ARCHIVES
of
FOUNDRY ENGINEERING

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

ISSN (1897-3310)
Volume 13
Special Issue
1/2013
139–142

27/1

Assessment of Quality of EN AC-43300 Alloy with Use of ATND Method

J. Pezda

Faculty of Chipless Forming Technology, University of Bielsko-Biała, Willowa 2, 43-309 Bielsko-Biała, Poland
Corresponding author. E-mail address: jpezda@ath.bielsko.pl

Received 12.04.2013; accepted in revised form 08.05.2013

Abstract

Application of the silumins expands together with nowadays tendency to reduction of design structures mass. Technological and mechanical properties of Al-Si casting alloys depend mainly from structure of eutectic mixture, which is modified in result of introduction of micro alloying elements to liquid alloy, and that is why proper use of knowledge on crystallization to control of crystallization kinetics of produced alloys to optimize obtained structure is a significant factor leading to improvement of quality of the castings. In the paper one depicts use of the ATND method (thermal-voltage-derivative analysis) and regression analysis to assessment of quality of the EN AC-43300 alloy modified with strontium on stage of its preparation, in aspect of obtained mechanical properties ($R_{0,02}$, $R_{0,2}$, R_m, A_5). Obtained dependencies enable prediction of mechanical properties of the investigated alloy, basing on values of characteristic points from the ATND method.

Keywords: Aluminum alloy, Modification, ATND, Mechanical properties

1. Introduction

Silumins belong to the alloys, which owing to their mass, good thermal conductivity, corrosion resistance and processing properties like machinability, shrinkage and castability, as well as relatively low price, have become the most widespread alloys on base of aluminum.

Broad application of the silumins in foundry industry became possible after discovery of how to change solidification shape of eutectic mixture Al-Si. Silicon precipitations, present in the Al-Si alloys in form of compact primary precipitations and branched plates in the eutectic mixture α-Al+Si, are nearly pure wall-oriented crystals of this chemical element [1-3], which form areas of stress concentrations and initiation of micro-cracks. Spheroidization of eutectic silicon through modification treatment plays a significant role in elimination of such adverse phenomena. Investigations of modification process of aluminum alloys go back to twenties of the previous century [4] and have been carried out up-to-now [5-9].

There exist a numerous hypothesis attempting to explain a phenomena occurring during modification treatments diverging each other, so it is very difficult to formulate a single coherent theory of this process.

Process of modification of the alloys can result, depending on type of the alloy and type of modifying agent, in a number of phenomena, e.g.: formation of additional nuclei of crystallization, formation of inclusions limiting growth of crystals (structure of the alloys is of polycrystalline character), local changes of elementary substances concentration and surface tension, change of conditions of superfusion of the alloy, deoxidation and degassing of the metallic bath, ect.[1, 5-6, 10-13]

In result, owing to application of the modification we can obtain a fine-grained structure, being characterized by minimal interfacial distance of eutectic mixture, rounding of contours of silicon precipitations and bigger portion of dendrites of plastic phase α, what creates favorable conditions for growth of tensile strength, elongation and impact resistance.

Standard process of the modification of the Al-Si alloys is connected with introduction of small quantities of various metallic elements, known as modifiers to these alloys, e.g. Na, Sb, Sr, P, Ti and rare earth [1-2, 5-7, 13-16].

Among the modifiers, the broadest application within industry have found strontium and sodium. The strontium is counted among durable modifiers due to a longer time of its modification effect with respect to modification with use of the sodium, and similarly to sodium, it can be used in a castings poured in sand moulds, poured in permanent moulds in process of gravity casting, and in low pressure casting [5].

However, even the best selected modifier can not fulfill its task at wrongly selected technological conditions of the modification process (suitable quantity of the modifier, temperature of metal, duration of performed treatment).

Recording of solidification and crystallization processes based of analysis of temperature change (ATD, DTA, ATDG) [x], electric conductivity change (ATD-AED) and electric voltage generated on probes during the crystallization and phase transitions (ATND) [17] enables controlling of technological processes aimed at obtainment of optimal material structure, and hence mechanical and technological properties of a casting on stage of its preparation, i.e. melting and refinement (modification).

2. Metodology of the research

To the investigations one used the EN AC-43300 (AlSi9Mg) alloy, which can be characterized by very good castability, good machinability, workability and corrosion resistance. Chemical composition of the alloy is presented in the Table 1

Table 1.
Chemical composition of the EN AC-43300 alloy

Chemical composition / mass %				
Si	Cu	Zn	Fe	Mg
9,3	0,12	0,10	0,50	0,12
Ti	Mn	Pb	Cr	Al
0,01	0,24	0,01	0,01	rest

The analysis of the chemical composition was performed with the use of the emission spectroscopy (spectrometer type ARL 3440).
To prepare specimens to the testing one melted the alloys in electric resistance furnace in temperature of about 750 - 760 °C. The next treatment consisted in refining of the investigated alloys. To the refining one used Rafal 1 preparation in quantity of 0,4% mass of charge.

Refined alloys, after removal of oxides and slag from metal-level , were modified with AlSr10 master alloy in quantity of: 0,6% mass of charge (0,06% Sr) in temperature 760 °C.
Static tensile strength test was performed on the Schenck testing machine according to the EN ISO 6892-1:2010 standard. Measurement of elongation was performed with use of extensometer of the Schenck-DSA 25/10M type.

In the Fig. 1 is depicted exemplary diagram from the tensile test of modified EN AC-43300 alloy.

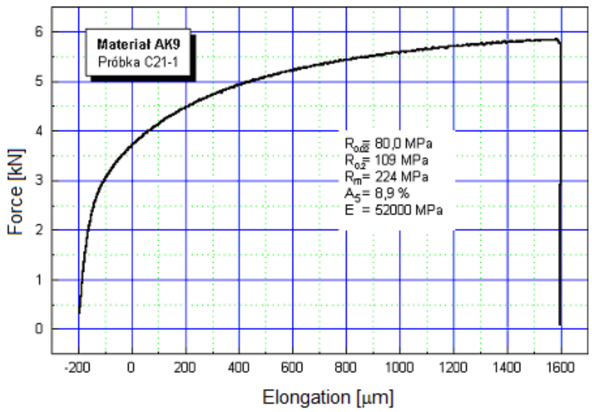

Fig. 1. Examplary diagram of static tensile test of the investigated alloy

Crystallization course of the investigated alloy recorded with use of the ATND method, with marked characteristic points of the thermal (t_1 - t_4) and voltage (U_1 - U_4) curves, are shown in the Fig. 2.

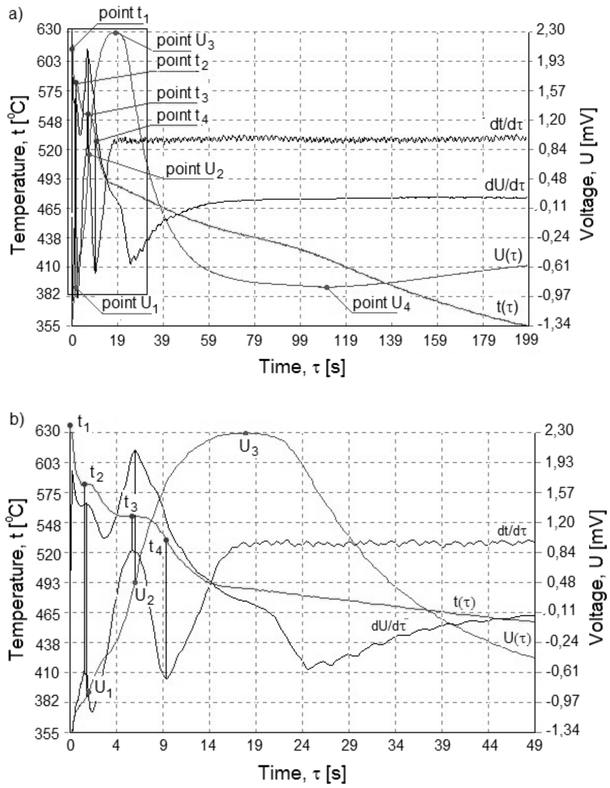

Fig. 2. Curves of the ATND method with marked characteristic points for the investigated alloy: a) full range of the crystallization process, b) magnification of a selected area

On the base of obtained values of the characteristic points from the ATND method (independent variables) and mechanical properties (dependent variables) one created a computer files containing data to regression analysis, performed with use of the Statistica version 10 packet developed by StatSoft.
The first order polynomial was assumed as a function of the testing object (1).

$$z = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \ldots + b_n x_n \pm \varepsilon \quad (1)$$

where:

z – dependent variable ($R_{0,02}$, $R_{0,2}$, R_m, A_5),
$x_1, x_2, \ldots, x_n$ – independent variables ($T_1 \div T_4$, $U_1 \div U_4$),
$b_0, b_1, \ldots, b_n$ - estimator of regression,
ε - standard error of estimation.

3. Description of obtained results

In the Table 2 are listed obtained mechanical properties of the investigated alloy after performed modification treatment.

Table 2.
Mechanical properties of investigated alloys

$R_{0,02}$	**$R_{0,2}$**	**R_m**	**A_5**
[MPa]	[MPa]	[MPa]	[%]
64 - 80	100 - 114	196 - 230	4,7 – 12,3

In result of performed regression analysis one obtained the dependencies (2-5), presenting effect of characteristic points values on change of mechanical properties of the EN AC-43300 alloy modified with strontium.

$$R_{0,02} = -1455 - 0,28t_1 + 2,37t_3 + 0,72t_4 - 3,21U_2 \pm 2,85 \text{ [MPa]} \quad (2)$$

The dependency (2) contains five variables fulfilling condition of significance. Elimination of the variables was terminated on the fourth step. Coefficient of determination R^2 = 0,74. Corrected coefficient R^2 amounts to 0,68. It means, that obtained dependency „fits", and to the equation are introduced significant variables.

Total effect of influence of the independent (explaining) variables on the dependent variable $R_{0,02}$ is statistically significant. There was fulfilled condition - $F_{obl} > F_{(\alpha;df1;df2)}$ (F_{obl} = 13,18 > $F_{(0,05;4;19)}$ = 2,89). Value of the test is high, what results in critical level of significance p = 0,000025.

$$R_{0,2} = -257,8 - 0,21T_1 + 0,93T_4 - 5,31U_2 \pm 1,85 \text{ [MPa]} \quad (3)$$

The dependency (3) contains only a variables fulfilling condition of significance. Elimination of the variables was terminated of the sixth step (the lowest: C_p = 2,85, √ŚKR = 1,85). Coefficient of determination R^2 amounts to 0,90. Corrected coefficient R^2 amounts to 0,79. To the equation one introduced three variables with significant effect, simplifying structure of the equation.

Total effect of influence of the independent (explaining) variables on the dependent variable $R_{0,2}$ is statistically important. There was fulfilled condition - $F_{obl} > F_{(\alpha;df1;df2)}$ (F_{obl} = 29,42 > $F_{(0,05;3;20)}$ = 3,09). Value of the test is high, what results in critical level of significance having minimal value p = 0,000001.

The Figs. 3-4 show how are shaped values predicted on the base of the dependences (2) and (3) and values observed (from the test) for the $R_{0,02}$ and $R_{0,2}$.

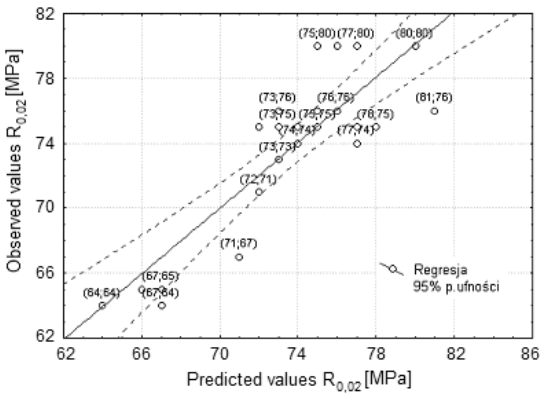

Fig. 3. Diagram of predicted and observed values for the variable $R_{0,02}$

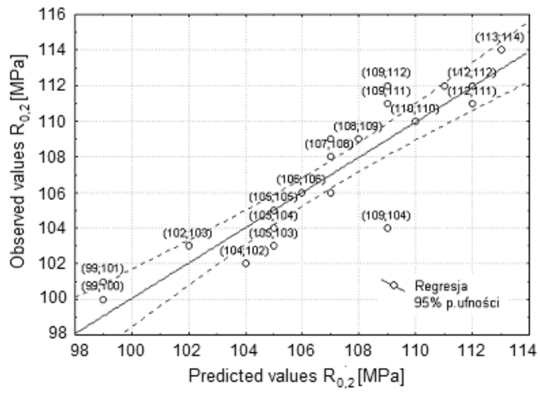

Fig. 4. Diagram of predicted and observed values for the variable $R_{0,2}$

$$R_m = -1480,5 + 2,88T_2 - 8,8U_1 \pm 4,59 \text{ [MPa]} \quad (4)$$

Coefficient of determination R^2 amounts to 0,80. Corrected coefficient R^2 being a comparative measure for the models with different number of variables amounts to 0,78. It means, that obtained dependency (4) „fits", and to the equation were introduced three variables, simplifying its structure.

Total effect of influence of the independent (explaining) variables on the dependent variable R_m is statistically significant. At vestigial critical level p = 0,000001 < ∝ = 0,05, there was fulfilled condition - $F_{obl} > F_{(\alpha;df1;df2)}$ (F_{obl} = 42,48 > $F_{(0,05;2;21)}$ = 3,46.

The Fig. 5 presents a system of predicted values (from the dependences) and observed values (from the test) for the tensile strength R_m.

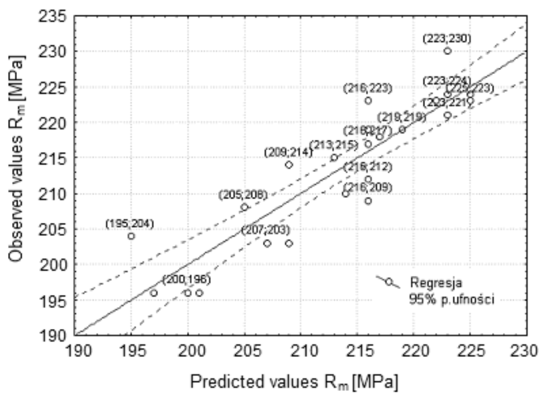

Fig. 5. Diagram of predicted and observed values for the variable R_m

$$A_5 = -320{,}6 + 0{,}05T_1 + 0{,}5T_2 - 0{,}9U_1 + 1{,}49U_2 \pm 1{,}0\ [\%] \quad (5)$$

Obtained dependency (5) contains five variables (inclusive of the free term) complying with condition of significance at coefficient of determination $R^2 = 0{,}75$, and corrected coefficient $R^2 = 0{,}69$.

Total effect of influence of the independent variables on the dependent variable A_5 after elimination of insignificant variables at minimal critical level $p = 0{,}000015 < \propto = 0{,}05$ and $F_{obl} > F_{(\alpha;df1;df2)}$ ($F_{obl} = 14{,}441 > F_{(0{,}05;4;19)} = 2{,}89$) is statistically significant.

In the Fig. 6 is presented a system of predicted values and observed values for the dependent variable A_5 with marked observation, having maximal percentage error of the estimation with respect to observed value.

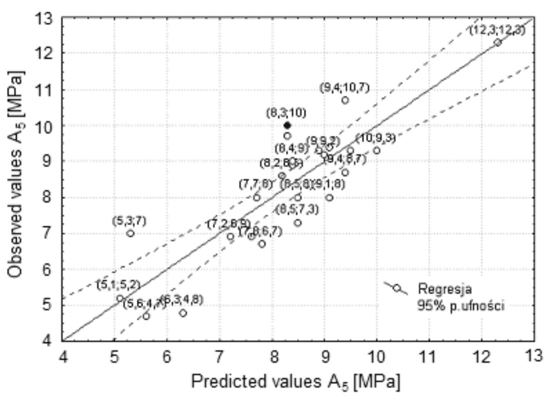

Fig. 6. Diagram of predicted and observed values for the variable A_5

4. Conclusions

On the base of obtained test results one can confirm correlation between values of characteristic points from curves of the ATND method and the mechanical properties ($R_{0,02}$, $R_{0,2}$, R_m, A_5) of the EN AC-43300 alloy modified with strontium.

Usage of the obtained dependences enables prompt quality control of the investigated alloy on stage of its preparation in aspect of possibly prompt prediction of its mechanical properties..

References

[1] Poniewierski, Z. (1989). *Crystallization, structure and properties of silumins*. Warszawa. WNT.

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

[3] Mondolfo, L. F. (1976). *Aluminium alloys, structure and properties*. London-Boston. Butterworths.

[4] Pacz, A. (1921). US Patent No. 1,387,900. Washington, D.C.: U.S. Patent and Trademark Office.

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

[6] Pietrowski, S. (2001). *Silumins*. Łódź. Technical University Editorial.

[7] Górny, Z. (1992). *Cast alloys of non-ferrous metals*. Warszawa. WNT.

[8] Pezda, J. (2008). Effect of modification with strontium on machinability of AK9 silumin. *Archives of Foundry Engineering*. 8(1), 273-276.

[9] Łągiewka, M. & Konopka, Z. & Zyska, A. & Nadolski, M. (2010). The influence of modification on the flow and the solidification of AlSi10Mg alloy. *Archives of Foundry Engineering*. 10(4), 119-122.

[10] Makhlouf, M. M. & Guthy, H. V. (2001). The aluminum–silicon eutectic reaction: mechanisms and crystallography. *Journal of Light Metals*. 1(4), 199-218.

[11] Braszczyński, J. (1989). *Theory of foundry processes.* Warszawa. PWN.

[12] Fraś, E. (1992). *Crystallization of metals and alloys*. Warszawa. PWN.

[13] Sobczak, J. (1997). *Fundamentals of synthesis of alloys.* Krakow. Foundry Institute.

[14] Kaufman, J. R. & Rooy, E. L. (2004). *Aluminium Alloy Castings: Properties, Processes & Applications*, ASM International.

[15] Dahle, A. K. & Nogita K. & McDonald S. D. & Dinnis C. & Lu L. (2005). Eutectic modification and microstructure development in Al–Si Alloys. *Mater. Sci. Eng. A*. 413-414, 243–248.

[16] Knuutinen, A. & Nogita, K. & McDonald, S. D. & Dahle, A. K. (2001). Modification of Al–Si alloys with Ba, Ca, Y and Yb. *Journal of Light Metals*. 1(4), 229-240.

[17] Wasilewski, P. (2003). Comparison methods of solidification and crystallization alloys of metals. *Archives of Foundry*. 3(10), 323-337.