

J. PEZDA*,#

EFFECT OF THE T6 HEAT TREATMENT ON CHANGE OF MECHANICAL PROPERTIES OF THE AISi12CuNiMg ALLOY MODIFIED WITH STRONTIUM**WPŁYW OBRÓBKİ CIEPLNEJ T6 NA ZMIANĘ WŁAŚCIWOŚCI MECHANICZNYCH STOPU AISi12CuNiMg MODYFIKOWANEGO STRONTEM**

The paper presents test results concerning an effect of the heat treatment on microstructure and mechanical properties of eutectic EN AC-AISi12CuNiMg (EN AC-48000) alloy according to the EN 1706:2010 (tensile strength – R_m , hardness – HB 10/1000/30) modified with strontium. Solution heat treatment and ageing treatment temperature ranges were selected on base of heating (melting) curves recorded with use of the ATD method. Temperatures of the solution heat treatment were 500, 520, and 535°C \pm 5°C, while the solution time ranged from 0.5 to 3 h (0.5; 1.5 and 3 h). Temperature of the solution heat treatment amounted to 180, 235 and 310°C, while the ageing time ranged from 2 to 8 h (2, 5 and 8 h).

Obtained results have enabled determination of optimal parameters of the T6 heat treatment in aspect of improvement of tensile strength R_m and hardness HB of the alloy, with reduced time of individual treatments and determination of mathematical relationships enabling prediction of these mechanical properties.

Keywords: aluminum alloys, heat treatment, mechanical properties

W pracy przedstawiono wyniki badań dotyczące wpływu obróbki cieplnej na właściwości mechaniczne (wytrzymałość na rozciąganie – R_m , twardość – HB 10/1000/30) i mikrostrukturę eutektycznego stopu EN AC-AISi12CuNiMg (EN AC-48000) zgodnie z PN-EN 1706:2011 modyfikowanego strontem. Zakresy temperatur zabiegów przesycania i starzenia zostały dobrane w oparciu o krzywe nagrzewania (topienia) zarejestrowane metodą ATD. Temperatury przesycania wynosiły 500, 520 i 535°C \pm 5°C, a czas przesycania mieścił się w zakresie od 0.5 do 3 godzin (0.5; 1.5 i 3 h). Temperatura starzenia wynosiła 180, 235 i 310°C. Czas przesycania mieścił się w zakresie od 2 do 8 godzin (2, 5 i 8 h).

Uzyskane wyniki pozwoliły na określenie optymalnych parametrów obróbki cieplnej T6 w aspekcie poprawy wytrzymałości na rozciąganie R_m i twardości HB stopu, przy ograniczeniu czasu poszczególnych zabiegów oraz wyznaczenie zależności matematycznych umożliwiających predykcje tych właściwości mechanicznych.

1. Introduction

Contemporary engineering materials are required to be light weight and corrosion resistant, coupled with high strength and hardness. In the recent years, aluminum alloys had attracted attention of many researchers, engineers and designers, as promising structural materials for automotive industry or aerospace applications [1-4]. To the most popular casting alloys belong silumins (Al-Si), which are characterized by low density equal to about 3,0 g/cm³; low density advantageously increased weight to strength, which is determined by ratio between tensile strength and specific gravity (R_m/ρ) [5].

Mechanical properties of the Al-Si casting alloys, especially elongation, depend on alloy's structure and eutectic silicon, which may have an acicular or lamellar form [6]. Strontium is also used as modifier for the Al-Si-Mg alloys [7]. It possesses certain advantages over the sodium in that it is easier to add to the melt, and it offers a semi-permanent modified Al-Si-Mg alloys.

The addition of alloying elements such as Mg and Cu make the alloys heat treatable, further improving their mechanical properties and allowing their use in new, more demanding applications (e.g. engines, cylinder heads, etc.) [1]. The most used heat treatment for these Al-Si-Cu cast alloys is the solution heat treatment followed by age hardening, that is required for the precipitation of the Al₂Cu hardening constituent. The solution heat treatment of the Al-Si-Cu cast alloys affects the microstructure, improvement of eutectic silicon morphology (fragmentation, spheroidization and coarsening) and ensures changes in fracture zones [8-10].

The T6 heat treatment comprises three stages: solution heat-treating, quenching and artificial aging [11-12]. Application of suitable parameters of individual heat treatments determines obtainment of improved mechanical properties of processed materials [13-17].

The AISi12CuNiMg eutectic aluminum alloy, investigated in the present work, is widely used for load-bearing structural components, for example: pistons for combustion engines,

* DEPARTMENT OF PRODUCTION ENGINEERING AND AUTOMATION, UNIVERSITY OF BIELSKO-BIALA, 2 WILLOWA STR., 43-300 BIELSKO-BIALA, POLAND

Corresponding author: jpezda@ath.bielsko.pl

gears or pump parts, and wear-resistant and heat-resistant parts due to high strength at increased temperature and low thermal expansion.

Objective of the present work is to determine optimal parameters of the T6 heat treatment for the EN AC- AlSi12CuNiMg alloy in aspect of improvement of its mechanical properties (R_m and HB) and a possibility of their prediction.

2. Experimental procedure

Investigated alloy was melted in crucible-type electric furnace and underwent treatments of refinement (Rafal 1 – 0.4% mass of charge) and modification (AlSr10 – 0.4% mass of charge).

Chemical composition of the investigated alloy is presented in the Table 1. Analysis of chemical composition was performed with use of spectrometric method (spectrometer GDS 850A type).

TABLE 1
 Chemical composition of EN AC- AlSi12CuNiMg (EN AC-48000) alloy

Alloy	Element content, % mas.							
	Si	Cu	Zn	Fe	Mg	Ti	Mn	Ni
EN AC- AlSi12CuNiMg	11.53	1.15	0.02	0.29	1.30	0.03	0.20	1.06

The heat treatment was performed for the modified alloy. It consisted in operations of solution heat treatment and ageing treatment. Temperatures of these treatments were selected on base of values of points on melting (heating) curves recorded with the ATD method (Fig. 1), using automated "Crystatdimat" analyzer.

In the Table 2 are presented parameters of the heat treatments for three-stage plan of the testing with four variables.

Test pieces were prepared in accordance with the PN-88/H-88002 standard. Static strength tests were performed on the ZD-20 tester. Measurement of the Brinell hardness was performed according to the PN-75/H04350 standard with

use of the Brinell hardness tester of the PRL 82 type, with \varnothing 10 mm steel ball, at 9800 N load sustained for 30 seconds. Microstructure photos of the alloy were made with use of the Neophot 32 optical microscope and the MultiScan picture analyzer. To obtain the dependencies and plot the diagrams depicting effect of the heat treatment parameters on the mechanical properties of the investigated alloys it has been used the "Statistica" ver. 10 software, from the StatSoft Company.

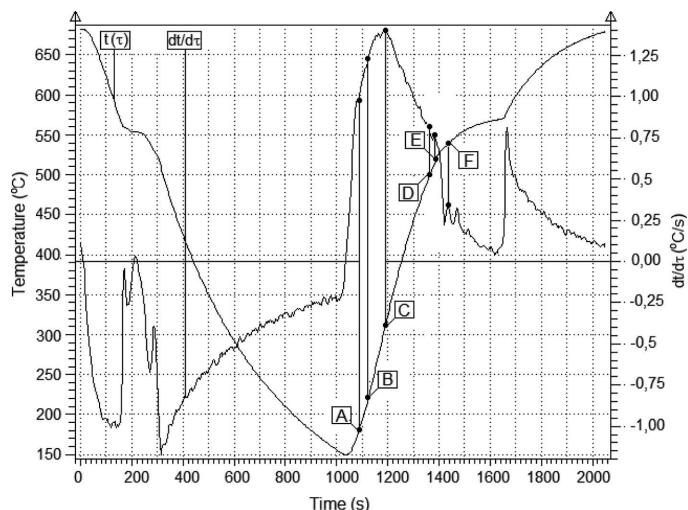


Fig. 1. Melting and crystallization curves from the ATD of the investigated alloy

3. Results and discussion

Refined and modified alloy has been subjected to heat treatment T6 type. The tensile strength R_m was determined for the refined and modified alloy (initial alloy), and the alloy after solution heat treatment and ageing treatment.

In the Fig. 2 are presented average values of the tensile strength R_m of the EN AB-48000 alloy after the heat treatment, in reference to the alloy without the heat treatment for 27 systems of applied testing plan.

Heat treatment parameters of the alloy

TABLE 2

Designation	Ageing temperature, [°C]	Ageing time, [h]	Designation	Solutioning temperature, [°C]	Solutioning time, [h]
A	180	2	D	500	0.5
B	235	5	E	520	1.5
C	310	8	F	535	3.0

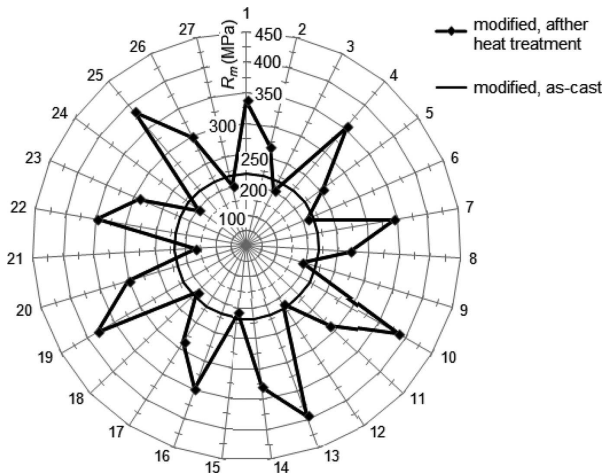


Fig. 2. Change of the tensile strength R_m of the investigated alloy for individual systems of the testing plan

The tensile strength R_m obtained for the refined and modified alloy amounted from 218 to 230 MPa. After performed heat treatment, the tensile strength R_m was contained within range from 184 to 393 MPa.

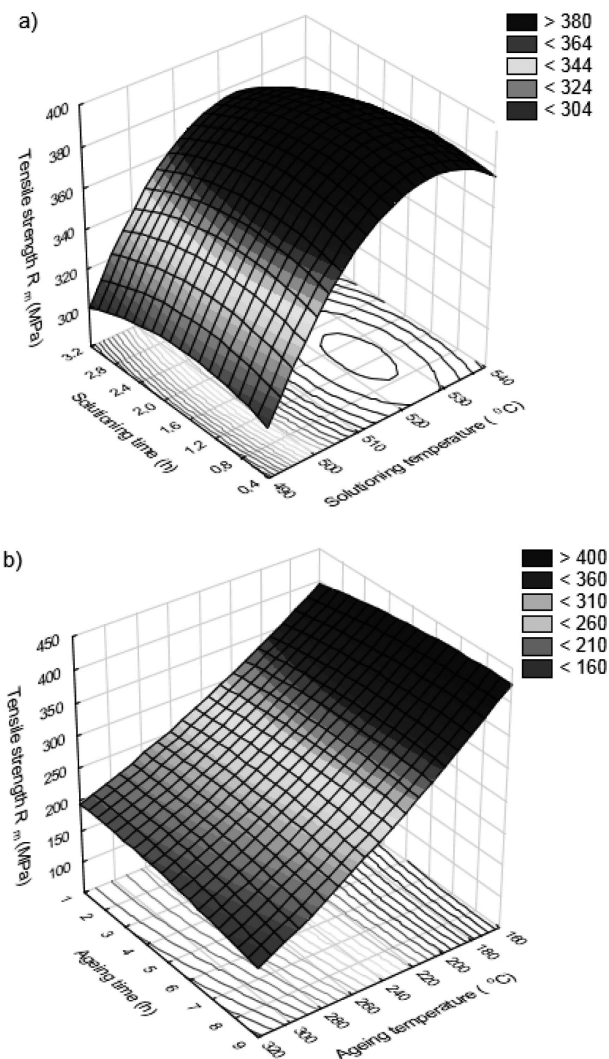


Fig. 3. Effect of temperature and time of the solutioning on tensile strength R_m of the EN AB-48000 alloy: a) for A = 180°C, 5 hours, b) for F = 535°C, 0.5 hours

In the Fig. 3 are depicted spatial diagrams of an effect of temperature and duration of solutioning and ageing treatments on change of the tensile strength R_m of the investigated alloy.

Making comparison of obtained average values of the parameters from tests of the alloy after heat treatment and without heat treatment, one ascertained a growth of the tensile strength R_m up to 170% (system no.13, Fig. 2) with respect to the modified alloy, without the heat treatment.

The highest tensile strength $R_m = 393$ MPa was obtained for: solutioning temperature 520°C, solutioning time 1.5 hour, ageing temperature 180°C and ageing time 5 hours. Whereas, the lowest tensile strength R_m (176 MPa) was obtained in case of the test pieces solutioned for 1.5 hour at temperature 500°C, and aged for 2 hours at temperature 310°C.

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

$$R_m = -18198.7 - 0.1x_1^2 + 46.3x_2 - 5.1x_2^2 + 1.4x_3 - 0.4x_4 - 0.6x_4^2 - 0.1x_1x_2 + 0.9x_2x_4 - 0.1x_3x_4 \text{ [MPa]} \quad (1)$$

where: x_1 – solutioning temperature, x_2 – solutioning time, x_3 – ageing temperature, x_4 – ageing time. Correlation coefficient (for $\alpha = 0,05$): $R = 0.99$; $R^2 = 0.97$; corr. $R^2 = 0.93$.

Obtained values of the correlation coefficient close to 1 have confirmed that mathematical dependence (1) sufficiently describes effect of heat treatment parameters on change of the tensile strength R_m of the investigated alloy. In the Fig. 4 are presented experimental (real) and predicted values of the tensile strength R_m of the investigated alloy.

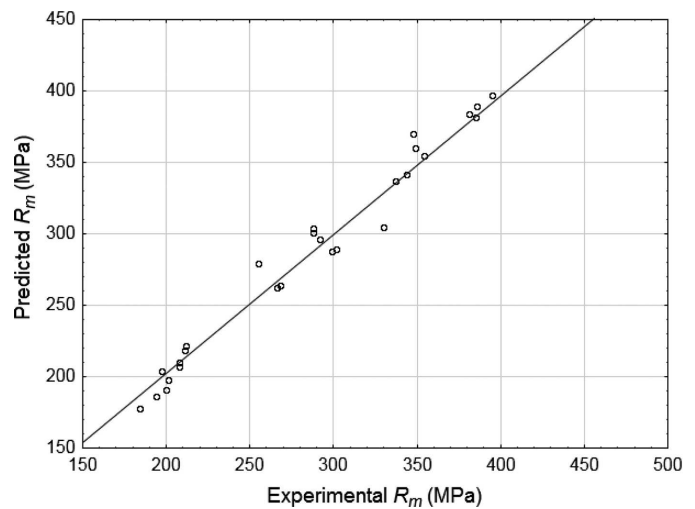


Fig. 4. Diagram of experimental and predicted values of the tensile strength R_m

The hardness HB of the alloy after refinement amounted to 75 HB 10/1000/30. The modification did not result in any visible growth of the hardness, which amounted to 77 HB 10/1000/30. After performed heat treatment of the alloy, obtained hardness HB 10/1000/30 was included within range from 59 to 143.

In the Fig. 5 are presented average values of the hardness HB for the EN AC-AlSi12CuNiMg (EN AB-48000) alloy after the heat treatment with respect to the values obtained for the

alloy without the heat treatment for 27 systems of applied plan of the testing.

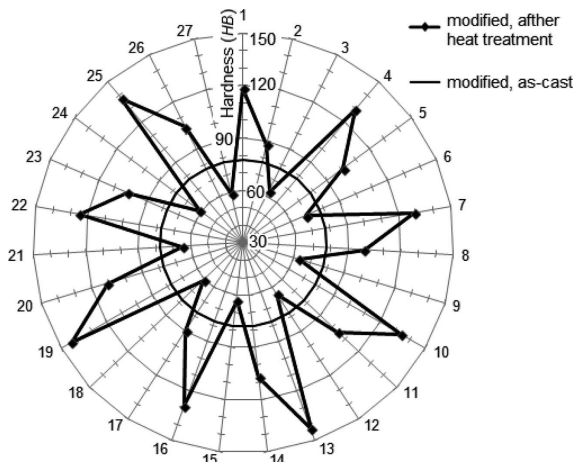


Fig. 5. Change of the hardness *HB* of the investigated alloy for individual systems of the testing plan

Spatial diagrams of the effects of temperature and time of solutioning and ageing treatments on change of the hardness *HB* of the investigated alloy are shown in the Fig. 6.

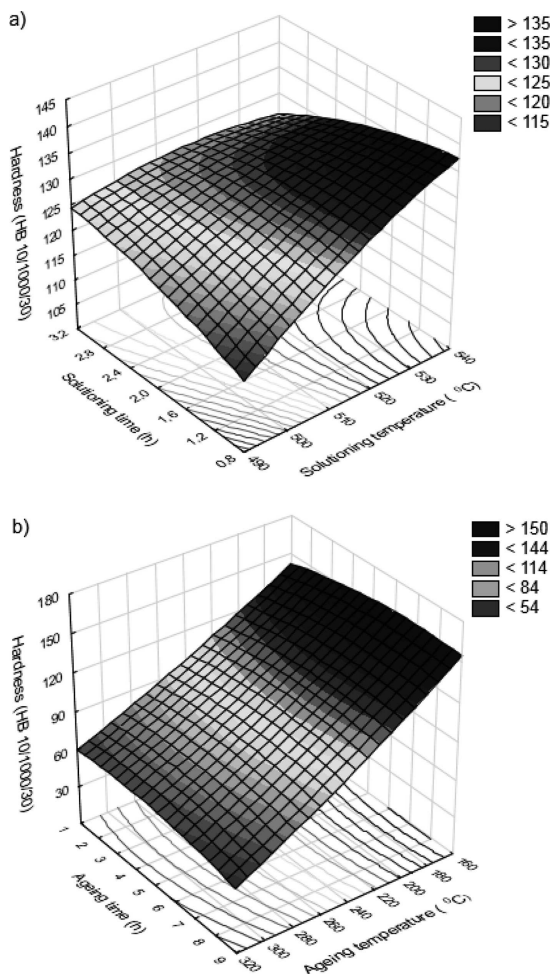


Fig. 6. Effect of temperature and time of the solutioning on hardness *HB* of the EN AB-48000 alloy: a) for $A = 180^{\circ}\text{C}$, 2 hours, b) for $F = 535^{\circ}\text{C}$, 1.5 hours

Making comparison of obtained average parameters from the investigations of the alloy after the heat treatment and without the heat treatment, one confirmed the highest growth of the hardness *HB* 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 the system no. 25 (solutioning temperature – 535°C ; solutioning time – 0.5 hour; ageing temperature – 180°C ; ageing time – 5 hours) ($143 \text{ HB } 10/1000/30$). The lowest hardness *HB* was obtained in case of the systems 7, 9, 18, 26, which were characterized by high temperature of the ageing (310°C) in complete range of ageing times. Its value was included within range of 59-65 $\text{HB } 10/1000/30$, what represents a decrease with respect to refined and modified alloy.

Based on results of the performed investigations one described, with mathematical dependence (2) in form of second-degree polynomial, an effect of heat treatment parameters on change of the hardness *HB* of the alloy.

$$\begin{aligned}
 HB = & -1252.03 + 4.58x_1 + 101.1x_2 - 1.23x_2^2 + 0.94x_3 \\
 & - 2.14x_4 - 0.4x_4^2 - 0.18x_1x_2 + 0.02x_1x_4 \\
 & - 0.01x_2x_3 - 0.03x_2x_4 - 0.02x_3x_4 \quad [HB \ 10/1000/30]
 \end{aligned}
 \tag{2}$$

where: x_1 – solutioning temperature, x_2 – solutioning time, x_3 – ageing temperature, x_4 – ageing time. Correlation coefficient (for $\alpha = 0.05$): $R = 0.99$; $R^2 = 0.98$; corr. $R^2 = 0.96$.

Taking into account obtained values of the correlation coefficients, likewise in case of the dependence (1), the dependence (2) describes in satisfactory way an effects of heat treatment parameters on change of the hardness *HB* of the investigated alloy. In the Fig. 7 are presented experimental (real) and predicted values of the hardness *HB* of the investigated alloy.

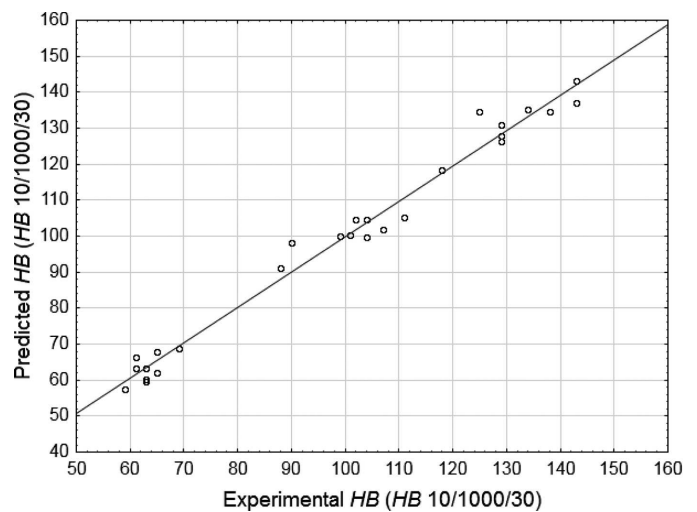


Fig. 7. Diagram of experimental and predicted values of the hardness *HB*

In the Fig. 8 are shown structures of the alloy after refinement and modification.

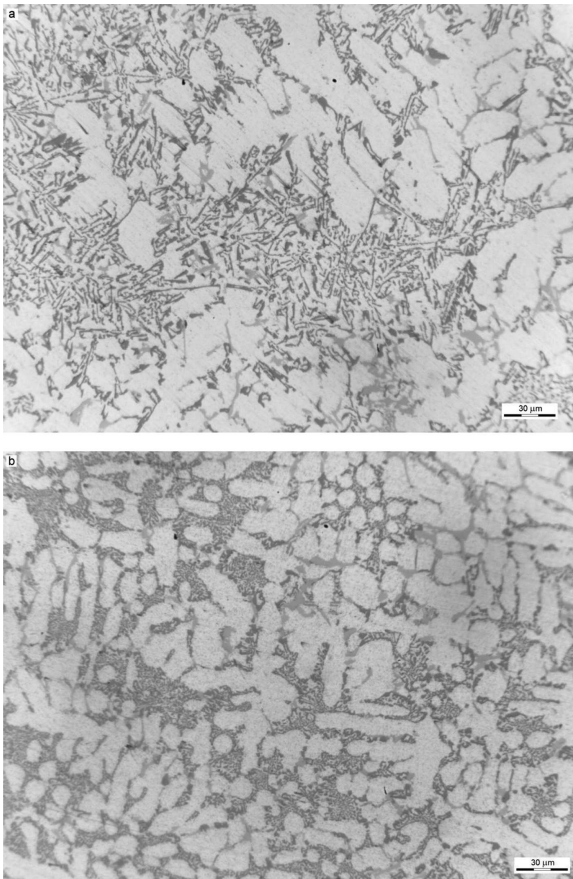


Fig. 8. Microstructure of the EN AC-48000 alloy: a) after refinement, b) after modification

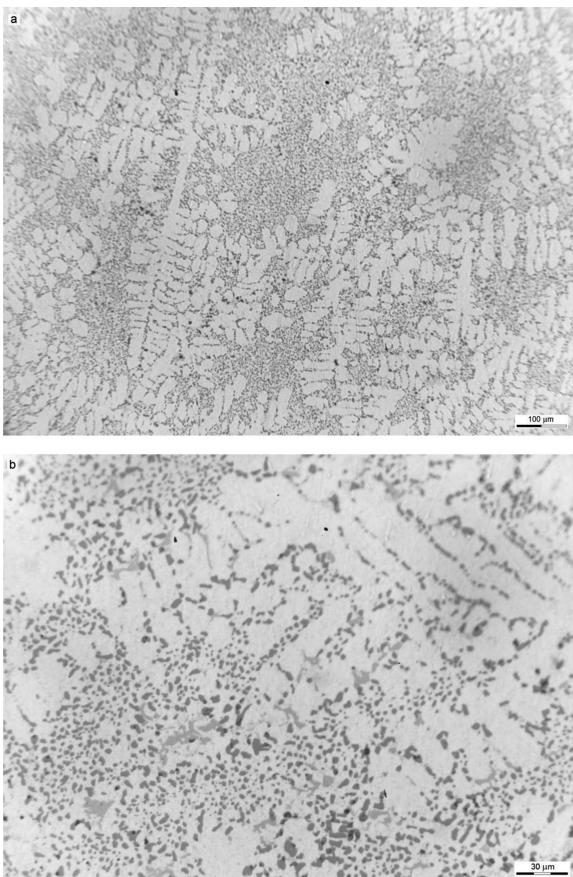


Fig. 9. Microstructure of the EN AC-48000 alloy: a) after refinement and modification; b) after heat treatment T6 type

Performed treatment of the modification resulted in change of morphology of eutectic silicon precipitations from a lamellar to a stripped ones (Fig. 8b).

Structures of the alloy after performed heat treatment operations in case of the test pieces from the system characterized by the highest value of the hardness (system no. 13 – solutioning temperature – 520°C; solutioning time – 1.5 hour; ageing temperature – 180°C; ageing time – 5 hour) are shown in the Fig. 9.

As it can be seen from the Fig. 9b, morphology of the microstructure changed obviously after the T6 heat treatment. The irregular eutectic phase was converted into fine spheroidized Si particles uniformly distributed in the Al matrix, what significantly improved the mechanical properties.

4. Conclusion

Performed T6 heat treatment has an effect on change of mechanical properties of the investigated alloy. Selection of adequate temperatures and times of solution heat treatments and ageing treatments determines growth of the tensile strength R_m and hardness HB .

Obtainment of the highest tensile strength R_m and hardness HB determines adoption of:

- ageing temperatures up to 180°C,
- ageing times from 2 to 8 hours,
- solutioning temperatures in range of 520-535°C,
- solutioning times from 0,5 to 1,5 hour.

Usage of increased temperatures of the ageing treatment has adverse effect on change of the HB hardness of the investigated alloy, resulting in its decrease.

REFERENCES

- [1] M. Panušková, E. Tillová, M. Chalupová, Strength of Materials **40**, 1, 98-101 (2008).
- [2] S. Kozhar, D. Regener, H. Zak, H. Altenbach, International Foundry Research/Giessereiforschung **62**, 2, 26-31 (2010).
- [3] F. Zupanič, T. Bončina, N. Rozman, B. Markoli, RMZ – Materials and Geoenvironment **58**, 1, 1-14 (2011).
- [4] J.C. Williams, E.A. Starke Jr., Acta Materialia **51**, 19, 5775-5779 (2003).
- [5] L.A. Dobrzański, L. Reimann, G. Krawczyk, Archives of Materials Science and Engineering **31**, 1, 37-40 (2008).
- [6] B. Closset, J.E. Gruzleski, Metallurgical Transactions A **13**, 6, 945-951 (1982).
- [7] J.R. Davis, Aluminium and Aluminium Alloys, ASM International 1993.
- [8] E. Ogris, A. Wahlen, H. Lüchinger, P.J. Uggowitzer, Journal of Light Metals **2**, 4, 263-269 (2002).
- [9] Z. Górny, Odlewnicze stopy metali nieżelaznych, PWN Warszawa 1992.
- [10] D.K. Dwivedi, A. Sharma, T.V. Rajan, Materials and Manufacturing Processes **20**, 5, 777-791 (2005).
- [11] A.S.M. Handbook-Committee, ASM handbook. Heat Treating **4**, American Society for Materials (1991).
- [12] J.G. Kaufman, E.L. Rooy, Aluminum Alloy Castings: Properties, Processes And Applications, ASM International 2004.
- [13] Z. Lech, E. Czekaj, J. Nykiel, B. Kułaga, Archiwum Odlewnictwa **2**, 6, 75-90 (2002).

- [14] K.V. Sudhakar, K. Konen, K. Floreen, Archives of Metallurgy and Materials **57**, 3, 753-757 (2012).
- [15] E. Sjölander, S. Seifeddine, Journal of Materials Processing Technology **210**, 10, 1249-1259 (2010).
- [16] J. Pezda, Archives of Foundry Engineering **10**, 1, 131-134 (2010).
- [17] P. Ouellet, F.H. Samuel, Journal of Materials Science **34**, 19, 4671-4697 (1999).

Received: 20 November 2014.