5 hour, ageing temperature - 180 °C; ageing time - 5 hours) and system no. 19 (solutioning temperature - 535 °C; solutioning time - 0,5 hour; ageing temperature - 180 °C; ageing time - 5 hours) (143 HB 10/1000/30).

The lowest hardness was obtained in case of the systems 7, 9, 18, 24, which were characterized by the high temperature of ageing (310 °C) in the full range of ageing times. Its value was within the range of 59 - 65 HB 10/1000/30, and it was decreased in comparison to the refined and the modified alloy.

Figure 3 shows a spatial diagram of the effect of temperatures and solutioning time on HB hardness 10/1000/30 for the investigated alloy with fixed value of the ageing temperature - 180 °C and the time of ageing – 2 hours.

The effect of temperature and time of ageing treatment on HB hardness 10/1000/30 at constant temperature (535 °C) and solutioning time (0,5 hour) is presented in Figure 4.

Figure 5 shows structures of the alloy after refinement and modification.

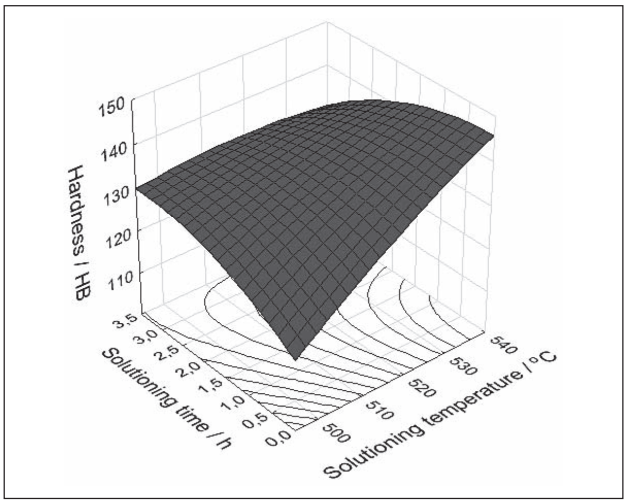

Figure 3 The effect of temperature and time of solutioning on HB hardness of the EN AB-48000 alloy (ageing temperature - 180 °C; ageing time - 2 hours)

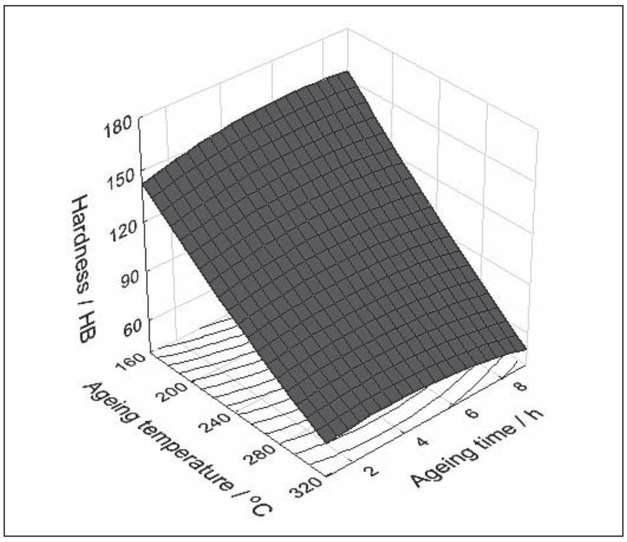

Figure 4 The effect of temperature and time of ageing treatment on HB hardness of the EN AB-48000 alloy (solutioning temperature - 535 °C; solutioning time - 0,5 hour)

Alloy structures after performing heat treatment operations in case of the test pieces taken from the system characterized by the highest value of hardness (system no. 13 - solutioning temperature - 520 °C; solutioning time - 1,5 hour; ageing temperature - 180 °C; ageing time - 5 hour) are shown in Figure 6.

As it can be seen in Figure 6, the morphology of the microstructure changed after the T6 heat treatment. The irregular eutectic phase was converted into fine spheroidized Si particles uniformly distributed in the Al matrix, what significantly improves the mechanical properties.

Based on the results of the performed investigations one described, with mathematical dependence (1) in form of second-degree polynomial, an effect of heat treatment parameters on the change of HB hardness of the alloy.

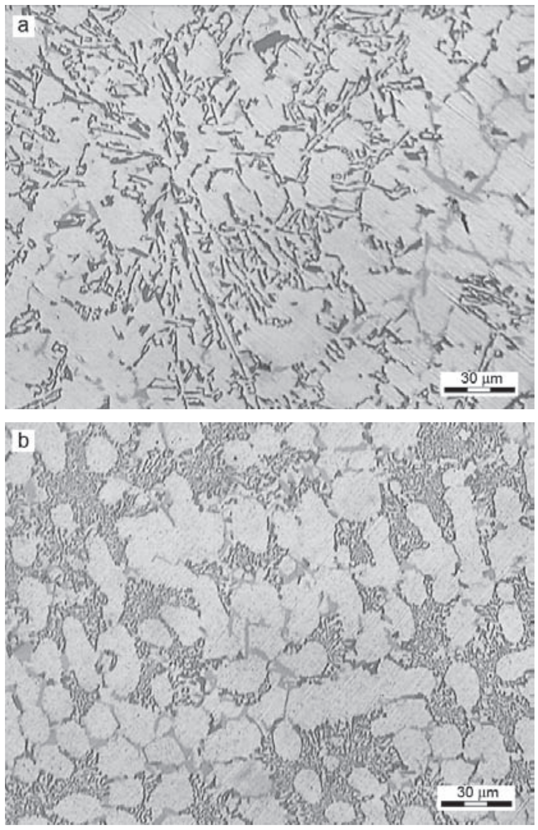

Figure 5 Microstructure of the EN AC-48000 alloy: a) after refinement, b) after modification

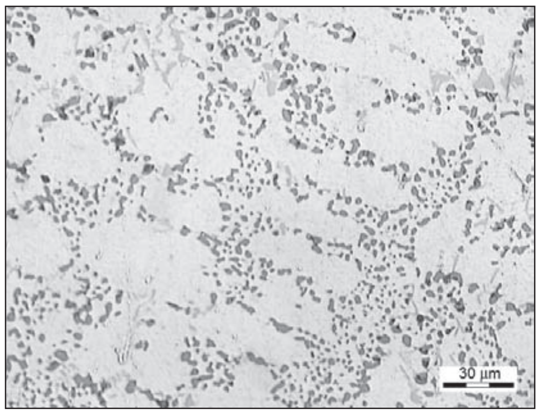

Figure 6 Microstructure of the EN AC-48000 alloy after heat treatment

$$HB = -1252{,}03 + 4{,}58x_1 + 101{,}1x_2 - 1{,}23x_2^2 + 0{,}94x_3 - 2{,}14x_4 - 0{,}4x_4^2 - 0{,}18x_1x_2 + 0{,}02x_1x_4 - 0{,}01x_2x_3 - 0{,}03x_2x_4 - 0{,}02x_3x_4 \quad (1)$$

where: x_1 – solutioning temperature, x_2 – solutioning time, x_3 – ageing temperature, x_4 – ageing time. Correlation coefficient R^2=0,98.

Figure 7 shows the observed (real) and the forecast values of the HB hardness of the investigated alloy.

Three ranges of HB hardness (60 - 70; 90 - 110; 120 - 150) shown in Figure 7 are directly related with temperature of ageing treatment amounted respectively to (310, 235 and 180 °C).

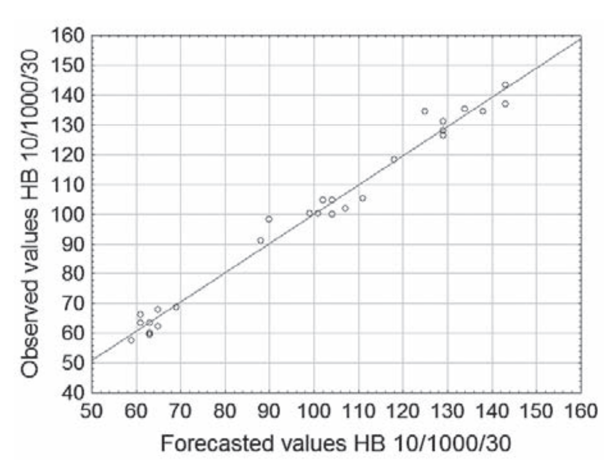

Figure 7 The diagram of the forecast and the observed values of the HB 10/1000/30 hardness

CONCLUSIONS

The improvement of mechanical properties of the EN AB-42000 silumin in the aspect of its hardness change due to the performance of the T6 heat treatment is possible only in case of the selection of suitable solutioning and ageing treatment parameters.

The implementation of the ATD method enabled initial determination of the temperature range of solutioning and ageing treatments of the investigated alloy.

Obtaining the highest hardness determines the adoption of:

- ageing temperatures up to 180 ^{o}C,
- ageing times from 2 to 5 hours,
- solutioning temperatures in the range of 520 - 535 ^{o}C,
- solutioning times from 0,5 to 1,5 hour.

The usage of increased temperatures of ageing treatment has an adverse effect on the change of HB hardness of the investigated alloy, causing its decrease.

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Note: The responsible translator for English language is Rafał Mazur, Bielsko-Biała, Poland