L. KUCHARIKOVÁ, E. TILLOVÁ, J. BELAN, A. VAŠKO, I. ŠVECOVÁ

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# QUANTITATIVE ASSESSMENT OF ALUMINIUM CAST ALLOYS` STRUCTURAL PARAMETERS TO OPTIMIZE ITS PROPERTIES

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The present work deals with evaluation of eutectic Si (its shape, size, and distribution), dendrite cell size and dendrite arm spacing in aluminium cast alloys which were cast into different moulds (sand and metallic). Structural parameters were evaluated using NIS-Elements image analyser software. This software is imaging analysis software for the evaluation, capture, archiving and automated measurement of structural parameters. The control of structural parameters by NIS Elements shows that optimum mechanical properties of aluminium cast alloys strongly depend on the distribution, morphology, size of eutectic Si and matrix parameters.

*Key words:* Al-Si-Cu-Mg cast alloy, casting method, microstructure, mechanical properties, Si phase

## INTRODUCTION

In the family of cast Al-Si alloys, the Al-Si-Cu-Mg grades are frequently used in the automotive and aerospace industries. These alloys are the most versatile materials, comprising 85 - 90 % of the total aluminium cast parts produced by the automotive industry due to their highest strength to weight ratio, good thermal conductivity, excellent fluidity, hot tear resistance and feeding characteristics which allow casting intricate shapes such as engine blocks, cylinder heads or chassis components [1-3]. The versatility of aluminium makes it the most widely used metal after steel [3-4]. One of the most influential factors for better properties of aluminium alloys is optimal morphology of structural parameters, especially eutectic Si and aluminium matrix [5].

Understanding of microstructure evolution during solidification is of general importance due to the requirements put on mechanical, technological and corrosion properties of materials [6]. It depends on many factors such as chemical composition (Figure 1), melt treatment, grain refinement, eutectic modification, cooling rate, casting process and heat treatment [6, 7].

Alloys from the Al-Si-Cu group play an important role in the automotive industry for various motor pistons, cylinder heads, heat exchangers, wheels, transmission housing and suspension components due to their high strength at room and elevated temperatures [6, 9-11]. The morphology study of structural parameters in Al-Si alloys is not new and it has been a subject of many studies before, but due to a wide range of properties that are adjustable via different methods effecting the morphology of structural parameters, much more systematic work is needed to fully characterize this alloy system.

L. Kucharíková, E. Tillová, J. Belan, M. Chalupová, A. Vaško, I. Švecová, University of Žilina, Faculty of Mechanical Engineering, Slovakia

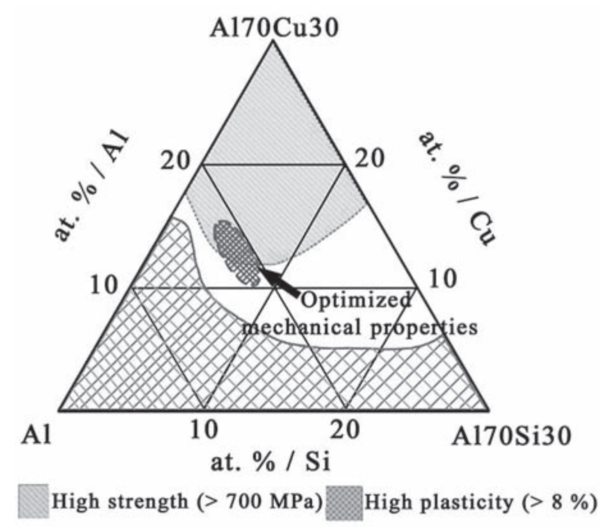


**Figure 1** Mechanical characteristic maps of Al-Si-Cu alloys [8]

## RESEARCH MATERIALS

AlSi9Cu3 cast alloy was used as the experimental material. Alloys ingots were remelted and from the melt were cast rod samples into metallic moulds with 18-mm diameter and 150-mm length and into sand moulds with 20-mm diameter and 300-mm length. Arc spark spectroscopy was used to control the chemical composition of materials (Table 1 and Table 2).

## RESEARCH METHODOLOGY

Structural parameters identification was performed by light microscopy (NEOPHOT 32). The experimental samples for metallographic observations were prepared by standard metallographic procedures (wet ground, polished with diamond pastes, finally polished with commercial fine silica slurry - STRUERS OP – U) and

**Table 1** Chemical composition of $AlSi_9Cu_3$ alloy cast into metallic moulds / wt. %

| Si | Cu | Fe | Mg | Mn | Zn | Sn | Pb | Ti | Ni | Cr | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9,4 | 2,4 | 0,9 | 0,28 | 0,24 | 1,0 | 0,03 | 0,09 | 0,04 | 0,05 | 0,04 | remainder |

**Table 2** Chemical composition of $AlSi_9Cu_3$ alloy cast into sand moulds / wt. %

| Si | Cu | Fe | Mg | Mn | Zn | Sn | Pb | Ti | Ni | Cr | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10,4 | 2,4 | 0,9 | 0,26 | 0,25 | 1,0 | 0,02 | - | 0,05 | 0,1 | - | remainder |

etched by standard (Dix - Keller; 0,5 % HF) reagent. The morphology, size and distributions of eutectic Si and dendrite cell size, and dendrite arm spacing were evaluated using the STN 42 0491 standard and quantitative image analyser software NIS Elements [12].

The experimental tensile and hardness specimens for experimental procedures were made from the casting with turning and milling operations. Mechanical properties were measured according to the standards: STN EN 10002-1 and STN EN ISO 6506-1 [13-14]. Hardness measurement for secondary aluminium alloy was performed by a Brinell hardness tester with a load of 62,5 Kp (1Kp = 9,80665 N); 2,5 mm diameter ball and a dwell time of 15 s. The evaluated Brinell hardness reflects average values of at least six separate measurements. Tensile strength was measured on testing machine ZDM 30. The evaluated $R_m$ reflects average values of at least six separate bars.

## RESULTS AND DISCUSSION

The structure of hypoeutectic AlSi9Cu3 cast alloy consists of dendrites α-phase, eutectic (α-phase + eutectic silicon) and different intermetallic phases. The microstructure affected by different casting method is shown in Figure 2. The melt was not modified or grain refined, and so the eutectic Si particles are in a platelets form – the needles (Figure 2) on metallographic samples. The eutectic Si particles are thinner in samples cast into a metallic mould than the needles observed in the samples cast into a sand mould (Figure 2a,b; Table 3), which influences the mechanical properties.

The evaluation of eutectic silicon shape in both experimental materials shows that:

- according to standards, the two materials have eutectic silicon formed as needles (marking I) and the distribution is undirected;
- using NIS Elements software the shape factor (Table 3) confirmed that the shape is the same in both the experimental materials.

The best shape of eutectic silicon in aluminium materials is when shape factor is 1 (the perfectly rounded grain). When the shape factor approache 0, the shape is undesirable, because it takes needle form, and such morphology reduces the mechanical, fatigue, and other properties of aluminium alloy.

The quantitative assessment results show that the average area of eutectic Si particles in alloys cast into the sand mould is 97 $\mu m^2$, and 75 $\mu m^2$ in alloys cast into

a)

b)

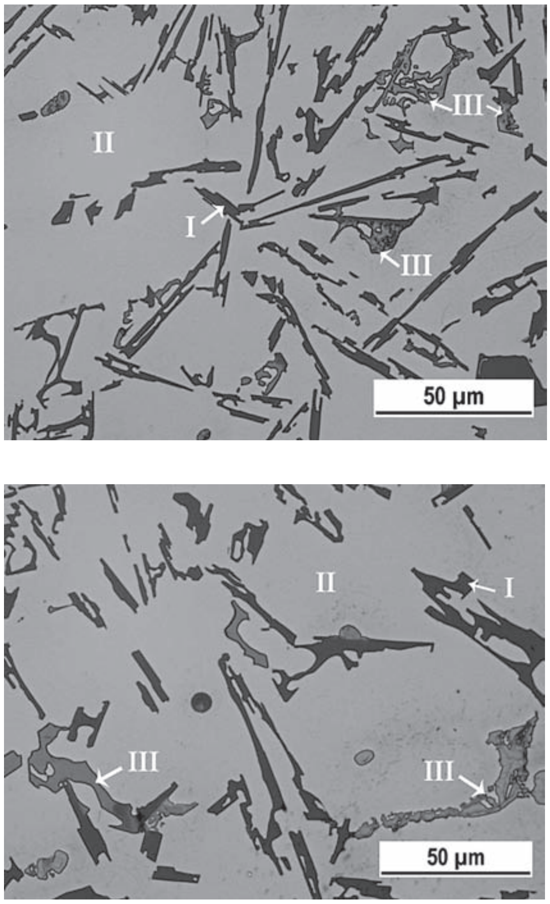


**Figure 2** Microstructure of AlSi9Cu3 a) material cast into metallic mould b) material cast into sand mould; etch Dix - Keller; I - eutectic Si; II - matrix, III - intermetallic phases.

the metallic mould (Table 3). The length and width are greater in the material cast into the sand mould, too (Table 3).

Table 3 **Evaluation of eutectic Si particles**

| Assessment of Si particles using NIS Elements | | |
|---|---|---|
| | Sand mould | Metallic mould |
| Average area / $mm^2$ | 97 | 75 |
| Length / mm | 38 | 35 |
| Width / mm | 2.6 | 2 |
| Shape factor | 0.39 | 0.35 |

The effect of the casting method on the matrix is shown in Figure 3. The fineness of dendrites in the material cast into the metallic mould is lower, compared to the material cast into the sand mould (Table 4).

For confirmation smallest dendrites in material casted into the metallic mould the evaluation of distance between secondary dendrite arms in both materials a)

b)

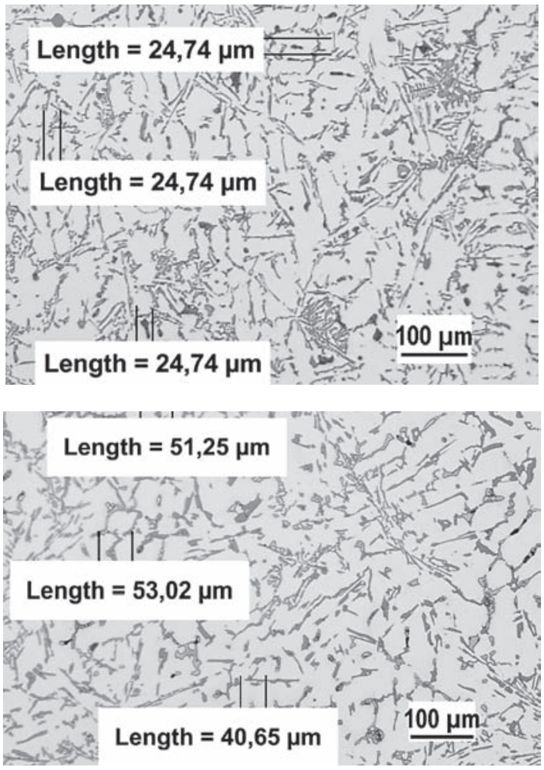


**Figure 3** The distance between secondary dendrites arms in AlSi9Cu3 a) cast into metallic mould b) cast into sand mould; etch. Dix - Keller

Table 4 **Evaluation of $\alpha$ phase = matrix**

| Evaluation of matrix | | Fineness of dendrite cell | Surface area of matrix |
|---|---|---|---|
| According to standards | Sand mould | T5 (34 - 51 mm) | D 75 |
| Metallic mould | | T6 (22 - 34 mm) | D 75 |
| Using NIS Elements | Sand mould | 40 mm | 75 % |
| | Metallic mould | 31 mm | 73 % |

were used (Figure 3). The evaluation using imaging analysis software NIS Elements confirmed this reality. The distance between secondary dendrite arms in the material cast into the metallic mould was 32 mm. The material cast into the sand mould had the distance between secondary dendrite arms of 40 mm. This fact confirmed that dendrite in the material cast into the metallic mould are smaller in comparison with dendrite in the material cast into the sand moulds. Evaluation using standards and image analysis software shows that surface area of the matrix in both materials is approximately the same (Table 4).

The mechanical properties of primary AlSi9Cu3 alloy according to standards are: tensile strength (240 ÷ 310 MPa), offset 0,2 % yield stress (140 ÷ 240 MPa), however the low ductility limits (0,5 ÷ 3 %) and hardness HBW 80 ÷ 120.

The microstructure (morphology of structural parameters) has a great influence on mechanical properties of Al-Si alloys. Alloy AlSi9Cu3 cast into the sand mould has expressively smaller values of HBW and $R_m$ than some alloys cast into the metallic mould (Figure 4). The tensile strength of materials cast into the sand mould was 143 MPa and of material cast into the metallic moulds 211 MPa (Figure 4). The material cast into the metallic mould has about 32 % higher tensile strength when, compare with the material cast into the sand mould. The Brinell hardness of materials cast into the sand mould was 73, and of material cast into the metallic moulds 98 (Figure 4). The material cast into the metallic mould has Brinell hardness higher by about 25 %, compared to the material cast into the sand mould.

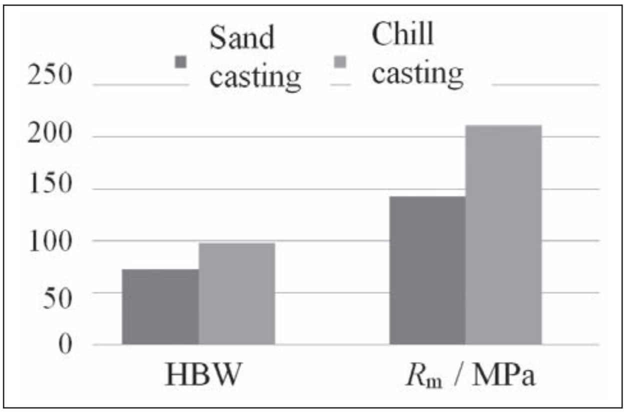


**Figure 4** Mechanical properties of the two experimental materials

## CONCLUSIONS

This work confirms that the different casting methods generate different size of evaluated structural parameters and different properties in aluminium silicon cast alloys.

- The morphology of eutectic silicon particles was the same (needles form) in both experimental materials. The shape factor was comparable.
- The size of eutectic silicon particles was different. The average area of Si particles was greater by 22,6 % in the samples cast into the sand mould, compared to the samples cast into the metallic mould. The length was greater by about 3 mm and the width by about 0.6 mm.
- The different casting methods caused changes in the matrix, too. The distance between secondary dendrite arms in the material cast into the metallic mould was 32 mm and 40 mm in the material cast into the sand mould, which is a distance greater by about 20 %. The fineness of dendrite in the material casted into the metallic mould was 31 mm and 40 mm in the material cast into the sand mould, which is dendrite thicker by about 20 %.
- The matrix surface area in the two experimental materials was comparable.
- The study shows that samples cast into the metallic mould have about 25 % higher hardness and 32 % higher strength tensile, compared to the material cast into the sand mould.

Considering the results it can be report that the material cast into the metallic mould must have better properties thanks to the better size and distribution of the evaluated structural parameters.

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Note: The responsible translator for the English language is Mgr. Jana Súkeníková, Žilina, Slovak Republic