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Use of the TVDA Method to Assessment of EN AC-AlSi9Mg Alloy Hardness Moulded in Metal Moulds

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Abstract

Mechanical properties of aluminum-silicon alloys are defined by condition of alloying components in the structure, i.e. plastic metallic matrix created from solid solution α on the basis of Al, as well as hard and brittle precipitations of silicon. Size and distribution of silicon crystals are the main factors having effect on field of practical applications of such alloys. Registration of crystallization processes of the alloys on stage of their preparation is directly connected with practical implementation of crystallization theory to controlling technological processes, enabling obtainment of suitable structure of the material and determining its usage for specific requirements. An attempt to evaluate correlation between values of characteristic points laying on crystallization curves and recorded with use of developed by the author TVDA method (commonly denominated as ATND method) is presented in the paper together with assessment of hardness of tested alloy. Basing on characteristic points from the TVDA method, hardness of EN AC-AlSi9Mg alloy modified with strontium has been described in the paper in a significant way by the first order polynomial.

Keywords: Aluminum alloys, Crystallization, Hardness, Regression analysis

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1. Introduction

Al-Si casting alloys are characterized by soft matrix and hard precipitations of silicon. Except silicon, these alloys can consist of small additions of other elements having effect on mechanical properties of the alloys by change of structure and course of crystallization process [1-7]. Mechanical and technological features of aluminum-silicon alloys, originated mainly from size, shape and distribution of precipitations of primary silicon crystals (hyper-eutectoid alloys) and eutectic ones (hypo-eutectoid and eutectoid alloys) directly affect application field of these alloys [1,4,6,8-10]. Standard methods enabling improvement of mechanical properties are based on change of morphology of silicon precipitations by modification of the alloy, maintaining correct temperature of superheating and pouring into mould, and on a possible heat treatment. Modification is the most effective method enabling obtainment of optimal structure of castings. Quality of modification depends on technological conditions of the process, i.e. correct selection and batching of inoculants, temperature of the alloy and time of modification elapsing from introduction of the inoculant to solidification of the alloy [1,6,11-14]. In case of hypoeutectic and near-eutectic alloys the modification results in change of precipitations morphology of silicon crystals from flakes to fibrous and spherical; also results in changes of interfacial space in α(Al)+β(Si) eutectic mixture [13]. Recording of solidification and crystallization processes enables suitable control of technological properties to obtain proper microstructure of castings, which determine operational properties of the alloys. Thermal analysis belongs to the most often used methods to monitoring solidification processes of the alloys. Except thermal analysis, TDA [15,16], DTA and DSC [16-19], TDA-EDA [20,21] and TVDA [21-23] methods can be used in course of the investigations. The TVDA method consists in continuous, simultaneous measurement of temperature and electric voltage arisen on probes during crystallization and phase transformations of solidifying alloy. Course of crystallization is depicted in form of diagram created during solidification of the alloy. Value of generated voltage is included within range of ± 5 mV. Thermal curves (t and dt/dτ) in the TVDA method are supplemented with voltage curves (U and dU/dτ).

The main objective of this work is to make use of the TVDA method together with regression analysis to develop a dependency, in form of the first order polynomial, enabling estimation of HB 10/1000/30 hardness of tested AlSi9Mg alloy at stage of its preparation.

2. Experimental methods

Alloy of EN AC-43300 (AlSi9Mg) brand has been used to the testing. This alloy contains, except silicon (9.3%) and magnesium (0.12%), also impurities such as Fe (0.5%), Mn (0.24%), Cu (0.12%) and Zn (0.1%), and residual (0.01%) quantities of Ti, Pb, Cr. Chemical composition of the alloy was evaluated with use of ARL3440 type spectrometer.

Melting of the alloy was accomplished in electric resistance furnace with use of graphite-made melting crucible. Refining treatment, consisted in adding of Rafal 1 refining agent (0.4% mass of charge) at temperature 760 °C. Modification treatment was carried out by adding AlSr10 master alloy (0.4% mass of charge) with overheating of metal bath to temperature 780 °C.

The investigated alloy was poured into metallic mould, heated-up to temperature 250 °C. The mould was adapted to recording of crystallization processes using the TVDA method [22]. Block diagram of the measuring stand is presented in Fig. 1.

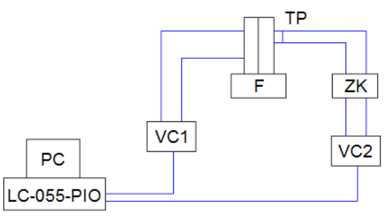

Fig. 1. Block diagram of measuring stand from TVDA method: PC computer with LC-055-PIO measuring module, VC1, VC2 – digital voltmeters, F – metallic mould, TP – thermocouple of k (Ni-NiCr) type, ZK – cold ends

Measurement of the hardness using Brinell method was taken on surface of milled gripping sector of test piece, having gauge length of 50 mm and 10 mm diameter, with use of PRL82 hardness meter according to PN-EN ISO 6506-1:2008 standard. Regression analysis was performed on the basis of the Statistica ver. 10 computer system developed by StatSoft Company, using files with values of characteristic points taken from curves recorded with use of the TVDA method (independent variables) and from measured HB 10/1000/30 hardness (dependent variables). The first order polynomial was taken as object function of the investigations (1).

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + ... + b_nx_n \pm \varepsilon \qquad (1)$$

where:
y – hardness HB 10/1000/30,
$x_1, x_2, ..., x_n$ - values of the points ($t_1 \div t_4$, $U_1 \div U_4$),
$b_0, b_1, ..., b_n$ - regression estimators,
ε - standard error of estimation.

3. Research results and analysis

In the Fig. 2 are presented recorded curves from the TDVA method of tested alloy, with characteristic points $t_1 \div t_4$ for the thermal curve t = f(τ) and points U_1 - U_4 for the voltage curve U = f(τ).

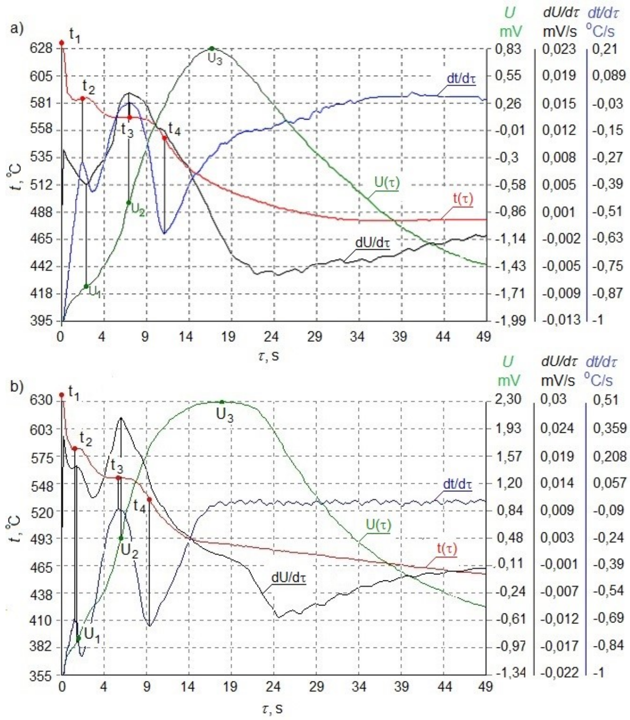

Fig. 2. Curves of the TVDA method for the AlSi9Mg alloy: a) refined, b) modified

HB10/1000/30 hardness of the alloy was included within range of 61-64.5 for the refined alloy, and 59.5-63 for the modified alloy.

Complete linear model of the dependent variable HB10/1000/30, described by the equation (2), has been obtained as result of the performed regression analysis.

$$HB10/1000/30 = -113.5 + 0.07t_1 - 0.007t_2 + 0.09t_3 + 0.16t_4 + 1.8U_1 - 0.03U_2 - 1.26U_3 + 2.74U_4 \quad \pm 0.91 \tag{2}$$

Value of correlation factor amounts to R=0.83 for the equation (2), while determination factor amounts to R^2 = 0.70, denoting that 70% of general variability of the HB 10/1000/30 hardness was explained by the model. Corrected coefficient of determination R^2 amounts to 0.55. For presented here dependency only three variables (t_1, U_1 and U_3 - Table 2) belong to significant variables, other variables do not comply with condition of significance ($p<\alpha=0.05$), and belong to variables with insignificant share.

Table 2.
Summary of regression of the HB 10/1000/30

Multiple regression N=24	correlation coefficient R = 0.84; coefficient of determination R^2 = 0.70; correction R^2 = 0.55; F(8,15) = 4.574; p < 0.005; standard error of estimation: 0.91					
	BETA	Std. error BETA	B	Std. error B	Test t(15)	Significance level p
free term			-113.5	161.9	-0.701	0.493
t_1	0.839	0.213	0.075	0.019	3.939	0.001
t_2	-0.009	0.186	-0.007	0.137	-0.051	0.959
t_3	0.059	0.175	0.092	0.271	0.337	0.74
t_4	0.443	0.249	0.162	0.09	1.782	0.094
U_1	1.014	0.324	1.8	0.575	3.128	0.006
U_2	-0.018	0.205	-0.036	0.392	-0.091	0.928
U_3	-0.65	0.252	-1.266	0.491	-2.577	0.021
U_4	0.371	0.2	2.74	1.484	1.849	0.084

In result of performed elimination of irrelevant variables it has been obtained dependency (3), for which regression coefficient amounts to R=0.84, deformation coefficient amounts to R^2 = 0.71, while correction R^2 amounts to 0.64. Statistical significance of the effect of independent variables on dependent variable HB 10/1000/30 is fulfilled at the level of p=0.00018<a=0.05 ($F_{obl} > F_{(\alpha;df1;df2)}$) ($F_{obl} = 9.13 > F_{(0,05;5;18)} = 2.77$).

$$HB10/1000/30 = -68.1 + 0.07t_1 - 0.16t_4 + 1.75U_1 - 1.23U_3 + 2.45U_4 \quad \pm 0.84 \tag{3}$$

The above equation consists of six variables (together with the free term), significance level of these variables does not exceed assumed significance level of $\propto = 0.05$ (table 3).

Standard deviation as percent of the mean amounts to 3%, informing about suitability of obtained dependency (3) to estimation of HB10/1000/30 hardness value.

Table 3.
Summary of regression results of HB 10/1000/30 hardness after elimination of variables with insignificant share

Multiple regression N=24	correlation coefficient R = 0.84; coefficient of determination R^2 = 0.71; correction R^2 = 0.64; F (5,18) = 8.282; p < 0.0003; standard error of estimation: 0.84					
	BETA	Std. error BETA	B	Std. error B	Test t(15)	Significance level p
free term			-68.9	30.2	-2.249	0.03
t_1	0.836	0.173	0.075	0.015	4.817	0.0001
t_4	0.449	0.161	0.163	0.058	2.78	0.012
U_1	0.987	0.232	1.753	0.413	4.239	0.0004
U_3	-0.635	0.192	-1.237	0.375	-3.299	0.003
U_4	0.332	0.157	2.459	1.16	2.107	0.04

In the Fig. 3 is presented system of forecasted and observed values for HB10/1000/30 hardness, with marked minimal and maximal percentage error of the estimation in relation to observed value (brown – minimum, blue – maximum). Percentage error of the estimation of value amounts to 2.4%.

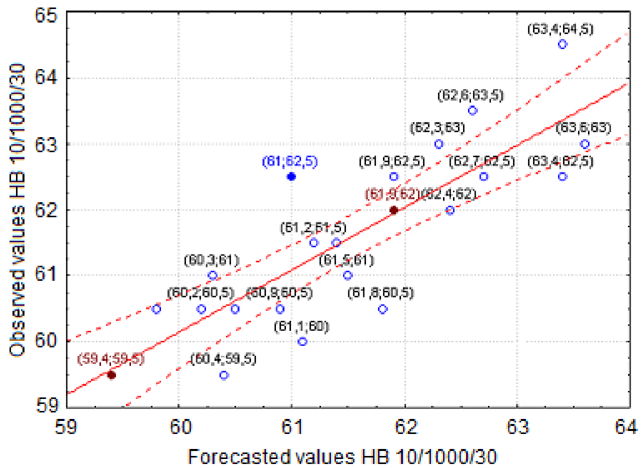

Fig. 3. Anticipated and real values of HB10/1000/30 hardness for the EN AC-AlSi9Mg alloy

4. Conclusions

The TVDA method reflects crystallization process of the investigated alloy. Results obtained from the tests have confirmed correlation between HB10/1000/30 hardness of EN AC-AlSi9Mg alloy, modified with strontium, and values of characteristic points from the TVDA method. Obtained dependency enables, in laboratory conditions, prediction of hardness of investigated alloy on stage of its preparation (melting) with significance level of α = 0.05. There exists a necessity to verify obtained results in industrial conditions.

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