ANALYSIS OF THE INFLUENCE OF SILUMINE CASTINGS MICROSTRUCTURE ON FAILURE RESISTANCE

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Abstract

The contribution deals with the relationship between the casting structure of AlSi9Cu3 alloy and its failure resistance. After the crash and fatigue tests the metallographic analysis of casting microstructure was performed. The objective of this work was to define causes of reduced resistance to mechanical damage that had occurred for several types of castings. Macro- and micro-porosity, metallographic structure and presence and distribution of particular phases were investigated. Micro-analysis of phase composition was carried out. All of samples showed pores and cavities. The distribution of these flaws was so much different, even in near sections of the same casting, that no significant correlation has been found. Based on the metallographic analysis it is possible to assume that the structure of mechanically more resistant castings is coarser grained with larger alpha-phase aluminum surfaces and features ferrum only in form of tiny edgy-shaped particles always accompanied by manganese. The structure of less resistant castings contains larger stellar-shaped particles of Al15(MnFe)3Si2 intermetallic phase, and more importantly, it has sharp, hard and brittle needles of Al5FeSi intermetallic phase, which dramatically deteriorate mechanical properties due to their notch effect. The creation of these particles is connected with solidification conditions.

Keywords: silumine, casting, failure resistance, structure analysis, metallography.

1. INTRODUCTION

The crash and fatigue tests were carried out for the several casting versions during the development of high mechanically loaded casting part. In some period of the component development after the reinforcement of the critical areas the lower mechanical properties of the structure turn up. Based on these results it was apparent that mechanical properties of the component are significantly influenced by manufacturing technology, firstly by solidification rate in the critical areas, gas trunk during the cooling and pressure conditions during the casting. These factors influence the macrostructure and microstructure of the material with strong impact to the mechanical and fatigue behaviour of the product. Therefore the objective of the paper is to find relationship between the microstructure and the failure resistance of the casting.

2. MATERIAL AND SPECIMEN DESCRIPTION

Six pieces of the casting were used for the metallographic analysis. Particular specimens were marked by number with respect the fact that number:
- 1 corresponds to the first version of component.
- 2 corresponds to the version with geometry extension of critical cross sections (and at the same time with the worst failure resistance) both with original technological process of the casting.
- 3 represents version with cross sections modification (a little bit smaller cross section compared with the second version) and with three different casting conditions (a, b, c).
- 4 represents final version of the component with the best mechanical properties.

Castings were made from hypoeutectic unmodified silumine EN AC-46000 (EN AC-Al Si9Cu3(Fe), ČSN 42 4339), that approximately corresponds to US material AA 380.0. Chemical composition of the alloy illustrates Table 1. This material is often used mainly in the automotive industry. The mechanical and fatigue properties of products made from this material depends not only on average chemical composition but also on macro and micro structure. The relevant parameters influencing the properties of the structure are:

- a) Porosity - cavities (bubbles, microshrinkage, gas pores).
- b) Type, size, number and shape of intermetallic phases.
- c) Structural parameters (dendrite cells size, morphology, etc.).

### Table 1. Typical chemical composition of Al Si9Cu3 alloy [ wt %].

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Ni</th>
<th>Zn</th>
<th>Pb</th>
<th>Sn</th>
<th>Ti</th>
<th>Others</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN AC-46000</td>
<td>8.0-11.0</td>
<td>1.3</td>
<td>2.0-4.0</td>
<td>0.55</td>
<td>0.55</td>
<td>0.15</td>
<td>0.55</td>
<td>1.2</td>
<td>0.35</td>
<td>0.25</td>
<td>0.05</td>
<td>0.25</td>
</tr>
</tbody>
</table>

The needle of eutectic silicon with typical branching, particles with iron and manganese in the shape of the star and “Chinese script”, particles with cuprum and single sharp needles of iron occur in alloy AlSi9Cu3 [1], [2], [3], [4] and [5].

### 3. EXPERIMENT

Samples were cut out by IsoCut4000 saw and prepared by standard metallographic procedures (grinded, polished with diamond suspensions and some of them etched by Dix-Keller or 0.5%HF). After it the microstructural details were analysed using optical microscopy (Olympus GX51, SZ40) with different magnifications up to 1000x. Also Nomarski DIC illumination technique was used. All samples were analysed with respect to the documentation of porosity.

Other samples (one from 1, 2 and 4 specimens) were prepared during the “New trends in metallographic” seminar organized by Faculty of Mechanical Engineering, Brno University of Technology.

The chemical composition of the intermetallic phases was determined by scanning electron microscopy equipped with EDAX. Mrs. Ing. Jandová carried out the microanalysis of two specimens during the above mentioned seminar. Based on this analysis the shape of different particles was identified. The content of intermetallic particles for samples 1 (first version), 2 (the worst mechanical behaviour) and 4 (final version with the best mechanical properties) was determined.
4. RESULTS AND DISCUSSION

4.1 Porosity

Porosity was documented on all cutting surfaces of specimens. Fig. 1 illustrates the typical macrographs corresponding to specimen 2 (the worst mechanical behaviour) and specimen 4 (the best failure resistance). Fig. 2 shows the largest and typical cavity on micrographs.

![Fig. 1. Typical macrographs of specimen 2 (top) with 5 mm cavity and specimen 4 (bottom).](image)

The cavity and pores were detected in all specimens. The considerable inhomogeneity from point of view of bubbles, shrinkages and pores distribution was documented in the different sections of castings. Even if the several cutting surfaces were cut out from the same casting very close each other (distance between each of them was from 4 to 8 mm) the porosity there is very different. The maximum size of the cavity is about 5 mm (see Fig. 1 - top left). Such big and deep bubble was found in one cutting surface of specimen 2 only. In the other cuts of this specimen the cavities had not been bigger then in the other castings. Next highest sum of length cavity (see Fig. 2 - bottom) was found in one of metallographic sample of specimen 4 (the best failure resistance). This cavity seems to be more like shrinkage and it is very shallow. Smaller and shallow combination of bubbles and shrinkages or tiny pores was detected only. This is a reason why we were not successful to find any significant relation between the biggest cavity shape and failure resistance. We can
consider the big and deep bubble as dangerous from point of view of failure resistance.

Fig. 2. Micrographs of typical cavities corresponding to metallographic sample of specimen 2 (top), specimen 4 - with shallow cavity and its revolved part (total length of these cavities is 5 mm)(middle), specimen 3a - small pores in the left bottom and specimen 3c – cavities and porosity in the right bottom (magnification 50x, without etching).
4.2 Material microstructure

Microstructure of the castings 1, 2 and 4 which were analyzed more in detail by optical methods was found to be not much different. Material with the best mechanical properties (specimen 4) has a little coarser grained structure in general, with larger areas of dendrite alpha phase of aluminium. In this structure there are no big star shaped particles but edgy shaped and smaller ones only. **Fig. 3** shows the microstructure comparison of castings 1 and 4.

![Fig. 3. Microstructure comparison of castings 1 and 4. Structures of casting 1 with a big star shaped particles (left), structures of casting 4 with tiny particles (right). (Magnification 500x, Nomarski DIC illumination)](image)

4.3 Material microanalysis

Microanalysis had been performed on the metallographic samples of castings 1 and 4. The micrographs of structure acquired from electron microscope with marks on analyzed points are in **Fig. 4** and **Fig. 5**.

![Fig. 4. Micrograph of casting 1 structure.](image)

Sample made from specimen 1 (**Fig. 4**): In the big star shaped particle (spot 1) was detected presence of iron, manganese and smaller amount of chrome. It is
possible to consider these particles as the brittle and hard intermetallic phase \( \text{Al}_{15}(\text{MnFe})_3\text{Si}_2 \) as can be found in the literature.

Iron and manganese presence was detected also in the tiny edgy shaped particle – spot 6 and in the particle marked 7.

Particle 3 and white margins around particle 1 (spot 2) and part of needle 4 shows high percentage of copper with Mg and Ni traces. In the similar way it is in spot 8.

Needle 5 contains Fe with very low percentage of Mn, which corresponds with very hard and brittle phase \( \text{Al}_5\text{FeSi} \). Even its shape effects in very negative way.

Very similar composition was determined in spot 9.

Tiny bright point 10 is Pb-rich particle.

Hardly detectable needle 11 is Si-rich. This is needle of eutectic silicon.

Sample made from specimen 4 (see Fig. 5): Microanalysis shows that edgy, approximately hexagonally shaped particles contain Al, Si, Fe, Mn and Cr.

In the needles (spot 3) and neighbouring areas (spot 2) there is high content of Si.

### 4.4 Intermetallic phase analysis

Comparison of intermetallic phase occurrences was performed on the base of former analyses by comparison of micrographs with 1000x magnification. Fig. 6 and Fig. 8 document the presence of single particles which are in the microstructure. In Fig. 6 and Fig. 8 which were acquired using different techniques for scratch pattern we can find particles containing Fe, or Fe and Mn as plastically emerging differently from Fig. 7 where single particles are detectable, but without the 3D topography. Cu features by significant perforation, eutectic Si differs by colour only.

In the individual pictures there are marked:

- Particles A – intermetallic phase \( \text{Al}_{15}(\text{MnFe})_3\text{Si}_2 \).
- Needles and facets B – eutectic silicon.
- Particles C – Cu presence.
- Needles D – Fe needle of phase \( \text{Al}_5\text{FeSi} \).

Comparisons of presence and morphology of phases in the samples made from casting 1, 2 and 4 lead to the following conclusions:

In the more failure resistance structures there are only smaller edgy shaped particles containing iron and manganese. No iron-rich needles of phase \( \text{Al}_5\text{FeSi} \) are present in these structures.
Fig. 6. Image of phases in the metallographic sample of specimen 1.  
(Magnification 1000x, Nomarski DIC illumination)

Fig. 7. Image of phases in the metallographic sample of specimen 2.  
(Magnification 1000x, Nomarski DIC illumination, etching with 0.5 % HF)

Fig. 8. Image of phases in the metallographic sample of specimen 4.  
(Magnification 1000x, Nomarski DIC illumination)
5. CONCLUSIONS

Microstructure of higher failure resistance castings is a little coarser grained with larger areas of Al\(\alpha\)-phase. In castings like this iron is present in smaller particles only and always with manganese together. No sharp, hard and brittle needles of ferrous phase Al\(_5\)FeSi occurs. These particles would have a negative notch effect which significantly degradation of the mechanical properties of material. Occurrence of these particles is probably the main reason of castings failure resistance decreasing. Other cause of mechanical properties degradation can be the presence of cavities. The big deep bubbles seem to be peril for material behaviour; shallow shrinkages have probably no influence to the failure resistance.

Acknowledgement

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LITERATURE