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# Effect of Shortened Heat Treatment on the Hardness and Microstructure of 320.0 Aluminium Alloy

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## Abstract

Improvement of Al-Si alloys properties in scope of classic method is connected with change of Si precipitations morphology through: using modification of the alloy, maintaining suitable temperature of overheating and pouring process, as well as perfection of heat treatment methods. Growing requirements of the market make it necessary to search after such procedures, which would quickly deliver positive results with simultaneous consideration of economic aspects. Presented in the paper shortened heat treatment with soaking of the alloy at temperature near temperature of solidus could be assumed as the method in the above mentioned understanding of the problem. Such treatment consists in soaking of the alloy to temperature of solutioning, keeping in such temperature, and next, quick quenching in water (20 °C) followed by artificial ageing. Temperature ranges of solutioning and ageing treatments implemented in the adopted testing plan were based on analysis of recorded curves from the ATD method. Obtained results relate to dependencies and spatial diagrams describing effect of parameters of the solutioning and ageing treatments on HB hardness of the investigated alloy and change of its microstructure. Performed shortened heat treatment results in precipitation hardening of the investigated 320.0 alloy, what according to expectations produces increased hardness of the material.

**Key words:** Aluminum alloys, ATD, Heat treatment, HB hardness

## 1. Introduction

Well known advantages of aluminum alloys, like low mass, good mechanical properties, corrosion resistance, machinability, high percentage of recycling, and low costs, are the driving force for their development, i.e. usage in new applications as early as in stage of development of a structures, as well during development of new technological solutions. Mechanical and technological properties of castings from 3xx.x group depend mostly on properly performed process of melting and pouring, design of a casting and mould, and possible heat treatment. Using knowledge on crystallization course in manufacturing processes of pouring in order to improve their structure, and launching a modern methods

of the heat treatment [1-3] belong to important factors having effect on better quality of the castings, and thereby causing that the alloys from 3xx.x group are so attractive in many applications, inclusive of e.g. cylinder heads of combustion engines. Still growing demands in terms of mechanical properties of material for castings, resulting from e.g. downsizing of engines and strong competition on automotive market force the search for optimal solutions assuring proper mechanical and technological properties without increased manufacturing costs of a given component. Numerous studies on heat treatment parameters were already performed for the Al-Si-Cu alloys, both with and without addition of Mg [4-8]. Han in the study [5] reports that in case of the 319 alloy the solutioning temperature is included within range of 490-

505 °C and solutioning time in range of 8-12 hours (for Cu contents of 3-4%), however he allows temperature 520 °C [9] being initial stage of melting of  $Al_3Mg_8Cu_2Si_6$  phase and waning with time of not-solved blocky  $Al_2Cu$  precipitations, and spheroidization of Si precipitations, what in result have direct effect on obtainment of suitable mechanical properties [10]. Górný [11] reports for  $AlSi_5Cu_3Mg$  alloy that solutioning temperature is 510 °C during 5 hours and ageing during 10 hours at 170 °C.

Additive of Mg in Al-Si-Cu alloys accelerates and intensifies hardening process of the alloy. Han [4] reports, that  $AlSi_7Cu_3$  alloy requires solutioning at 490 °C during 8 hours to obtain high, uniform concentration of Cu in the solution, while in case of Mg additive only 4 hours are enough. Increase of Mg contents to 0,45 % facilitates the heat treatment, but in case of the alloys modified with Sr, its contents on the level of 0,45% has a negative effect on ductility due to interaction of Mg-Sr [12] (optimal combination of Mg and Sr contents is reported in the study [12] and amounts to 0,3% Mg at 150 ppm Sr). Hardness of the 319 alloy with 0,3 % additive of Mg rapidly increases during 2 hours together with increase of the temperature to 180 °C (in case of the 319 alloy without additive of Mg it is temperature 220 °C), and next the hardness decreases as the temperature increases [13].

Objective of the present paper is determination of optimal parameters of shorted heat treatment of the 320.0 alloy in aspect of improvement of its HB hardness and possibility of prediction (control) of its value on the basis of temperature and duration of solutioning and ageing treatments.

## 2. Methodology of the research

The 320.0 ( $AlSi_7Cu_3Mg$ ) alloy, belonging to group of Al-Si-Cu-Mg alloys, is used to production of, inter alia, castings of cylinder heads and cylinder blocks [14-16] and in other applications of automotive industry, mainly in casting process in sand moulds (engine crankcases, engine oil pans) and in metal moulds. Chemical composition of the alloy is presented in Table 1.

Table 1.

Chemical composition of the 320.0 alloy

Chemical composition / mass %				
Si	Cu	Zn	Fe	Mg
7,5	3,0	0,8	0,5	0,45
Ni	Mn	Pb	Cr	Al
0,04	0,28	0,03	0,01	rest

Analysis of chemical composition was performed with use of optical emission spectrometry method with inductively coupled plasma on PerkinElmer, model Optima 4300 Dv, optical emission spectrometer in Bosmal R&D Institute in Bielsko-Biala.

Investigated alloy was melted in electric resistance furnace and was subjected to treatment of refining (Rafal 1 - 0,4%). In the next stage the investigated alloy was poured into metallic mould used to production of standardized strength test pieces according to PN-88/H-88002 standard. Measurement of Brinnell hardness was

performed in compliance with PN-EN ISO 6506-1:2008 standard with use of Brinnell hardness tester of PRL 82 type, with steel ball having diameter of 10mm under load of 9800 N maintained for 30 seconds. As a measurement surfaces were used milled heads of the strength test pieces. Process of solidification and melting of the alloy was recorded with use of automatic Crystallimat analyzer.

In the Fig. 1 are depicted crystallization curves of the investigated alloy, recorded with use of the ATD method, with marked characteristic points.

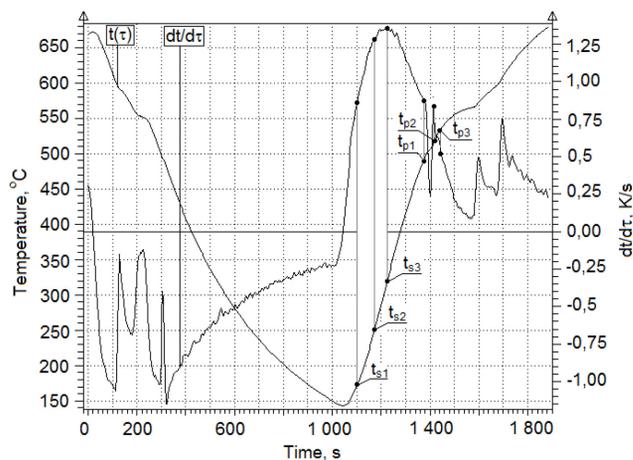


Fig. 1. Curves of the ATD method for the 320.0 alloy

Temperatures of solutioning and ageing treatments were selected on the base of values of points on melting curves from the ATD method (Fig. 88). In the Table 2 are presented parameters of the heat treatment operation.

Table 2.

Heat treatment parameters of the 320.0 ( $AlSi_7Cu_3Mg$ ) alloy

Solutioning temperature $t_p$ [°C]	Solutioning time $\tau_p$ [h]	Ageing temperature $t_s$ [°C]	Ageing time $\tau_s$ [h]
$t_{p1}$ - 485	0,5	$t_{s1}$ - 175	2
$t_{p2}$ - 510	1,5	$t_{s1}$ - 250	5
$t_{p3}$ - 530	3	$t_{s1}$ - 320	8

## 3. Description of obtained results

Hardness of not heat treated HB10/1000/30 alloy was included within limits of 80-84. After performed heat treatment of the alloy, obtained hardness HB10/1000/30 amounted from 52 to 138. Making comparison of obtained values from the test of the alloy without and with the heat treatment (Fig. 2) it has been confirmed the highest increase of the HB hardness for the systems marked as No. 4 ( $t_p$  - 485 °C;  $\tau_p$  - 1,5 hour;  $t_s$  - 175 °C;  $\tau_s$  - 8 hours), No. 7 ( $t_p$  - 485 °C;  $\tau_p$  - 3 hours;  $t_s$  - 175 °C;  $\tau_s$  - 5 hours) and No. 13 ( $t_p$  - 510 °C;  $\tau_p$  - 1,5 hour;  $t_s$  - 175 °C;  $\tau_s$  - 5 hours). With a slightly lower hardness, amounted to 110-121 HB10/1000/30, were characterized test pieces from the systems

No. 1, 16, 8, 10, 19 and 25, for which ageing temperature amounted to 175 °C.

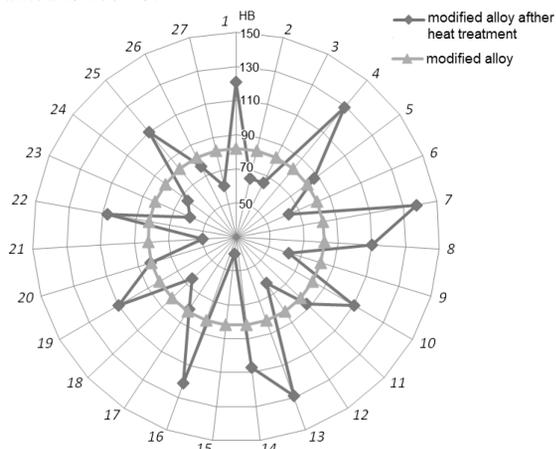


Fig. 2. Change of the HB hardness of the investigated alloy for the systems of adopted testing plan

The lowest HB hardness (within limits 52-62 HB10/1000/30) was obtained in case of the systems No. 15, 21, 23 which were characterized by high ageing temperature (325 °C) during 8 hours, what resulted in decrease of obtained hardness, relative to the alloy without heat treatment.

Obtained results of performed investigations have enabled formulation of the dependency (1) in form of the 2nd degree polynomial, describing effect of heat treatment parameters on change of the HB hardness of the investigated alloy, and generation of spatial diagrams (Fig. 3-4) showing influence of temperature and time of the heat treatment operations on the HB10/1000/30 of the investigated alloy.

$$HB = -1044,73 + 5,519t_p - 60,12 \cdot 10^{-4}t_p^2 + 107,58\tau_p - 0,43\tau_p^2 - 1,96t_s + 8,58 \cdot 10^{-4}t_s^2 + 7,73\tau_s \quad (1)$$

$$- 0,653\tau_s^2 - 0,2t_p\tau_p + 24,5 \cdot 10^{-4}t_p t_s + 0,002t_p\tau_s - 0,01\tau_p t_s + 0,338\tau_p\tau_s - 0,02\tau_s\tau_s$$

where:  $t_p$  - solutioning temperature,  $\tau_p$  - solutioning time,  $t_s$  - ageing temperature,  $\tau_s$  - ageing time. Correlation coefficients:  $R = 0,98$ ;  $R^2=0,96$ ; corr.  $R^2=0,9$ .

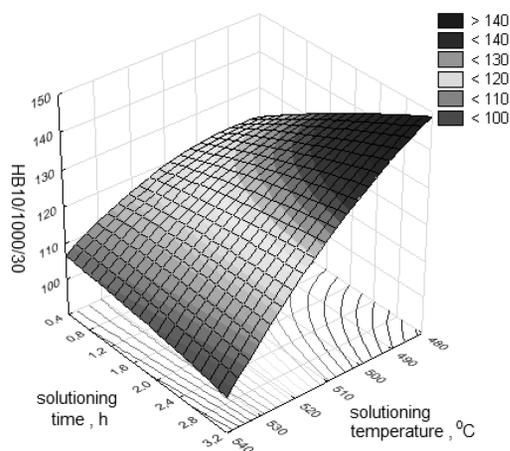


Fig. 3. Effect of solutioning parameters on the HB hardness of the 320.0 alloy for  $t_s$ - 175 °C and  $\tau_s$ - 5 hours

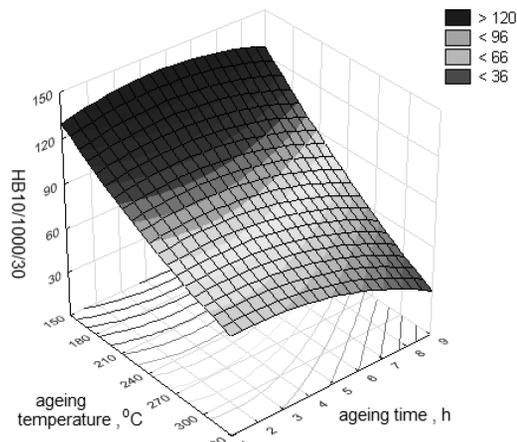


Fig. 4. Effect of ageing parameters on the HB hardness of the 320.0 alloy for  $t_p$  -500 °C and  $\tau_p$ - 1 hour

The highest HB hardness can be obtained for the test pieces solutioned at temperature 485-500 °C during 1 to 3 hours, quenched in water and aged at temperature 175 °C during 2 to 6 hours. Ageing at temperatures above 250 °C has adverse effect on change of the HB hardness, resulting in its decrease comparing to the alloy without heat treatment. In the Fig. 5 are presented microstructures of the 320.0 alloy before the heat treatment

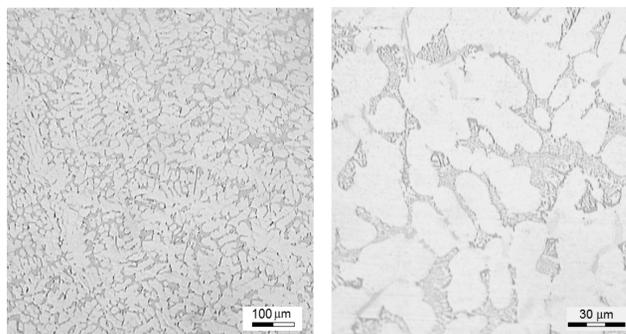


Fig. 5. Microstructure of the 320.0 alloy before the heat treatment

Microstructure of the alloy before the heat treatment (Fig. 5) is characterized by Al+Si eutectic with fine, fibrous precipitations of Si and rounded contours of plastic phase Al, characteristic of the alloys after modification [17-20].

Microstructure of the alloy, which features the lowest tensile strength  $R_m$  (Fig. 6) after performed heat treatment is characteristic of distinctly coagulated, big precipitations of Si. It is connected with high solutioning temperature (530 °C) and high ageing temperature (325 °C) conducive to improved ductility of the alloy with simultaneous decrease of mechanical properties, which is characteristic of so-called overageing of the alloy.

After performed heat treatment of microstructure of the 320.0 alloy (Fig. 7) in case of the test pieces characterized by the highest HB hardness, precipitations of Si present within interdendritic spaces of phase Al (on boundaries of grain) feature rounded shapes (Fig. 7 a) and/or shape of fine spheroidal precipitations (Fig. 7 b). However, form of silicon precipitations

has no significant effect on obtained HB hardness after performed heat treatment.

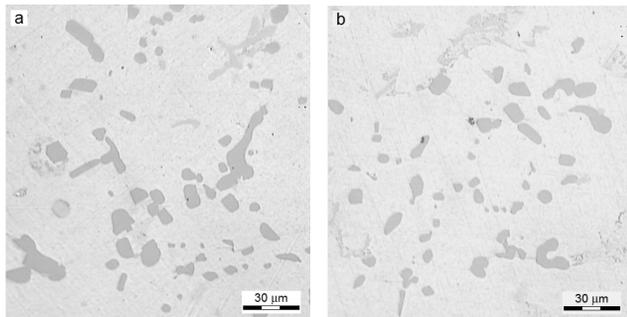


Fig. 6. Microstructure of the 320.0 alloy after heat treatment for the test pieces characterized by the lowest HB hardness: a) system No. 23, b) system No. 21

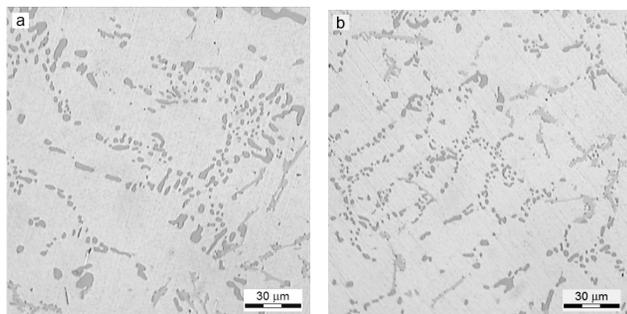


Fig. 7. Microstructure of the 320.0 alloy after the heat treatment for the test pieces characteristic of the highest HB hardness: a) system No. 7, b) system No. 4

## 4. Conclusions

Performed shortened heat treatment of the 320.0 alloy has resulted in explicit improvement of the HB hardness, which maximal values in light of performed investigations can be obtained after solutioning of the alloy at temperature 485-500 °C during 1 to 3 hours and ageing at temperature 175 °C during 2 to 6 hours.

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