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Sr addition and its effect on the melt cleanliness of A356

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Abstract

Strontium modification of Al–Si alloys has known to have several beneficial effects such as increased feedability, the formation of fibrous Si and increased mechanical properties. However, in the presence of Sr, during melting and holding durations, the oxide structure of the dross may change which leads to several problems during casting operations. In this work, the amount of Sr was changed and the melt was held for 1 h. Reduced Pressure Test (RPT) was used to asses melt quality change and it was found that cleanliness was increased due to the fading of Sr.

1. Introduction

One of the most prominent features of aluminium is its lightweight and variability in its mechanical properties by the addition of alloying elements. A356 alloy generally has high elongation values, good machinability with high strength values. Its ductility can be improved by Ti addition as a grain refiner and Sr addition as Si modifier [1]. However, one of the defects that deteriorate the properties of cast Al-alloys is porosity. Porosity is formed by the presence of bifilms [2, 3]. Turbulence is the major source of bifilm formation. When surface oxide of the melt is entrained into the melt, the two non-wetted sides of the oxides come in contact to form the bifilm defect which deteriorates the properties of the cast part. Therefore, it is important that these defects are not formed, or removed from the melt prior to casting.

There is a long going discussion in the literature as to whether Sr modification increases pore formation or not [4–9]. Some researchers claimed that Sr addition alters the surface tension of the melt and thus enhances pore formation. Some conclude that feedability increases with Sr modification and thus porosity is decreased. De Giovanni [10] used x-ray tomography for the visualisation of pores in Sr containing Al–Si alloys. It was found that porosity was increased with increased Sr and pores were associated with intermetallics. Barrirero [11] and Fortini [12] also found similar results. Nampoothiri [13] claimed that Sr was beneficial for eutectic modification, however, porosity was increased and localised particularly in the interdendritic region. They also claimed that by ultrasonic treatment of the melt, bifilms were broken up and oxides had become smaller and less harmful for mechanical properties. Samuel [14] showed that porosity was increased by Sr modification and pores had become more spherical. Nateghian [15] had found that Al_2O_3 was transformed into SrO when Sr content was as low as 50 ppm and after 5 h of holding, these oxides bond to each other which is known as 'healing' of the bifilms. Chen [16] reported that bifilm quantity and amount of porosity was increased when A356 was modified with Sr.

As summarised above, the reported results in the literature are based on the findings of the final cast part. In this work, the aim was targeted to characterise the effect of Sr on the quality assessment of liquid metal cleanliness. Therefore, in this work, an excess amount of Sr was added to A356 and pore formation was investigated by means of duration and holding time of the liquid metal. Reduced pressure test (RPT) method was used and bifilm index was measured in order to quantify the porosity and melt cleanliness. Bifilm index is the sum of the maximum length of pores measured in millimetres from the sectioned surface of the RPT samples. A356 alloy was used in the studies and the chemical composition is given in table 1.

Table 1. Chemical composition of A356 (wt%).

Si	Fe	Cu	Mn	Zn	Ti	Al
6.8	0.35	0.02	0.03	0.04	0.04	Rem.

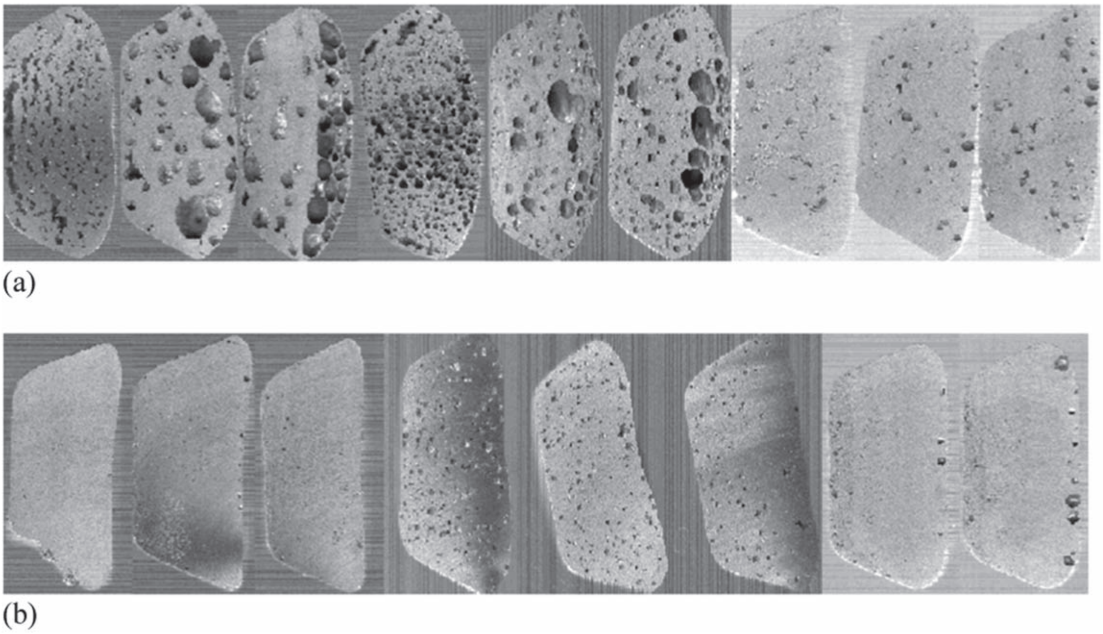

Figure 1. Cross-section of RPT samples collected at (a) 10 min, and (b) 1 h of holding.

Excess Sr addition and its effect on A356 is examined in this study. 1 wt% Sr was targeted by using Al–10Sr master alloy where there was no Sr in the melt as can be seen in table 1. Typical addition values are between 200–400 ppm of Sr, therefore the terminology 'excess' was used in this work. 2 kg of charge was melted in a graphite crucible in a resistance furnace at 775 °C. Although this temperature is higher than the usual standard applications, for this work, the selection of such high temperature was based on the particular foundry which was working at this temperature. Samples were collected from the melt to be solidified in RPT machine in a steel cup. The dimension of the mould was 34 mm diameter at the bottom, 44 mm diameter on top with a height of 30 mm.

3 consecutive tests were carried out and 3 RPT samples were collected to be solidified in the steel cup under 100 mbar at each time. Consecutive sample collection was carried out one after another, after 10 min and 1 h of holding time. The delay between the RPT sampling was 5 min Bifilm index was measured from the cross-section of these samples and Weibull statistics were used to evaluate the results.

The cross-section of RPT samples collected after 10 min and 1 h of holding is given in figure 1.

Bifilm index change of the melts cast after 10 min and 1 h of holding of 1 wt% Sr added A356 alloy is given in figure 2.

As can be seen in figure 2, there is a significant difference between the bifilm index of two melts: 10 min and 1 h of holding. The average bifilm index is around 250 mm for 10 min held melt and it is around 50 mm for 1 h held melt. There are five times difference between the quality which indicates that in the presence of excess Sr, holding time of the melt can significantly increase the melt quality.

Another interesting observation is the decrease in bifilm index after the duration of melt as the consecutive castings were followed. This gives another indication that melt quality was improving as the holding time was increased. The decrease in 1 h holding of the melt is more predominant. After the 8th sample, the bifilm index of 1 h and 10 min of holding becomes very close to each other. This shows that the change in bifilm quantity in the presence of Sr is so rapid and after a long period of holding, it stabilises; juts like the observation reported for 1 h holding duration, the bifilm index is almost constant around 50 mm.

The scatter of the data was also analysed by Weibull distributions which are given in figures 3 and 4. In these figures, P is the probability calculated by Hazen method [17]. As can be seen in figure 3, The reproducibility of the bifilm index for 10 min and 1 h holding time is almost the same. Nevertheless, the difference between the values is almost five times and the data are parallel to each other.

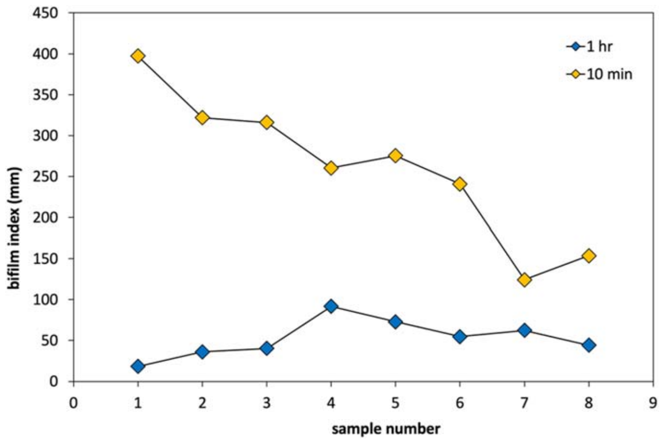

Figure 2. Bifilm index change of samples collected from the melts after 1 h and 10 min.

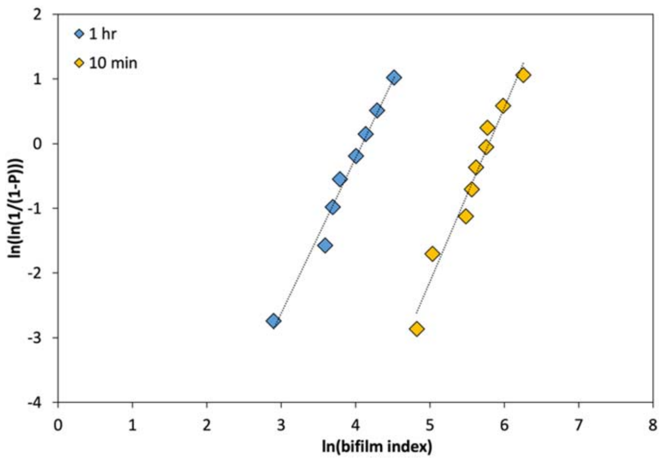

Figure 3. 1 h and 10 min holding time and its effect on bifilm index.

Bifilm index is measured by the pore length from the cross-section of RPT samples. In addition, the number of bifilm can also be calculated. These results are given in figure 4 which is quite similar to bifilm index measurements.

As seen from figure 3, the change in the number of bifilms after 1 h of holding time reveals that actually the number of bifilms were decreased which caused the increase in the melt quality. A possible reason for the decreased number of bifilms can be explained by the formation of $SrO.Al_2O_3$ spinel oxide which sediments to the bottom of the crucible. SEM images and EDS analysis in figure 5 shows SrO and presence of Al–Sr and Al–Si–Sr intermetallics. The main observation can be seen on the RPT samples cross-sections (figure 1) where the size of pores is getting smaller and the number of pores is decreasing. Uludag [18] had reported a similar finding where the Sr modified melt had shown an increased number of smaller pores. Liu [8] also reported the same findings. Additionally, hydrogen builds up in between the bifilms may result in the floatation of bifilms to the surface which also increases melt cleanliness. Denton [19] had shown that hydrogen pick-up was increased in Sr modified melts. Eguskiza [20] had shown that Sr was fading after 5 h of holding.

Sr modification leads to smaller, fragmented and higher number of bifilms. Hence, bifilm index is decreased which leads to improved melt quality. It was found that the size of pores decrease and the number of pores increase as the holding duration of Sr-containing A356 is increased. Thus, melt quality starts to increase.

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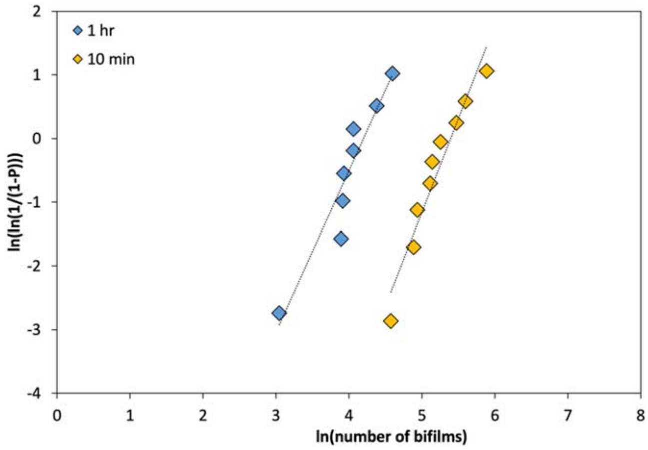

Figure 4. Number of bifilm change in samples 1 h and 10 min with 1% strontium.

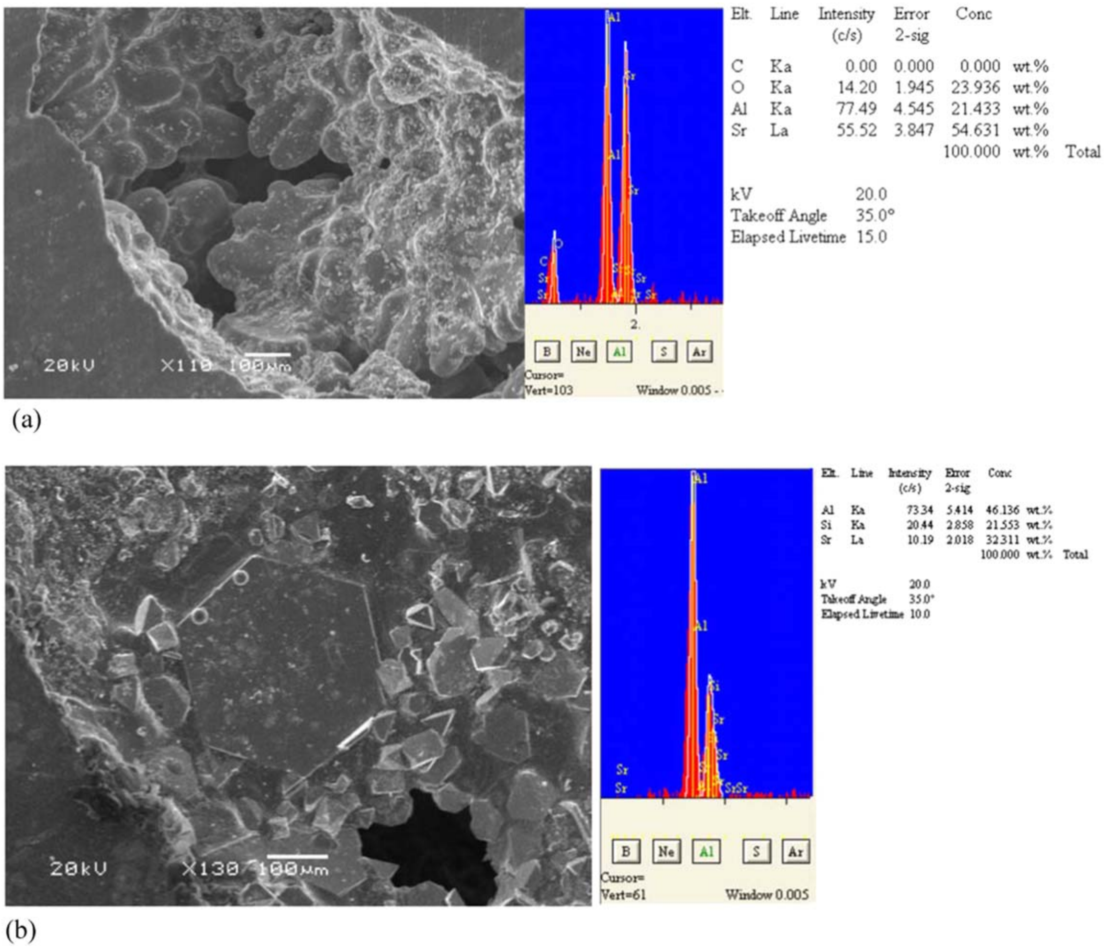

Figure 5. SEM and EDS results of (a) Al–Sr–O and (b) AlSr4 intermetallics.

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