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DETERMINATION OF R_m TENSILE STRENGTH OF AL-SI ALLOYS WITH USE OF ATND METHOD

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Summary

In the paper is presented an attempt of assessment of melting and modification effect on R_m tensile strength of Al-Si alloys poured into metallic moulds. Investigated alloys underwent refining and modification with AlSr10 master alloy. Run of the crystallization process was presented with the help of solidification curves, making use of thermal-voltage-derivative analysis (ATND). Obtained results comprise registered curves of solidification, strength tests, microstructure of the alloy and regression analysis. On base of performed regression analysis one obtained a dependencies enabling evaluation of R_m tensile strength of Al-Si alloys as early as on stage of their preparation (melting).

Keywords: crystallization, tensile strength, ATND

Wytrzymałość na rozciąganie stopów Al-Si określona metodą ATND

Streszczenie

W pracy przedstawiono próbę oceny wpływu warunków procesu topienia i modyfikacji na wytrzymałość na rozciąganie R_m stopów Al-Si odlewanych do form metalowych. Stopy Al-Si poddano rafinacji i modyfikacji zaprawą AlSr10. Przebieg procesu krystalizacji charakteryzowano za pomocą krzywych krystalizacji. Stosowano metodę analizy termiczno-napięciowo-derywacyjnej (ATND). Wykonano próbę statyczną rozciągania oraz badania mikroskopowe wytworzonych stopów Al-Si. Analiza regresji stanowiła podstawę do uzyskania zależności pozwalającej określić prognozowaną wytrzymałość na rozciąganie R_m stopów Al-Si w procesie topienia i krystalizacji.

Słowa kluczowe: krystalizacja, wytrzymałość na rozciąganie, ATND

1. Introduction

Development of modern techniques creates supply of better and better structural materials having higher strength. Light metals and their alloys are more and more often used for metal structures, whereas aluminium and its alloys are the most widespread among them. The most widespread group among aluminum alloys found in foundry industry are technical alloys of aluminum with silicon – called as silumins – where silicon is the main alloying constituent [1]. Aluminum-silicon casting alloys are essential to the automotive, aerospace

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and engineering sectors. Al-Si alloys allow complex shapes to be cast; however the silicon forms brittle needle-like particles which reduce impact strength in cast structures. Mechanical and technological properties of silumins are connected to high degree with shape and method of distribution of hard and brittle crystals of silicon in plastic metallic matrix of solid solution α(Al) [2-7].

Essential effect on mechanical properties can be obtained due to interaction in direction of production of fine-grained microstructure with uniform distribution of structural constituents. Fine-grained microstructure favors increase of tensile strength, elongation, impact strength, hardness and improved machinability of the alloy. Suitable methods of modification are the most effective methods being at ones disposal in foundry industry to obtain advantageous, fine-grained microstructure of cast materials.

Meaning of the modification can be interpreted as “introduction to liquid metal a slight additives to change microstructure of the casting” [8]. Strontium is the preferred modifier in current use. Addition of strontium in the near-eutectic Al-Si alloy not only results in a modification of the eutectic silicon, but also an obvious increase in the amount of α-Al dendrites and promotion of columnar growth of these dendrites, increasing both the strength and ductility of the alloy considerably [9].

Al-Si eutectic mixture obtained in result of correct modification is typical of minimal interfacial distance of the eutectic mixture, rounding of its contours and higher portion of dendrites of plastic α phase.

Among inoculants, the Na, Sr and Sb have found their practical application as inoculants of prolonged action [1, 2]. Contents of strontium should be included within range of 40-100 ppm [2-4]. Due to it, quantity of the strontium introduced to liquid alloy should be within limits of 0,04-0,07% [2].

In case of hypereutectoid alloys, objective of the modification is to refine primary silicon, which precipitates in not modified alloys are very big and can create hard and brittle inclusions having size of a few millimeters. To attain such objective one implements modification with use of phosphorus additives.

Growth of requirements demanded from new structures, both with respect to quality and economically reasonable profitability, has enforced development of a new methods of recognition of alloy properties as early as before its casting. Methods implemented for analysis of crystallization processes in alloys, based on examination of temperature change runs (thermal – ATD, DTA) [9-18], electric conductance (electric – AED) [13, 19-21] and thermal-voltage-derivative (ATND) [13, 22-26], analysis enable to register a phenomena arisen in result of crystallization process in alloys.

Objective of the investigations is attempt of implementation of the ATND method to assessment of mechanical properties of silumins on base of temperature and voltage read outs for characteristic points of the ATND method curves. Values of temperature and voltage, read out from these characteristic points become a basis to starting regression analysis to evaluate a dependencies enabling determination of mechanical properties of alloys as early as in stage of their preparation.

2. Methodology research

In course of the experiment one used the Al-Si alloys:

- EN AC-AlSi9Mg, hypoeutectoid alloy which can be characterized by good casting properties and good machinability and corrosion resistance. It is used for big castings with complicated shapes and high strength, heavy loaded.
- EN AC-AlSi13Cu2, near eutectic, multicomponent alloy commonly used in foundry industry.
- EN AC-AlSi21CuNi, hypereuctoid, multicomponent alloy commonly used in production of heavy duty combustion engine pistons, because of high abrasion resistance, high mechanical properties in increased temperatures and very low thermal expansion.

Analyzed alloys were melted in electric resistance furnace. Refining treatments were performed with use of the Rafal in quantity of 0,4% of mass of metallic charge. After completion of the refining, from level of liquid metal were removed oxides and slag, and modification treatment with strontium with use of AlSr10 master alloy in quantity of 0,6% of metallic charge mass was performed the for EN AC-AlSi9Mg and EN AC-AlSi13Cu2 alloys, and with CuP10 in quantity of 0,1% metallic charge mass for the EN AC-AlSi21CuNi alloy. Analyzed alloys were poured into metallic mould served to production of standardized strength test pieces according to the PN-88/H-88002-2 standard; the mould was adapted to control of crystallization process using the ATND method.

In plotted diagrams of the crystallization process characteristic points of thermal and voltage curves are marked. Values read out from these points (independent variables) constitute the base to creation of files designated to regression analysis. As dependent variable a predetermined R_m tensile strength was taken. Static tensile tests were performed in Kraków Foundry Engineering Institute on SCHENCK testing machine.

3. Research results and their analysis

In the Fig. 1 is shown a diagram of crystallization process run for the refined and modified EN AC-AlSi9Mg alloy with marked characteristic points.

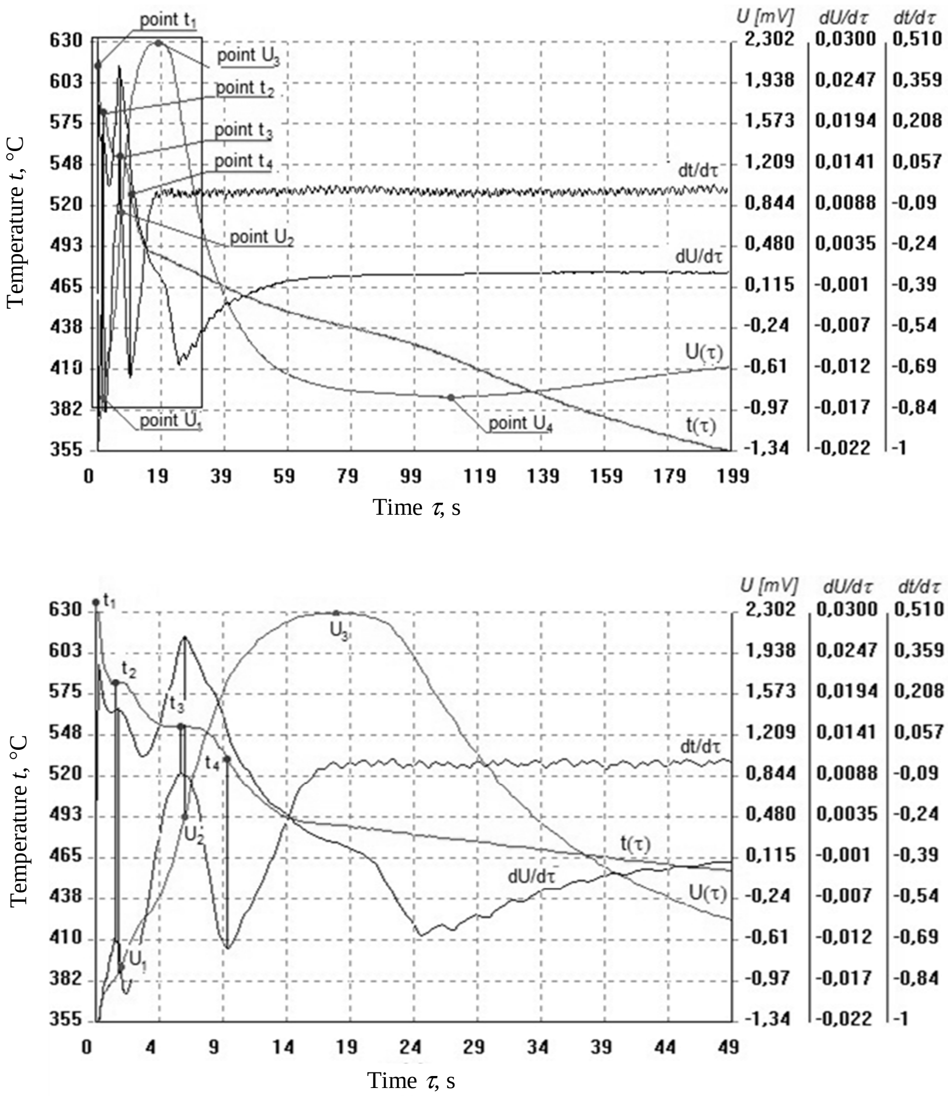


Fig. 1. Curves of the ATND method for the EN AC-AlSi9Mg alloy: a) complete run of the crystallization process, b) magnification of the marked area

For the EN AC-AlSi9Mg alloy after refining and modification one obtained the R_m tensile strength in range of 196 to 230 MPa.

Growth of the tensile strength for modified alloy was connected with production of an “enriched” structure and explicitly shaped dendrites of α phase and refined (α+Si) eutectic mixture in the interdendritic space.

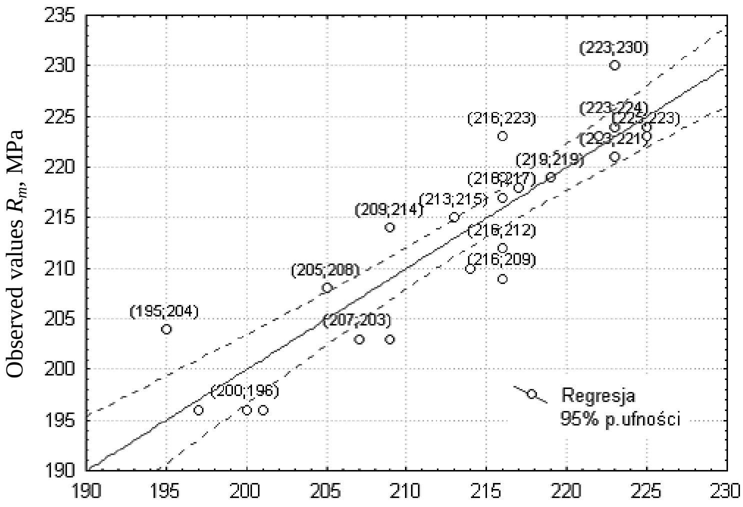
In result of performed analysis one obtained dependence (1) illustrating effect of change of characteristic points value on the R_m tensile strength for the EN AC-AlSi9Mg alloy after refinement and modification.

$$R_m = -1480.5 + 2.88 t_2 - 8.8 U_1 \pm 4.59 \text{ MPa} \quad (1)$$

when: $R = 0.89$; $R^2 = 0.80$; $F_{obl} = 42.48 > F_{(0,05;2;21)} = 3.46$.

Anticipated and observed (real) values, received on base of obtained dependency and performed tensile tests are included in the Fig. 2.

Dependent variables R_m, MPa



Forecasted values R_m, MPa

Fig. 2. Diagram of forecasted and observed values of R_m for the EN AC-AlSi9Mg alloy

In the Figs. 3 and 4 a diagram of crystallization process run for the refined and modified EN AC-AlSi13Cu2 alloy is shown with marked characteristic points.

For the EN AC-AlSi13Cu2 alloy after refining and modification one obtained the R_m tensile strength in range of 230 to 288 MPa. In result of performed analysis one obtained dependence (2) illustrating effect of change of characteristic points value on the R_m tensile strength for the EN AC-AlSi13Cu2 alloy after refinement and modification.

$$R_m = -703.8 + 4.16t_2 - 2.54t_3 + 11U_1 - 12.22U_3 \pm 5.4 \text{ MPa} \tag{2}$$

when: $R = 0.93$; $R^2 = 0.88$; $F_{obl} = 24.65 > F_{(0,05;4;13)} = 3.17$

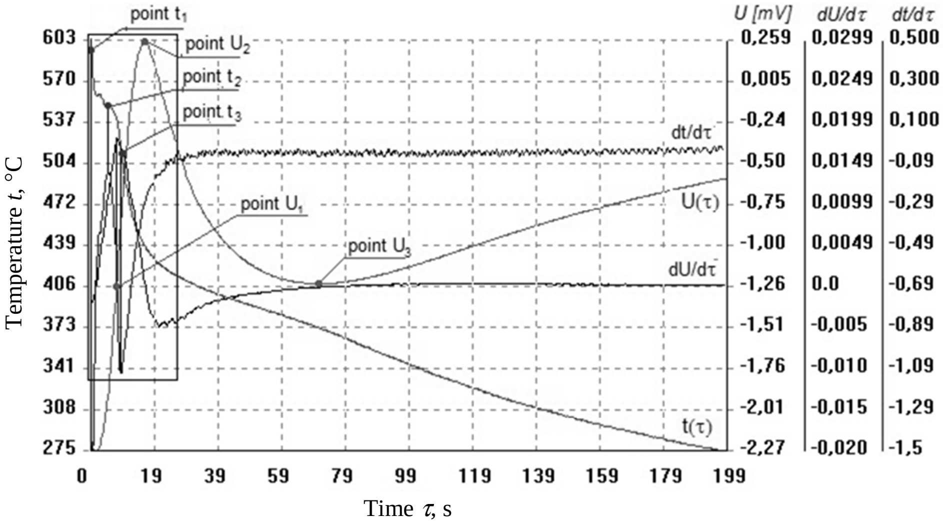


Fig. 3. Curves of the ATND method for the EN AC-AlSi13Cu2 alloy – complete run of the crystallization process

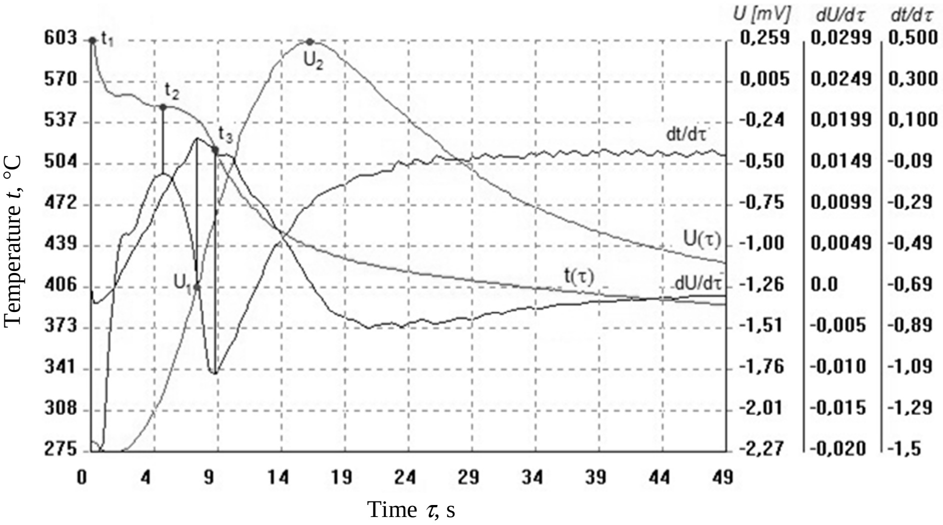


Fig. 4. Curves of the ATND method for the EN AC-AlSi13Cu2 alloy – magnification of the marked area

Anticipated and observed (real) values, received on base of obtained dependency and performed tensile tests are included in the Fig. 5.

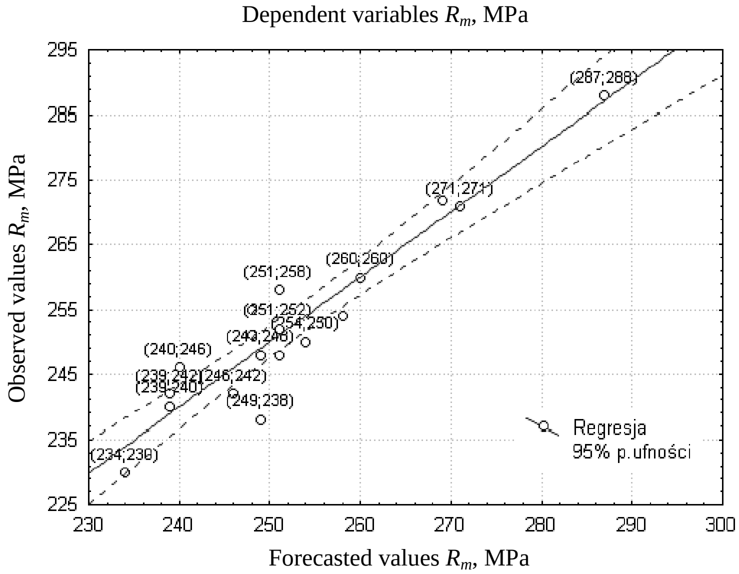


Fig. 5. Diagram of forecasted and observed values of R_m for the EN AC-AlSi13Cu2 alloy

In the Figs. 6 and 7 a diagram of crystallization process run for the refined and modified EN AC-AlSi21CuNi alloy is shown with marked characteristic points.

For the EN AC-AlSi21CuNi alloy after refining and modification one obtained the R_m tensile strength in range of 154 to 192 MPa.

In result of performed analysis one obtained dependence (3) illustrating effect of change of characteristic points value on the R_m tensile strength for the EN AC-AlSi21CuNi alloy after refinement and modification.

$$R_m = 600.8 - 0.69t_1 - 34.7U_2 \pm 5.39 \text{ MPa} \quad (3)$$

when: $R = 0.92$; $R^2 = 0,85$; $F_{obl} = 41,64 > F_{(0,05;2;15)} = 3,68$.

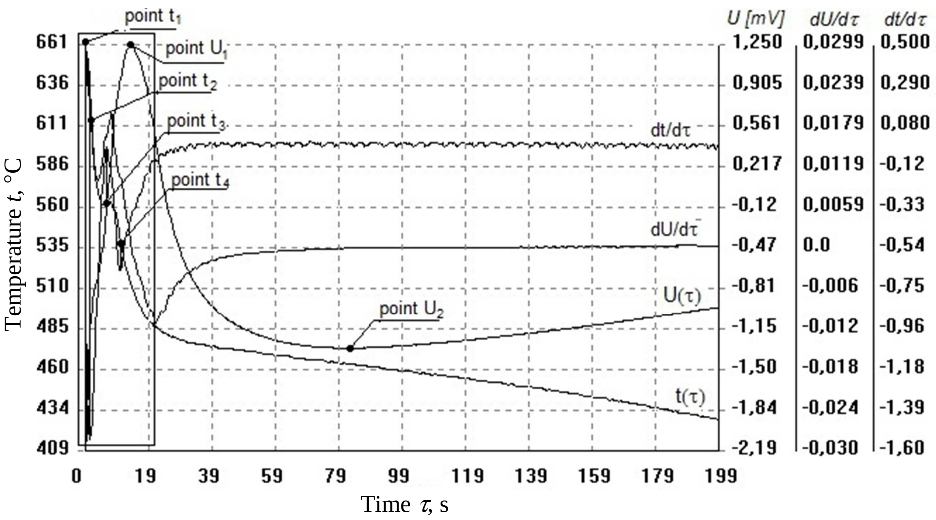


Fig. 6. Curves of the ATND method for the AC-AlSi21CuNi alloy – complete run of the crystallization process

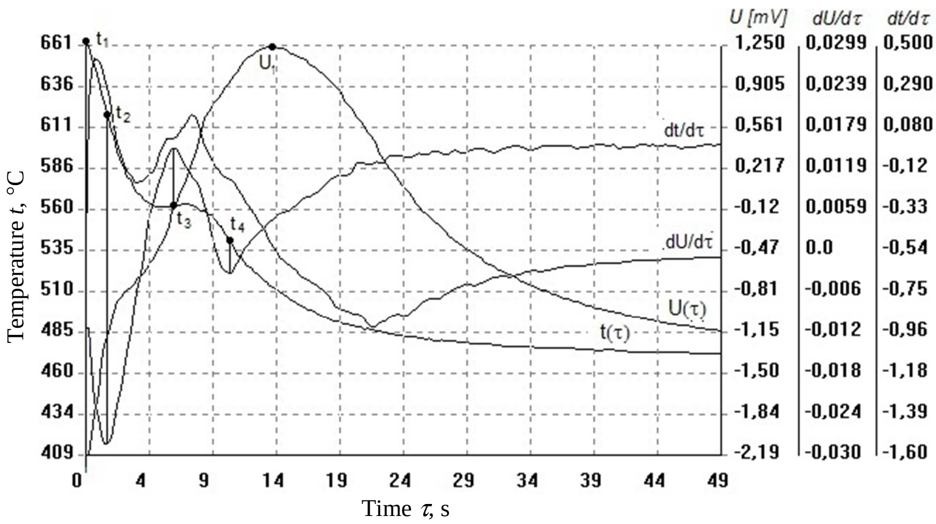


Fig. 7. Curves of the ATND method for the EN AC-AlSi13Cu2 alloy – magnification of the marked area

Anticipated and observed (real) values, received on base of obtained dependency and performed strength tests are shown in the Fig. 8.

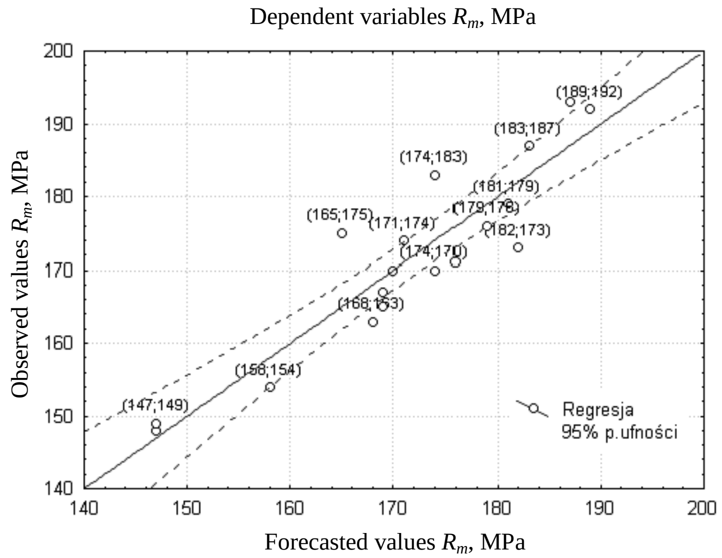


Fig. 8. Diagram of forecasted and observed values of R_m for the EN AC-AlSi21CuNi alloy

4. Conclusion

On base of obtained test results it was stated that the ATND method:

- can be used to registration of crystallization processes of Al-Si alloys,
- enables assessment of alloy's quality on the basis of the effect of its microstructure change on thermal and voltage curves.

On thermal and voltage curves characteristic points are present, values at these points can be used to prompt assessment of the R_m tensile strength of crystallizing Al-Si casting alloys.

Obtained dependencies enable determination of the R_m tensile strength of the tested silumins in laboratory conditions with confidence level of $\alpha = 0.05$.

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