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INFLUENCE OF HEAT TREATMENT PARAMETERS ON THE MECHANICAL PROPERTIES OF HYPOEUTECTIC Al-Si-Mg ALLOY

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Preliminary Note – Prethodno priopćenje

The effect of the heat treatment on mechanical properties of the A356 alloy was verified in course of tensile tests. Keeping of the alloy during 0,5 to 3 hours in temperature 520 - 550 °C, and subsequent ageing in temperature 165 °C during 5 ÷ 8 hours, enables obtainment of maximal tensile strength R_m. In case of the elongation A_5, ageing is of the main importance, and should be performed in temperature 325 °C during 2 ÷ 5 hours.

Key words: Al-Si casting alloys, modification, thermal analysis, heat treatment, mechanical properties

INTRODUCTION

The aging-hardenable cast aluminum alloys, such as A356 alloy, are being increasingly used in automotive industry systems due to their high strength to weight ratio, excellent casting characteristics, and good mechanical properties including wear resistance, low coefficient of thermal expansion, high thermal conductivity, high corrosion resistance and low cost, providing affordable improvements in fuel efficiency. The alloys are mainly used in the automotive industry (e.g., production of water-cooled cylinder blocks, suspension arms, and wheels), aerospace (e.g. aircraft pump parts, aircraft fitting and control parts) and engineering applications, where are used heavy duty structural parts requiring high strength [1-7].

Solidification after casting process predetermines technological and mechanical properties of cast components via the resulting microstructure. To commonly used methods aimed at improvement of mechanical properties of the Al-Si castings belong grain refinement, modification and heat treatment.

Grain refinement is done by adding of Ti-B or Ti-C based grain refiners into the melt to refine the grain size of the casting into fine-equiaxed structure [8-9].

The modification most often resolves itself into metal batch of such elements like Na, Sr, Sb etc. in order to change the silicon morphology from acicular flake to fibrous, resulting in improved ductility and toughness [10-11]. Of these, only Sr, Na, and Sb produce significant modification at low levels of addition [12-14]. Thus, they are the only elements used widely in industry.

Further improvement of mechanical properties enables is possible owing to use of heat treatment. The most used heat treatment for the Al-Si-Mg alloy is T6 treatment, which consists in solution heat treatment and natural or artificial ageing [15].

The precipitation hardening through heat treatment will precipitate the alloying elements in the form of fine coherent particles of Mg_2Si and Al_2Cu inside the grains during the aging stage to harden the alloy.

Reduction of manufacturing costs of castings enforces implementation of a procedures ensuring optima (short) time of performer heat treatment.

Objective of the present work is determination of an effect and selection of optimal parameters of T6 heat treatment for the A356 alloy in aspect of obtainment of improvement of its mechanical properties.

EXPERIMENTAL METHOD

To the investigations was used hypo-eutectic A356 (EN AC-AlSi7Mg0,3) alloy, having chemical composition as shown in Table 1.

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

Si	Cu	Zn	Fe	Mg	Ti	Mn	Ni	Pb	Al
7,2	0,25	0,3	0,6	0,3	0,05	0,27	0,04	0,02	rest

Investigated alloy 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).

To define temperature ranges of solutioning and ageing treatments, one performer registration of heating (melting) of the alloy with use of thermal-derivative analysis method (ATD).

In the Figure 1 are presented curves of the ATD method of the investigated alloy.

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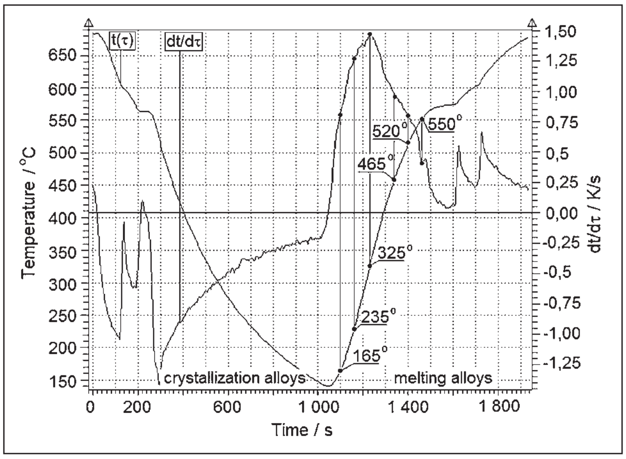

Figure 1 Curves of the ATD method

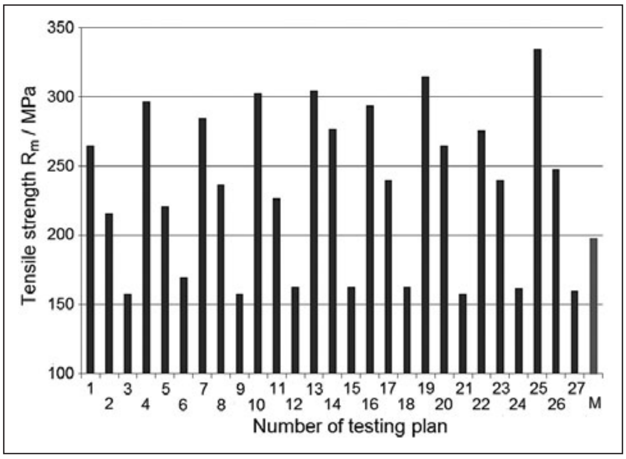

Figure 2 The tensile strength R_m change of the A356 alloy for individual systems of the testing plan

Implemented ATD method consists in continuous registration of temperature of the alloy in course of its crystallization, resulting in generation of a thermal curve (t = f(τ)), depicting proceeded thermal processes, and simultaneously plotted its derivative (dt/dτ), which emphasizes less distinct transformations on the thermal curve. It enables quick and accurate assessment of quality of liquid metal.

Modified alloys were poured into permanent mould to production of standardized specimens of castings to the strength tests. Permanent mould was heated to temperature of 250 °C. The heat treatment was performed for the refi ned and modifi ed alloy. Poured specimens had under gone dispersion hardening with holding in temperature near to temperature of solidus. The treatment consisted in heating of poured specimens to temperature of solutioning, holding in such temperature, and subsequent cooling down in cold water (20°C), and next artificial ageing.

The temperature range of solutioning heat treatments of the investigated alloy (465 - 550 °C) and the range of ageing temperatures (165 - 325 °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.

After performed heat treatments, top determine obtained mechanical properties of the investigated alloy , one performed tensile tests on the ZD-20 testing machine according to the EN ISO 6892-1:2010 standard.

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

RESULTS

The tensile strength R_m of the alloy after refinement and modification amounted to 196 - 203 MPa.

After performed heat treatment, obtained tensile strength R_m was included within the range from 154 to 335 MPa.

In the Figure 2 are presented values of the tensile strength R_m of the investigated alloy for individual 27 systems of assumed tree-stage plan of the testing with four variables (tensile strength of initial alloy prior the heat treatment was marked with symbol "M").

The highest growth of the tensile strength in case of the system no. 25 (solutioning temperature - 550°C; solutioning time - 3 hours, ageing temperature - 165 °C; ageing time - 8 hours) and system no. 19 (solutioning temperature - 550 °C; solutioning time - 0,5 hour; ageing temperature - 165°C; ageing time - 5 hours), respectively 335 and 315 MPa. Slightly lower tensile strength within limits of 300 MPa was obtained for the systems no. 4, no. 10 and no. 13, being characterized by, like in case of the systems no. 19 and no. 25, low ageing temperature (165 °C) during 5 to 8 hours.

The lowest tensile strength was obtained in case of the systems 3, 9, 12, 21, 27, which were characterized by high temperature of the ageing (325 °C) in the full range of ageing times. Obtained tensile strength for these systems, amounting to 158 - 163 MPa shows a distinct drop, comparing with the alloy without the heat treatment.

Effect of temperature and time of performed solutioning and ageing heat treatments on change of the tensile strength R_m is presented in the spatial diagrams (Figure 3). In case of temperature and time of ageing treatment (Figure 3a) were taken constant values of ageing parameters - ageing temperature - 180 °C and time of the ageing – 8 hours. For temperature and time of the ageing (Figure 3b), one applied temperature of the solutioning equal to 550 °C and solutioning time equal to 0,5 hour.

Obtaining the highest tensile strength determines adoption of solutioning temperatures in the range of 520 - 550 °C, solutioning times from 0,5 to 3 hours, ageing temperatures up to 165 °C and ageing times from 5 to 8 hours.

In case of the elongation A_5, its value for the alloy after refinement and modification amounted to 6 - 7 %. After performed heat treatment, obtained elongation A_5 was included within range from 3,7 to 15,8 %.

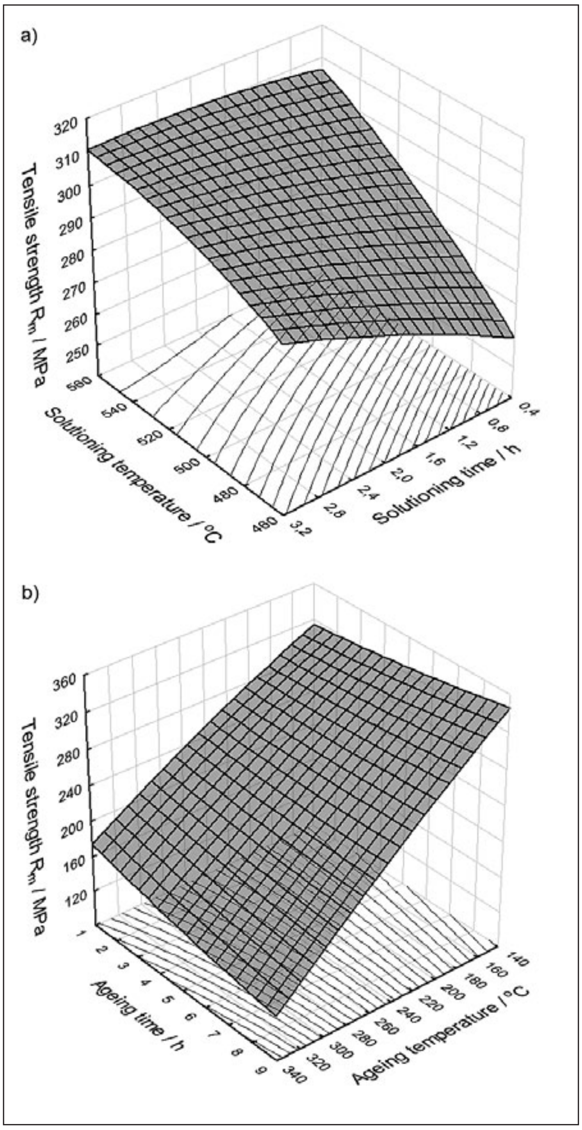

Figure 3 The effect of temperature and time of heat treatment on tensile strength of the A356 alloy: a) for temperature and time of solutioning, b) for temperature and time of ageing treatment

In the Figure 4 are presented, in the same way like in case of the tensile strength R_m, changes of the elongation for individual systems of the testing plan.

The highest elongation A_5, amounting to 15,8 % was obtained for the system no. 21 (Figure 4), which was characterized by the following parameters of the heat treatment: solutioning temperature - 550°C; solutioning time - 3 hours ageing temperature - 165 °C; ageing time - 8 hours. Equally high elongation (15,3 and 14,9 %) was obtained for the system no. 12 (solutioning temperature - 520 °C; solutioning time - 0,5 hour, ageing temperature - 325 °C; ageing time - 2 hours), system no. 27 (solutioning temperature - 550 °C; solutioning time - 3 hours, ageing temperature - 325 °C; ageing time - 2 hours) and system no. 24 (solutioning temperature - 550 °C; solutioning time - 1,5 hour, ageing temperature - 325 °C; ageing time - 5 hours).

The lowest elongation amounting from 3,8 to 5,7 % was obtained for the systems no. 4, 7, 10, 14, 20, which were characterized by the low temperature of the ageing

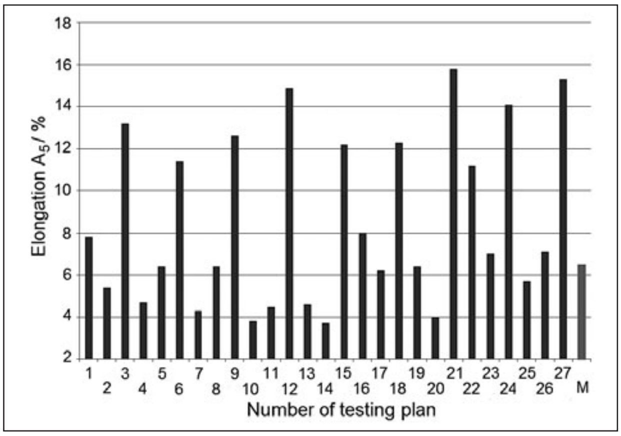

Figure 4 The elongation A_5 change of the A356 alloy for individual systems of the testing plan

(165 - 235 °C) and time of ageing 5 - 8 hours. Hence, obtained elongation A_5 for these systems constitutes a drop with respect to initial alloy (without heat treatment).

In the Figure 5 is presented an effect of temperature and time of solutioning treatments on change of the elongation A_5 of the investigated alloy at constant parameters of ageing treatment (Figure 5a) amounting to 180 °C and 2 hours, and constant parameters of the solutioning (Figure 5b) amounting to 535 °C and 0,5 hour.

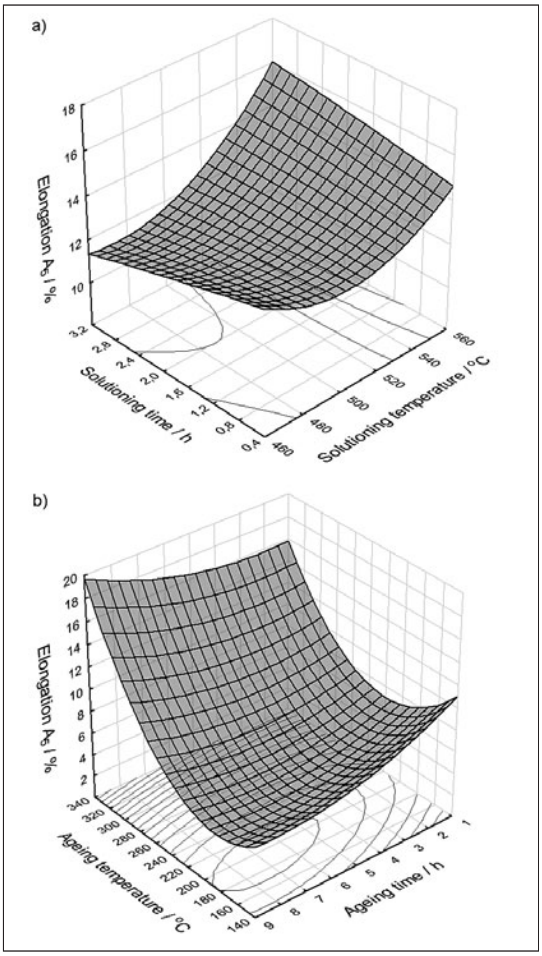

Figure 5 The effect of temperature and time of heat treatment on elongation A_5 of the A356 alloy: a) for temperature and time of solutioning, b) for temperature and time of ageing treatment

Obtaining the highest tensile strength determines adoption of solutioning temperatures in the range of 520 - 550 °C, solutioning times from 0,5 to 3 hours, ageing temperatures 325 °C and ageing times from 2 to 5 hours.

Limitation of tendency to rapid drop of the elongation A, due to ageing in low temperatures, is connected with shortening of ageing duration to 2 hours (system no. 1, 16 and no. 22 - Figures 2 and 4), what enables obtainment of the tensile strength within limits of 280 MPa and elongation A_5 from 8 - 11 %.

CONCLUSIONS

Selection of suitable parameters of performed T6 heat treatment is a prerequisite to obtain required effects in form of changed mechanical properties (R_m and A_5) of the investigated alloy.

Ageing heat treatment is of the main importance in process of the heat treatment, because temperature and time of the ageing have fundamental effect on growth of the tensile strength R_m and obtained elongation A_5.

Low ageing temperatures (165 °C) effect advantageously on growth of the tensile strength, being simultaneously a factor limiting (reducing) the elongation. Whereas, increased temperatures of the ageing (325 °C), having effect on improvement (growth) of the elongation, result in distinct drop of the tensile strength.

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Note: The responsible translator for English language is Andrzej Kapłon, Bielsko-Biała, Poland