Grain Refinement, Modification, Degassing and Melt Quality Relationship in Al-7Si-0.3Mg

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Abstract

In this work, Al-7Si-0.3Mg alloy was studied. The alloy conditions was selected to be as-received, AlB_3 grain refined and Sr modified. For each parameter, castings were made before and after degassing. In order to quantify the melt quality, reduced pressure test was used and bifilm index measurements were made. All the cast parts were subjected to metallographical examination, and thus, porosity measurements, distribution, area fraction were compared for each of the casting conditions.

Keywords: Casting, Grain refinement, Modification, Casting quality, Porosity

Özet

Bu çalışmada, ötektik altı alaşımlardan Al-7Si-0,3Mg çalışılmıştır. Deneysel parametreler, tane inceltme (AlB_3) ve Modifikasyon (Sr) seçilmiştir. Her parametre için gaz gidermeli ve gaz gidermesiz dökümler yapılmıştır. Döküm kalitesini incelemek için azaltılmış basınç test numuneleri alınmıştır. Tane inceltme ve gaz giderme işlemlerinin gaz gidermeli ve gidermesiz dökümleri için döküm kalitesi detaylı bir şekilde irdelenmiştir. Döküm kalitesinin ölçümünde kullanılan bifilm indeksleri ayrı ayrı çıkarılarak her parametre için sayısal bir kalite değeri belirlenmiştir. Mikroyapıda meydana gelen değişimler ve sayısal olarak belirlenen kalite tüm parametreler göz önünde bulundurularak ilişkilendirilmiştir. Gaz gidermeli dökümlerde porozite dağılımının ve miktarının gaz gidermesiz dökümlere kıyasla kaliteyi yükseltecek nitelikte olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Döküm, Tane İnceltme, Modifikasyon, Döküm kalitesi, Porozite

1. Introduction

Aluminum cast parts are widely used in several applications and industries from automotive to electronics, from nuclear to weaponries [1]. Therefore, it is important that high quality products need to be produced without any defects. Typically, it has been aimed to obtain finer grain structure by addition of grain refiners. It has been shown that the level of impurity decrease with increased area of grain boundary and decreased grain size [2] . For Al-Si alloys, Al-Ti-B grain refiners can be added to alter the coarse α-Al to finer dendrites without changing the morphology of eutectic Si [3]. As an alternative to Ti grain refinement, Al-3B alloy can also be used. This master alloy contains B, AlB_2 and AlB_{12} particulates. AlB_{12} can be unstable depending on the B content of the melt; and reacts with Al to form AlB_2 which is a peritectic reaction [4, 5].

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$$AlB_{12}(s) + 5Al(l) \rightarrow 6AlB_2(s)$$

AlB_2 is dissolved in liquid aluminium. Together with the remaining dissolved B, both AlB_2 and B reacts with Al to act as heterogeneous nucleants for grain refinement process [6]. Arberg [7, 8] has done a study with B grain refinement in the absence of Ti and show that more globular dendrites were obtained and improved efficiency was achieved compare to Ti. Dispinar [9] had done a work where the porosity distribution between Ti and B grain refinement was studied. It was found that more localised porosity was observed with B grain refinement compare to the evenly distributed pores with Ti grain refinement. It is also well known that Ti tends to sink to the bottom due to higher density which is known as the fading act. On the other hand, with B grain refinement, due to the eutectic reaction, there is no fading effect.

For the modification of the Si structure in Al-Si alloys, 200 ppm Sr is enough to alter the lamellar coarse morphology to finer fibrous form [10].

Dispinar has carried out an extensive study to quantify aluminium melt quality by using reduced pressure test. The test is done at 100 mbar and the cross section of the samples are used to analyse the number and the length of the pores as an indication of bifilm content and bifilm length. The sum of the maximum length of pores are taken as the bifilm index that is given in millimetres [11].

In this work, Al-7Si-0.3 Mg alloy was used and AlB_3 was selected as the grain refiner and Sr was used for Si modification. The change in the melt quality with various treatment of the melt was studied in detail.

2. Experimental work

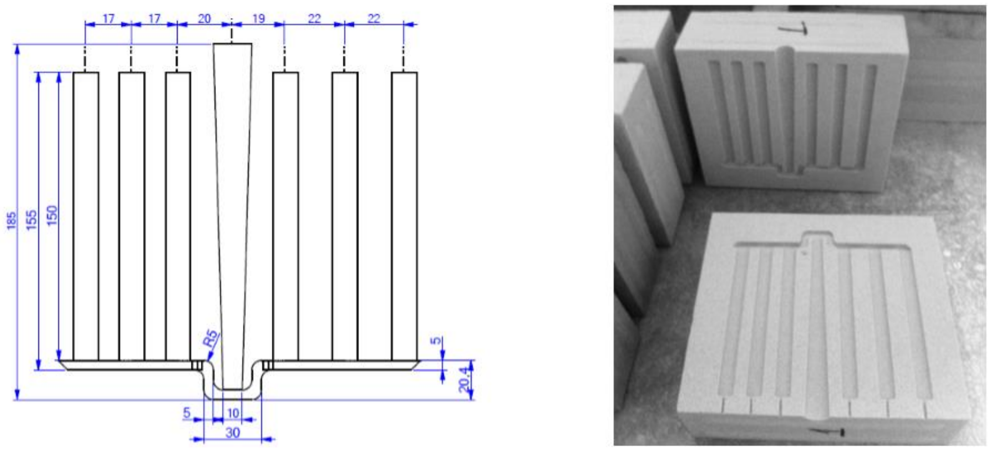
Chemical composition of the alloy studied is given in Table 1. The melting process was carried out in a 20 kg capacity resistance furnace in a coated SiC crucible. The castings were made into the sand moulds where the dimension is given in Figure 1.

Table 1. AL-7Si-0.3Mg alloy chemical composition

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
6,60-7,40	0,20	0,02	0,03	0,30-0,45	0,04	0,08-0,14	Rem

The casting conditions were as follows: the charge in the as-received condition, AlB_3 grain refined, Sr modified, AlB_3 + Sr modified. For each melt, degassing process was carried out with Ar for 12 minutes and samples were produced before and after this step. Thus, overall, there were eight conditions obtained.

Microstructural examination was carried out on the castings obtained by grinding, polishing, etching and microstructures were investigated by Nikon optical microscope.



(a) (b)

Figure 1. a) The dimension of the mould b) The sand mould used in the casting trials

For measuring the melt quality, reduced pressure test (RPT)as used to cast 100 g of samples in plate like geometry sand moulds. The solidification was completed under 80 mbar. The samples were then sectioned, grinded and subjected to image analysis (Clemex) to measure the pore size, pore area and shape factor.

3. Results

The cross section of the RPT samples of all the casting conditions are given in Figures 2 and 3.

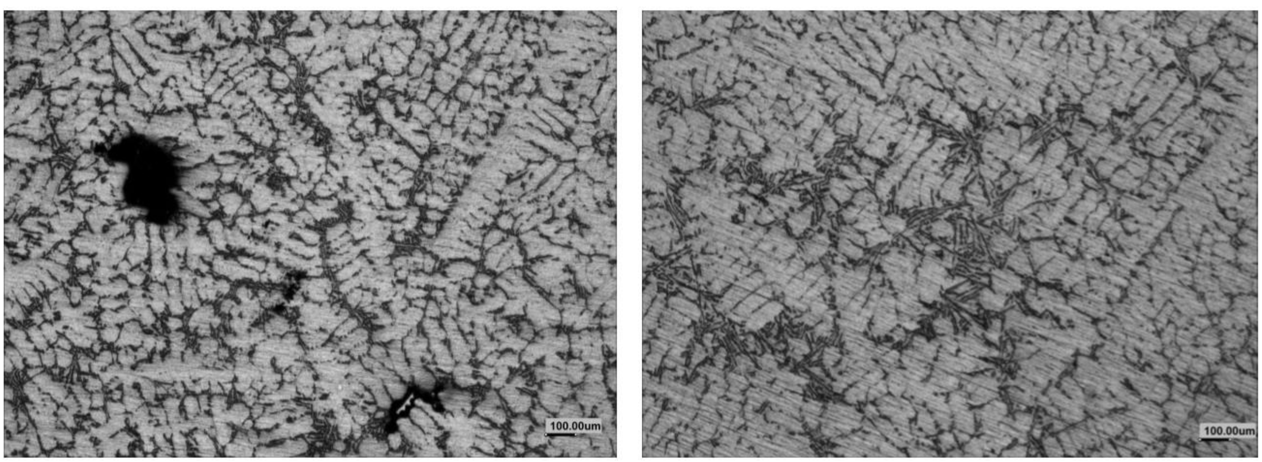
(a) (b) (c)

Figure 2. RPT samples produced from the untreated melt (a) as-received, (b) Sr modified, (c) AlB_3 grain refined

(a) (b) (c)

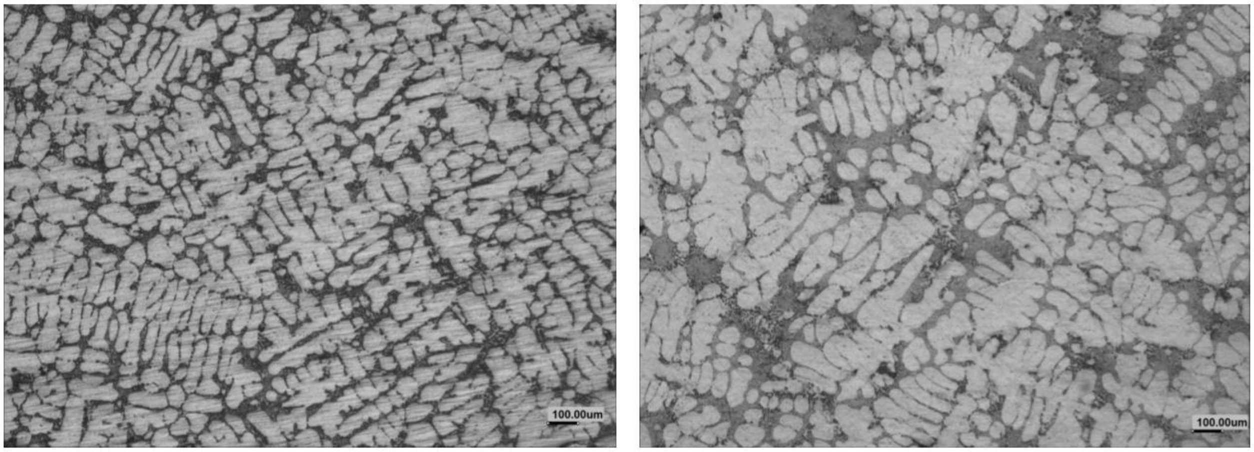
Figure 3. RPT samples produced from the degassed melt (a) as-received, (b) Sr modified, (c) AlB_3 grain refined

From Figures 4 to 6, the microstructure of the samples are given for as-received, Sr modified, AlB_3 grain refined, respectively.



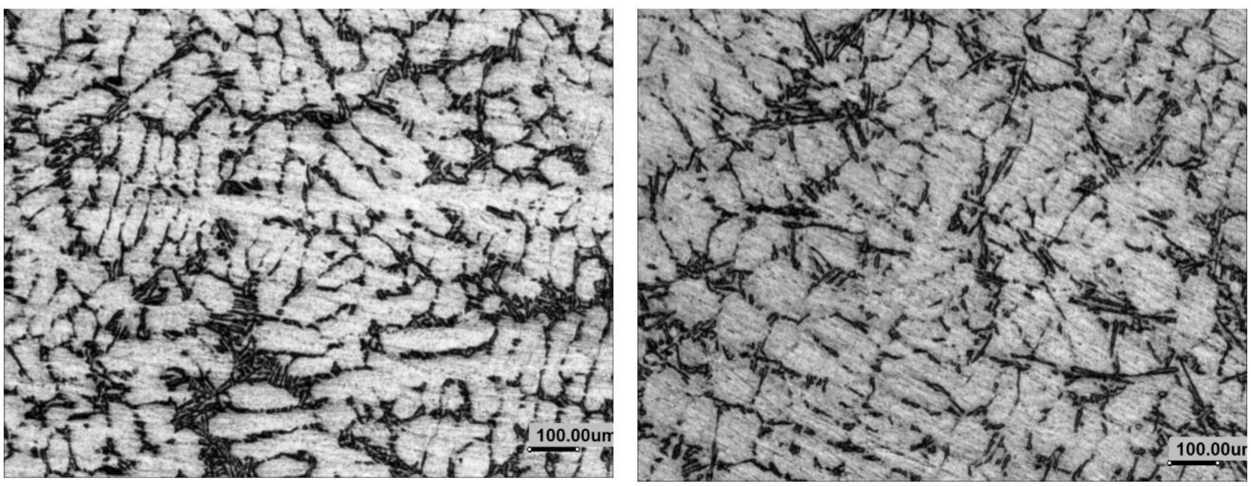
(a) (b)

Figure 4. Microstructures of the as-received alloy
a) Untreated melt, b) degassed melt



(a) (b)

Figure 5. Microstructures of the Sr modified alloy
a) Untreated melt, b) degassed melt



(a) (b)

Figure 6. Microstructures of the AlB_3 grain refined alloy
a) Untreated melt, b) degassed melt

Bifilm index measurement from the sectioned surface of RPT samples are given in Figure 7.

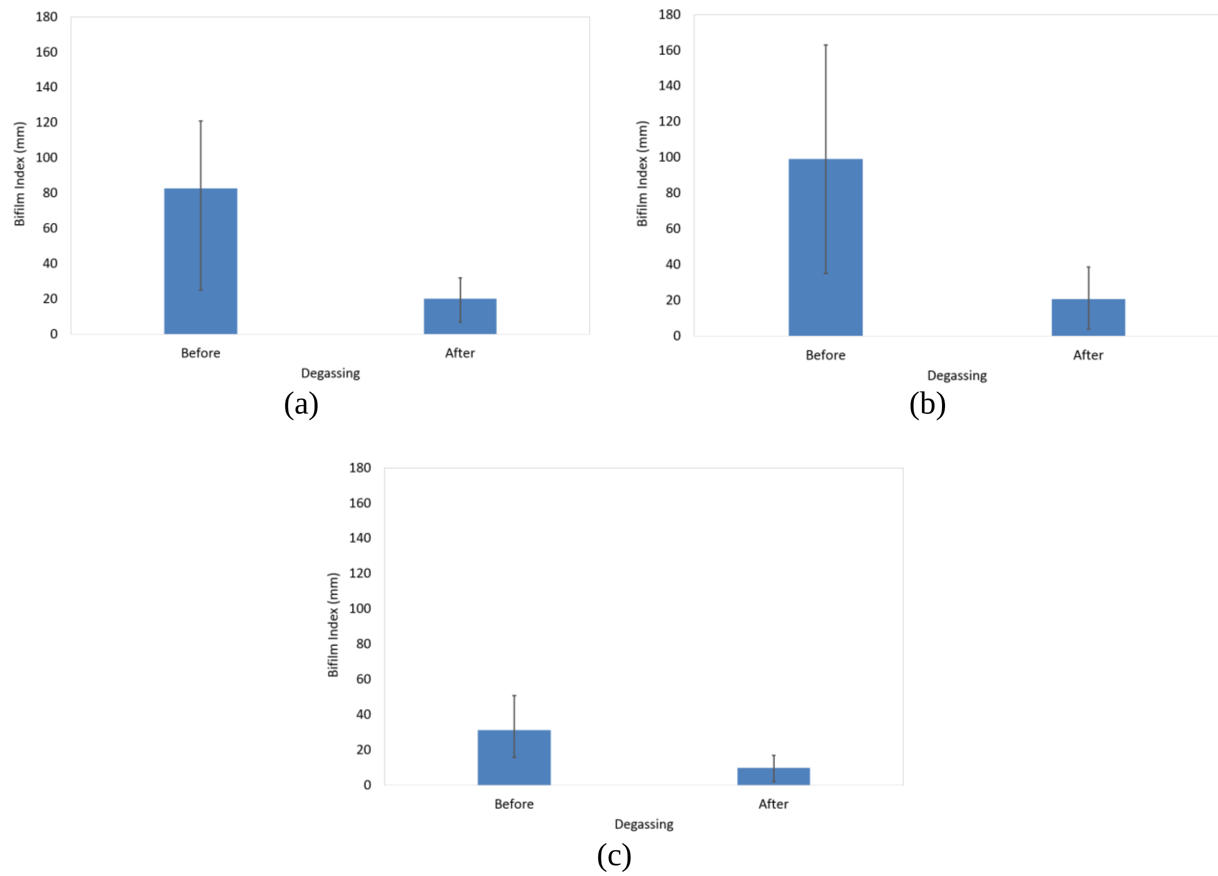


Figure 7. Bifilm index change of the melt before and after degassing
(a) As-received, (b) Sr modified, (c) B grain refined

4. Discussion

The degassing process in the treatment of aluminium melts are typically carried out to decrease the hydrogen content of the melt. And thus, it is expected to obtain minimised porosity in cast parts. However, Dispinar has shown that hydrogen is not the major source for porosity formation in aluminium castings. It only acts as a contributor to the pore formation. As long as bifilms are present in the melt, due to the unbonded folded oxide skin, these defects start to open up by the negative pressure generated during liquid-solid contraction (i.e. shrinkage). It has also been shown by Campbell that bifilms can be opened by the solidification mode such that growing dendrites can push the bifilms and physically force them to unravel. Therefore, when a grain refiner is added to the melt, the globular and homogeneous dendritic structure will results in faster growth and bifilms may not find the time open; thus porosity will not form. It is important to note that in this case, if bifilms may exist in the melt but they will not be observed as pores simply because they are not opened. On the other hand, the mechanical properties would decrease due to the presence of bifilms in the form of non-metallic inclusions.

Since there exists no porosity that can be created only by hydrogen, the decrease in the porosity after degassing process can only be explained by the removal of bifilms with the rising bubbles in the melt. Dispinar had shown this effect by changing the hydrogen level of the melt by degassing and upgassing. And this could be quantified and measured using reduced pressure test.

In this work, a series of melt treatments were investigated. Al-7Si-0.3Mg alloy was obtained and 10 kg of charge was melted in a resistance furnace. RPT samples were collected before and after degassing. In another test, same procedure was carried out, but this time, the melt was modified with Sr. In the third test, the melt was grain refined by AlB_3. The results were given in Fig 2,3 and 7. As can be seen from the sectioned surfaces of RPT samples in Figure 2, the untreated melt samples have quite high number of pores. These values are 50, 70 and 20 for as-received, Sr modified and AlB_3 grain refined melts respectively. The corresponding bifilm index values are 82 mm, 125 mm and 32 mm respectively. After the degassing of the melt with Ar for 12 minutes, the bifilm index values dropped down to 20 mm, 20 mm and 9 mm for as-received, Sr modified and AlB_3 grain refined melts respectively.

It is important to note that the decrease in the bifilm index was 4 folds for as-received melt and 5 folds for Sr modified alloy. In other words, after degassing, the melt quality was increased 4 to 5 times. This increase in the melt quality was around 3 times for the AlB_3 grain refined melt. It might be assumed that grain refinement has not affected the melt quality significantly. However, the most interesting finding in this work is the achievement of lowest bifilm index by the grain refinement even before degassing process. The bifilm index of the untreated and as-received melt was 82 mm. When AlB_3 was added, the index was dropped down to 32; almost 2.5 times lower. This indicates that the addition of grain refinement has some influence over the bifilms. It is possible that the grain refiner reacts with bifilm; i.e. heterogeneous nucleation takes places and sediments the bifilms to the bottom of the crucible. This conclusion can be made by looking at the cross section of the untreated melt (Fig 2a) and AlB_3 grain refined samples (Fig 2c). It can be clearly seen that the number of pores were significantly decreased. From the image analysis results, these values were calculated to be 57 (Fig 2a) and 21 (Fig 2c), respectively. A further detailed explanation of this phenomena is still being studied to be discussed in the future.

Conclusion

By the degassing of aluminium melts, 4 to 5 times higher quality melts can be obtained simply by removing bifilms with the rising bubbles in the melt. The bifilm index values were decreased from 100 and 80 mm to 20 mm after degassing for the as-received and Sr modified melts respectively.

Bifilm index can be used to quantify aluminium melt quality. There are no other liquid metal cleanliness measurement methods that can give numerical indication of melt quality.

The number and size of pores decreases when Sr and AlB_3 is added to Al7Si alloy.

Grain refinement of Al7Si-0.3Mg by AlB_3 increases the melt quality possibly due to the heterogeneous nucleation of AlB on bifilms and sedimenting them to be collected at the bottom of the crucible.

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