www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES of FOUNDRY ENGINEERING

DOI: 10.1515/afe-2016-0064

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

DE GRUYTER OPEN

ISSN (2299-2944)
Volume 16
Issue 3/2016

129 – 132

Usable Properties of AlSi7Mg Alloy after Sodium or Strontium Modification

M. Tupaj *, A.W. Orłowicz, M. Mróz, A. Trytek, O. Markowska
Department of Casting and Welding, Rzeszow University of Technology,
al. Powstańców Warszawy 12, 35-959 Rzeszów, Poland
*Corresponding author. E-mail address: mirek@prz.edu.pl

Received 19.04.2016; accepted in revised form 09.05.2016

Abstract

The paper deals with the effect of microstructure diversified by means of variable cooling rate on service properties of AlSi7Mg cast alloy refined traditionally with Dursalit EG 281, grain refining with titanium-boron and modified with sodium and a variant of the same alloy barbotage-refined with argon and simultaneously grain refining with titanium-boron and modified with strontium. For both alloy variants, the castings were subject to T6 thermal treatment (solution heat treatment and artificial aging). It turned out that AlSi7Mg alloy after simultaneous barbotage refining with argon and grain refining with titanium-boron and modified with strontium was characterised with lower values of representative microstructure parameters (SDAS – secondary dendrite arm spacing, λ_E, l_{max}) and lower value of the porosity ratio compared to the alloy refined traditionally with Dursalit EG 281 and grain refining with titanium-boron and modified with sodium. The higher values of mechanical properties and fatigue strength parameters were obtained for the alloy simultaneously barbotage-refined with argon and grain refining with titanium-boron and modified with strontium.

Keywords: AlSi7Mg0.3 alloy, Refining and modification, Cooling rate, Microstructure parameters, Usable properties

1. Introduction

Service properties of Al-Si alloys depend on size, shape, and distribution of precipitates of silicon and intermetallic phases in the matrix. It is a well-known fact that alloy refining decreases the gas porosity, while an addition of titanium and boron to the alloy reduces size of α(Al) phase dendrites [1–3] which also contributes to a decrease of gas porosity and shrinkage porosity. An addition of sodium or strontium has a favourable effect on morphology of silicon precipitates. The refining and comprehensive modification results in improvement of mechanical properties [4–6] and an increase of fatigue strength of aluminium-silicon alloys [7–11] (Fig. 1).

Available technical literature does not include sufficiently thorough studies on the effect of diversified technological processes used to manufacture aluminium-silicon alloys on their service properties. Carrying out such studies seems to be important as the acquired new knowledge would wide the range of possibilities offered to designers and users of heavily loaded and responsible castings. Such knowledge constitutes a base on which decisions can be taken to use these alloys for castings operated in critical conditions.

In view of the above, this paper concerns determination of the effect of refining, modification, and cooling conditions on microstructure and service properties of industrial AlSi7Mg alloy.

2. Research material and methodology

The material put through examination was a hypoeutectic aluminium-silicon alloy (AlSi7Mg) made in production conditions.

To obtain high compactness of the material and diversified structure of the alloy to be examined, castings with an additional feed bob on the thicker side and a steel chill at the base were designed, similar to those described in [5, 11] (Fig.1).

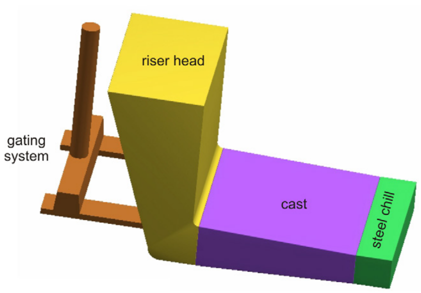

Fig. 1. The idea behind production of the test castings

It has been decided that the study would concern an alloy refined with hexachloroethane after modification with Ti-B and sodium (Variant I of the alloy treatment) and an alloy subjected to simultaneous barbotage refining with argon and modification with Ti-B salts and strontium (Variant II of the alloy treatment). For each of the variants, four similar moulds of self-curing sand were prepared. To evaluate cooling rate in individual regions of wedge castings, thermocouples were mounted in two of the moulds, one for each of the alloy variants, in such a way that their junctions were situated in the middle of individual cross-sections and at distances 10 mm and 110 mm from the chill surface. Thermocouples were mounded in steel shields with outer diameter 1.75 mm and thickness 0.35 mm. Temperature changes in the period after pouring the moulds with liquid metal were recorded with the use of multi-channel input module ADAM 4018. The cooling rate was measured from temperature vs. time data obtained during solidification in liquidus-solidus range of temperature.

The alloy to be examined in the total quantity of 600 kg was prepared in a gas-fired Selas furnace type (Table 1) of which 300 kg base alloy was transferred to a preheated casting ladle with capacity of 400 kg.

Table 1.
Chemical composition of base AlSi7Mg alloy

Si	Mg	Cu	Mn	Fe	Al
7.04	0.31	0.01	0.01	0.09	to balance

The liquid metal was subject to refining with tablets containing hexachloroethane marketed under trade name Dursalit EG 281 and grain refining with titanium-boron using AlTi5B1 master alloy and modified with vacuum-packed sodium traded under name Navac (Variant I of the alloy treatment). Liquid metal at temperature 710°C was poured to wedge-shaped moulds and samples for chemistry analysis were taken. Chemical analysis shows that to the base alloy were added 0.014% Na, 0.15%Ti and 0.01%B.

The other 300 kg of liquid metal remaining in Selas furnace was transferred to a preheated casting ladle. The refining and grain refining and modification process was carried out in automated metal treatment station MTS 1500 (Foseco). The liquid metal was subjected to barbotage refining with argon. The refining time was 5 minutes. Next, without interrupting the process, titanium-boron salts were added in the form of flux with trade name Coveral MTS 1582 as well as AlSr10 master alloy(Variant II of the alloy treatment). The liquid metal prepared this way was poured at temperature 705° into wedge moulds and samples were taken for analysis of chemistry. Chemical analysis shows that to the base alloy were added 0.01%Sr, 0.15%Ti and 0.01%B. The cast wedges were thermally treated with the use of parameters developed in [12]. The heat treatment included: solution treatment (540°C / 6 h / water 20°C) followed by ageing (175°C / 8 h / air).

Specimens for metallographic examination were cut out from those regions of wedge castings in which temperature changes vs. time were evaluated. Microstructure was examined with the use Neophot 2 optical microscope and Jeol JSM-5502V scanning electron microscope quipped with LINK ISIS 300 X-ray spectrometer (Oxford Instruments). The specimens were used for evaluation of porosity ratio according to methodology described in [6].

Evaluation of λ_{2D} (SDAS) parameter required identification of dendritic cells with secondary arms. The evaluation was carried out in line with methodology described in papers [13–15]. 100 cells were taken into account each case the determination of the parameter was carried out. When evaluating the parameter λ_E, 350 crossings of the measuring line with individual particles were analysed. For calculations aimed at determining maximum length of silicon precipitates l_{maxSi}, significance of which in Al-Si alloys cracking tests is emphasised in [16, 17], distances between 100 pairs of particles were taken into account.

Example microstructures of the casting are presented in Fig. 2.

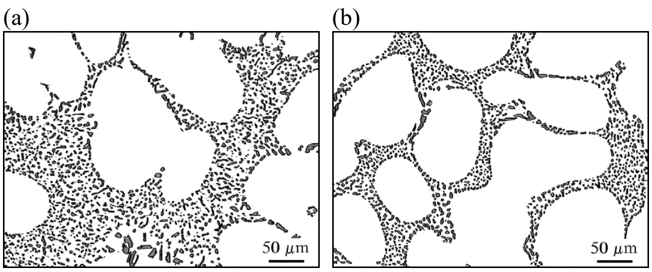

Fig. 2. Microstructure of AlSi7Mg alloy after (a) refining with Dursalit EG 281 and grain refining with Ti-B and modifying with Na, and (b) simultaneous barbotage refining with argon and grain refining with Ti-B salts and modification with Sr

The material for evaluation of compactness, microstructure and mechanical properties as well as specimens for fatigue resistance tests were cut out from these regions of castings where the cooling rate was 94.5°C/min and 12.5°C/min which corresponded to the distance from the chill equalling 10 mm and 110 mm, respectively. The shape and dimensions of specimens for static tensile test are presented in Fig 3, whereas the shape and dimensions of samples for fatigue resistance test are shown in Fig. 4.

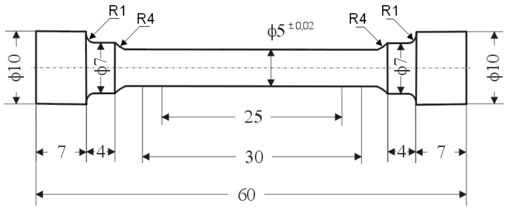

Fig. 3. Shape and dimensions of specimens for static tensile test

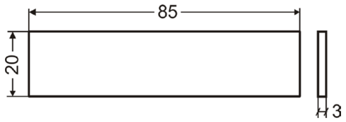

Fig. 4. Shape and dimensions of specimens for fatigue resistance tests

Measurements of the tensile strength, the yield strength, and the elongation of specimens were carried out on the ZWICK 1474 universal test machine with computer-aided recording of results. The tensile strength was tested in conditions of periodically variable stresses induced by swinging flat bending on the device GZ-1 [18, 19] according to the standard PN-76/H/04326-5. The adopted frequency of forced vibration was f = 73 Hz.

3. Research results

Results of measurements aimed at determination of values of microstructure parameters SDAS, λ_E, and l_{maxSi} for two variants of AlSi7Mg alloy are presented in Table 2.

Table 2.
Values of microstructure parameters SDAS, λ_E, and l_{maxSi} for both variants of AlSi7Mg alloy teratment

Variant alloy treatment/ cooling rate v_{cool}, °C/min	Microstructure parameters			Porosity index P, %
	SDAS, µm	λ_E, µm	l_{max}, µm	
I / 12.5	86.5	7.9	49.4	1.208
I / 94.5	28.8	4.3	11.3	0.737
II / 12.5	85.4	6.6	39.2	0.976
II / 94.5	27.4	4.1	9.9	0.553

Heat treatment:
solution (540°C / 6 h / water 20°C), ageing (175°C / 8 h / air)

The obtained results indicate that with increasing cooling rate, compactness of the material increases for both alloy variants. As a result, value of parameter SDAS decreases about three times which hinders nucleation and development of gas cavities. The cooling rate change from 12.5°C/min to 94.5°C/min resulted in over 1.5-fold decrease of parameter λ_E and about fourfold decrease of value of l_{max} for both variants of the alloy. It should be however noted that the lower value of the porosity ratio characterised the alloy barbotage-refined with argon and grain refined with Ti-B and modified with Sr. This variant of the alloy demonstrated also the lowest values of microstructure parameters SDAS, λ_E, and l_{max}.

Results of static tensile and fatigue strength tests are presented in Table 3.

Table 3.
Results of static tensile tests and fatigue strength tests for both variants of AlSi7Mg alloy

Variant alloy treatment / cooling rate v_{cool}, °C/min	Static tensile test			Fatigue strength, Z_{gw}, MPa
	R_m, MPa	$R_{0.2}$, MPa	A_5, %	
I / 12.5	260	233	1.1	56.6
I / 94.5	303	261	4.7	75.6
II / 12.5	280	257	1.5	64.6
II / 94.5	318	278	5.2	81.3

Heat treatment:
solution (540°C / 6 h / water 20°C), ageing (175°C / 8 h / air)

The obtained results indicate that the effect of increased cooling rate consisted in an increase of the tensile strength, the yield strength, and the elongation. The improvement is an effect of decreased tendency of the alloy to develop large gas cavities as a result of a decrease of the value of parameter SDAS and the effect of refinement of microstructure evidenced by a decrease of values of parameters λ_E and l_{max}. The change of cooling rate from 12.5°C/min to 94.5°C/min resulted in increase of the tensile strength R_m by about 15%, the yield strength $R_{0.2}$ by about 10%, and over 3.5-fold increase of value of the elongation A_5. It should be noted that the highest values of mechanical strength parameters for the analysed cooling rates were observed in the alloy barbotage-refined with argon and grain refined with Ti-B and modified with Sr.

Results of individual fatigue endurance tests constituted the base for development of fatigue curves. Fig. 4 shows S-N fatigue curves (Wöhler diagrams) for the alloy prepared according to Variant I, while Fig. 5 shows the fatigue curves for the alloy described as Variant II.

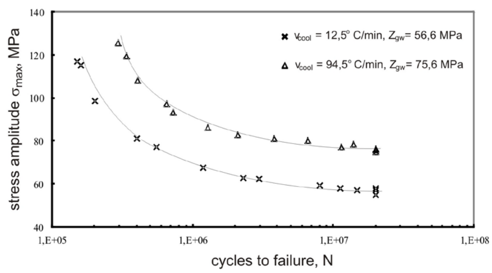

Fig. 4. Wöhler diagrams for thermally treated AlSi7Mg alloy refined with Dursalit EG 281 and grain refined with Ti-B and modified with Na, cooled at rate 12.5°C/min and 94.5°C/min

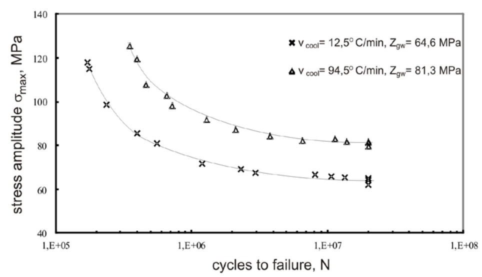

Fig. 5. Wöhler diagrams for AlSi7Mg alloy barbotage-refined with argon and grain refined with Ti-B salts and modified with Sr, cooled at rate 12.5°C/min and 94.5°C/min

The obtained results indicate that about 8-fold increase of cooling rate resulted in an increase of fatigue strength Z_{gw} by more than 25% for both variants of the alloy. Also in this case, the higher fatigue strength value characterised the alloy barbotage-refined with argon and modified with Ti-B salts and Sr.

4. Conclusions

Based on the conducted examinations the following conclusions have been formulated:

- The alloy cooling rate change from 12.5°C/min to 94.5°C/min has a prominent effect on decrease of the value of spacing between secondary dendrite arms (parameter SDAS) in phase α(Al), values of the distance between silicone precipitates in the eutectic (parameter λ_E), and the maximum size of silicon precipitates (parameter l_{max}) for both alloy variants.
- AlSi7Mg alloy after barbotage refining with argon and simultaneous grain refining with Ti-B and modification with Sr was characterised with lower value of the porosity ratio compared to the alloy refined traditionally with Dursalit EG 281 and grain refined with Ti-B and modified with Na.
- The lowest values of microstructure parameters (SDAS, λ_E, l_{max}) and the porosity ratio were obtained for the alloy barbotage refined with argon and simultaneously grain refined with Ti-B and modified with Sr, cooled at rate 94.5°C/min.
- The increase of AlSi7Mg alloy cooling rate and its comprehensive grain refining with Ti-B and modification with Na or Sr resulted in a distinct improvement of its mechanical properties and the fatigue strength.
- The highest values of parameters determining mechanical properties and fatigue strength were obtained for the alloy simultaneously barbotage-refined with argon and grain refined with Ti-B and modified with Sr, cooled at rate 94.5°C/min.

References

[1] Fuoco, R., Correa, E.R. & de Andrade Bastos, M. (1998). Effect of grain refinement on feeding mechanisms in A356 aluminum alloy. *AFS Transactions*. 78, 401-409.

[2] Easton, M.A. & StJohn, D.H. (2000). The effect of grain refinement on the formation of casting defects in alloy 356 castings. *Int. J. Cast Metals Res.* 12, 393-408.

[3] Kim, W.B., Lee, W.-S., Ye, B.J. & Loper, C.R. Jr. (2000). Effect of casting conditions and grain refinement on hot-tearing behavior in A356 Al alloy. *AFS Transactions*. *38*, 541-546.

[4] Pietrowski, S. (2001). Silumins (Siluminy). Łódź: Politechnika Łódzka. (in Polish).

[5] Orłowicz, A., Tupaj, M. & Mróz, M. (2008). Effect of cooling rate on the λ_{2D} - parameter with sodium modified AlSi7Mg alloy. *Archives of Foundry Engineering*. 8(1), 245-248.

[6] Orłowicz, A., Tupaj, M. & Mróz, M. (2008). Effect of cooling rate on the structure of hypoeutectic silumin after sodium modification. *Rudy i Metale Nieżelazne*. 53(7), 425-429.

[7] Maier, E. & Lang, G. (1985). Preparation and properties of aluminum casting alloy AlSi7Mg after modification with Na, Sr and Sb (Herstellung und Eigenschaften der Aluminium Gusslegierungen AlSi7Mg unter Berücksichtigung ihrer Veredelung mit Na, Sr und Sb). *Aluminium, 61 Jahrgang*. 12, 897-906. (in German).

[8] Zhang, B., Poirier D.R. & Chen, W. (1999). Microstructural effects on high-cycle fatigue-crack initiation in A356.2 casting alloy. *Metallurgical and Materials Transactions A*. 30A, 2659-2666.

[9] Orłowicz, A. & Mróz, M. (2003). Microstructure and fatigue strength of A 356 alloy castings refined on the surface by rapid crystallization. *Zeitschrift fur Metallkunde*. 94(12), 1320-1326.

[10] Horng, J.H., Lui, T.S. & Chen, L.H. (2001). Effect of area fraction and morphology of silicon particles on fracture behavior of hypoeutectic Al-Si alloys under resonant vibration. *Int. J. Cast Metals Res*. 14, 121-130.

[11] Orłowicz, A., Tupaj, M. & Mróz, M. (2008). Mechanical properties of AlSi7Mg alloy modified with sodium. *Archives of Foundry Engineering*. 8(1), 241-244.

[12] Orłowicz, A.W., Tupaj, M. & Mróz, M. (2006). Selecting of heat treatment parameters for AlSi7Mg0,3 alloy. *Archives of Foundry*. 6(22), 350-356.

[13] Cáceres, C. H. & Wang, Q.G. (1996). Dendrite cell size and ductility of Al-Si-Mg casting alloys: Spear and Gardner revisited. *Int. J. Cast Metals Res*. 19, 157-162.

[14] Spear, R.E. & Gardner, G.R. (1963). Dendrite cell size. *AFS Transactions*. 71, 209-215.

[15] Ronto, V. & Roosz, A. (2001). The effect of cooling rate and composition and com-position on the secondary dendrite arm spacing during solidification Part I: Al-Cu-Si alloy. *Int. J. Cast Metals Res*. 13, 337-342.

[16] Stolarz, J., Madelaine-Dupuich, O. & Magnin, T. (2001). Microstructural factors of low cycle fatigue damage in two phase Al-Si alloys. *Materials Science and Engineering A*. 299, 275-286.

[17] Stolarz, J. & Foct, J. (2001). Specific features of two phase alloys response to cyclic deformation. *Materials Science and Engineering A*. 319-321, 501-505.

[18] Tupaj, M., Orłowicz, A.W., Mróz, M. & Trytek A. (2015). Fatigue Properties of AlSi7Mg Alloy with Diversified Microstructure. *Archives of Foundry Engineering*. 15(3), 87-90.

[19] Mróz, M., Orłowicz, A., Tupaj, M. & Trytek A. (2010). Fatigue of strength of MAR-M509 alloy with structure refined by rapid crystallization. *Archives of Foundry Engineering*, 10(3), 119-12