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The Effect of Refining and the Cooling Rate on Microstructure and Mechanical Properties of AlSi7Mg Alloy

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Abstract

The paper presents results of research on the effect of conventional refining with hexachloroethane and the cooling rate $v_{cool.}$ ranging within the solidification temperature regime from 12.5°C/min to 94.5°C/min on compactness of the material, values of microstructure parameters $\lambda_{2D,}$ λ_E, l_{maxSi}, and mechanical properties R_m, $R_{0,2}$, A_5 of unmodified AlSi7Mg alloy after heat treatment (solution treatment 540°C/6 h/water 20°C and aging 175°C/8 h/air). It has been found that as a result of refining and increased cooling rate, an improvement of material compactness occurred (reduction of the density index by 0.4%) accompanied by a decrease of values of parameters characterizing the microstructure: λ_{2D} by 54.4 μm; λ_E by 4,6 μm; and l_{maxSi} by 50 μm. As a result of these changes, the value of R_m increased by about 40 MPa and $R_{0.2}$ improved by about 36 MPa, while the value of A_5 decreased by 1.3%.

Keywords: Cast aluminum-silicon alloy, Material compactness, Microstructure, Mechanical properties

1. Introduction

Alloys based on Al-Si system have a well-established position as structural materials widely used in industries manufacturing motor vehicles, electric machines, precision instruments, and household appliances. The rationale behind popularity of silumins consists in their attractive physicochemical and technological properties. Unquestionable merits of these alloys include low mass density at relatively high tensile strength, relatively low melting point, good electrical and thermal conductivity, small thermal coefficient of expansion and small hysteresis demonstrated at heating/cooling, good chemical resistance, vibration damping ability, good tightness, satisfactory hardness, and satisfactory resistance to abrasive wear and cavitation [1–3]. Moreover, favorable technological properties (good runnability, small casting shrinkage, low tendency for hot cracking, good machinability, and good weldability) allow to manufacture casting components with complex forms. These are the features thanks to which, in view of the universal trend to reduce the overall mass of structures perceived as one of determinants of modernity of any design, the use of silumins continually increases [4–6].

A well-known flaw of silumins is their tendency to form coarse-grained structures which is accompanied in deterioration of service properties. Substantial structure refinement is usually achieved by special improvement operations performed on liquid alloy and changing thermal conditions of the solidification process. A further improvement of microstructure and thus also the service properties of silumins is obtained after subsequent heat treatment [2, 7–9].

The paper deals with the assessment of possible effect of conventional refining and an increase of cooling rate within the solidification temperature regime on the material compactness, values of parameters λ_{2D}, λ_E, l_{maxSi} characterizing the microstructure, and the effect of these quantities on mechanical properties R_m, $R_{0.2}$, A_5 of AlSi7Mg alloy after heat treatment (solution treatment and aging).

2. The material and the research method

The casting model selected for the present study was a wedge-shaped casting with a chill at the mould base. Castings of this very shape are often used for the purpose of scientific research in view of the possibility to induce specifically oriented crystallization which has a positive effect on compactness of the material within the whole of its volume provided that areas solidifying as the last ones are fed. The shape and dimensions of the test castings are shown in Fig. 1.

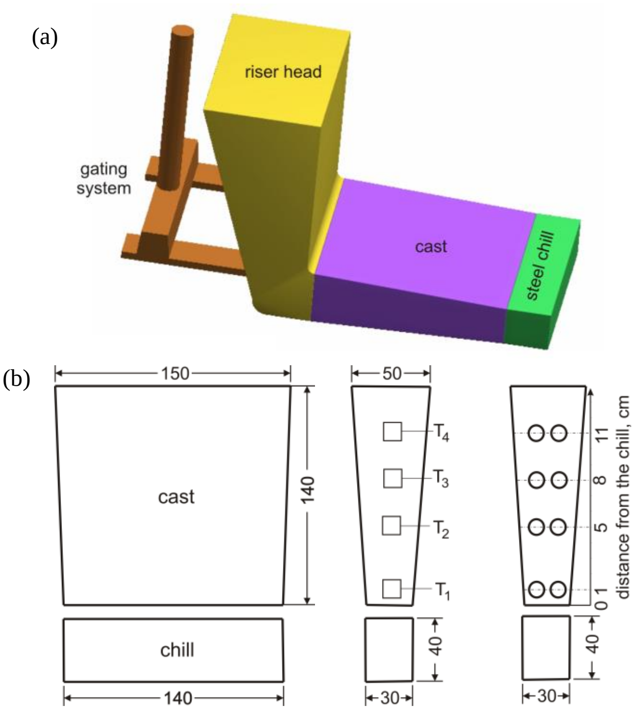

Fig. 1. (a) The idea behind production of the test castings. (b) Location of thermocouples and places from where samples of the material were taken for measurements of compactness, microstructure, and mechanical properties

To design a wedge-shaped casting characterized with high compactness of the material, MAGMASOFT computer simulation program was used.

The castings were cast in moulds made of self-curing mass in production conditions typical for an aluminum foundry shop. Casing moulds were poured with liquid metal with the following composition: 7.06%Si; 0.32 %Mg; 0.01%Cu; 0.01%Mn; 0.09%Fe, Al to balance, at temperature 705–710°C. Eight test wedges were fabricated which subsequently were subjected to heat treatment according to the schedule developed in [10] where it has been found that soaking the alloy at temperature 540°C for 6 hours and subsequent cooling in water at temperature 20°C is sufficient to dissolve Mg_2Si precipitations. For such parameters of the solution treatment it has been found that silicon precipitates showed a tendency to segmentation and rounding off. Results of a study on aging kinetics depending on soaking temperature and time proved that from the point of view of alloy hardness, the most favorable temperature was 175°C and the optimum aging time was 8 hours.

The value of the density index, which is a quantity related to alloy porosity, was assessed by means of comparing the alloy mass density Q_p measured on the grounds of the Archimedes' principle by means of WPS 510/C/2 precision balance adapted specifically for density measurements with the calculated mass density Q_t. The density index values were thus calculated with the use of formula:

$$I = (Q_t - Q_p)/Q_p \times 100\%. \quad (1)$$

Microstructure was examined with the use of Neophot 2 optical microscope and Jeol-JSM-5502V electron microscope equipped with LINK ISIS 300 adapter.

Assessment of value of the parameter λ_{2D} (secondary dendrite arm spacing, SDAS) required identification of dendritic cells with side arms. The evaluation was carried out in line with methodology proposed in [11–13]. Each time, a sample of 100 cells was taken into account. To assess value of the parameter λ_E, 350 particle crossings along the measuring line was taken into account. When calculating the maximum length of silicon precipitates l_{maxSi}, significance of which in Al-Si alloy breaking tests is emphasized in [14, 15], distance between 100 pairs of particles were analyzed.

In the present paper, following the approach proposed by a number of other authors, certain simplification has been adopted as far as the microstructure is concerned. It has been assumed that the morphology of intermetallic phase precipitation is similar to this of silicon precipitates and the role played by both elements of microstructure in creation of defects is also similar.

Mechanical properties tested according to the standard PN-EN 10002-1+AC1 were carried out on ZWICK 1474 materials testing machine with computer-based test data recording. The specimens with diameter d_o = 5 mm were used for the tests (Fig. 2).

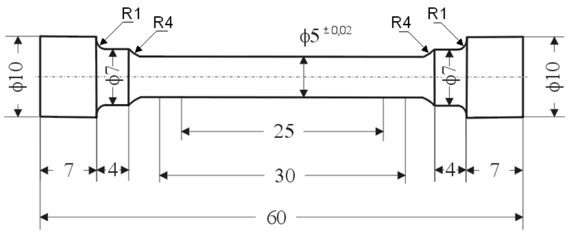

Fig. 2. Shape and dimensions of specimens used for static tensile tests

3. Research results

Results of the study on conditions of AlSi7Mg alloy cooling after traditional refining on the density index and values of parameters characterizing the microstructure are presented in Table 1.

Table 1.
The effect of the rate of cooling of conventionally refined AlSi7Mg alloy on values of the density index and microstructure parameters λ_{2D}, λ_E, and l_{maxSi}

Cooling rate °C/min	Density index I, %	Microstructure parameters, µm		
		λ_{2D}	λ_E	l_{maxSi}
12.5	1.05	89.2	14.1	89
14.5	0.91	82.5	13.3	81
29.2	0.81	62.2	11.1	57
94.5	0.64	34.8	9.5	39

Example microstructures of AlSi7Mg alloy after conventional refining are presented in Figs. 3 and 4.

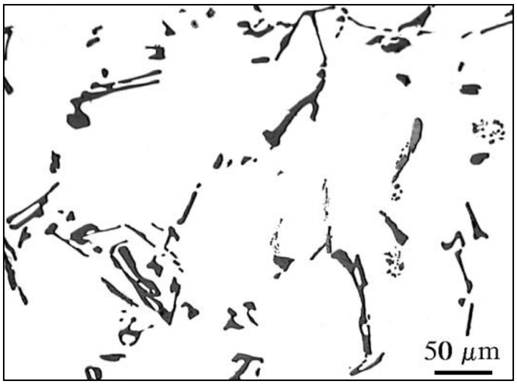

Fig. 3. Microstructure of AlSi7Mg0.3 alloy after conventional refining. Cooling rate 12.5°C/min

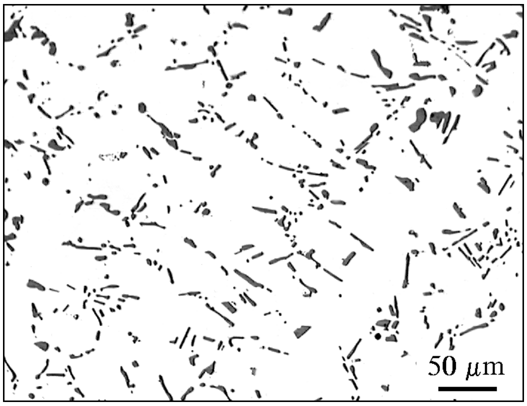

Fig. 4. Microstructure of AlSi7Mg0.3 alloy after conventional refining. Cooling rate 94,5^{o}C/min

The obtained results indicate that with increasing cooling rate, compactness of unmodified AlSi7Mg alloy after traditional refining increases. This is the effect of decrease of the structural parameter λ_{2D} which hinders both nucleation and growth of gas bubbles [16–17].

The analysis of silicon precipitate size distribution proved that the share of precipitates with dimensions of l_{maxSi}. accounted for 2% of the analyzed sample. It turned out that the value of the parameter l_{maxSi} was sensitive to the cooling rate. The cooling rate change from 12.5°C/min to 94.5°C/min resulted in reducing the value of l_{maxSi} by the factor of four. Reduction of value of the parameter l_{maxSi} is important for mechanical properties of AlSiMg alloys characterized with high compactness of the material, as first micro-cracks nucleate on the largest silicon and intermetallic phase precipitations [14, 18, 19].

Results of examination of the effect of refining and the increase of the cooling rate on mechanical properties of unmodified AlSi7Mg alloy are listed in Table 2.

Table 2.
The effect of the rate of cooling of conventionally refined AlSi7Mg alloy on its mechanical properties

Cooling rate °C/min	Mechanical properties		
	R_m, MPa	$R_{0.2}$, MPa	A_5, %
12.5	222	196	0.6
14.5	228	200	0.8
29.2	253	222	1.1
94.5	263	232	1.9

The obtained results show that the increase of cooling rate resulted in an increase of the tensile strength, the yield strength, and elongation. The obtained results can be attributed to the decreased tendency of the alloy to create large gas bubbles as a result of decreased value of the microstructure parameter λ_{2D} as well as to the microstructure grain refining, evidenced by decreased values of structural parameters λ_E and l_{maxSi}.

4. Conclusions

As a result of the studies on the effect of traditional (hexachloroethane) refining and the cooling rate on microstructure and mechanical properties of unmodified AlSi7Mg alloy it has been found that:

- Increase of the alloy cooling rate within the regime of solidification temperatures resulted in a decrease of α(Al) phase secondary dendrite arm spacing distances (SDAS), distance between silicon precipitations in the eutectic (λ_E), and the maximum size of silicon precipitates (l_{maxSi}).
- Reduction of the value of SDAS parameter resulted in absence of large gas bubbles and therefore had a favorable effect on the decrease of susceptibility of the alloy to origination of cracks.
- Reduction of the value of SDAS parameter, the distance between silicon precipitations in the eutectic λ_E, and the maximum length of silicon precipitations l_{maxSi} in the alloy without any discontinuities had a favorable effect on improvement of mechanical properties of the material.

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