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Evolution of Aluminium Melt Quality of A356 After Several Recycling

O. Gursoy [a], E. Erzi [b], K. Tur [c], D. Dispinar *, [d]
[a] University of Padova, Italy
[b] Istanbul University-Cerrahpasa, Turkey
[c] Atilim Univeristy, Turkey
[d] Istanbul Technical University, Turkey
* Corresponding author: Email address: derya.dispinar@gmail.com

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Abstract

Recyclability is one of the great features of aluminium and its alloys. However, it has been typically considered that the secondary aluminium quality is low and bad. This is only because aluminium is so sensitive to turbulence. Uncontrolled transfer and handling of the liquid aluminium results in formation of double oxide defects known as bifilms. Bifilms are detrimental defects. They form porosity and deteriorate the properties. The detection and quantification of bifilms in liquid aluminium can be carried out by bifilm index measured in millimetres as an indication of melt cleanliness using Reduced Pressure Test (RPT). In this work, recycling efficiency and quality change of A356 alloy with various Ti additions have been investigated. The charge was recycled three times and change in bifilm index and bifilm number was evaluated. It was found that when high amount of Ti grain refiner was added, the melt quality was increased due to sedimentation of bifilms with Ti. When low amount of Ti is added, the melt quality was degraded.

Keywords: A356, Bifilm index, Recycling, Melt quality, Reduce pressure test

1.Introduction

The use of aluminium is increasing in many applications. Due to energy and environmental issues, recycling of aluminium has been an attractive field of research. Recycled aluminium is also known as secondary aluminium. Energy-wise, only 5% of the energy of primary production consumption is required to recycle aluminium [1]. Thus, this makes the recyclability of aluminium an economic way to produce raw materials or cast parts. It has been reported that 30% of aluminium is being recycled around the world [1]. Main challenges during the recycling of aluminium is the dross formation and the entrainment of the surface oxide into the melt. The incorporation of the oxide occurs in such mechanism that the folded oxides include an air gap. Thus, oxide and porosity can be mechanically submerged into the cast part. This is known as a bifilm defect [2]. The number of bifilms in the melt has to be decreased prior to casting. This can be detected by using Reduced Pressure Test (RPT). A sample is solidified under vacuum and image analysis is carried out on the cross-section in order to quantify bifilm content which is known as bifilm index [3]. It has been proposed by Dispinar [4] that the quality can be classified as:

0-10 mm: best quality
10-50 mm: good quality
50-100 mm: bad quality
> 100 mm: do not cast

Another important parameter besides the melt quality is the mechanical properties. Tuncay [5] showed that when Fe content was as low as 0.2 wt%, higher and more reproducible tensile properties were achieved compare to 1.2 wt% Fe. Puga [6] used ultrasonic degassing to improve melt cleanliness. It was found that oxides were removed efficiently and when the mould was filled below the critical velocity (0.5 m/s), Weibull modulus of mechanical properties were increased. Matejka [7] used A319 alloy and reported that after 4th recycling, the melt quality was decreased and tensile properties were lowered. Gyarmati [8] assessed the melt cleanliness by RPT using CT scan. The presence of oxides were reported inside the pores which revealed that bifilms had initiated pore formation. Davami [9] concluded that turbulent filling would result in bifilm entrainment and as a result, Weibull modulus of tensile properties would decrease. Quality index of A356 alloy subjected to different heat treatments was compared by Czekaj [10]. Do Lee [11] reported that oxides in the pores had resulted in lowered fatigue properties.

For enhanced mechanical properties, the elongation at fracture is required to be high. In order to accommodate this property, grain refiners are added to aluminium alloys. The most preferred grain refiners are Al-Ti, Al-B, Al-Ti-B or Al-Ti-C. These alloys have peritectic reactions that aid the heterogeneous nucleation which results in finer dendritic structure. Krajewski [12] added different ratios of Ti and found that damping coefficients were remained almost unchanged after 25 ppm Ti. Li [13] added Sc and Zr as grain refiner and modifier and found that 0.5wt% Sc was enough to grain refine 10 times. There are several mechanisms found in the literature that define the mechanism of grain refinement [14]. The most common conclusion is the sedimentation of Ti in the liquid state [15]. It has been proposed by Gursoy [16] that Ti can actually sedimented bifilms as well and thus may have the possibility to improve melt quality.

Recyclability of aluminium alloys are quite high which makes it a popular alloy. However, the melt quality change after recycling has not been studied, particularly in terms of the change in bifilm content. Therefore, in this work, the effect of different level of Ti addition on the melt quality change and recycling efficiency have been investigated in A356 alloy.

2.Experimental Procedure

Secondary A356 alloy was used in this work where the chemical composition is given in Table 1. It can be seen that the composition is within the ASTM B26 standard.

Table 1.
Chemical analysis of secondary A356 alloy

	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
standard	6.5-7.5	0.2-0.6	<0.2	<0.10	0.25-0.45	<0.1	<0.20	bal.
analysis	6,60	0,35	0,02	0,03	0,28	0,04	0,14	bal.

The charge was melted in a resistance furnace at 750^{o}C. SiC crucible was used to prepare 5 kg of charge. Every 5th minute an RPT sample was taken and led to solidify under 100 mbar. RPT mould was a steel cup with dimension given in Figure 1.

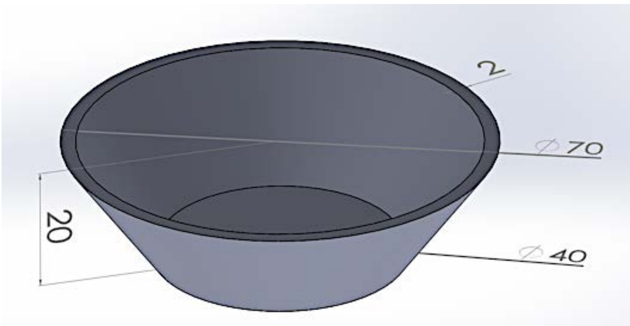

Fig. 1. Dimension of RPT steel cup

Al-5Ti-1B master alloy was added to the melt in two different ratios: 0.1 and 1 wt%. The tests were repeated three times and bifilm index [17] was measured in every test. Kameram image analysis software was used to measure pores on the cross-section of samples and Minitab was used for statistical analysis.

3. Results and Discussion

The change in the bifilm index and bifilm number after 3 consecutive remelting tests of A356 with 0.1 and 1 wt% Ti added charge is given in Fig 2 and 3.

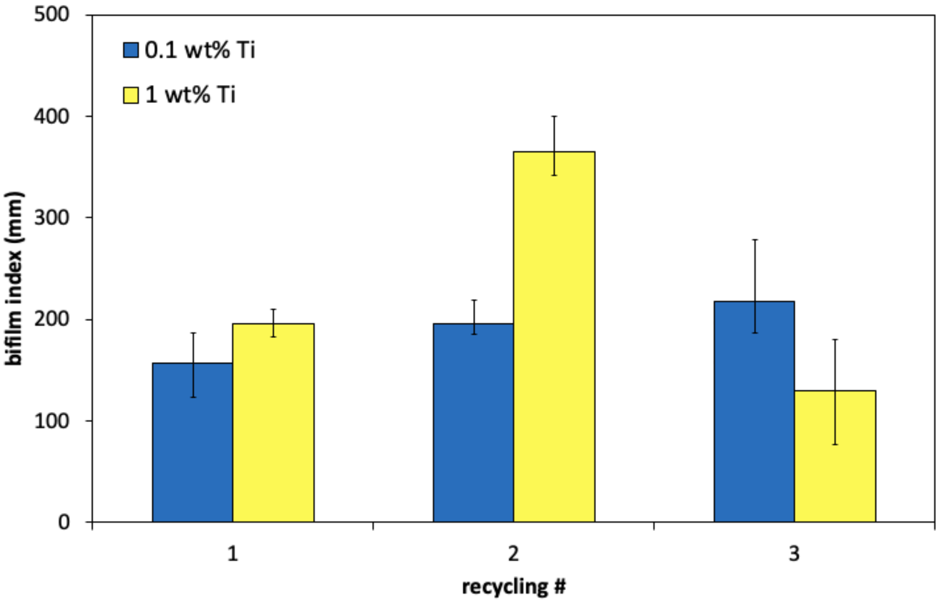

Fig. 2. Bifilm index of 3 times recycled 0.1 and 1 wt% Ti added A356

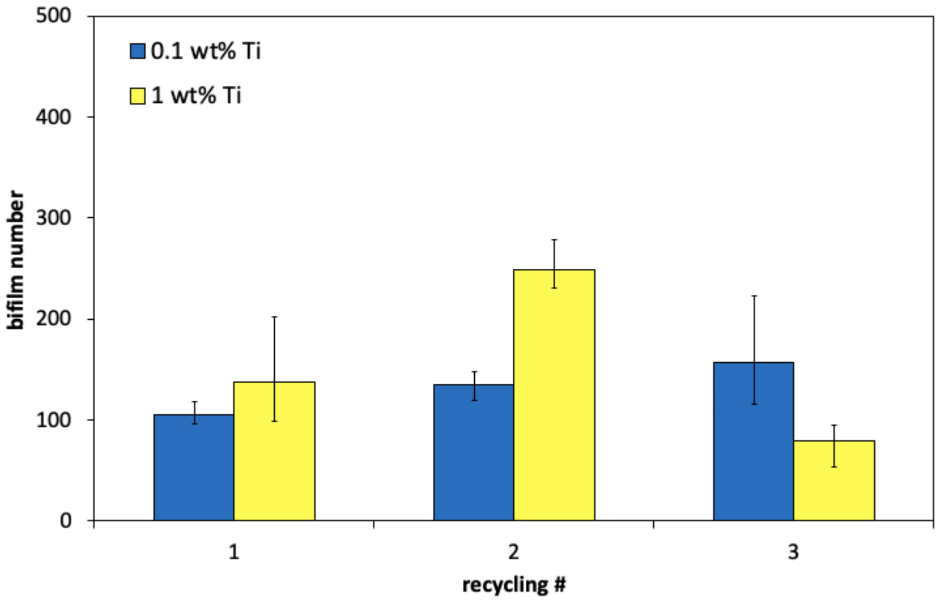

Fig. 3. Number of bifilm change of 3 times recycled A356 with 0.1 and 1 wt% Ti

The general trend in Fig 2 where 0.1 wt% Ti was added to A356 show that towards the third recycling, the bifilm index and number of bifilm increased linearly. This suggests that every time Ti grain refiner was added and the material was recycled, the bifilm content was increased. On the other hand, when excess amount of Ti was added (1 wt%), the melt quality was decreased significantly after the second recycling where bifilm index was increased from 200 mm to 400 mm. However, in the third recycling, bifilm index was decreased to 150 mm which shows that melt quality was improved.

In Figure 3, the change in number of bifilms of 0.1 and 1 wt% Ti added A356 are given. In contrast to the castings where 0.1 wt% Ti was used, these castings show opposite behaviour. There is a similar trend of number of bifilms with the bifilm index. For the 0.1wt Ti added and recycled A356, the number of bifilms increase from 100 to 125 to 160 after three recycling respectively. For the 1 wt% Ti added alloy, this increase in the second recycling was from 120 to 280. However, after third recycling, the number of bifilms were decreased to 80.

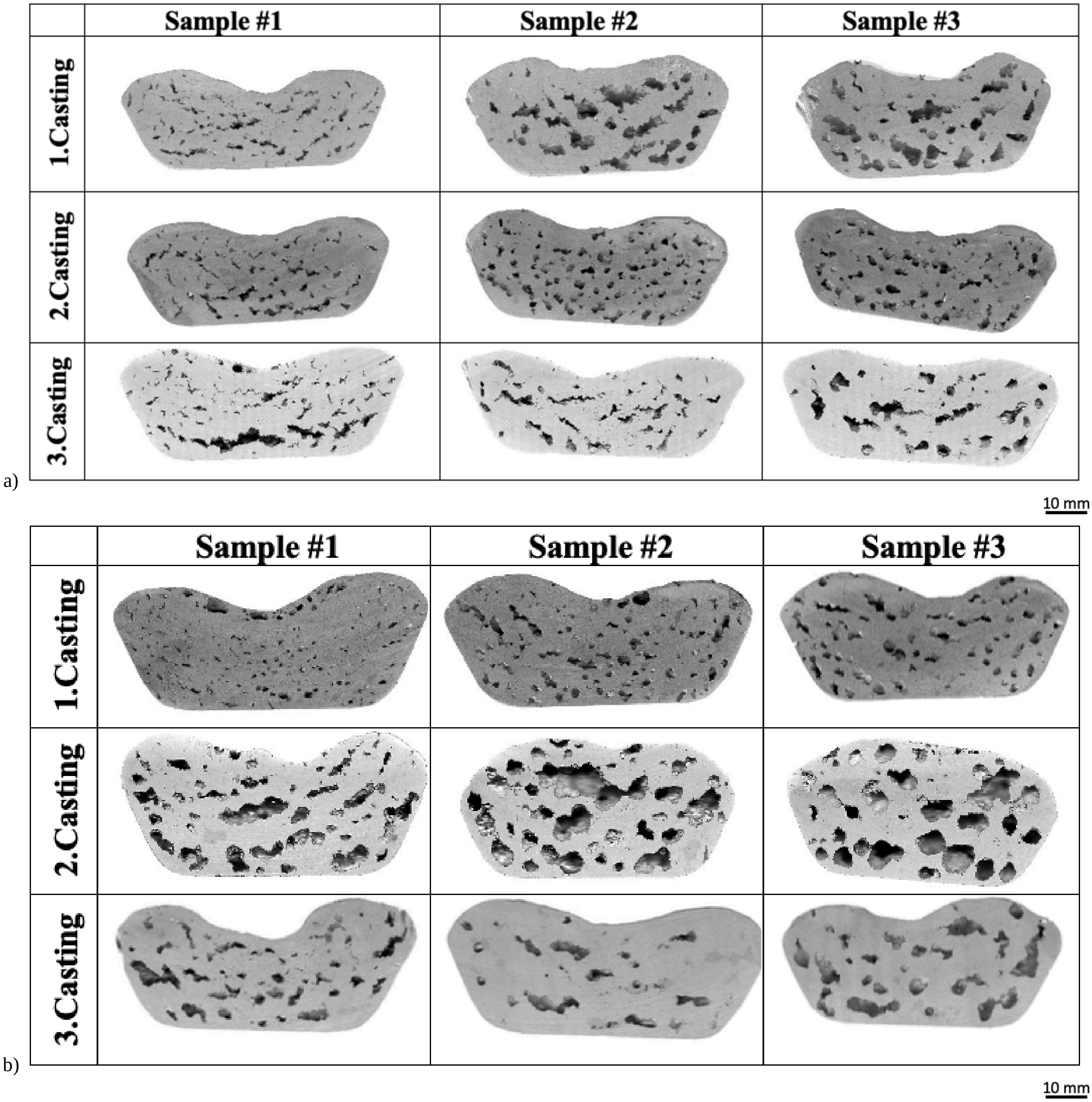

Fig. 4. Cross section of samples after three recycling: a) 0.1 wt% Ti added, b) 1 wt% Ti added A356

This reveals that as Ti content was increased, the Ti-intermetallic would nucleate on bifilms; and due to their high density, they would sedimented the bifilms together to the bottom of the crucible. The cross-section of RPT samples are given in Figure 4. It can be seen that pores are elongated and crack-like in 0.1 wt% Ti added alloys whereas the pores appear larger but their number decreases in 1 wt% Ti added and recycled A356. It is also important to note that the sample sequence represents the top, middle and bottom of the crucible. As seen in Figure 4, in each case for all castings, as the melt is consumed, number of the pores decreases (from Sample #1 towards Sample #3. However, the pore size increases.

For statistical analysis, density distribution function results of pores measured on the cross section of RPT samples were analysed. The results are given in Figure 5 and 6. As seen in Figure 4, the pore size (i.e. bifilm size) is almost unchanged in 0.1 wt% Ti added and recycled A356. The density distribution gets slightly wider towards third recycling but the average bifilm index is almost the same.

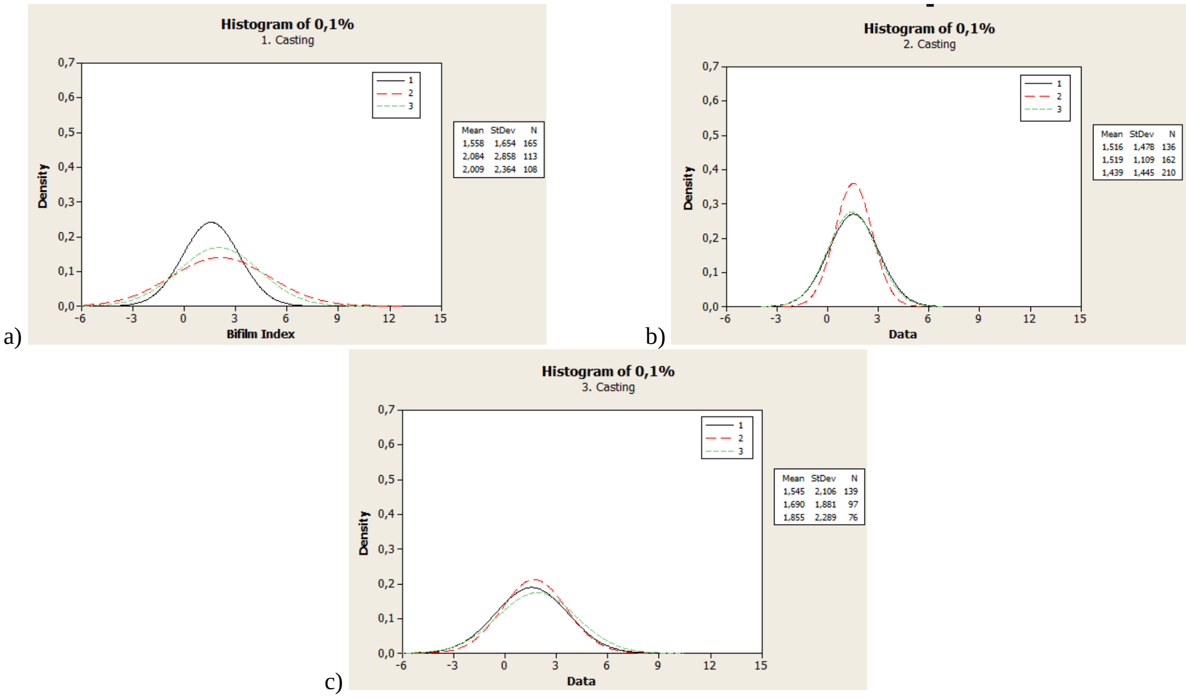

Fig. 5. Density distribution function of pores measured on the cross-section of reduced pressure test samples 0.1 wt% Ti added and recycled A356: a) 1st recycling, b) 2nd recycling, c) 3rd recycling

When 1 wt% Ti is added to A356 and recycled three times, the density distribution changes significantly. In the first recycling, the distribution is narrow and steeper. After second recycling, the density decreased and wider distribution of pores are observed. In the third recycling, the distribution gets even wider which indicates that the size distribution of pores is scattered.

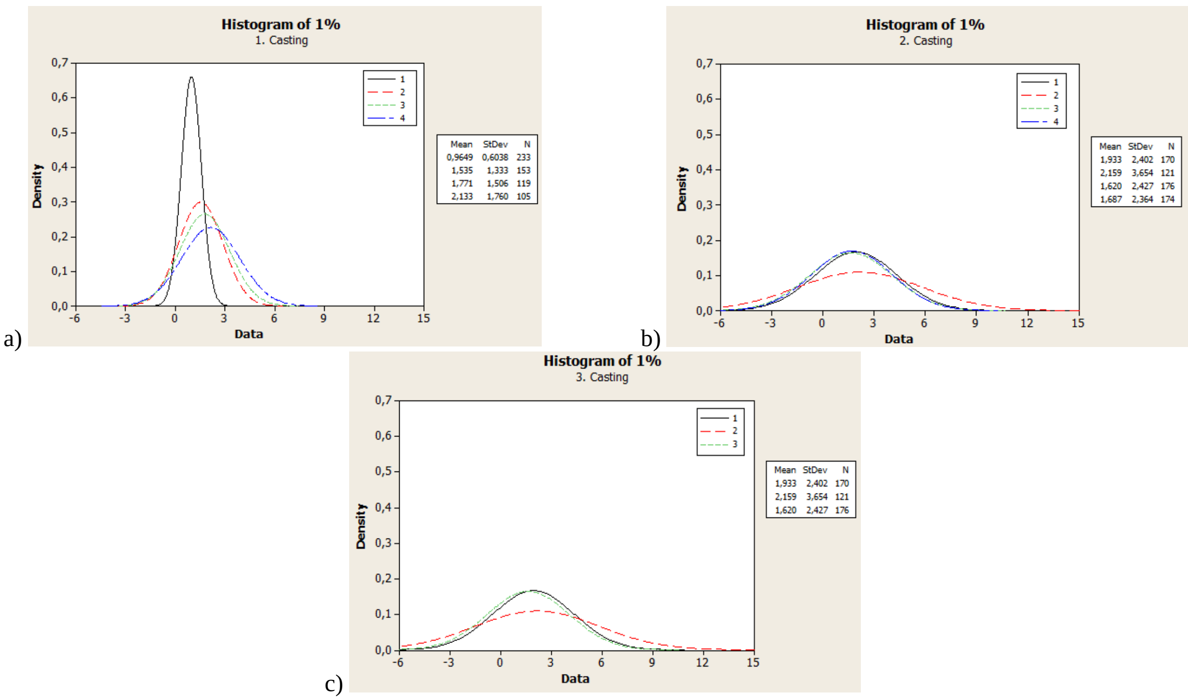

Fig. 6. Density distribution function of pores measured on the cross-section of reduced pressure test samples 1 wt% Ti added and recycled A356: a) 1st recycling, b) 2nd recycling, c) 3rd recycling

4. Conclusion

In a regular casting procedure of Al-Si alloys, typically, 0.1 wt% Ti is added as a grain refiner. In this work, recycling of 0.1 wt% Ti added A356 alloy exhibited that the melt quality was decreased after each recycling operation. Bifilm index was increased from 120 mm to 200 mm. On the other hand, when Ti content of the melt was increased to 1 wt%, the quality of the recycled melt was increased where the bifilm index was decreased from 200 to 80 mm.

Acknowledgments

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