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Modification of the Al–9%SiMg Alloy with Aluminum, Boron, and Titanium Fast Cooled Mixtures

T. Lipiński*

University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences, St. Oczapowskiego 11, 10-957 Olsztyn, Poland

The mechanical properties of hypoeutectic silumins can be improved through chemical modification as well as chemical elements or technological processing. This study presents the results of modification of an Al–9%SiMg alloy with aluminium, boron, and titanium. The experiments were conducted following a factor design 2^3 for 3 independent variables. The influence of the analyzed modifiers on the microstructure and mechanical properties of the processed alloy was presented in graphs. The modification of a hypoeutectic Al–9%SiMg alloy improved the alloy's properties. The results of the tests indicate that the mechanical properties of the modified alloy are determined by the components introduced to the alloy.

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1. Introduction

Hypo-eutectic silumins are a popular group of casting alloys owing to their relatively low price, low melting temperature, low density, good electric and thermal conductivity, high resistance to corrosion and high strength relative to specific gravity. Those attributes have contributed to the wide use of hypo-eutectic silumins in aviation, motor, and ship building industries [1–3].

In hypo-eutectic alloys of aluminum and silicon, solid solution dendrites which crystallize first are typical crystals, showing isotropic properties [2, 4]. Similarly to pure aluminum, solid solution α (silicon in aluminum) has a regular cubic face-centered lattice of the type A1. The growth rate of those crystals, and the growth rate of eutectic mixture crystallizing at the next stage $(\alpha + \beta)$ is a function of supercooling at the crystallization front. This dependence is a complex function of: the chemical composition of the liquid and solid phase, surface curvature of the crystallization front, crystallization heat emission, and structural defects [2, 5].

The mechanical properties of hypo-eutectic silumins can be improved through modification as well as traditional or processing. Several modifiers are known (e.g., strontium, antimony, sodium, barium, calcium), of which strontium is the most frequently used in the Al–Si alloy industry because it is easy to handle, has a good modification rate, a long incubation time and a low fading effect [6–12]. Modification improves the material's mechanical properties through grain refinement. Other interesting methods of modifying hypo-eutectic silumins involve the use of homogeneous modifiers [7] as well as modifiers that produce exothermic effects [8]. The interactions between "opposing" chemical elements used as modifying agents may have an adverse effect on successive alloy modifications. An example may be the interactions between Sb and Sr, and between Sb and Na, which are a serious concern during further processing of modified alloys [1, 12–16].

In view of the growing popularity of modified alloys, the aim of this study was to determine the mechanical properties of hypo-eutectic silumins Al–9%SiMg modified with aluminum, boron, and titanium fast cooled mixtures.

2. Materials and methods

The experimental material was Al–9%SiMg alloy which was regarded as representative of hypoeutectic silumins. The alloy was obtained from industrial piglets. The alloy was melted in an electric furnace, and the modification process was carried out with Al $\in \langle 1, 5\rangle$ [%] + B$\in \langle 0.04, 0.08\rangle$ [%] and Ti $\in \langle 0.1, 0.5\rangle$ [%] by weight. To obtain a modifier, Al–Si alloy was melted and then cooled on a metal plate at rate about 50 °C/s. This enabled to produce component, which were refined immediately before adding to the alloy. The alloy was modified at a temperature of 850 °C for 5 min. The 2^3 factorial design with three independent variables was applied. The results were analyzed mathematically, which enabled to formulate the factor equation for three variables, for the parameters studied, at the level of significance = 0.05. The adequacy of the above mathematical equation was verified using the Fischer criterion for $p = 0.05$.

Cylindrical samples, 8 mm in diameter and 75 mm in length, were poured into a mold made of molding sand. Casts were removed from molds, and specimens were collected for mechanical tests. Hardness was determined by the Brinell method by applying a test load of 612.9 N to a ball with a diameter of 2.5 mm. The side surface of the head of the specimen used in a static tensile test was ground to a depth of 2 mm. Three measurements

*corresponding author; e-mail: tomekl@uwm.edu.pl

were taken per sample (6 measurements per cast). All measurements were carried out according to standard PN-EN 6506-1:2008 “Metallic materials. Brinell hardness test. Part 1: Testing methodology” in the HPO 250 hardness tester. The tensile stress test was performed on a specimen with a length-to-diameter ratio of 5:1 in the ZD-30 universal tensile tester. Ultimate tensile strength and percentage elongation were determined. A tensile strength test was performed on two samples, $\phi 6$ mm, for each melting point, according to standard PN-EN 6892-1: 2010 “Metallic materials. Tensile testing. Part 1: Testing methodology at room temperature”.

3. Results

The chemical composition of the Al–9%SiMg alloy is presented in Table I. The example of presence of modifying elements in the alloy was confirmed by quantitative X-ray analysis (Fig. 1) and parameters of phases in Table II. The ultimate tensile strength (UTS) of the Al–9%SiMg alloy after chemical treatment is presented in Fig. 2. Percentage elongation (A) of the Al–9%SiMg alloy after chemical treatment is shown in Fig. 3. The Brinell hardness of the Al–9%SiMg alloy after chemical treatment is presented in Fig. 4.

TABLE I

Chemical composition [wt.%] of the Al–9%SiMg raw alloy

Si	Cu	Mg	Mn	Fe	Ti	Zn	Ni	Al
8.9	0.17	0.24	0.30	0.40	0.10	0.15	0.01	bal.

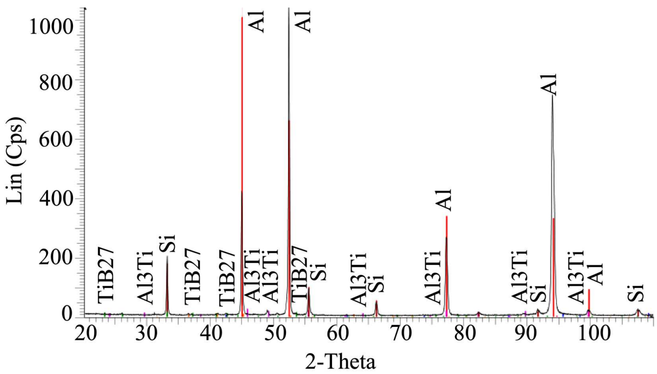

Fig. 1. Quantitative X-ray analysis of the Al-9%SiMg alloy with 5% Al + 0.08% B + 0.5% Ti.

TABLE II

X-ray analysis parameters of the Al-9%SiMg alloy with 5% Al + 0.08% B + 0.5% Ti.

Phase	a	C	z	Space group	Lattice
Al	4.04940		4	14/mmm (139)	face-centered cubic
Si	5.43029		8	P42nnm (134)	face-centered cubic
Al_3Ti	3.84400	8.59600	4	Fm-3m (225)	body-centered tetragonal
TiB_{27}	8.83000	5.07200	1	Fd-3m (227)	tetragonal

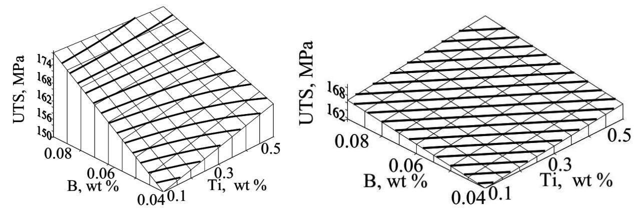

Fig. 2. The ultimate tensile strength (UTS) Al-9%SiMg alloy with B $\in \langle 0.04, 0.08\rangle$ [%] and Ti $\in \langle 0.1, 0.3\rangle$ [%] for Al + 1% (left) and for Al + 5% (right).

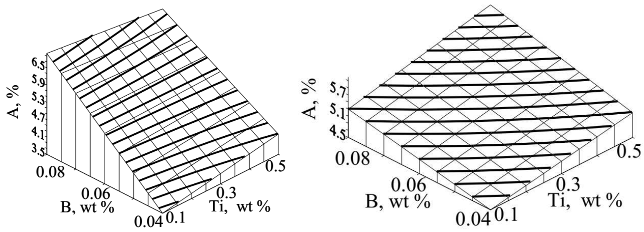

Fig. 3. Percentage elongation (A) Al-9%SiMg alloy with B $\in \langle 0.04, 0.08\rangle$ [%] and Ti $\in \langle 0.1, 0.3\rangle$ [%] for Al + 1% (left) and for Al + 5% (right).

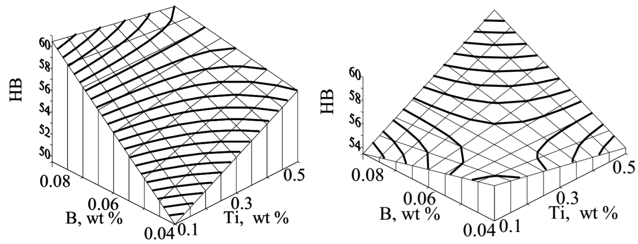

Fig. 4. Brinell hardness (HB) Al-9%SiMg alloy with B $\in \langle 0.04, 0.08\rangle$ [%] and Ti $\in \langle 0.1, 0.3\rangle$ [%] for Al + 1% (left) and for Al + 5% (right).

In a non-modified Al–9%SiMg alloy, ultimate tensile strength UTS was determined at 142 MPa, elongation A at 1.8%, and the Brinell hardness at 50 HB. Treatment with 1% Al + 0.04% B + 0.1% Ti a little increased ultimate tensile strength to 150 MPa and elongation to 3.5% Brinell hardness is the same. An increase in the B content of the modifier to 0.08% increased tensile strength by 26 MPa to 176 MPa (Fig. 2 left) (increased by 34 MPa comparison to raw alloy), elongation by 3.5% to 7.0% (Fig. 3 left) and hardness by 11 HB to 61 HB (Fig. 4 left). An next increase in the Ti content of the modifier to 0.5% decreased tensile strength by 2 MPa to 174 MPa (Fig. 2 left), elongation by 0.5% to 6.5% (Fig. 3 right) and hardness to 59 HB (Fig. 4 right). For all modifiers on higher level tensile strength is 172 MPa (Fig. 2 right), elongation 6.2% (Fig. 3 right) and hardness 60 HB (Fig. 4 right).

The SEM micrographs of fractured surface of tensile test specimens of Al–9%SiMg alloy tested with

1% Al + 0.04% B + 0.1% Ti is shown in Fig. 5, and with 5% Al + 0.08% B + 0.5% Ti in Fig. 6. After modifications the fracture surface consists of cleavage planes and grain boundaries. It is a mixed pattern of transgranular and intergranular fracture.

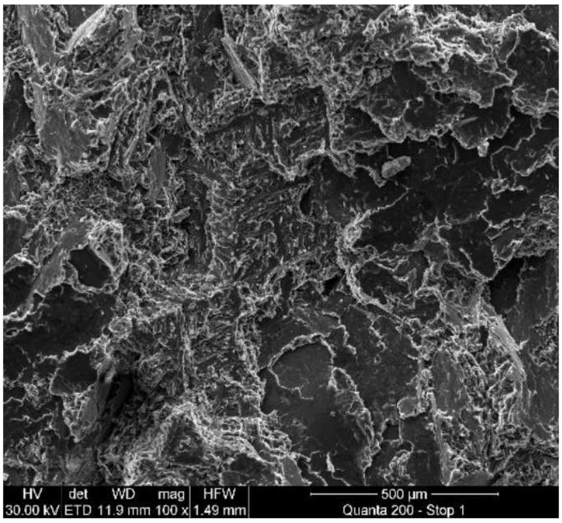

Fig. 5. SEM micrographs of fractured surfaces of Al–9%SiMg alloy with 1% Al + 0.04% B + 0.1% Ti.

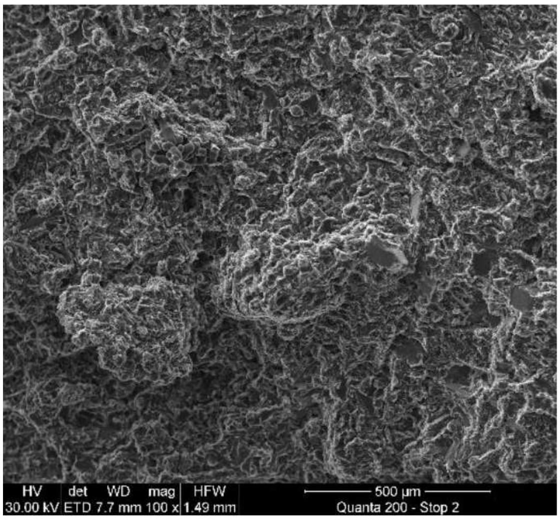

Fig. 6. SEM micrographs of fractured surfaces of Al–9%SiMg alloy with 5% Al + 0.08% B + 0.5% Ti.

4. Conclusions

Based on the results obtained in this work the following conclusions could be drawn:

- quantitative X-ray analysis of Al–9%SiMg alloy confirms the introduction of boron and titanium with a modifier to the tested alloy; Al–Ti and Ti–B phases may be formed during the modifier manufacturing step then survived in liquid Al–Si alloy modifying it;
- the highest: tensile strength UTS=176 MPa, percentage elongation A =7%, and the Brinell hardness 61 HB were achieved by enriching the alloy with a fast cooling mixture of 1% Al+0.1% Ti+0.08% B;
- in this work it has been shown that the use of rapidly cooled alloys as a modifier is more effective than modifiers produced in traditional methods. In this way modifier elements with Al have higher efficiency than boron.

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