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Effect of Shortened Heat Treatment on Change of the R_m Tensile Strength of the 320.0 Aluminum Alloy

J. PezdaUniversity of Bielsko-Biala, Faculty of Chipless Forming Technology,
ul. Willowa 2, 43- 300 Bielsko - Biala, Poland

Corresponding author. E-mail address: jpezda@ath.bielsko.pl

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Abstract

Mechanical and technological properties of castings made from 3xx.x alloys depend mainly on properly performed process of melting and casting, structure of a casting and mould, as well as possible heat treatment. Precipitation processes occurring during the heat treatment of the silumins containing additives of Cu and/or Mg have effect on improvement of mechanical properties of the material, while choice of parameters of solutioning and ageing treatments belongs to objectives of research work performed by a number of authors. Shortened heat treatment, which is presented in the paper assures suitable mechanical properties (R_m), and simultaneously doesn't cause any increase of production costs of a given component due to long lasting operations of the solutioning and ageing. Results of the research concern effects of the solutioning and ageing parameters on the R_m tensile strength presented in form of the second degree polynomial and illustrated in spatial diagrams. Performed shortened heat treatment results in considerable increase of the R_m tensile strength of the 320.0 alloy as early as after 1 hour of the solutioning and 2 hours of the ageing performed in suitable.

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

1. Introduction

The silumins are the largest group among aluminum based casting alloys [1-4]. Production volumes of poured elements from these alloys amount to 85-90% of total quantity of the castings from aluminum alloys [5, 6].

Mechanical properties of the casting alloys depend mainly on their chemical composition and parameters of casting process. For the Al-Si alloys containing additives of the Mg and Cu it is possible to improve these properties by the heat treatment. For the aluminum casting alloys, further improvement of the mechanical properties through the heat treatment in case of machinery

elements from these alloys concerns the 3xx.x series of the alloy (Al-Si-Cu/Mg and Al-Si-Cu-Mg).

The heat treatment of aluminum alloys, aimed mainly at increase of their strength, consists in dispersion hardening (precipitation one), which can be obtained in result of successively performed operations of solutioning of solid solution and ageing. Reduction of the solubility limit of the alloying elements in solid state together with decrease of temperature is the main condition on which the process of the precipitation hardening of the alloys is based.

Typical heat treatment used for the alloys from the 3xx.x series is the T6 treatment comprising the following steps:

- *solutioning* at temperature near to eutectic temperature in order to dissolve inter-metallic phases rich in Cu (Al_2Cu)

- and Mg (Mg_2Si), formed during solidification, homogenization of the alloying elements in the solid state, and spheroidization of eutectic molecules of the Si [7],
- *rapid cooling*, i.e. cooling down to room temperature, to obtain supersaturated solid solution of dissolved atoms and vacancies [1, 2],
 - *ageing*, resulting in precipitation from the solid solution, both in the room temperature (natural ageing) and in increased temperature (artificial ageing), of the strengthening phases featuring certain degree of dispersion [2].

Different cycles of the heat treatment, and the same different combinations of temperature and duration of individual treatments, are used depending on a pouring process, composition of the alloy and requirements related to the mechanical properties.

Output structure of the alloy has a clear impact on the time needed to treatment of the alloy in order to dissolve the precipitations and to form uniform distribution of the copper in the matrix – only 10 minutes of the solutioning at temperature of 495 °C is enough to obtain high and homogeneous concentration of the copper in the solid solution for a material characterized by a fine microstructure (SDA from 10 μm), while in case of a coarse microstructure (SDA from 50 μm) is needed more than 10 hours (for the AlSi8Cu3,1 alloy) [8]. Values of the strength obtained for the ternary Al-Si-Cu alloys are lower than in case of the alloys with additive of Mg. Ouellet [9] reports that additive of Mg results in increase of the $R_{0,2}$ from 337 to 415 MPa after ageing at temperature 150 °C, with elongation smaller than 1%. In the study [10] the author obtained the best mechanical properties for the 319 alloy with additive of Mg, after solutioning at temperature 500 °C for 8 hours and ageing during successive 8 hours at temperature 170 °C, while Elsebaie [11] with the same durations, but at temperatures 485 and 180 °C obtained the highest impact strength.

Additive of Mg to the Al-Si-Cu alloys accelerates and intensifies hardening process of the alloy. Han [12] reports that for the AlSi7Cu3,5 alloy, to obtain high and homogenous concentration of Cu in solid solution, requires solutioning at 490 °C for 8 hours, whereas in case of Mg addition only 4 hours are enough. Increase of the Mg additive from 0,1 to 0,28 % also contributes to increase of cutting forces during machining operation and reduction of operational life of cutting tools. [13].

Ageing of the alloy at temperatures above 200 °C [14] results in gradual, permanent decrease of the strength up to 50 MPa, at 400 °C and slight increase of plasticity of the material (elongation 2-3%), in case of the ageing at temperature up to 300 °C [15]. In case of the ageing, none typical linear relation between temperature and time of the ageing can be observed. It can therefore, as reports author of the study [14], obtain maximal strength of the alloy, e.g. after 24 hours at temperature up to 150 °C or after 8 hours at temperature 180 °C. Sokolowski proposed in his study [16] completely different approach, namely two-stage solutioning at temperature 495 °C during 2 hours, and next at 515°C for 4 hours. and ageing at temperature 250 °C for 3 hours, what in result effects in optimal combination of the strength and plasticity ($HB > 98$; $R_m > 215$ MPa; $R_{0,2} > 169$ MPa; elongation $> 1:8$ %; impact strength $KC > 5$ J/cm²) comparing to traditional, single-stage solutioning at temperature 495 °C for 8 hours.

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

2. Methodology of the research

The 320.0 alloy (AlSi7Cu3Mg) belongs to the group of Al-Si-Cu-Mg alloys. Chemical composition of the alloy is presented in the Table 1.

Table 1.

Chemical composition of the 320.0 alloy [17]

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

Analysis of the chemical composition was performed using an optical emission spectrometry method, with inductively coupled plasma on the PerkinElmer optical emission spectrometer, Optima 4300 Dv model, in the 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 the PN-88/H-88002 standard.

Temperature ranges of solutioning and ageing operations were selected basing on analysis of recorded curves from the ATD method. The ATD method consists in permanent recording of temperature of the alloy during its crystallization, what enables obtainment of the $T=f(t)$ curve, describing course of the thermal processes dT/dt , emphasizing the less evident changes present in the thermal curve $T=f(t)$. Process of the solidification and melting of the alloy was recorded with use of fully automatic Crystaldimat analyzer (Fig. 1).



Fig. 1. The Crystaldimat analyzer [18]

The heat treatment consisted of the solutioning followed by rapid cooling of the material in water having temperature 20 °C, and subsequent artificial ageing with cooling in the air.

After performed heat treatment, the test pieces to determination of the tensile strength (R_m) were prepared according to the PN-EN ISO 6892-1:2010P standard (the test piece with measuring length 50 mm and diameter 10 mm). Static tensile tests were performed according to the PN-EN ISO 6892-1:2010P standard, on the testing machine of the ZD-20 type. 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. Scheme of the performed heat treatment process of the investigated alloy, taking into consideration temperature ranges of individual operations, based on curves from the ATD method, is presented in the Fig. 2.

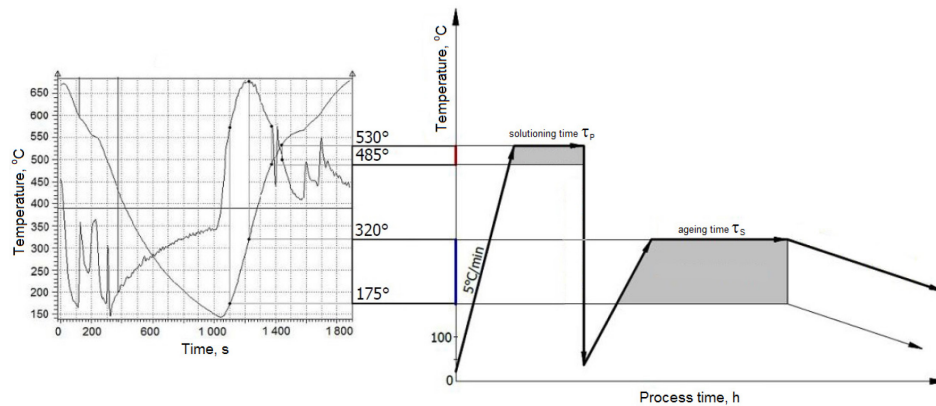


Fig. 2. Scheme of the heat treatment of the 320.0 alloy

3. Description of the results

The tensile strength of the alloy without the heat treatment was included within range from 194 to 205 MPa. After performed heat treatment of the 320.0 alloy, obtained tensile strength was within range from 158 to 368 MPa. Comparing obtained values of the R_m strength of the alloy with and without the heat treatment (Fig. 3) it has been confirmed the highest increase of the R_m strength for the following systems: No. 4 (solutioning temperature - 485 °C; solutioning time - 1,5 hour; ageing temperature - 175 °C; ageing time - 8 hours), No. 7 (solutioning temperature - 485 °C; solutioning time - 3 hours; ageing temperature - 175 °C; ageing time - 5 hours), and No. 13 (solutioning temperature - 510 °C; solutioning time - 1,5 hour; ageing temperature - 175 °C ageing time - 5 hours). Slightly lower tensile strength (R_m) within limit of 300 MPa was obtained for the systems Nos. 1 and 10, characterized by ageing temperature amounted to 175 °C during 2 and 8 hours.

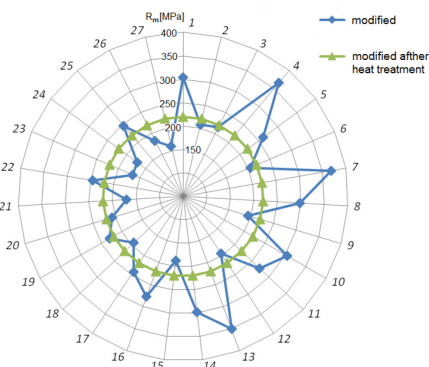


Fig. 3. Change of the R_m strength of the investigated alloy for the systems of adopted testing plan

The lowest tensile strength (R_m) was obtained for the systems marked with Nos. 21, 24 and 27, which were characterized by both the highest solutioning temperature (530 °C), and the highest ageing temperature (320 °C), in complete range of these operations. Obtained values of the R_m for these systems, amounted to 158 - 162 MPa, show a clear decline, comparing to the alloy without the heat treatment.

Obtained results of the performed study have led to the formulation of the equation in form of the second degree polynomial, describing effect of the heat treatment parameters on change of the R_m tensile strength of the investigated alloy.

$$R_m = -13082,9 + 56,01t_p - 58,34 \cdot 10^{-3}t_p^2 + 329,4\tau_p - 9,674\tau_p^2 - 5,859t_s + 6,48 \cdot 10^{-4}t_s^2 + 34,884\tau_s - 1,407\tau_s^2 - 0,551t_p\tau_p + 10,2 \cdot 10^{-3}t_p t_s - 0,017t_p\tau_s - 0,065\tau_p t_s + 0,769\tau_p\tau_s - 0,062t_s\tau_s$$

where: t_p - solutioning temperature, τ_p - solutioning time, t_s - ageing temperature, τ_p - ageing time.

Correlation coefficients: $R = 0,96$; $R^2 = 0,93$; $\text{corr. } R^2 = 0,85$.

Effect of temperature and time of performed operations of the solutioning and ageing treatments on change of the R_m tensile strength is presented in the spatial diagrams (Fig. 4).

For the solutioning operation were assumed constant values of the ageing parameters: temperature t_s - 175 °C and time τ_s - 5 hours, while for the ageing operation, taken parameters of the solutioning are : temperature t_p - 500 °C and time τ_p - 1 hour.

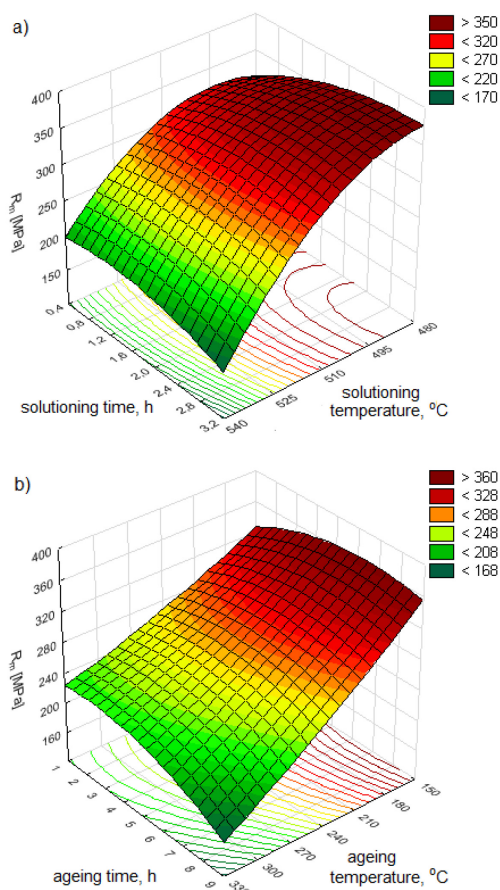


Fig. 4. Effect of parameters of the solutioning and ageing operations on the R_m tensile strength of the 320.0 alloy for: a) t_s - 175 °C and τ_s - 5 hours, b) t_p -500 °C and τ_p - 1 hour

Obtaining the maximal increase of the R_m tensile strength of the 320.0 alloy is conditioned by its solutioning at temperature 485 - 510 °C, for 1 to 3 hours followed by cooling in cold water, and next ageing for 2 to 8 hours at temperature 175 °C.

4. Conclusions

Selection of suitable parameters of solutioning and ageing operations enables reduction of duration of these operations with consideration of a clear improvement of the tensile strength of the investigated alloy. Solutioning of the alloy at temperature range 485 - 510 °C during 1 to 3 hours and subsequent artificial ageing for 2 to 6 hours at temperature 175 °C allows for considerable increase of the R_m strength of the investigated alloy.

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