ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 8
Issue 1/2008

169 – 172

32/1

Heat treatment of AlSi9Mg alloy

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Received 04.07.2007; accepted in revised form 07.08.2007

Abstract

Processes of crystallization of alloys have decisive impact on structure of castings, and the same their utility characteristics. Knowledge about those processes constitutes a source of information to development of preparation of liquid metal and control of alloy preparation process within industry. Method of Thermal-Voltage-Derivative Analysis (ATND), developed by Faculty of Chipless Forming Technology enables registration of temperature and voltage curves, on which one can observe thermal and voltage effects being result of crystallization of phases and eutectic mixtures present on these curves in form of characteristic “peaks”. Temperature value read offs for these characteristic points become a basis to taking regression analysis aimed at obtaining of mathematical dependences illustrating effect of changes of these values on change of impact resistance of dispersion hardened AK9 alloy. The paper presents an attempt of implementation of Thermal-Voltage-Derivative Analysis method to determination of temperature of hyperquenching and ageing processes of AK9 (AlSi9Mg) silumin. Investigated alloy had undergone typical treatments of refining and modification, and next the heat treatment. Temperature range for the heat treatment has been determined on base of ATND melting curves.

Keywords: ATD, ATND, Heat treatment, Regression analysis

1. Introduction

Silumins are the most often used aluminum alloys in foundry industry [1, 2].

There alloys, based on Al-Si equilibrium system contain additive compounds (e.g. Mg, Cu) enabling, except modification, improvement of mechanical properties attained in result of heat treatment.

Release of dissolved constituent from supersaturated solution α during cooling down leads to change of mechanical properties of the alloy. Release of structural constituent from supersaturated solid solution can be obtained through annealing in temperature in which solid solution has equilibrium structure, and next cooling it into lower temperature in which solid solution is labile, whereas mixture of two phases constitutes stable structure.

Condition which needs to be fulfilled in order to implement the ageing is solubility of the constituent changing as temperature decreases. In silumins containing magnesium or copper only, release-type strengthening can be obtained in result of release of Mg_2Si, Al_2CuMg and Al_2Cu phases in ageing process after previous hyperquenching [3].

Used soaking treatment of castings in process of hyperquenching effects not only in growth of concentration of elementary substances constituting potential source of releasing processes in solid solution α, but also can effect in advantageous change of morphology of eutectic crystals of silicon– their coalescence and spheroidization. It improves mechanical properties of silumins and does not show any worsening of plastic properties, in spite of strenghtening of solid solution α due to more late ageing of castings [4].

Form of eutectic mixture has significant impact on susceptibility of eutectic silicon to coalescence and spheroidization [5]. Phenomena of the coalescence and spheroidization of eutectic silicon proceed more easy and more fast because molecules of eutectic silicon are more dispersed prior the heat treatment.

Making use of theories on crystallization processes in technological process control enables obtaining a suitable structure of material, which determines its application to a given requirements [3,6]. Therefore, a methods based on analysis of temperature's change run (thermal ones - ATD, DTA), electric conductance (electric ones - AED) and method of Thermal-Voltage-Derivative Analysis (ATND). The methods enable making registration of phenomena arisen in result of solidification processes of alloys [7].

The ATND method consists on continuous measurement of temperature and electric voltage generated on probes during crystallization and phase transitions of solidifying alloy.

In the Fig. 1 is shown a scheme of measuring bench of the ATND method.

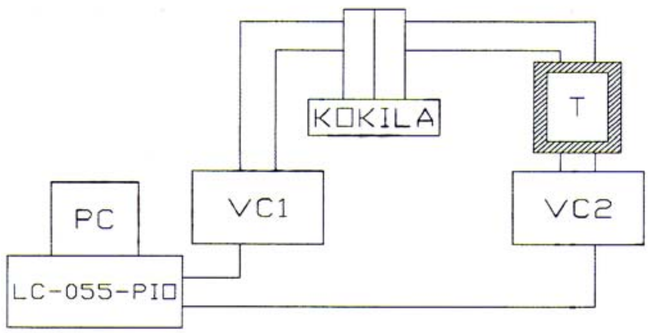

Fig. 1. Scheme of measuring bench of the ATND method: PC – computer with measurment module, VC1 – digital voltmeter (drop voltage), VC2 - digital voltmeter (drop SEM in termocouple) T- thermos (ok. 0^oC)

In course of the measurements there were measured generated voltage and temperature of tested specimen. Run of crystallization is illustrated in form of diagram created during solidification of the alloy [8, 9]. In the ATND method the thermal curves (T and dT/dτ) are supplemented with voltage curves (U and dU/dτ).

AlSi9Mg (AK9) alloy is rated among hypoeutectic silumins. It features very good cast properties and is designed for castings with complicated shapes and high strength. Presence of additive of magnesium enables to use heat treatment (Mg_2Si phase).

2. Methodology of the research

Investigated alloy was refined with Rafal in quantity of 0,4% of metallic charge's mass, and next modified with strontium in quantity of 0,06% of metallic charge's mass.

On base of solidification of alloy and crystallization with simultaneous continuous measurement of voltage and temperature (ATND method) there were registered curves of solidification and crystallization of investigated alloy (Fig. 2)

In the Fig. 3,4 is shown a curves for ATND method for selection of hyperquenching temperatures and selection of ageing temperatures.

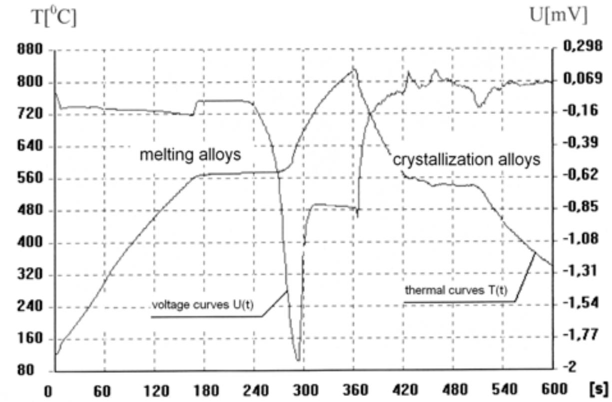

Fig. 2. Curves of ATND method for AK9 alloy

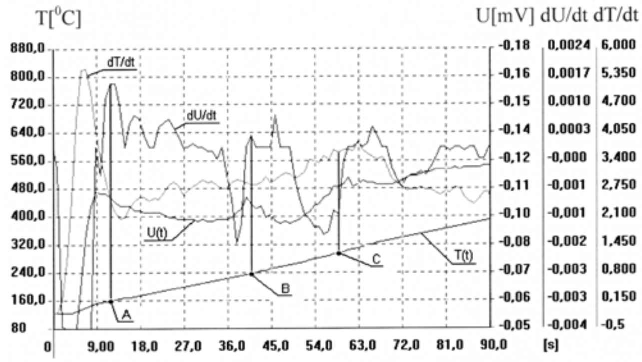

Fig. 3. Curves for ATND method - selection of hyperquenching temperatures

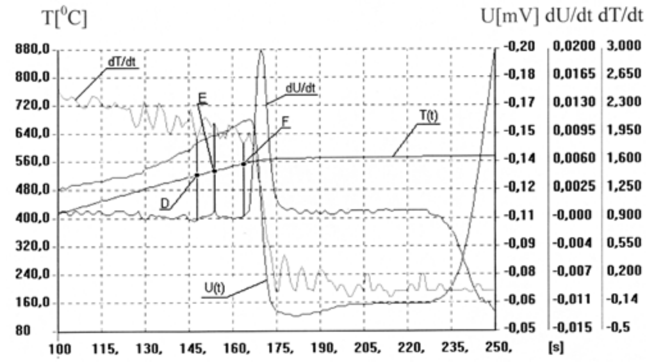

Fig. 4. Curves for ATND method - selection of ageing temperatures

Heat treatment was performed for modified alloy. The treatment consisted on hyperquenching and ageing of the material. Temperatures of these treatments were selected on base of values of points on ATND solidification curves.

In the Table 1 are shown parameters of heat treatments for tri-stage plan of experiments with four variables for which there were determined values of temperatures and duration of hyperquenching and ageing treatments to obtain the best KCV impact resistance of the alloy.

Table. 1. Heat treatment parameters of the alloy

ageing temperature [^oC]	duration of ageing [h]	hyperquenching temperature [^oC]	duration of hyperquenching [h]
A - 160	1	D - 520	4
B - 235	3	E - 535	8
C - 295	5	F - 555	12

Impact strength test of the investigated alloy was the next stage of experiment. Impact strength test was performed with use of Charpy pendulum machine.

After completion of the impact strength test there was performed regression analysis with determination of correlation coefficient between change of ATND characteristic point's values and impact strength of the investigated alloy.

3. Description of obtained results

Obtained impact strength values of the investigated alloy after heat treatment have amounted from 4,9 to 27,6 J/cm^2

After input of independent variables (durations and temperatures of the treatment) and dependent variables (impact strength) there was obtained relation (1) illustrating influence of input values on impact strength of the investigated alloy.

$$KCV = -2881{,}92 + 10{,}61x_1 - 0{,}01x_1^2 + 1{,}37x_2 - 0{,}27x_2^2 + 0{,}16x_3 - 75\cdot 10^{-6} x_3^2 - 0{,}09x_4 - 0{,}02x_4^2 \quad (1)$$

$R^2 = 0{,}95$

where: x_1 – hyperquenching temperature, x_2 – duration of hyperquenching, x_3 – ageing temperature, x_4 – duration of ageing

Assuming values of the fixed points, corresponding maximal mean extremes (calculated values of KCV) there were drawn three-dimensional diagrams of influence of input variables on change of impact strength (Figs 5-8).

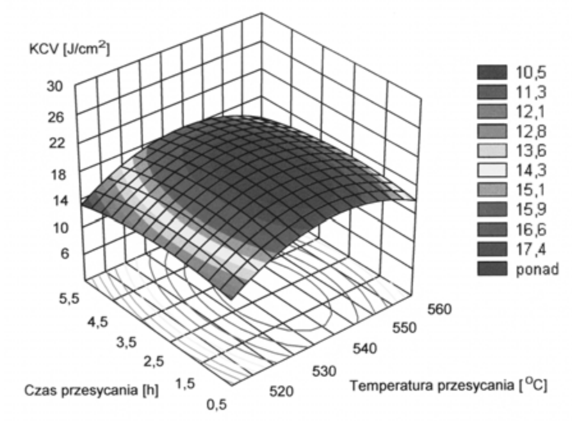

Fig. 5. Influence of temperature and time of hyperquenching on impact strength of AK9 alloy (at t_s= 8 h,T_s=235 ^oC)

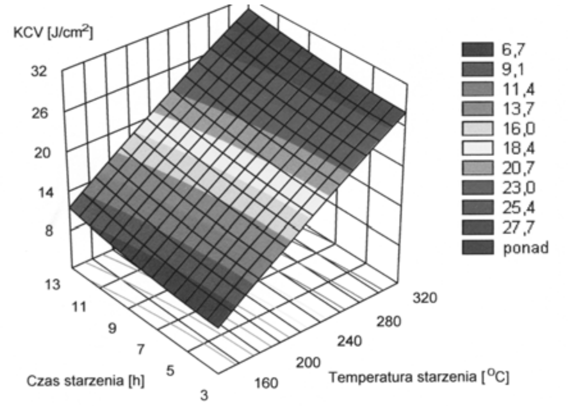

Fig. 6. Influence of temperature and time of ageing on impact strength of AK9 alloy (at t_p= 3 h, T_p= 535 ^oC.)

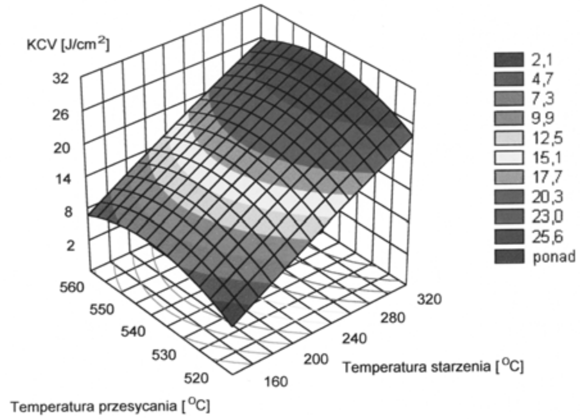

Fig. 7. Influence of temperature hyperquenching and temperature of ageing on impact strength of AK9 alloy (at t_p= 3 h,t_s= 8 godz.)

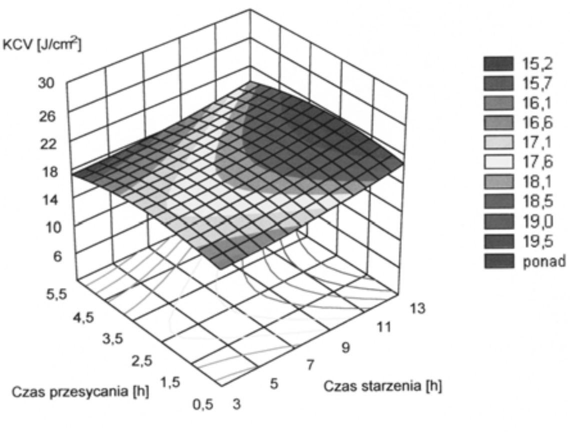

Fig. 8. Influence of time hyperquenching and time of ageing on impact strength of AK9 alloy (at T_p= 535 ^oC, T_s= 235 ^oC)

4. Conclusions

The ATND method enables registration of solidification and crystallization curves of investigated alloy, and on base of it selection of heat treatment temperatures for heperquenching and ageing.

On base of preliminary tests results one can state that heat treatment of AK9 alloy effects in growth of its impact strength.

Selection of values of temperatures and times of hyperquenching and ageing treatments, taking into consideration strength parameters, was completed with determination of their ranges:

a) temperature of hyperquenching - 530 ÷ 550 ^{o}C,

b) duration of hyperquenching - 1,5 to 3 hours,

c) temperature of ageing - above 280 ^{o}C,

d) duration of ageing - 10 to 13 hours.

For the specified above ranges of input variables' values one has obtained maximal values of strength parameters of AK9 alloy.

Further investigation is connected with necessity of determination of influence of ageing temperature growth (together with its growth impact strength increases) on other mechanical properties of heat treated alloy.

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