

# Derivative thermo analysis of the Al-Si cast alloy with addition of rare earths metals

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## Abstract

In this paper the dependence between chemical composition, structure and cooling rate of Al-Si aluminium cast alloy was investigated. For studying of the structure changes the thermo-analysis was carried out, using the UMSA (Universal Metallurgical Simulator and Analyzer) device. For structure investigation optical and electron scanning microscopy was used, phase and chemical composition of the Al cast alloy also using qualitative point-wise EDS microanalysis.

**Keywords:** Aluminium alloy; Cerium, Lanthanum, Derivative thermo-analysis; UMSA

## 1. Introduction

The present day state-of-the-art technology renders exceptionally lightweight engines with high-cooling performance characteristics. Control of the hypereutectic alloy microstructures is imperative in the design of both superior tribological properties at the bore surface and for exceptional mechanical strength. However the solidification kinetics and the sequence of the phase transformations in relation to the as-cast and heat-treated structures needs still to be further understood, quantified and implemented for further improvement of the casting technology and cast component service characteristics [1].

These alloys are mostly used in production of machines and car engine elements made in the technological processes. Aluminium alloys are especially preferred in designs thanks to their good mechanical properties and possibility to make very complicated castings with high service properties. Thanks to the contemporary casting and heat treatment technologies, castings from the aluminium alloys have the suitably high mechanical

properties and simultaneously decrease the part weight. Therefore, there are more and more frequently used in the means of transport industry [2,3].

A newly developed investigation technology is the application of derivative thermo analysis using the Universal Metallurgical Simulator and Analysator. The UMSA device used for investigations is designed to overcome the existing problem of laboratory and industrial equipment on the present market. This platform combines computer controlled melting and heat treatment devices with a quench equipment, as well the device for thermal analysis and testing equipment for in-situ investigations of test sample crystallization characteristics [4-6].

The derivative thermo analysis makes it possible to determine the kinetic and dynamic of thermal the processes proceeding during the crystallization process of the alloys. This makes it possible to work out the statistical interdependence between the characteristic values of the ATD diagram curves, chemical composition, cooling speed rate of the alloy, parameters describing the structure as well mechanical properties [7,8].

The investigated Al-Si alloys is a near eutectic Al-Si alloys with addition of cerium and lanthanum as additive alloying elements, formation of aluminium rich ( $\alpha$ -Al) dendrites followed by development of two phase eutectic ( $\alpha$ -Al-Si). However, the additional alloying elements Ce, La, Cu, Mn leads to more complex solidification reaction, partially unidentified

## 2. Material and experimental procedure

For investigations the AC- $\text{AlSi12CuNiMg}$  (EN 1706:2001) aluminium alloy was used (table 1), alloyed with addition of 0.5g rare earths metals cerium and lanthanum. Following investigations were made:

- Alloy structure using MEF4A optical microscope supplied by Leica with image analysis software as well Zeiss Supra 25 SEM within high resolution mode,
- phase composition using qualitative and quantitative EDS microanalysis,
- derivative thermo analysis using the UMSA thermo simulator (fig. 1).

Table 1.  
Chemical composition of the AC- $\text{AlSi12CuNiMg}$  Al alloy

Mass fraction of the element, %							
Si	Cu	Mg	Mn	Fe	Ti	Zn	Ni
11,8	1	1	0,1	0,5	0,6	0,1	1

Thermo analysis of the investigated alloy was carried out using UMSA device [16]. The heating and cooling system, with experimental conditions is presented on figure 1. The samples were cooled using compressed gas supplied through the nozzles present in the heating inductor. The gas flowing rate for sample cooling will be regulated and controlled using a rotameter. The compressed gas flow rate was regulated for achieving of the cooling rate of 0.7 °C/s and 0.1 °C/s for furnace cooled sample.

For measurement a K-type (chromo–alumel) thermocouples was used. Tests were performed several times for each cooling speed for statistical estimation of the investigation results.

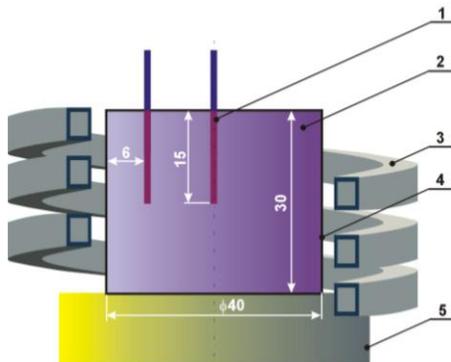


Fig. 1. UMSA device location scheme of the heating and cooling system, as well size of the samples for thermo analysis:

- 1 – thermocouple, 2 – heating inductor – cooling nozzles,  
3 – steel foil, 4 – sample, 5 – sampler isolation

## 3. Discussion of the experimental results

Metallographic investigation results performed on the optical microscope (fig. 2–4) and SEM (fig. 5-6) aloud to compare the microstructure achieved for the different cooling condition.

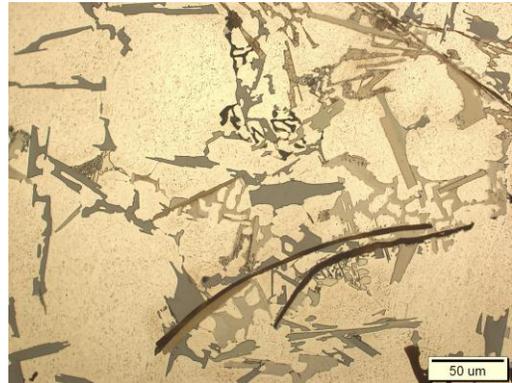


Fig. 2. Microstructure of the furnace cooled sample with 0.1 °C/s

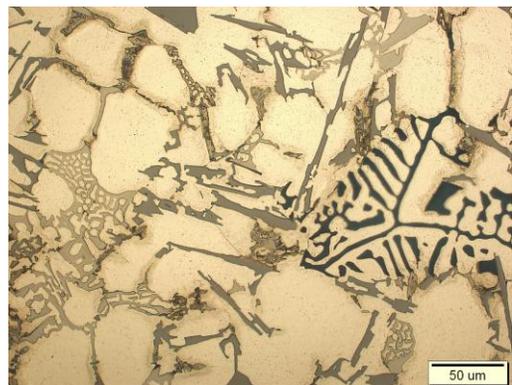


Fig. 3. Microstructure of the sample cooled with 0.7 °C/s

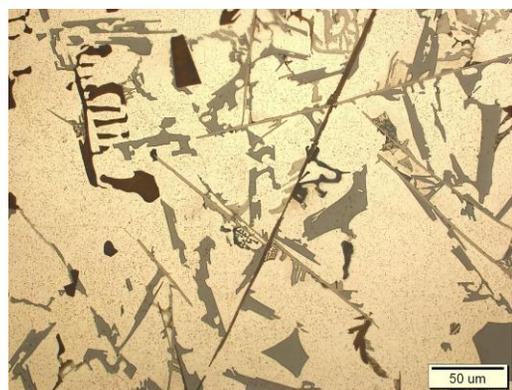


Fig. 4. Microstructure of the sample cooled with 0.1 °C/s, with addition of select rare earth metals

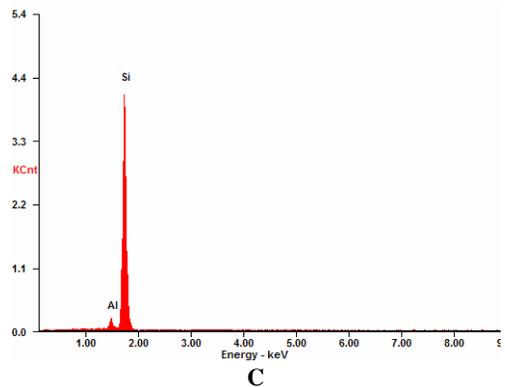
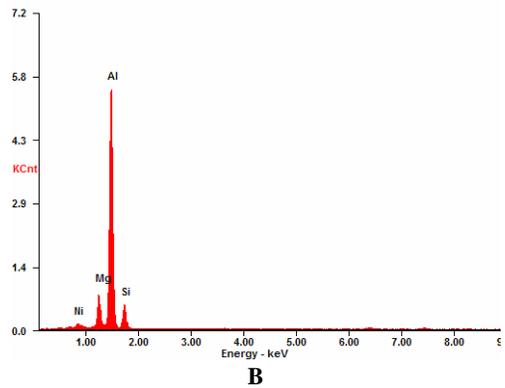
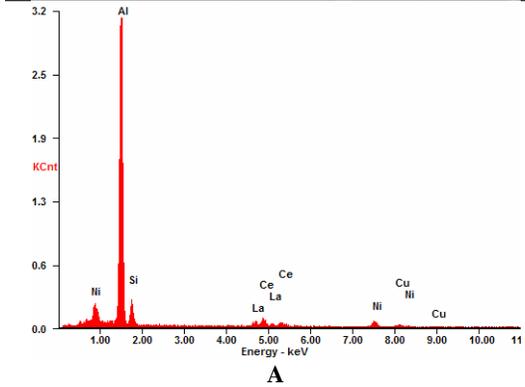
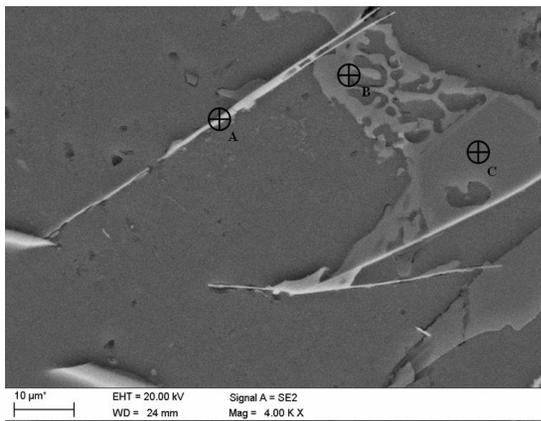


Fig. 5. SEM microstructure and EDS microanalysis performed in the marked points

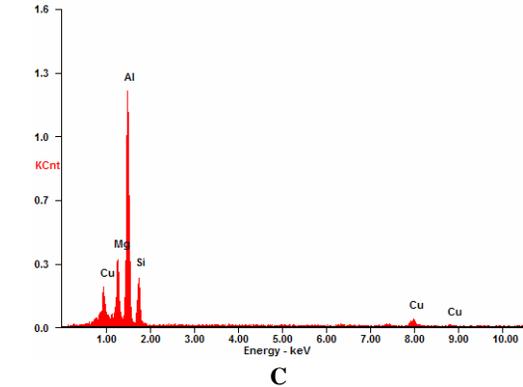
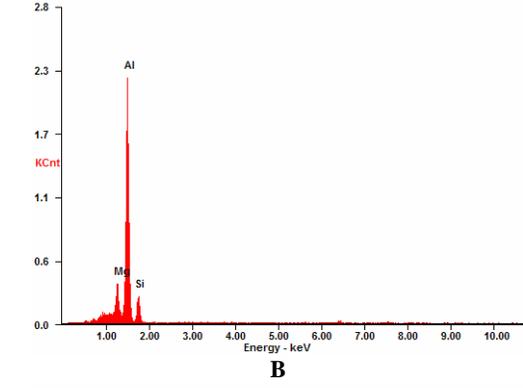
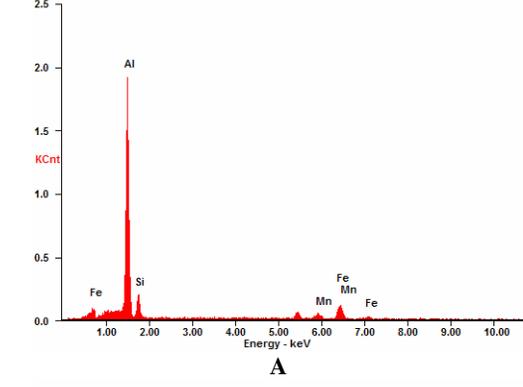
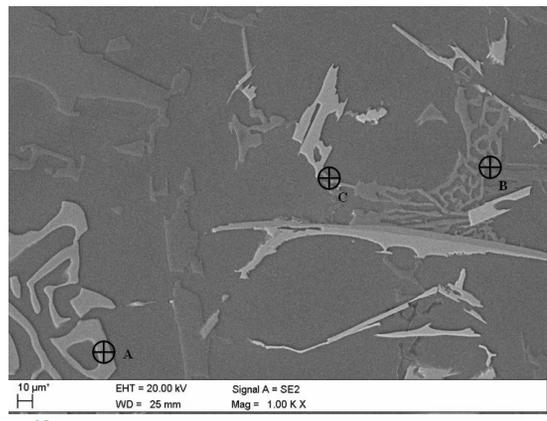


Fig. 6. SEM microstructure and EDS microanalysis performed in the marked points

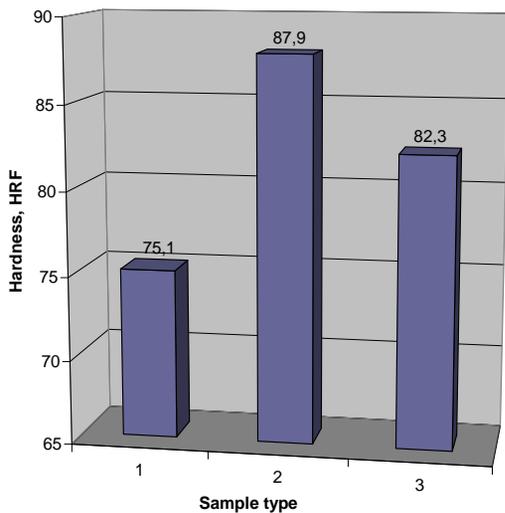


Fig. 7. Results of HRF hardness measurement of the samples in different experimental conditions

1 – cylindrical sample, cooling rate 0,1 °C/s, 2 – cylindrical sample, cooling rate 0,7 °C/s, 3 – cylindrical sample with addition of rare earth metals, cooling rate 0,1 °C/s

The performed microstructure observation using the scanning electron microscope as well formed quantitative X-ray analysis confirm the presence of  $\alpha+\beta$  eutectic occurred in the investigated alloys. Also as supposed a ternary eutectic  $\alpha+Al_2Cu+\beta$  is present

As a result of the carried out investigations, particularly EDS area distribution of the elements and quantitative point-wise analysis, performed using the EDS microanalysis, the occurrence of the main alloying additives was confirmed (fig. 5 and 6) Si, Cu, Ni, Mg, Mn, and Fe, as the alloying components of the investigated Al–Si–Cu cast alloy.

Using the thermal derivative analysis with baseline calculation the exactly cooling rates, assumed in the experiment, could be determined – for low cooling the value of 0,1 °C/s was estimated, whereas for the higher cooling rate the value of 0.7 °C/s was measured.

As a result of the investigation information about mass and atomic concentration of the elements in the investigated micro regions of the matrix and particles were achieved, where the main point are the identification of lanthanum and cerium concentration in a needle shaped precipitations (fig. 5a) were also nickel and silicon play as e structure element.

Hardness measurement result are given in fig. 7. whereas the highest value is achieved for the sample with highest cooling rate of 0.7 °C/s, what was assumed before the experiment, but addition of 1g of cerium and lanthanum has clearly decreased this value to 82 HRF also by 0.7 °C/ cooling rate.

During the derivative thermo analysis points were determined describing the thermal processes during crystallization of the investigated alloy.

## 4. Conclusions

Crystallization of the hypoeutectic Al–Si alloy starts with the crystallization of  $\alpha$ -Al, followed by cerium and lanthanum containing phases; Al+Si eutectic; Fe, Mn, Si, Al containing phase; Ni, Fe and Cu, Al, containing phase but there are some indices, mainly in the thermal analysis curve, that some less often occurred, undiscovered phases or phases transformations are present in this alloy for example the  $Mg_2Si$ .

Cooling rate has an important influence on the hardness, which has a value of 88 HRF for the samples cooled with 0.7 °C/s

Added cerium and lanthanum occurs in a longitudinal needle shaped precipitation and build a magnesium and silicon containing phases.

Cooling rate increase as well cerium and lanthanum addition has influence the morphology change of the precipitation occurred in the investigated alloys, confirmed by the mentioned hardness increase. Cooling rate increase leads to smaller more dispersive phases, but the addition of cerium and lanthanum causes a more irregular shape and edge deformation of the precipitations.

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