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EFFECT OF ENVIRONMENT-FRIENDLY MODIFICATION OF Al-12%Si ALLOY ON ITS STRUCTURE

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K e y w o r d s: al alloys, silumin, crystallization, modification, structure.

A b s t r a c t

The paper presents the results of a study on the modification of Al-12%Si alloy with a homogeneous modifier produced by fast cooling at a rate of 100 and 200 K/s. The homogeneous modifier had the chemical composition of the modified alloy, and it contained 0, 7, 12 and 20% Si. The modifier was mixed with liquid Al-Si alloy in the crucible for one minute. The effect of cooling rate and the modifier content of alloy mass on alloy structure was determined in the study. An analysis of the modification of eutectic Al-Si alloy with a homogeneous modifier obtained by fast cooling of the treated alloy showed that the modifier affected the structure of Al-12%Si alloy.

EKOLOGICZNA MODYFIKACJA STOPU Al-12%Si A JEGO STRUKTURA

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S ł o w a k l u c z o w e: stopy Al, krystalizacja, modyfikacja, struktura.

A b s t r a k t

W pracy przedstawiono wyniki badań nad modyfikacją stopu Al-12%Si modyfikatorem homogenicznym, wytworzonym przez szybkie studzenie modyfikatora z prędkością 100 i 200 K/s. Modyfikator homogeniczny ma skład chemiczny stopu modyfikowanego i zawiera 0, 7, 12 i 20% Si. Modyfikator dodawano do tygla wraz z ciekłym stopem Al-Si i przetrzymywano przez jedną minutę. W pracy przedstawiono wpływ prędkości studzenia i zawartości modyfikatora w odniesieniu do masy obrabianego stopu na jego strukturę. Analiza procesu modyfikacji eutektycznego stopu Al-Si modyfikatorem homogenicznym otrzymanym z obrabianego stopu przez szybkie studzenie wykazała oddziaływanie modyfikujące na strukturę stopu Al-12%Si.

Introduction

Among the numerous characteristics that allow to differentiate between particular types of aluminum casting alloys, the most significant role is played by their mechanical properties (hardness, tensile strength, elongation), physical properties (specific gravity, electrical conductivity, thermal conductivity) and chemical properties (resistance to corrosion). In most cases, construction materials are selected so as to attain the optimal technological properties at the lowest possible weight and cost. These criteria are often met by silumin – a series of popular alloys of non-ferrous metals. Studies on the improvement of the properties of casting alloys have been continuously conducted over the recent years. Both the microstructure and properties of alloys may be altered via modification with chemical components, optimization of the crystallization process, heat treatment or a combination of these methods (ATASOY 1984, BORKOWSKI 1999, NOVA 2004, SZAJNAR 2008).

The initial structure of Al-12%Si alloy is composed of granular and acicular β phase, with α phase as matrix. The hard, irregular, often pointed β phase is responsible for the poor mechanical properties of said alloy. Therefore, the analyzed alloy can be used for practical purposes following the disintegration of its structure, in particular of the eutectic β phase.

One of the methods applied to enhance the properties of AlSi alloys is chemical modification. Particular chemical elements exert different types of influence on the structure of alloys and the related mechanical properties. Silumin modified with sodium has desirable mechanical properties and can be used for casting in different branches of industry, but certain problems are encountered during alloy recycling. Chemical elements (modifiers) added to the mixture at the stage of alloy production may enter into interactions, thus limiting the recycling capacity of alloy, even if they occur in small amounts (KRUPIŃSKI 2008, LIPIŃSKI 2000, 2008, LJUTOVA 2008, OLEJNIK 2007, PEZDA 2007, PTACEK 1999, ROMANKIEWICZ 2006, VALENCIK 2008, WOŁCZYŃSKI 1980, 1990, ZYSKA 2007).

While searching for alternative methods of improving the engineering properties of Al-12%Si alloy, an attempt was made to modify its structure with the use of a constituent with the chemical composition of the treated alloy. The tested homogenous modifier (with the chemical composition of the treated alloy, obtained by fast cooling) was expected to have a significant effect on the modification process, resulting in changes in the microstructure of eutectic silumin.

Aim of the study, methods and results

The objective of the present study was to determine whether eutectic alloy Al-12%Si can be modified by means of Al-12%Si alloy cooled at various rates, used as a modifier.

Homogenous modifiers are additions designed for modification of the same alloys from which they were obtained. To obtain a homogenous modifier, Al-12%Si alloy was melted and then cooled on a metal plate at three different rates, i.e. v_1 = 100 K/s, and v_2 = 200 K/s. This enabled to produce three different components (cooled at v_1, and v_2), which were refined immediately before adding to the alloy. The components were put into a crucible containing liquid Al-12%Si alloy, and kept there for one minute. The alloy temperature was 750°C. The modifier content of the alloy is given as weight in weight concentration (mass fraction). For comparative purposes, two castings were produced (without additions), at the beginning and at the end of the study.

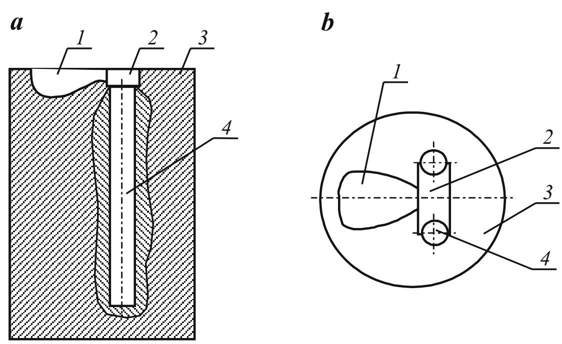

Fig. 1. Mould sections *a*) section, *b*) top view of the casting mold: *1* – reservoir, *2* – cross-gate, *3* – mold, *4* – sample for strength testing

Two samples, 16x140 mm, were obtained in each experiment. A 10 mm strip was cut off at the bottom of each sample. The face of cut served as metallographic specimen for microstructure analysis. Samples for mechanical tests were obtained from the upper part of the casting. A structural analysis was performed using an OLYMPUS IX70 microscope (magnification 2.5-1000x), and OLYMPUS DP-SOFT and MultiScan software. Samples for metallographic tests were taken from the lower part of the samples designed for mechanical tests. Hardness tests were performed on the upper parts of strength test samples (six measurements per sample). Prior to measurements, side surfaces of samples, 5 mm wide, were grinded. All measurements were carried out according to the standard EN 10003-1 Metallic materials-Brinell test-Part1: Test method, using a Brinell/Vickers hardness tester, model HPO-250, with a standard ball, 2.5 mm in diameter, at a load of 612.9 N. A tensile strength test was performed according to the Polish Standard PN-EN 10002-1+AC1: 1998 Metals-Tensile test-Test method, at ambient temperature, using a universal strength testing machine (W.P.M. Germany), determining tensile strength R_m and percentage elongation A.

Results and Discussion

An analysis of the structural composition of Al-12%Si alloy treated with Al-12%Si modifier cooled at different rates revealed that cooling at v_1 = 100 K/s resulted, within the analyzed range, in a gradual improvement in the structure and mechanical properties of the alloy along with an increase in the content of the above modifier. Alloy treatment with Al-12%Si modifier cooled at v_2 = 200 K/s allowed to improve alloy structure within a relatively short period of time. A noticeable effect was reported following the addition of 0.2% modifier, but an increase in the amount of this constituent to 0.8% caused no considerable changes. An approximately 0.8% content of the modifier in the mixture resulted in reduced eutectic dispersion and worsened the mechanical properties of alloy, which are directly related to its structural composition. The modifier produced at a cooling rate of v_2 = 200 K/s was found to have the most beneficial influence. An increase in its content did not cause rapid changes in the mechanical properties of alloy, which remained at an optimal level following the addition of said modifier. Of particular note is also the high activity of this constituent.

Figure 2 presents the structure of Al-12%Si alloy cast without prior treatment with alloying constituents, while Figure 3 shows the structure of this alloy after such treatment. The microstructure of Al-12%Si alloy not treated with alloy-forming elements comprises primary silicon crystals dispersed in a solid solution of silicon in aluminum – α and a solid solution of aluminum in silicon – β as a eutectic mixture ($\alpha + \beta$) – Figure 2. The eutectic is composed of irregular-shaped grains of β phase. As a result, the mechanical properties of the alloy are relatively poor.

Alloy treatment with a constituent produced from Al-12%Si alloy by cooling at v_1 = 100 K/s contributed to the refinement of alloy structure, proportional

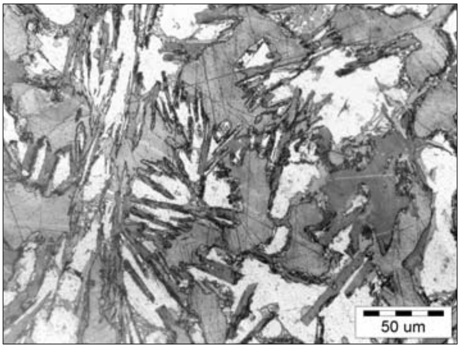

Fig. 2. Microstructure of Al-12%Si alloy cast without prior treatment with alloying constituents

to the increasing content of the modifier in the mixture. Following the addition of 02% modifier to Al-12%Si alloy, primary silicon crystals became oval and regular (Fig. 3), and they gradually passed into the eutectic mixture whose proportion is much higher in modified alloys than in non-modified ones.

After the treatment of Al-12%Si alloy with 0.4% modifier cooled at v_1 = 100 K/s, silicon crystals became much smaller and the formation of acicular structure began (Fig. 4). Visible are grains of α phase surrounded by acicular eutectic. Changes in the structural composition of alloy are reflected in changes in its mechanical properties, primarily in tensile strength (ATASOY 1984).

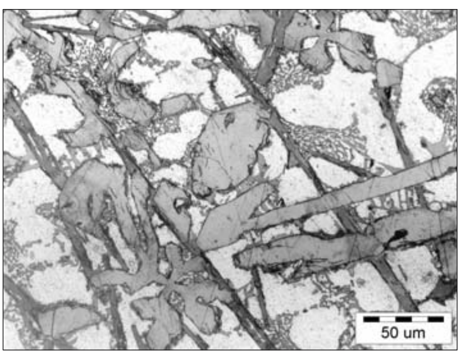

Fig. 3. Effect of 0.2% homogenous modifier produced at a cooling rate of v_1 = 100 K/s on the microstructure of Al-12%Si alloy

Further modification was observed as the amount of modifier was increased to 0.6% (Fig. 5). Branched crystals of AlSiFeMn phase became visible. The grain size of β phase decreased, and silicon crystals passed into the eutectic mixture. The structure comprised typical acicular eutectic (α +β) and small amounts of fine grains of β phase.

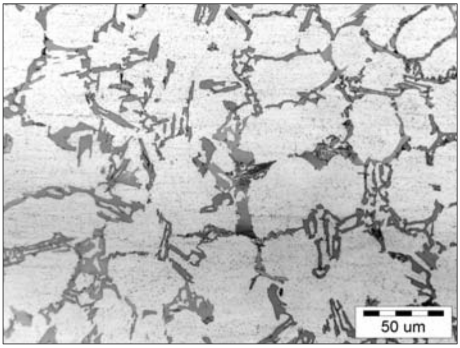

Fig. 4. Effect of 0.4% homogenous modifier produced at a cooling rate of v_1 = 100 K/s on the microstructure of Al-12%Si alloy

The treatment of Al-12%Si alloy with 0.8% modifier resulted in further refinement of the structure (Fig. 6). Visible are primary dendritic crystals of α phase, irregular eutectic cells in the inter-dendrite spaces and the branching of β phase. An improvement was noted in the mechanical properties of alloy, including an increase in percentage elongation. Primary silicon crystals disappeared as Al-12%Si alloy was modified with 1.0% homogeneous modifier cooled at v_1 = 100 K/s. Structure refinement was observed (Fig. 7), and eutectic cells became regular in shape.

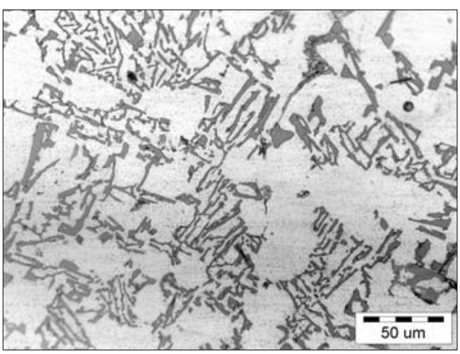

Fig. 5. Effect of 0.6% homogenous modifier produced at a cooling rate of v_1 = 100 K/s on the microstructure of Al-12%Si alloy

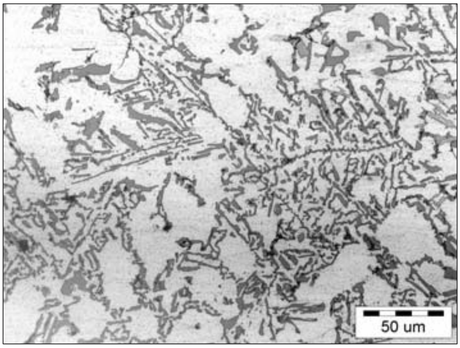

Fig. 6. Effect of 0.8% homogenous modifier produced at a cooling rate of v_1 = 100 K/s on the microstructure of Al-12%Si alloy

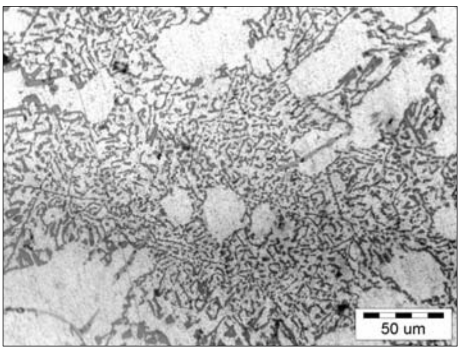

Fig. 7. Effect of 1.0% homogenous modifier produced at a cooling rate of v_1 = 100 K/s on the microstructure of Al-12%Si alloy

As the amount of modifier was increased to 0.4%, fine, regular-shaped eutectic ($\alpha + \beta$) cells could be observed in the inter-dendrite spaces of α phase (Fig. 8). This was supposed to greatly improve the mechanical properties of alloy (ATASOY 1984).

Alloy treatment with a constituent produced from Al-12%Si alloy by cooling at v_2 = 200 K/s permits structure refinement, proportional to the modifier content of the mixture. As illustrated in Figure 9, the treatment of Al-12%Si alloy with 0.2% modifier resulted in almost complete disappearance of grains of primary β phase. Visible is the branching of β phase.

An increase in the amount of homogeneous modifier to 0.6% resulted in the size reduction of eutectic cells, but larger precipitates of β phase were also noted (Fig. 10).

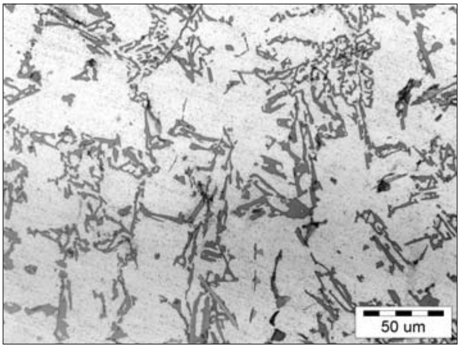

Fig. 8. Effect of 0.4% homogenous modifier produced at a cooling rate of v_2 = 200 K/s on the microstructure of Al-12%Si alloy

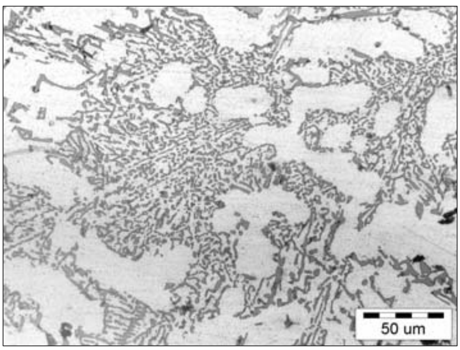

Fig. 9. Effect of 0.2% homogenous modifier produced at a cooling rate of v_2 = 200 K/s on the microstructure of Al-12%Si alloy

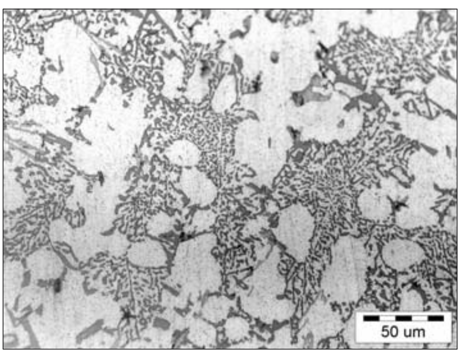

Fig. 10. Effect of 0.6% homogenous modifier produced at a cooling rate of v_2 = 200 K/s on the microstructure of Al-12%Si alloy

After the treatment of Al-12%Si alloy with 0.8% modifier, the primary α phase expanded and the dispersion of eutectic ($\alpha + \beta$) decreased (Fig. 11). The treatment of Al-12%Si silumin with 1.0% homogeneous modifier caused a further increase in the size of eutectic cells, particularly of β phase (Fig. 12).

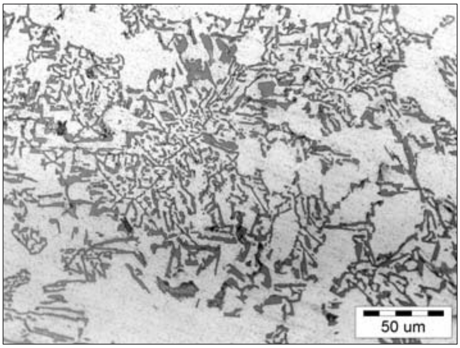

Fig. 11. Effect of 0.8% homogenous modifier produced at a cooling rate of v_2 = 200 K/s on the microstructure of Al-12%Si alloy

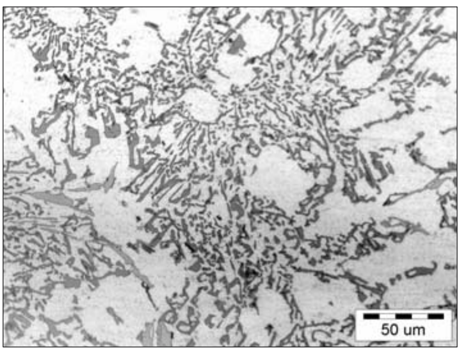

Fig. 12. Effect of 1.0% homogenous modifier produced at a cooling rate of v_2 = 200 K/s on the microstructure of Al-12%Si alloy

Conclusions

An analysis of the microstructure of hypereutectic and hypoeutectic silumin treated with a homogeneous modifier revealed lamellar structure. Interplanar distances were constant and comparable for all variants of treatment, which is indicative of stationary crystallization.

The effect of the grain size of homogeneous modifiers produced at various cooling rates on the modification process is analogous to the effect of the critical nucleus size on homogeneous nucleation.

A faster rate of cooling of homogeneous modifiers results in a shift in temperature and character of crystallization in accordance with the distribution of the cooperative growth zone. Structure dispersion also increases proportionally to cooling rate. An increase in the cooling rate of homogeneous modifiers is followed by a decrease in Si content and structure refinement of Al-Si alloys. Thus, the properties of such modifiers are determined by cooling rate.

The modification of hypereutectic and hypoeutectic silumin with a homogeneous modifier enabled to obtain an alloy with a desirable structure comprising fine eutectic cells ($\alpha + \beta$) and α phase dendrites. Fibrous eutectic was not observed in any of the analyzed cases, but its character may be indicative of a low temperature gradient.

The introduction of modifiers, in the form of chemical elements and compounds, to alloys may lead to certain problems with recycling (according to literature data, some of the constituents exert antagonistic effects). Therefore, environment-friendly modification may be a viable alternative for products whose physical and mechanical properties do not deteriorate during this process.

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