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The Influence of Material of Mould and Modification on the Structure of Alsi11 Alloy

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Abstract

The presented work discusses the influence of material of foundry mould on the effect of modification of AlSi11 alloy. For this purpose castings were produced in moulds made of four various materials. Castings of the first type were cast in a metal die, the second ones in the conventional mould of bentonite-bound sand, those of the third type in the sand mould with oil binder, the last ones in a shell mould where phenol-formaldehyde resin was applied as a binder. All the castings were made of AlSi11 alloy modified with strontium. For a purpose of comparison also castings made of the non-modified alloy were produced. The castings were examined with regard to their microstructures. The performed investigations point out that the addition of strontium master alloy results in refining of the alloy structure, particularly of the α-phase, causes some morphological changes in the alloy and the refinement of eutectics. The advantageous influence of modifier on the structure of the examined silumin was observed particularly in the case of alloy cast either in the conventional oil-bound sand mould or in the shell mould. The non-modified alloy cast into a metal die exhibits a structure similar to those of modified alloy solidifying in the other moulds. The improvement in both tensile strength and unit elongation suggests that the modification was carried out correctly. The best mechanical properties were found for the alloy cast in a metal die, both with and without modification treatment.

Keywords: Metallography, Aluminium alloys, Modification, Structure, Foundry mould

1. Introduction

Aluminium cast alloys, the so-called silumins, are one of the most commonly used non-ferrous cast alloys, mostly due to their excellent casting properties and very good functional properties. Thanks to these advantageous features they became highly appreciated structural materials for various industrial applications. They are applied mostly in engineering, shipbuilding, and power industry [1-4]. The structure of silumins, depending on the silicon content and the cooling properties, can consist of the mixture of solid solution grains (α), silicon crystals (β), aluminium-silicon eutectics, and precipitates of intermetallic compound phases. The properties of the resulting castings are influenced by many factors, including the size and the shape of silicon crystals arising during solidification. The size and the shape of precipitating silicon crystals can in turn be affected by performing modification of silumins. Such modification is aimed to increase the density of grain arrangement i.e. the nucleation power of metal, which directly influences the cooling and the solidifying processes occurring in a casting. This modifying treatment consists in introducing small amounts of particular additions, the so-called modifiers, into molten alloys. They change the course of crystallization and eventually the structure and properties of castings without changing chemical composition of the alloy [5-9].

The modifying effect of strontium on the structure of eutectic and hypoeutectic silumins is known from 1921. However the problem of modification with strontium was solved on industrial scale in Switzerland only in early seventies of

XX century. The additions occurring in alloys can either improve or deteriorate casting properties of the material, e.g. the castability of aluminium alloys can be decreased by the presence of small amounts of iron, silicon, or titanium, while the elements constituting the easy-to-melt eutectics enhance this property in all alloys [10, 11]. The conventional modification method employing sodium causes many technological problems in foundries, and besides, sodium exhibits only a limited influence as a nodulizer because it evaporates at the melting point of silumins. The problem was eliminated by use of either strontium or antimony as a nodulizer. Strontium is classified as the so-called modifier of prolonged action (or permanent modifier), because its effects of modification last for several hours as opposed to those caused by sodium [12]. The addition of strontium causes the development of the highly refined structure of silumin, while antimony addition gives the refined lamellar eutectic structure. Furthermore, strontium causes a reduction in interfacial tension which leads to the decrease of the critical radius of the newly created crystallization nuclei. Strontium, as well as sodium, can be used as a modifier for silumins cast in sand moulds and dies, the latter being either gravity poured or filled under low pressure. For a long time the authors of scientific reports have been disputing the quantity of strontium necessary to perform the modifying treatment correctly [12,13]. They, however, agree that the strontium content needed for modification depends on the silicon percentage in the alloy, on the quantity of impurities, most of all of phosphor, and on the cooling rate of a casting in the mould.

2. Methodology and the results of examination

The non-modified AlSi11 alloy and the same alloy modified with strontium were used for examination. The AlSr10 strontium master alloy was added in the quantity of 0.1%. The molten alloy, both modified and non-modified, was poured into:

- die,
- mould made of conventional moulding material with bentonite binder
- mould made of conventional moulding material with oil binder (OBB SAND E)
- shell mould bound with phenol-formaldehyde resin and hardened with urotropine.

All moulds cavities were cylindrical, with a diameter of 10 mm and a length of 150 mm. First the castings of the non-modified alloy were produced. Then after melting the next portion of metal, the modifier in the form of AlSr10 master alloy was added into the ladle. The temperature of melt did not need to be significantly risen, taking into account the characteristics of AlSr10 master alloy dissolution for surface introduction of the modifier. To make proper use of the modifier and in order to get it thoroughly melted, it was introduced into the molten metal at the temperature of 650°C. The alloy modified with strontium master alloy was also cast into four moulds made of the materials specified above with cavities of the aforementioned dimensions. Samples were cut out of the produced castings in order to prepare metallographic microsections. All the microsections were etched with HF etchant and then subjected to metallographic examination.

The typical structure of the non-modified AlSi11 alloy consists of the bright matrix, which is constituted by solid solution of silicon in aluminium, with visible needle-like eutectic (the α and the β phases) and characteristic longitudinal precipitates of primary silicon. The following figures present the microstructures of AK11 alloy (either modified or not) cast into moulds made of various materials (Figs 1-8, magn.200x).

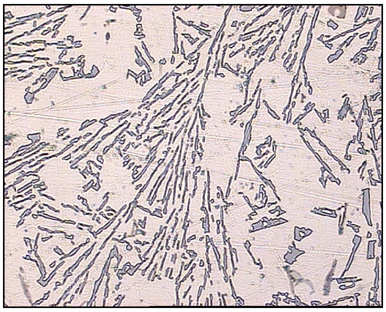

Fig. 1. Structures of AlSi11 alloy without modification (conventional moulding material with bentonite binder)

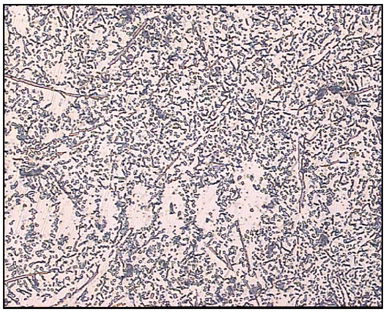

Fig. 2. Structures of AlSi11 alloy with modification (conventional moulding material with bentonite binder)

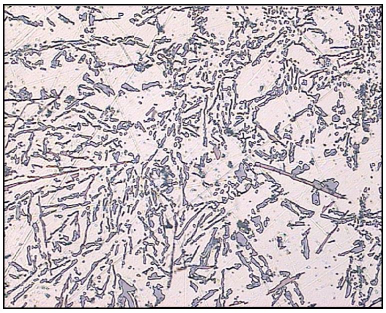

Fig. 3. Structures of AlSi11 alloy without modification (conventional moulding material with oil binder)

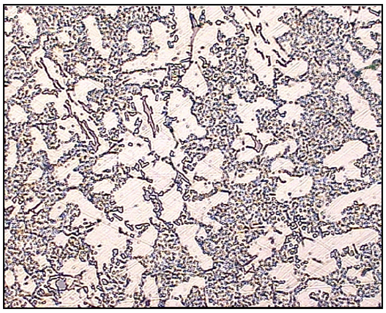

Fig. 4. Structures of AlSi11 alloy with modification (conventional moulding material with oil binder)

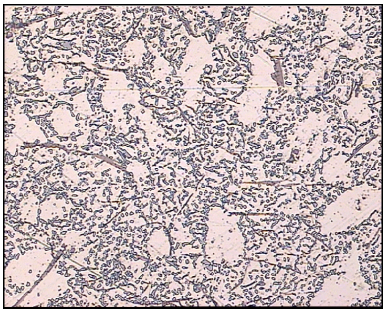

Fig. 5. Structures of AlSi11 alloy without modification (die)

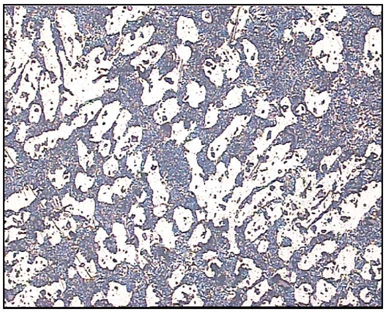

Fig. 6. Structures of AlSi11 alloy with modification (die)

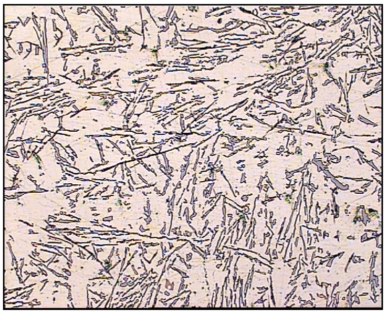

Fig. 7. Structures of AlSi11 alloy without modification (mould bound with phenol-formaldehyde resin)

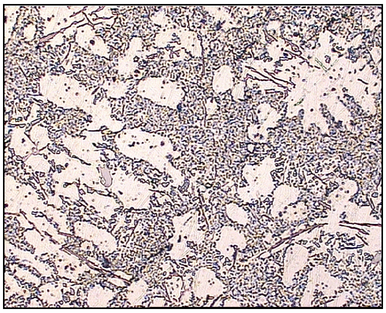

Fig. 8. Structures of AlSi11 alloy with modification (mould bound with phenol-formaldehyde resin and hardened with urotropine)

In order to assess the effects of modification, the tensile strength R_m and unit elongation A_5 were also examined for the non-modified and modified castings. All measurements were taken during the tensile strength test according to the PN-EN 10002-1:2004 Standard carried out by the ZWICK-1488 testing machine. Three readings have been taken for each type of casting. The average values are presented in Table 1

Table 1.
R_m and A_5 – average results for specimens cast in various types of moulds

Mould	Without modification		With modification	
	R_m [MPa]	A_5 [%]	R_m [MPa]	A_5 [%]
Conventional moulding material with bentonite binder	153	3,5	186	6,5
Conventional moulding material with oil binder	162	4,2	192	7,4
Die	175	5,2	201	12
Mould bound with phenol-formaldehyde resin	160	3,8	188	6,5

Fig. 9 presents the results of tensile strength tests for the modified and the non-modified alloy cast in moulds made of various materials, while Fig. 10 shows the examination results concerning unit elongation of the materials under consideration.

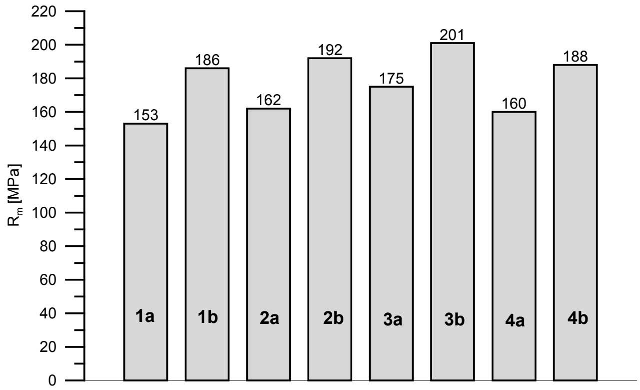

Fig. 9. Tensile strength of (a) the non-modified and (b) the modified AlSi11 alloy cast in: 1) a conventional bentonite-bound mould, 2) an oil-bound sand mould, 3) a die, 4) a shell mould (phenol-formaldehyde resin binder)

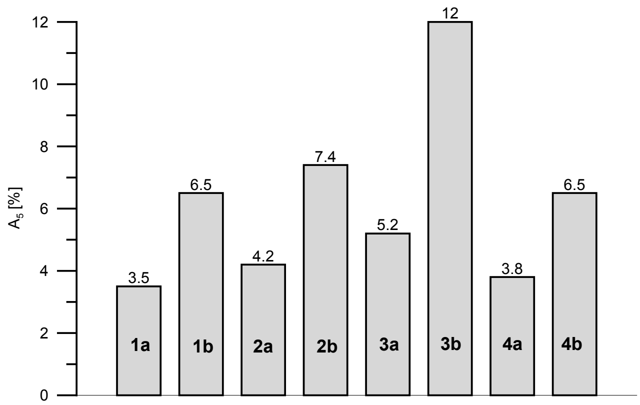

Fig. 10. Unit elongation of (a) the non-modified and (b) the modified AlSi11 alloy cast in: 1) a conventional bentonite-bound mould, 2) an oil-bound sand mould, 3) a die, 4) a shell mould (phenol-formaldehyde resin binder)

3. Conclusions

After the performed tests it should be stated that the addition of strontium master alloy to the AlSi11 silumin yields the refining of the alloy structure, particularly of the α-phase, causes the change in morphology and the refining of eutectics for each considered case. The refinement of eutectic structure obtained by modification resulted in an increase in tensile strength for each of the examined castings, no matter which moulding material was used. Further, there was observed an enhancement in plastic properties due to the presence of the refined α-phase. Also the change in silicon precipitates morphology contributes to the improvement of the examined alloy properties. Silicon crystals in the non-modified alloy occur in the shape of coarse needles placed between the α-phase dendrite arms, while after modification silicon is refined, and even changes its shape from needle-like to globular precipitates. The results of examination show that both the modifier percentage equal to 0.1% and the temperature of alloy modification were sufficient. Despite the slight variations in structure of the modified alloys, an increase in tensile strength was obtained for all the considered cases, namely by 33 MPa for castings produced in the conventional mould, by 30 MPa for the ones coming from the oil-bound mould, by 26 MPa for the castings from the metal die, and by 28 MPa for the castings made in the shell mould. The subsequent examined factor was the unit elongation, which was also increased for all considered cases after modification. An increase by 86% occurred for the castings produced in the conventional mould, by 76% for the ones coming from the oil-bound mould, by 130% for the castings from the metal die, and by 72% for the castings made in the shell mould. These results point out that a change in the rate of cooling attributable to the difference in moulding materials influences plastic properties of the AKlSi11 alloy to the greater degree than it affects its tensile strength.

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