ARCHIVES
of
FOUNDRY ENGINEERING

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

ISSN (1897-3310)
Volume 15
Special Issue
3/2015

89 – 90

17/3

Fatigue Properties of AlSi7Mg Alloy with Diversified Microstructure

M. Tupaj*, A.W. Orłowicz, M. Mróz, A. Trytek
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 30.06.2015; accepted in revised form 20.07.2015

Abstract

The paper discusses the effect of microstructure on the fatigue strength of AlSi7Mg casting alloy refined conventionally with hexachloroethane without modifying and modified with TiB and Na. Castings made of both alloy variants were subjected to T6 heat treatment. It turned out that the applied refining secured satisfactory compactness of the material. In view of absence of gas and shrinkage porosity in the castings, short cracks nucleated on largest silicon precipitates and largest intermetallic phase precipitations as these were the locations where stress concentrations reached their highest values. Comprehensive modification of the alloy resulted in reduction of the value of SDAS parameter characterizing α(Al) phase dendrites, a decrease of the distance between silicone precipitates in the eutectic λ_E, and a decrease of the maximum size of silicone precipitates l_{maxSi}. The ultimate effect of these changes was an increase of the fatigue strength.

Keywords: AlSi7Mg03 alloy, Refining, Modification, Cooling rate, Microstructure parameters, Fatigue strength

1. Introduction

The rationale behind the wide use of aluminum-silicon alloys in automotive, machine-building, and household equipment industry is relatively low mass and good mechanical properties of castings made out of the material. Al-Si alloys are used to fabricate structures subjected to cyclic loads, including those characterized with resonance frequencies. Service properties of Al-Si alloys depend on size, shape, and distribution of silicon and intermetallic phase precipitations in the matrix.

It is a well-known fact that refining an alloy reduces its gas porosity, while an addition of titanium and boron results in refinement of α(Al) phase dendrites [1–3] which also induces reduction of both gas and shrinkage porosity. An addition of sodium has a favorable effect on morphology of silicon precipitates. The ultimate effect of refining and comprehensive modification is an improvement of mechanical properties [4–8] and increased fatigue strength [9–13] of aluminum-silicon alloys.

There are no studies published in available technical literature which would elucidate comprehensively the issue of complex effect of the multifaceted technological process of producing aluminum-silicon alloys on their fatigue resistance. Studies on this subject seem to be of special importance as the new knowledge following from them broadens the scope of possibilities in design of highly loaded and responsible castings. Such knowledge facilitates also taking the decision to use Al-Si alloys for castings working in critical conditions.

For this reason, the present paper is focused on the effect of refining and modification methods as well as the cooling conditions on microstructure and fatigue resistance of the production AlSi7Mg alloy.

2. The material and the research methodology

The material used in the present study was a hypoeutectic aluminum-silicon alloy (AlSi7Mg) prepared in production conditions typical for an aluminum foundry.

To obtain high compactness of the material and diversify microstructure of alloy samples subjected to the study, casting moulds were designed with an additional head riser over the wedge wider side and a steel chill at the base, similar to those described in [7] and [13].

It has been decided that the study will concern the alloy refined with hexachloroethane without modifying (Variant I) and the same alloy refined with hexachloroethane after modification with TiB and sodium (Variant II). For each of the two alloy variants, four similar moulds have been prepared made of self-curing sandmix. For the purpose of evaluation of the cooling rate in individual areas of wedge castings, two moulds, one for each of the alloy variants, were provided with thermocouples mounted in such a way that their coupling points were located at half thickness of individual cross-sections and at distances 10 mm and 110 mm from the chill surface. The thermocouples were mounted in steel tubular shields with outer diameter of 1.75 mm and 0.35-mm thick. The course of temperature changes after pouring the moulds with liquid metal was registered with the use of multi-channel input module ADAM 4018. On the grounds of the obtained result, the alloy cooling rate was evaluated within the range of crystallization temperatures.

The test alloy was prepared in a gas-fueled Selas-type furnace and the amount of 300 kg of it was poured to a preheated casting ladle with capacity of 400 kg. The alloy was then refined by adding hexachloroethane-containing tablets marketed under trade name Dursalit EG 281 (Variant I of the alloy). The liquid metal at temperature 710°C was poured into wedge-shaped moulds and samples of it were taken for chemistry analysis. The metal remaining in the ladle was modified with titanium/boron with the use of AlTi5B1 master alloy and vacuum-packed sodium known under trade name Navac. The alloy prepared this way was poured at temperature 705°C into the remaining wedge moulds and its samples were taken for chemical composition analysis. The cast wedges were heat-treated as per parameters proposed in [14]. The heat treatment included a solution treatment (540°C/6 h/water 20°C) followed by aging (175°C/8 h/air). Chemical composition of both variants of the alloy are given in Table 1.

Table 1.
Chemistry of the AlSi7Mg alloys

Alloy variant	Elements content								
	Si	Mg	Cu	Mn	Fe	Na	Ti	B	Al
I	7.06	0.32	0.01	0.01	0.09	—	—	—	bal.
II	7.04	0.31	0.01	0.01	0.09	0.0138	0.15	0.01	bal.

Example microstructures are shown in Fig. 1. The material for test samples has been cut out from the casting regions where the cooling rate was 94.5°C/min and 12.5°C/min (see Fig. 2).

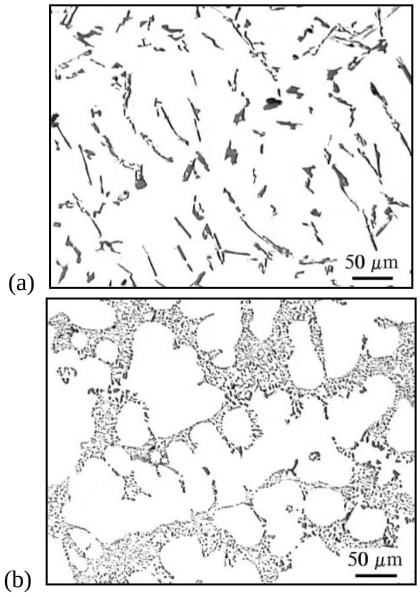

Fig. 1. Microstructure of AlSi7Mg alloy after: (a) refining with hexachloroethane and (b) refining with hexachloroethane and modifying with TiB and Na

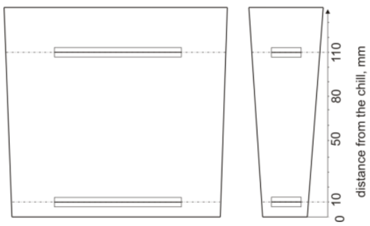

Fig. 2. Locations where material samples were taken for microstructure examination and fatigue strength tests

The shape and dimensions of samples used for fatigue strength tests are presented in Fig. 3.

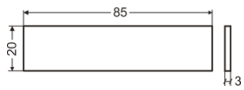

Fig. 3. Shapes and dimensions of samples for fatigue tests as per PN-76/H/04326-5

Fatigue strength tests were carried out in conditions of cyclically variable stresses induced by swinging flat bending carried out on GZ-1 machine [15, 16] as per PN-76/H/04326-5. The applied frequency of forced vibrations was $f = 73$ Hz.

3. Research results

Results of measurements of parameters characterizing the microstructure (SDAS, λ_E, and l_{maxSi}) and the fatigue strength values for two AlSi7Mg alloy variants are presented in Table 2.

Table 2.
Values of parameters characterizing microstructure and fatigue resistance for both AlSi7Mg alloy variants

Alloy variant / cooling rate $v_{cool.}$	Microstructure parameters			Fatigue strength Z_{gw}, MPa
	SDAS, μm	λ_E, μm	l_{maxSi}, μm	
I / 12.5°C/min	89.2	14.1	89.7	49.8
I / 94.5°C/min	34.8	9.5	39.6	65.5
II / 12.5°C/min	86.5	7.9	49.4	56.6
II / 94.5°C/min	28.8	4.3	11.3	75.6

Heat treatment: solution treatment — 540°C/6 h/water 20°C; aging —175°C/8 h/air.

Results of individual fatigue tests were used as a base for drawing up fatigue curves. Fig. 4 shows fatigue curves (Wöhler graphs) for two variants of AlSi7Mg alloy with microstructure diversified additionally as a result of different cooling rate, in condition after the heat treatment.

Fig. 5 shows example microstructures of AlSi7Mg alloy after fatigue strength tests observed in the plane normal to the fracture surface.

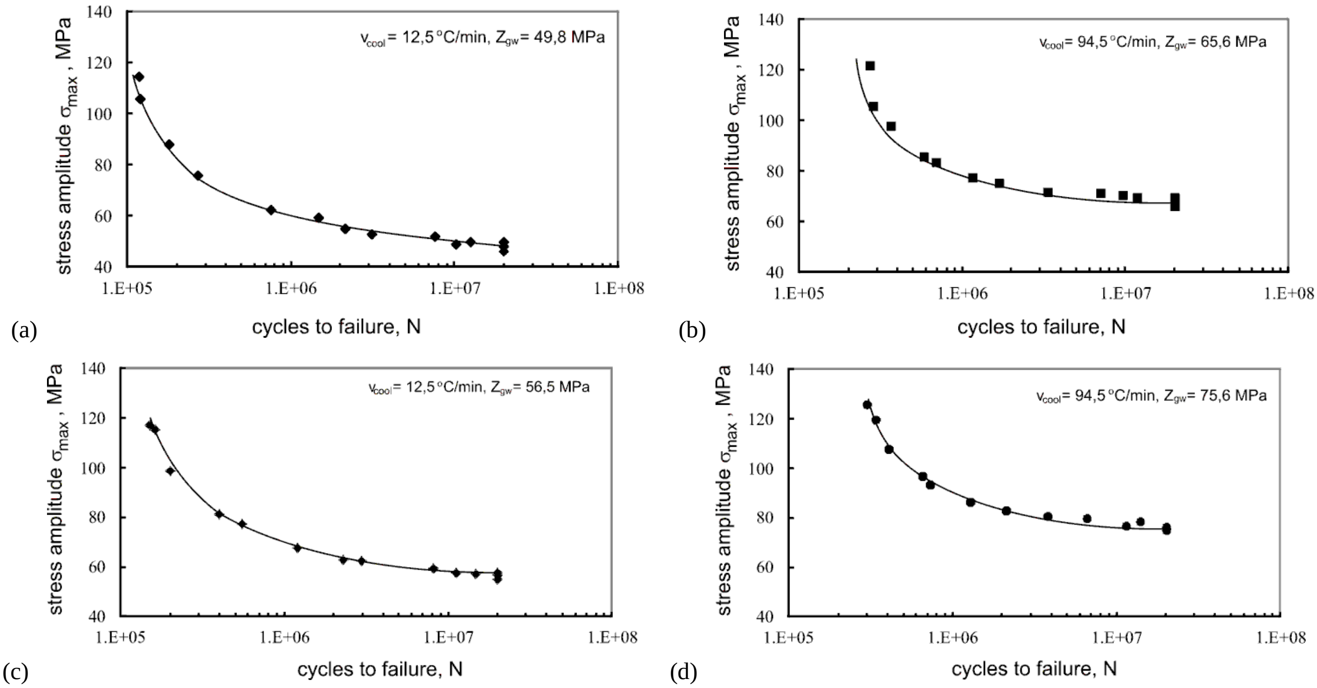

Fig. 4. Wöhler graphs for heat treated (solution treatment: 540°C/6 h/water 20°C, aging: 175°C/8 h/air) AlSi7Mg alloy: (a) alloy variant I, $v_{cool.}$ = 12.5°C/min; (b) alloy variant I, $v_{cool.}$ = 94.5°C/min; (c) alloy variant II, $v_{cool.}$ = 12.5°C/min; (d) alloy variant II, $v_{cool.}$ = 94.5°C/min

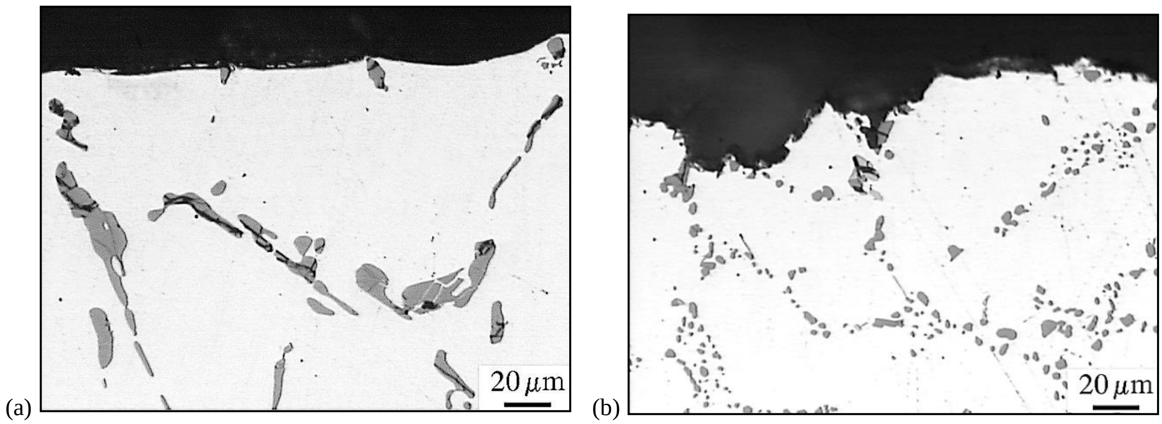

Fig. 5. Short cracks in silicon precipitates: (a) AlSi7Mg alloy variant I; (b) AlSi7Mg alloy variant II. Cooling rate 94.5°C/min

4. Conclusions

Application of modification with titanium, boron and sodium resulted, in particular in the case of low cooling rates, in a slight reduction of the SDAS parameter value in AlSi7Mg alloy. The increase of the cooling rate turned out to cause a significant reduction of the SDAS parameter for both variants of the material. A distinct effect in the form of refinement of α(Al) phase dendrites was obtained in the case of combination of modification and increased alloy cooling rate.

Comprehensive modification of AlSi7Mg alloy with titanium, boron, and sodium resulted in a distinct reduction of values of parameters λ_E and l_{maxSi}. The increase of AlSi7Mg alloy cooling rate from 12.5°C/min to 94.5°C/min caused the reduction of values of these parameters equally significant to this caused by comprehensive modification with titanium, boron, and sodium. By applying the two technological production process tools jointly, i.e. combining comprehensive modification with titanium, boron, and sodium with increased alloy cooling rate, a significant decrease of values of parameters λ_E and l_{maxSi} characterizing the AlSi7Mg alloy was obtained.

The combined effect of refining the alloy with hexachloroethane efficiently reducing the gas porosity, comprehensive modification with titanium/boron and sodium, and increased cooling rate, consisted in a distinct refinement of α(Al) phase dendrites and silicon precipitates in the alloy which ultimately resulted in increased fatigue resistance of the material.

It has been found that the fatigue cracking process in both variants of the alloy was initiated by formation of short cracks in silicon precipitates. As a result of reduction of silicon precipitation dimensions, lengths of the short cracks become also smaller which makes a difference as far as development of main cracks is concerned.

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] Poniewierski, Z. (1996). *Modification of silumins*. WNT: Warszawa. (in Polish).

[5] Wasilewski, P. (1993). Silumins, modification and its effect on structure and properties. A monograph. *Krzepnięcie Metali i Stopów*, *No. 21*. (in Polish).

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

[7] 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.

[8] 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.

[9] Maier, E. & Lang, G. (1985). Herstellung und Eigenschaften der Aluminium Gusslegierungen AlSi7Mg unter Berücksichtigung ihrer Veredlung mit Na, Sr und Sb. *Aluminium*, *61(12)*, 897–906.

[10] 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* (October), 2659–2666.

[11] 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.

[12] 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.

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

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

[15] Mróz, M., Orłowicz, A.W. & Tupaj, M. (2005). Fatigue strength alloy C355 solidifying in conditions of rapid solidification. *Archives of Foundry*, *5(15)*, 271–277. (in Polish).

[16] 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)*, 119–122.