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Impact of Various Types of Heat Treatment on Mechanical Properties of the EN AC-AlSi6Cu4 Alloy

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Abstract

The Al-Si-Cu alloys with content of the copper from 2 to 4 percent, after solutioning and artificial ageing treatments (T6 heat treatment), feature high strength and very high hardness, however their elongation is considerably reduced. Maintaining value of elongation on the level of initial alloy is possible due to homogenizing treatment performed prior the T6 treatment. Performed strength tests of the initial alloy and the alloy after individual types of the heat treatment enable comparison of obtained results and assessment of usability of the investigated alloy to production of a castings. Test pieces to the strength tests were poured in standardized metal moulds. Parameters of the heat treatment, temperature and duration of heating were established on base of the literature and the ATD diagram performed for the investigated alloy. Investigated EN AC-AlSi6Cu4 alloy after homogenizing treatment becomes plastic, its elongation A_5 and its impact strength *KC* increase nearly three times, with slight decrease of the tensile strength R_m. Dispersion hardening in connection with the homogenizing treatment results in increase of the tensile strength R_m with 68%, hardness and impact strength with 40% with elongation at level of the alloy without heat treatment. Making suitable selection of various types of the heat treatment it is possible, depending on needs, to control mechanical properties of the alloy.

Keywords: Heat treatment, Aluminum alloys, ATD, Elongation, Tensile strength

1. Introduction

Growing production of castings from aluminum alloys and more and more stringent requirements in area of mechanical and technological properties lead to research work on development of technology of alloy preparation in casting process, as well as heat treatment of ready alloy [1-6].

Alloys of the Al-Si-Cu type, commonly used for castings of machinery components, stand out from other casting alloys with high hardness, strength, and relatively low elongation. These alloys contain also magnesium, what facilitates the heat treatment [2, 7-9] and enables shortening of time and reduction of temperature of solutioning treatment [10,11].

Significant increase of the mechanical properties of such alloys can be obtained in result of heat treatment comprising operations of solutioning and artificial ageing. It enables increase of the tensile strength R_m and hardness with simultaneous decrease of the unit elongation of up to 50% [2,12-14]. Such high drop of the elongation can create important disadvantage in case of a castings produced from such alloys, and to eliminate it, the heat treatment has been extended by adding the homogenizing treatment prior the solutioning and artificial ageing.

Objective of the homogenizing treatment is removal, through diffusion, of differences in concentration of elementary substances in the crystals (micro-segregation). Diffusion type modifications require usage of high temperatures, slightly below the solidus line and long time of heating [7].

The present paper describes an effect of homogenizing treatment of the EN AC-AlSi6Cu4 alloy on change of its mechanical properties, and possibilities of implementation of such treatment prior solutioning heat treatment of the T6 heat treatment.

2. Methodology of the research

The research was performed for the EN AC-AlSi6Cu4 alloy, which is classified among commonly used silumin casting alloys with high content of copper. AlSi6Cu4 is used for castings, which are moderately highly stressed. (e.g. engine blocks, cylinder heads and pistons, clutch housings, exhaust ends, die-cast chassis) [15-17].

Chemical composition of the investigated alloy, reported in metallurgical certificate of the producer is presented in the Table 1.

Table 1.
Chemical composition of the EN AC-AlSi6Cu4 alloy

Chemical composition / mass %					
Si	Cu	Zn	Fe	Mg	Ni
6.49	3.96	0.75	0.48	0.27	0.03
Mn	Pb	Ti	Sn	others	Al
0.45	0.02	0.14	0.01	0.05	rest

From the ATD diagram (Figure 1) drawn for the investigated alloy, it has been taken temperature of the homogenizing treatment t_u=515°C (Point A) and the lowest from cited in the literature tome of heating τ_u=10 h [1, 7, 18]. The homogenizing treatment was performed with two methods of cooling:

- with furnace (p),
- on the air (a).

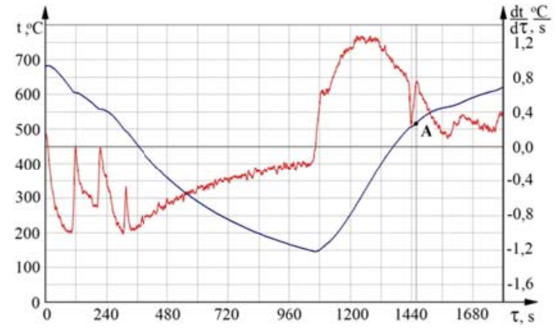


Fig. 1. The ATD diagram of the EN AC-AlSi6Cu4 alloy

The test pieces to strength tests were poured in standardized metal moulds kept at temperature 300°C. Temperature of the metal during pouring into the moulds amounted to 700°C. Poured test pieces were divided into groups destined to testing of the mechanical properties after operations of:

1. Initial alloy - without treatment (F);
2. Homogenizing (cooling with furnace - O3p);
3. Dispersion hardening (T6);
4. Homogenizing (cooling with furnace) and dispersion hardening (O3p+T6);
5. Homogenizing (cooling on the air) and dispersion hardening (O3a+T6).

Control of the temperature in course of the heat treatment was performed through measurement of temperature of control test piece positioned between hanging test pieces and additionally inside chamber of the furnace. During 10 hour heating cycle, temperature of the homogenizing was maintained within range of t_u=515 ± 5°C $t_u = 515^{+5}_{-3}$ °C To obtain possibly the highest values of the tensile strength R_m and the hardness of the treated alloy, the following parameters of the solutioning and artificial ageing were taken on the base of diagrams developed by the author [2]:

- solutioning temperature t_p=485°C,
- solutioning time τ_p=2h,
- ageing temperature t_s=180°C,
- ageing time τ_s=3,5h.

Homogenizing, solutioning and artificial ageing treatments for all groups of treated test pieces were performed simultaneously in chamber of the furnace to assure possibly the same conditions of the heat treatment. Temperature of the solutioning and artificial ageing was maintained within following range:

- t_p= 485 ±3°C,
- t_s= 180 ±3°C.

Cooling down of the test pieces after solutioning treatment was performed in water having temperature of 20°C, and next the test pieces underwent treatment of artificial ageing. The strength R_m and elongation A_5 were measured on quintuple test pieces with diameter □10 mm, prepared according to the PN-EN ISO 6892-1:2010P standard. Measurement of the hardness according to Birnell method was performed with use of the hardness tester of the PRL 82 type, with steel ball with diameter of □10 mm under load of 9800 N during 30 seconds. Impact strength test was performed on the base of simplified method [19] on cylindrical test pieces with notch, on the Charpy pendulum machine with initial energy of 50 J.

3. Description of obtained results

Mechanical properties of the investigated alloy, after performed heat treatment operations are presented in the Table 2.

Table 2.
Mechanical properties of the ENAC-AlSi6Cu4 alloy after heat treatment

No.	Implemented heat treatment	R_m	A_5	Hardness	Impact strength KC
		MPa	%	HB	kJ/cm²
1	F	232	2.4	93	28
2	O3p	184	6.6	58	100
3	T6	349	1.6	129	39
4	O3p+T6	377	20	131	40
5	O3a+T6	390	24	127	39

Engineering stress-strain curves of the test pieces for individual types of the heat treatment are presented in the Fig. 2. Confrontation of these curves enables illustration of changing mechanical properties of the investigated alloy. Making comparison of presented curves it is possible to assess how the unit elongation is changing (bend of final sectors of the curves), how are changing the tensile strength R_m and the Young's modulus [19, 20].

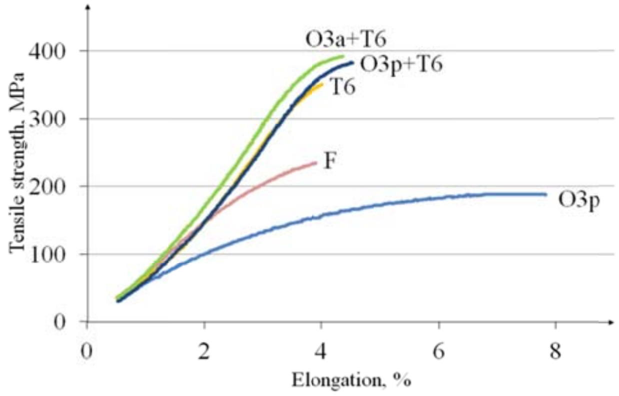


Fig. 2. Engineering stress-strain curves of the test pieces

The changes occurring in structure of the investigated alloy, starting from its initial condition through all types of performed heat treatments, are shown in the photos of microstructures (Figure 3).

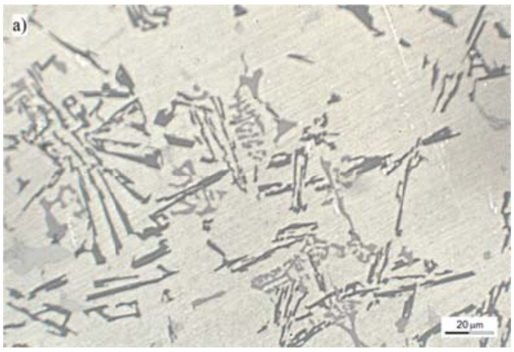
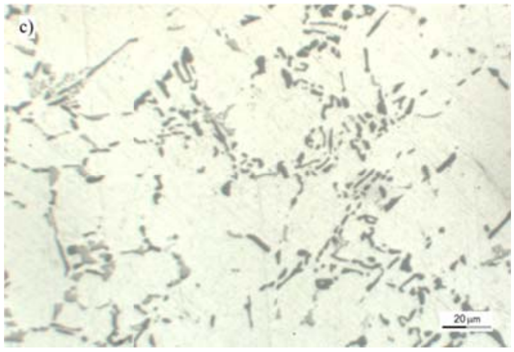
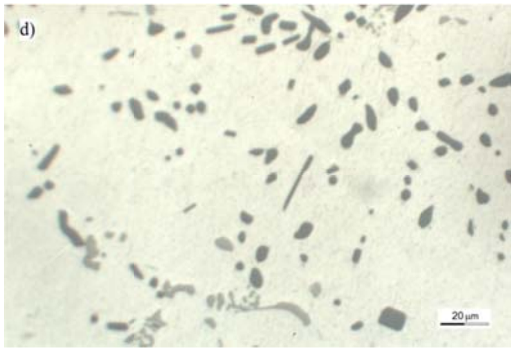


Fig 3. Microstructure of the ENAC-AlSi6Cu4 alloy: a) initial alloy F, b) the alloy after homogenizing O3p (cooling with furnace)





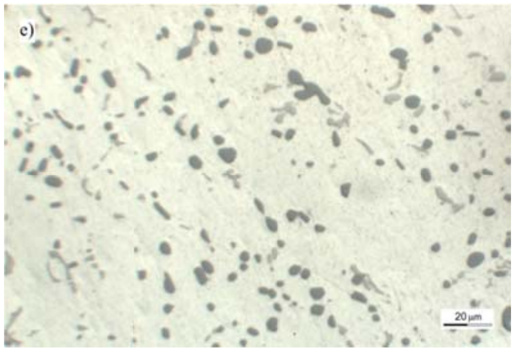


Fig 3. Microstructure of the ENAC-AlSi6Cu4 alloy: c) the alloy after the T6 treatment, d) the alloy after the O3p+T6 treatment, e) the alloy after the O3a+T6 treatment

Microstructure of the initial alloy (Fig. 3a) is characterized by big, not-modified lamellar precipitations of eutectic silicon, characteristic of sharp edges present on background of the phase α. Homogenizing treatment (Fig. 3b) has resulted in rounding of the edges of eutectic silicon and its partial balling and coagulation. The eutectic silicon seen on boundaries of the dendrites of phase α underwent high refinement after dispersion hardening (Fig. 3c).

Complex heat treatment consisting of the homogenizing treatment and dispersion hardening (Fig. 3d and 3e), enables obtainment of the most advantageous precipitation of silicon, resulted from long-lasting homogenizing treatment. Such form of silicon is the most advantageous from point of view of limited decrease of elongation of the alloy after dispersion hardening.

4. Conclusions

Homogenizing treatment performed prior dispersion hardening enables increase of the unit elongation A_5 up to 50%, comparing with the values obtained after dispersion hardening only. Simultaneously, the tensile strength R_m also increases and high hardness is maintained.

The best mechanical properties were obtained using connection of the homogenizing treatment with cooling down on the air, and dispersion hardening. Making selection of suitable type of the heat treatment it is possible to obtain, from the same alloy, the castings with very high strength or the castings with lower strength but with very good impact strength and plasticity.

Increase of costs connected with use of the homogenizing treatment is compensated in high degree by shortened time of heating during solutioning and artificial ageing.

References

[1] Dobrzański, L.A. (2006). *Engineering materials and materials design.* Warszawa: WNT. (in Polish).

[2] Pezda, J. (2014). *Effect of selected parameters of the heat treatment operations on technological quality of machinery components pored from silumins*. Bielsko-Biała: Scientific Publishers ATH. (in Polish).

[3] Wasilewski, P. (1993). *Silumins - Modification and its impact on structure and properties*. Katowice. PAN Solidification of metals and alloys. *21*, Monography. (in Polish).

[4] Szymczak, T., Gumienny, G., Pacyniak, T. (2015). Effect of Sr and Sb Modification on the Microstructure and Mechanical Properties of 226 Silumin Pressure Casts. *Archives of Foundry Engineering*. 15(1), 105-108.

[5] Zyska, A., Konopka, Z. & Cisowska, M. (2004). Investigation of the solidification process of the modified AlSi6Cu4 alloy. *Archives of Foundry.* 4(11), 317-325. (in Polish).

[6] Pezda, J. (2014). Effect of Shortened Heat Treatment on the Hardness and Microstructure of 320.0 Aluminium Alloy. *Archives of Foundry Engineering.* 14(2), 27-30.

[7] Domke, W. (1989). *Vademecum of materials.* Warszawa: WNT. (in Polish).

[8] Orłowicz, W., Mróz, M. & Tupaj, M. (2006). Selecting of heat treatment parameters for AlSi7Mg0,3 alloy. *Archives of Foundry*. 6(22), 350-357. (in Polish).

[9] Dobrzański, L. A., Reimann, L. & Krawczyk, G. (2008). Influence of the ageing on mechanical properties of the aluminium alloy AlSi9Mg. *Archives of Materials Science and Engineering*. 31(1), 37-40.

[10] Gauthier, J., Louchez, P. & Samuel, F. H. (1994). Heat treatment of 319.2 Al automotive alloy: Part 1, Solution Heat Treatment. *Cast Metals*. 8(2), 91-106.

[11] Mohamed, A. M. A., Samuel, F.H. (2012). A review on the heat treatment of Al-Si-Cu/Mg casting alloys. Czerwinski F. (Eds.). *Heat Treatment - Conventional and Novel Applications* (pp. 55-72). InTech. DOI: 10.5772/50282.

[12] Górny, Z. (1992). *Casting non-ferrous alloys.* Warszawa: WNT. (in Polish).

[13] Zolotorevsky, V. S., Belov, N. A., Glazoff, M. V. (2007). *Casting Aluminium Alloys.* Oxford: Elsevier.

[14] Pezda, J. (2010). Effect of heat treatment operations on the R_m tensile strength of silumins. *Archives of Foundry Engineering.* 10(4), 61-64.

[15] Medlen, D. & Bolibruchova, D. (2012). The Influence of Remelting on the Properties of AlSi6Cu4 Alloy Modified by Antimony. *Archives of Foundry Engineering*. 12(1), 81-86.

[16] Kliemt, C., Wilhelm, F., Hammer, J. (2014). Lifetime Improvement of AlSi6Cu4 Cylinder Head Alloy. *Advanced Materials Research*, 891-892, 1627-1632. DOI: 10.4028/www.scientific.net/AMR.891-892.1627.

[17] Davis, J. R. (1993). *Aluminium and aluminium alloys*. ASM Speciality Handbook, ASM International.

[18] Jabłoński, S. (1971). *Heat treater small guide-book*. Warszawa: WNT. (in Polish).

[19] Poniewierski, Z. (1989). *Crystallization, structure and properties of silumins*. Warszawa: WNT. (in Polish)

[20] Niezgodziński, M.E., Niezgodziński, T. (2010). *Strength of materials*. Warszawa: WNT. (in Polish).