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Influence of the structural changes on cavitation resistance of Al18SiCuMg alloy produced by rheocasting process

ABSTRACT

The influence of stirring speeds of 1000 and 1500 r/min on the microstructure of Al18SiCuMg alloy was investigated. The smaller size of Si particles of rheocast sample obtained by higher cooling rate and higher stirring speed was achieved. According to the results of cavitation test, the cavitation rate of the rheocast sample produced by 1500 r/min is lower than that of the rheocast sample obtained by 1000 r/min. The different results show that the mass loss as a function of time can be approximated either by liner or quadratic equations.
Keywords: *Al18SiCuMg alloy, rheocasting, microstructure, cavitation rate.*

1. INTRODUCTION

Hypereutectic aluminum-silicon (Al-Si) alloys are distinguished by the excellent wear and corrosion resistance, good strength, excellent castability and low density [1]. The properties of hypereutectic Al - Si alloys depend on the characteristics of cast microstructure and they can be improved by microstructure changes [2].

The improvements in the mechanical properties, wear and cavitation resistance are realized with the following changes: size, morphology (or shape), and distribution of primary and Si eutectic particles. Various methods can be employed to achieve previously mention improvements: the addition of some chemical elements such as Na, P, Sr [3**]**. Alternatively, physical method of modification include ultrasonic treatment [4], electromagnetic stirring and vibration [5,6], mechanical stirring [7]. One potential alternative to the tradition casting techniques is the application of rheocasting process [8]. This technique is based on the mechanical mixing of the melt during solidification produces rounded-shaped aluminium grains and fine primary silicon particles [9].

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The conventional aluminium alloys showed an insufficient cavitation erosion resistance. In previous studies was proved that the cavitation resistance of conventional materials depends on mechanical parameters (hardness, tensile strength, fatigue strength), microstructure (grain sizes, a number of material defects, phases) and also on surface roughness [10]. The objective of the present paper is to analysis microstructure and cavitation behavior of samples produced by rheocasting process. Moreover, based on the experimental observations adequate relations between mass loss and time is simulated. Good correlations between experimental data and calculated curve are obtained.

2. MATERIAL AND EXPERIMENT

The chemical composition of Al18SiCuMg alloy (matrix alloy) applied in this paper is listed in Table 1.

Table 1 - Chemical composition in wt.% of the matrix alloy

Si	Cu	Mg	Ni	Fe	Zn	Mn	Al
18.06	0.80	0.82	0.92	0.7	0.2	0.2	bala.

The rheocast process was conducted two series of experiments. The matrix alloy ingots of compositions shown in Table 1 was put into an alumina crucible that was then placed into an

electric resistance furnace and melted at 720°C to clean the slag from the melt surface. The thermocouple was immersed into the melt at position about 20 mm from the bottom of the crucible. During the casting procedure, the melt was cooled; when the temperature is dropped to the temperature range between liquidus and solidus temperatures and than stirring was applied. The active part of the platelike stirrer was then immersed into the semi-solid melt. Mixing of the melt was performed at stirring speeds of 1000 and 1500 r/min during solidification.

In the first group of experiments, the semi-solid melt was exposed to shear forces (stirring speed of 1000 r/min), and mixing time s: 99; 109; 120 then after these times, temperature of melt was dropped on (°C): 570; 565 and 559, respectively. After the (s): 85; 92; 103 of mixing, (at stirring speed of 1500 r/min) the melt was cooled to (°C): 570; 565 and 559 respectively. After reaching a given temperature at different mixing time the melt was poured into the steel mould. Metallographic samples were prepared by sectioning transversely at a level 20 mm from the bottom of crucible. On this way the microstructure changes were corresponded temperatures recorded by the thermocouple. Samples prepared for microstructural analysis underwent standard metallographic procedures (i.e. polishing and etching). Microstructural tests were carried out using both Carl Zeiss optical (OM) and JEOL JSM - 5800 scanning electron microscopy (SEM) with energy dispersive X - ray (EDX).The equivalent diameter is defined as the diameter of a circle having the same area as Si particles, measured by means of an image analysis program. Three measurements were taken from each sample. The equivalent diameter is calculated as follows:

$$D_{eq} = 2\sqrt{\frac{A}{\pi}} \qquad (1)$$

Based on the temperature data and the local solidification times, the local solidification rates for each casting were determined.

The following equation was used in order to calculate of solidification rate

$$T^* = \Delta T/\Delta t \qquad (2)$$

Where ΔT is the freezing range (°C) and Δt presents the solidification time (s), both are the measured values. Cavitation tests were performed using an ultrasonic device as described in the ASTM G32-92 Standard (the stationary specimen method) [11].

The duration of the tests was 4 h. Microstructural changes after cavitation erosion testing were recorded with the SEM.

3. RESULTS AND DISCUSSION

The experimental results of local solidification times and rates for Al18SiCuMg rheocast samples are presented in Table 2 for different speeds.

Table 2- Local solidification times and rates for Al18SiCuMg rheocast samples

Al-18wt.%Si	Rheocast samples		Local solidification time / s	Local solidification rate / °C s^{-1}
	1000 r/min	A	99	0.60
		B	109	0.59
		C	120	0.59
	1500 r/min	D	85	0.70
		E	92	0.70
		F	103	0.69

It is well known that shear rates and cooling rates have affect on the size and morphology of both, the primary and eutectic silicon particles. The cooling rates have a much greater influence on the refinement then the applied shear forces [12]. Rheocast microstructure is the result of a combination between the rapid solidification and the fragmentation of the dendrites α-Al in semi-solid state. In this way the microstructure of these samples is non dendritic. Agglomeration of the α-Al phase takes place also during rheocasting due to the influence of shear forces created by mixing.

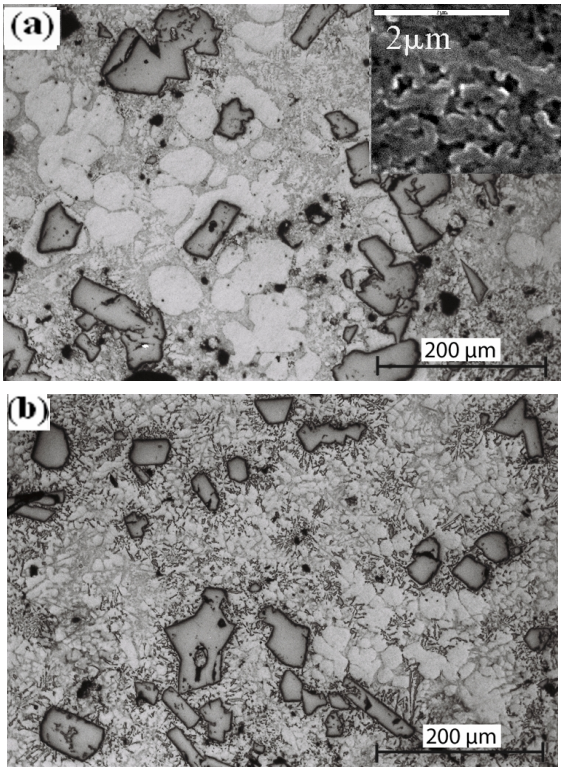

Figure 1 - Microstructures of samples a) A, b) D (OM, polished)

Nevertheless, the formation and evolution of rheocast microstructure is associated with the breakup of silicon particles (plate-like, polygonal) to small pieces after that these pieces agglomerated to form some large clusters. Representative micrographs of rheocast sample A and D are presented in Figure 1. Moreover, the microstructure of the eutectic zone was also shown on Figure 1a.

Further, the congregation of primary Si particles occurred in samples stirred at both stirring speeds (1000 and 1500 r/min) with decrease of temperature of melt. This indicates that the clusters were formed by congregating of many single primary Si particles.

Based on the OM micrographs and image analysis, the equivalent diameter of Si particles for all rheocast samples was determined (see, Figure 2). High cooling rate and stirring speed of the melt, lead to increasing of the number of the effective nucleus, decreasing of the average primary silicon particle size, especially for higher temperature of melt. The diameter of the Si particles is affected by the cooperation of the congregation effect and refining effect of stirring.

After cooling at 570°C, the equivalent diameter changes significantly. Increasing of equivalent diameter observed in the range of temperature 565°C - 559°C resulted by the agglomeration of Si particles.

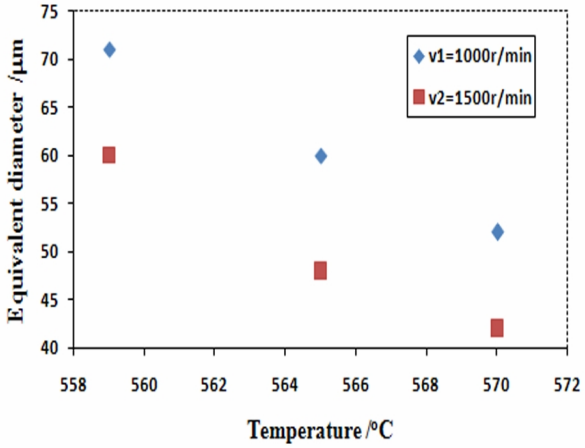

Figure 2 - Equivalent diameters of Si particles versus temperature

The samples A and D were used for cavitation test. The microstructure of the rheocast sample A after 4 h exposure cavitation is shown in Figure 3. In cavitation erosion, the α-Al phase was damaged by plastic deformation because it is softer then Si phase. In this way the high strength, eutectic Si phase was exposed the surface and protect the existing soft α-Al phase from cavitation erosion.

The Si particles with acicular morphology are responsible for the crack nucleation while modified eutectic Si morphology show more resistant to crack growth.

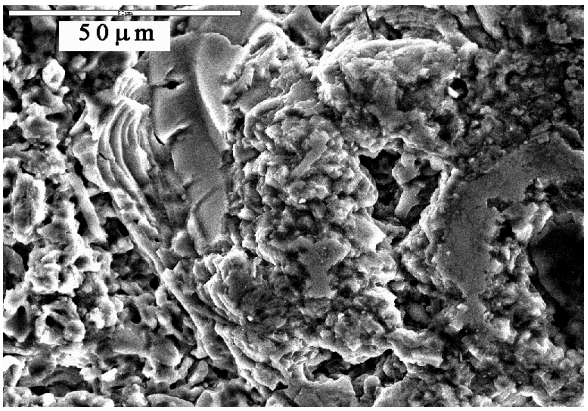

Figure 3 - Damage appearance of sample A

In this research, for the samples (A, D), reduced average primary silicon particle size and modification of eutectic silicon needle into fine fibrous (caused by stirring), improved cavitation erosion resistance. The common linear trendline between mass loss and testing time during cavitation is shown in Figure 4. The slope for rheocast sample A and D correspond to the cavitation rate of 0.147 mg/min and 0.139 mg/min respectively. The difference of the mass loss between samples (A and D) can not be recognized at the initial test time until 0.5 h (Figure 4). Namely, at the beginning of test, the difference between grain sizes had no effect on cavitation rates. However, after that, total mass loss was increased. Mass loss for sample A, after 1h of cavitation was higher than the sample D.

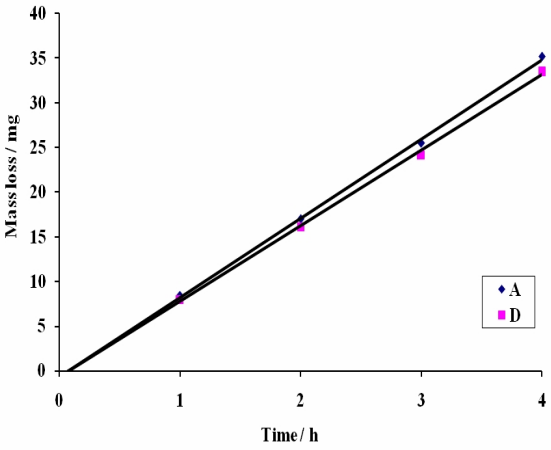

Figure 4 - Cavitation erosion of tested samples as a function of time

It can be observed from Figure 4 that the mass loss increases linearly with time and can be described by the following Equation (3, 4):

Sample A: $m = 8.88 * t - 0.695$ *(3)*

Sample D: $m = 8.458 * t - 0.715$ *(4)*

Moreover, the results of cavitation tests show that the relationship between the mass loss and the time can be approximated by a quadratic equation.

Function between mass loss and time for samples A, D (see Figure 4) can be simulated by the following relationships (5, 6).

Sample A: $m = 0.265 * t^2 + 7.555 * t + 0.63$ (5)

Sample *D:* $m = 0.28 * t^2 + 7.058 * t + 0.685$ *(6)*

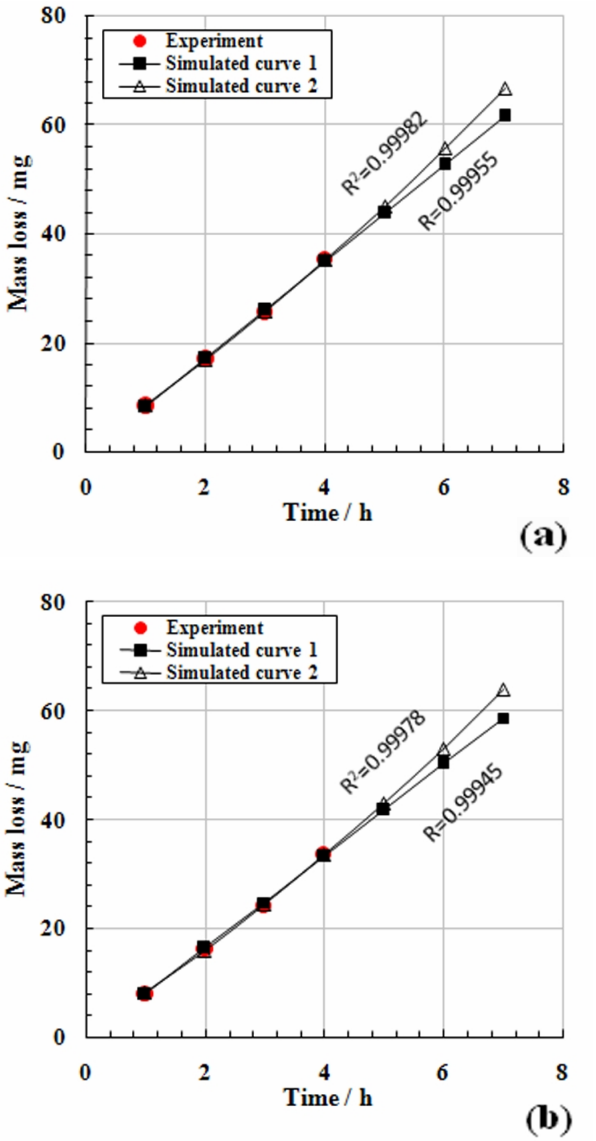

Figure 5 - Mass loss versus time: 1-Liner equation 2- Quadratic equation for sample a) A; b) D

Simulated curves (related to mass loss versus time) for considered samples (A,D) either as linear or quadratic are presented in Figure 5 a-b. All curves are in a good correlation with experimental results in the domain from 1 h to about 5 h.Those relationships can be used as a control of mass loss in the cavitation condition.

4. CONCLUSIONS

In this paper, the obtained results showed that the investigated material exhibited very good cavitation resistance. Experimental investigation mass loss has linear trend with time. Furthermore, the different size of silicon particles has not significant influence on cavitation behavior until 0.5 h for rheocast samples. The differences between of Si grain sizes are also responsible for different cavitation resistance of considered castings after 0.5 h testing. Experimental results for function between mass loss and time can be simulated by different equations. In this study based on experimental results linear and quadratic equations are suggested. These equations can be used as a control tool for monitoring of mass loss in the cavitation condition.

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IZVOD

UTICAJ STRUKTURNIH PROMENA NA KAVITACIONU OTPORNOST Al18SiCuMg LEGURE PROIZVEDENE REOKASTING PROCESOM

U radu je ispitivan uticaj brzine mešanja od 1000 i 1500 obrta/min na mikrostrukturu Al18SiCuMg legure. Manja veličina Si čestica u reokast uzorcima postignuta je pri većoj brzini hlađenja i većoj brzini mešanja. Prema rezultatima kavitacionog ispitivanja, kavitaciona brzina reokast uzoraka dobijenih pri brzini mešanja od 1500 obrta/min je niža u odnosu na reokast uzorke dobijene pri brzini mešanja od 1000 obrta/min. Rezultati ispitivanja pokazuju da se gubitak mase u funkciji vremena može aproksimirati ili pomoću linearnih ili kvadratnih jednačina.

Ključne reči: *Al18SiCuMg legure, reokasting, mikrostruktura, kavitaciona brzina.*

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