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MODIFICATION OF THE Al-Si ALLOYS WITH THE USE OF A HOMOGENOUS MODIFIERS

MODYFIKACJA STOPÓW Al-Si MODYFIKATOREM HOMOGENICZNYM

A homogenous modifier obtained by the rapid solidification at a cooling rate equal to v = 200 K/s was applied to the modification of the Al-12Si alloy. The different modifiers were obtained by means of the Al-Si alloys containing 0, 7, 12 and 20 at. % Si, respectively. The components Al, Al-7Si, Al-12Si, Al-20Si were put into crucible containing the liquid Al-12Si alloy and kept for one minute to obtain a new homogenous alloy which after break-up was homogenous modifier. Both, effect of cooling rate applied to obtain modifier and weight in weight modifier concentration in the melt on tensile strength, hardness, abrasive wear and structure of Al-12Si alloy are determined. A structural, physical and mechanical properties resulting from the Al-12Si alloy treatment by modifiers are studied in details.
Keywords: Al alloys, modification, silumin, solidification

W pracy przedstawiono wyniki badań nad modyfikacją stopu Al-12Si modyfikatorem homogenicznym, wytworzonym przez szybkie studzenie modyfikatora z prędkością 200°C/s. Modyfikator homogeniczny posiada skład chemiczny modyfikowanego stopu i zawiera 0, 7, 12 i 20% Si. Modyfikator dodawano do tygla wraz z ciekłym stopem Al-Si i przetrzymywano przez jedną minutę. Wpływ prędkości studzenia i zawartości modyfikatora w odniesieniu do masy obrabianego stopu na wytrzymałość na rozciąganie, wydłużenie procentowe, twardość oraz zużycie ścierne przedstawiono w formie graficznej. Analiza procesu modyfikacji eutektycznego stopu Al-Si modyfikatorem homogenicznym otrzymanym z obrabianego stopu przez szybkie studzenie wykazała oddziaływanie modyfikujące na strukturę oraz właściwości fizyczne i mechaniczne stopu Al-12Si.

1. Introduction

Studies on improving the physicochemical properties of eutectic and hypoeutectic aluminum-silicon alloys conducted so far have focused primarily on the interactions of chemical elements and compounds applied as modifying agents. During modification small quantities of modifiers are added to liquid alloy, which affects the crystallization process. Modifying elements do not cause significant changes in the chemical composition of alloys, but produce certain structural effects, such as grain (dendrite) refinement or considerable reduction in inter-phase spacing within eutectic grains. Particular elements introduced into the alloy may radically change its structure and properties. It follows that the range of applications of such an alloy may be also altered, since it depends upon the kind, size, shape and percentage of a given phase in the alloy structure.

The results of modification of eutectic and hypoeutectic aluminum-silicon alloys by sodium, strontium, antimony and other additions in the metallurgic process have been already analyzed and described by numerous authors [1, 2, 4] and directional solidification [3, 5]. However, literature on the topic provides scant information on silumin modification with modifiers obtained from the treated alloy by fast cooling. This problem is discussed in the present study.

2. Aim of the study and methods

The objective of the present study was to determine whether eutectic alloy Al-12Si can be modified by means of Al-Si alloy obtained by the rapid solidification, 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-Si alloy was melted and then cooled on a metal plate at rate 200 K/s. This enabled to produce component, which

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were refined immediately before adding to the alloy. The components were put into a crucible containing liquid Al-12Si 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. Hand molding was carried out. Figure 1 presents section of the casting mold.

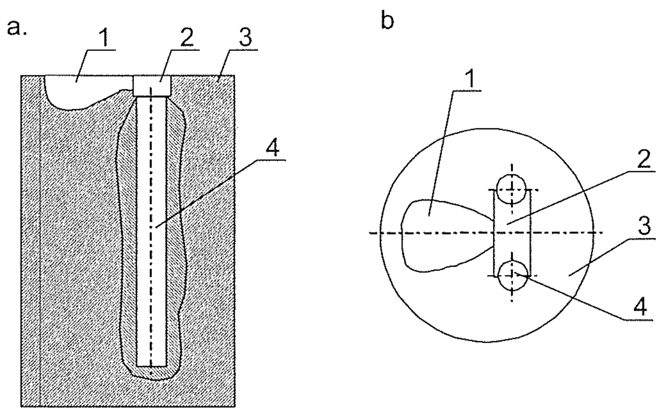

Fig. 1. a. section, b. top view of the casting mold: 1 – reservoir, 2 – cross-gate, 3 – mold, 4 – sample for strength tensile test

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. 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-Part 1: 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 Metallic materials-Tensile testing – Part 1: method of test (at ambient temperature), using a universal strength testing machine, determining tensile strength R_m and percentage elongation A.

Abrasive wear tested using Schopper machine by corundum abrasive disk at grainy 400 for parameters:

- abrasive disk diametr $\phi = 0.158$ m
- abrasive disk revolutions n = 14.1 r.p.m.
- sample revolutions n = 0 r.p.m.
- holding down F = 200 N
- unit pressure for area of samples N = 3.9 MPa
- working distance l = 400 m
- running speed v = 0.12 m.p.s.

3. Results

The structure of Al-12Si alloy cast without treatment with alloying elements is presented in Figure 2.

The microstructure of Al-12Si alloy prepared without additives 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 phase β. As a result, the mechanical properties of the alloy are poor.

The microstructure of Al-12Si alloy after treatment with a 0.6% modifier produced from Al by cooling at a rate of 200 K/s is presented in Figure 3. Visible are fine grains of phase β and a eutectic mixture ($\alpha + \beta$) with the acicular phase β in the inter-dendrite spaces of phase α. The dark Mg_2Si phase is also present. The introduction of 7% silicon into the modifier resulted in the refinement and branching of the eutectic (Fig. 4). The structure was further refined following the addition of 12% Si to the modifier (Fig. 5). At a higher percentage content of silicon in the homogenous modifier, the needles of the eutectic phase β became larger and the inter-phase spacing increased, indicating a lower degree of enrichment (Fig. 6).

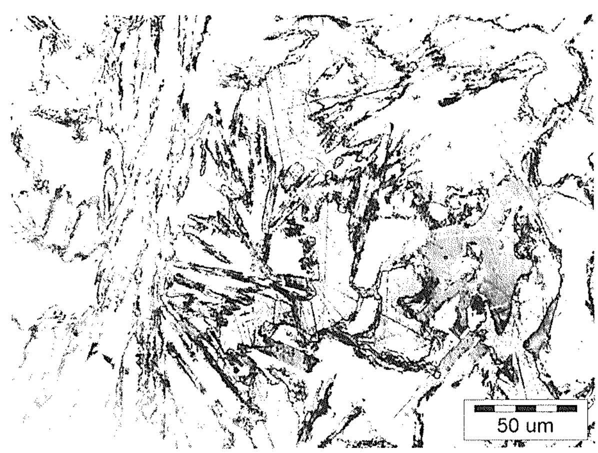

Fig. 2. Microstructure of the raw Al-12Si alloy

Fig. 3. Microstructure of the Al-12Si alloy with 0.6 at.% addition of the Al modifier cooled at the rate: 200 K/s

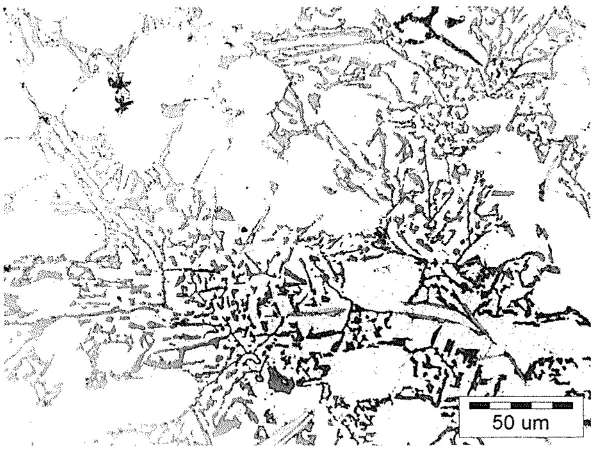

Fig. 4. Microstructure of the Al-12Si alloy with 0.6 at.% addition of the Al-7Si modifier cooled at the rate: 200 K/s

Fig. 5. Microstructure of the Al-12Si alloy with 0.6 at.% addition of the Al-12Si modifier cooled at the rate: 200 K/s

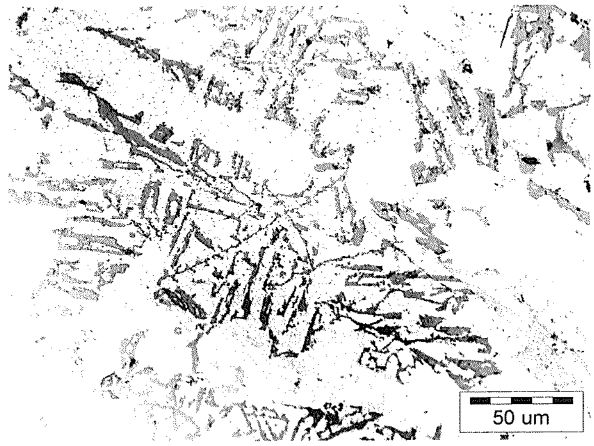

Fig. 6. Microstructure of the Al-12Si alloy with 0.6 at.% addition of the Al-20Si modifier cooled at the rate: 200 K/s

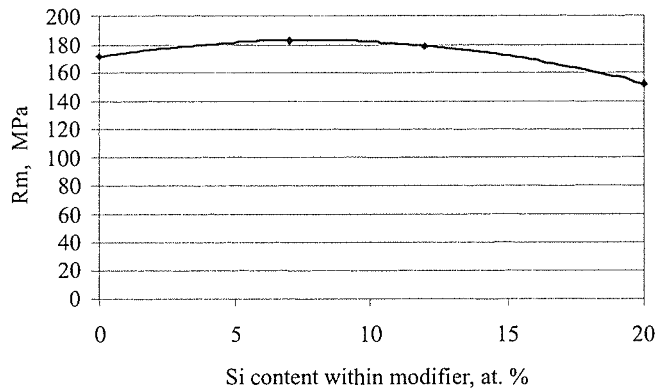

Fig. 7. Tensile strength R_m after a treatment of the Al-12Si alloy by means of the homogenous modifiers

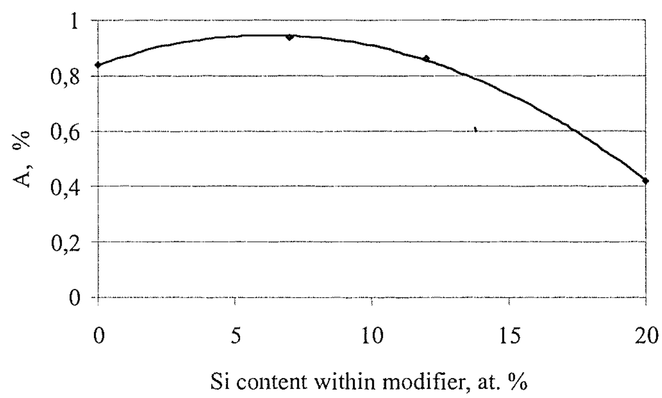

Fig. 8. Elongation A, after a treatment of the Al-12Si alloy by means of the homogenous modifiers

The results of a tensile strength test are shown in Figure 7.

The tensile strength of Al-12Si alloy after treatment with 0.6% primary aluminum cooled at V_2 = 200°C/s increased, compared to the initial alloy, by 47%, i.e. to 171 MPa. Treatment with an alloy containing 7% Si enabled to increase R_m by 58% (to 183 MPa) in relation to the non-modified alloy, and by 7% in relation to the Al-treated alloy. Following modification with an alloy containing 12% Si, tensile strength increased by 54%, reaching 179 MPa. This means that the value of the analyzed parameter decreased by over 2%, compared to the alloy treated with a modifier containing 7% Si, and increased by 5%, compared to the Al-modified alloy. The lowest value of R_m (152 MPa) was recorded in an alloy treated with a modifier containing 20% Si. This result is unsatisfactory – the above value is 30% higher than that obtained for the non-modified alloy, but 17% lower than the highest tensile strength achieved in this experimental series. Moreover, this result is also 15% lower than that obtained for the alloy modified with an additive containing 12% Si.

An analysis of the results of a tensile strength test for different percentages of silicon in Al-Si alloy used for modification confirmed the beneficial effect of the homogenous modifier in respect of the hypoeutectic proportions of its components.

The results of a percentage elongation test are presented in Figure 8.

The percentage elongation of Al-modified Al-12Si alloy increased by 460%, compared to the non-modified alloy, reaching A = 0.84%. Following the modification with an additive containing 7% Si, elongation increased by 526%, to 0.94%. This value was 12% higher than that obtained when the alloy was treated with Al alone. The treatment with a modifier containing 12% Si enabled to increase elongation by 353%, to 0.68%. However, this value was 28% lower than that recorded for an alloy containing 7% Si. After treatment with a modifier containing 20% Si, elongation increased by 180%, in relation to the non-modified alloy, reaching A = 0.42%. Compared to the alloy treated with 7 and 12% Si, this value was 55% and 38% lower, respectively.

It was found that modifiers containing up to 7% Si had a significant effect on the percentage elongation of Al-12Si alloy.

The results of Brinell hardness testing after alloy treatment with modifiers are illustrated in Figure 9.

In Al-treated alloy Brinell hardness decreased by 36%, to 96 HB. After treatment with an additive containing 7% Si, alloy hardness decreased by 37%, to 95 HB (in comparison with the non-modified alloy). The hardness of the alloy treated with a modifier containing 12% Si reached 96 HB, and was 36% lower than the hardness of the non-modified alloy. The lowest decrease in Brinell hardness was observed in AlSi12 alloy treated with a modifier containing 20% Si (Fig. 9). Compared to the non-modified alloy, the value of the analyzed parameter decreased by 29%, to 107 HB. The average difference in hardness between the above alloy and those treated with modifiers containing 0.7% and 12% Si was 10 HB. It was demonstrated that Brinell hardness was closely related to the strength properties of the alloy. Differences in hardness noted following the addition of Al, Al+7% Si and Al+12% Si were very small.

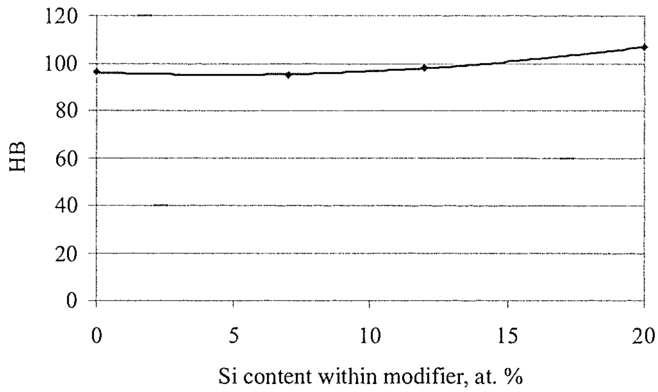

Fig. 9. Hardness HB, after a treatment of the Al-12Si alloy by means of the homogenous modifiers

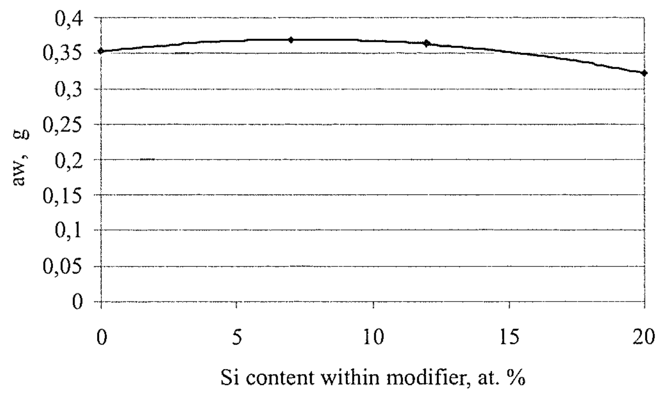

Fig. 10. Abrasive wear aw, after a treatment of the Al-12Si alloy by means of the homogenous modifiers

An analysis of the impact of particular modifiers on the tested mechanical properties of Al-12Si alloy showed that the most beneficial effect was exerted by a modifier containing up to 12% Si. When this value was exceeded, the strength parameters decreased considerably. This range of changes in the silicon content of modifiers based on Al-Si alloy will be studied in detail in another series of experiments.

Abrasive wear of alloy treated with modifiers is shown in Figure 10.

Abrasive wear of Al-treated alloy was 0.353 g. After alloy treatment with an additive containing 7% Si the value of the analyzed parameter increased by 4%, to 0.068 g. When the Si content of the homogeneous modifier was increased to 12%, abrasive wear decreased slightly, to 0.364 g. A further increase in the Si content of homogeneous modifier was followed by a 12% decrease in abrasive wear (compared to the previous value), which reached 0.322 g.

4. Conclusions

The analysis of the process of eutectic Al-Si alloy modification with the use of a homogenous modifier obtained from the analysed Al-Si alloy by rapid cooling shows that this modifying addition affected physical and mechanical properties of Al-12Si alloy.

A comparison of the structures of Al-12Si alloy treated by a homogeneous modifiers shows that all of the analyzed structures were modified. The effect of modification increases along with an increase of the silicon content within the homogeneous modifier, reaching the optimum at 12% Si. When Si content increases to 20%, the degree of alloy modification decreases. At that moment it is lower than at the zero content of silicon in the modifier. Changes in alloy structure are followed by changes in tensile strength (R_m), which reaches a maximum at 12% Si. The highest value of relative elongation is recorded for a homogeneous modifier containing 7% Si.

The pattern of changes in Brinell hardness is different. The lowest hardness is observed for Si content of 7%. The opposite trend is noted in the case of abrasive wear, which is the highest at 7% Si. An increase in Si content in modifier is accompanied by a decrease in abrasive wear. This is natural, since the level of alloy modification is lower at a higher Si content of homogeneous modifier. A thicker β phase is reflected in higher hardness and lower abrasive wear.

Based on the analysis of all mechanical properties tested in the study, it may be concluded that the optimum Si content in homogeneous modifier is 12%, although changes caused by modification with the use of additives containing 12% and 7% Si are comparable. When the Si content in homogeneous modifier exceeded 12%, the degree of modification gradually decreases, and structural differences becomes noticeable already at 20% Si. Therefore, the Si content in homogeneous modifier within the 7% to 12% range may be considered as optimal.

It should be emphasized that the method for Al-Si alloy modification with the use of a homogenous modifier obtained from studied alloy by fast cooling, proposed in this paper, meets relevant ecological and environmental standards, because no chemical elements that could hinder recycling are introduced into the alloy.

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