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Role of Metal Quality and Porosity Formation in Low Pressure Die Casting of A356: Experimental Observations

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Abstract

Porosity is one of the major problems in casting operations and there are several discussions in the literature about the porosity formation in aluminum castings. Bifilms are the defects that are introduced into the melt by turbulence. They can be detected with reduced pressure test and presented numerically by measuring bifilm index. The measure of bifilm index is the sum of total oxide length given in millimeters from the cross-section of reduced pressure test sample solidified under 0.01 MPa. In this work, low pressure die casting (LPDC) unit was built in an attempt to enhance the producibility rate. The unit consists of a pump housing that was placed inside the melt in the melting furnace where the pressure was applied instead of the whole melt surface. It was observed that the melt quality of A356 alloy was deteriorated over time which had led to higher porosity. This was attributed to the increased oxide thickness of the bifilm by the consumption of air in between the folded oxides. A relationship was found between bifilm index and pore formation.

Keywords: Cast, Solidification, LPDC, Aluminium, Metal quality, Bifilms, Porosity

1. Introduction

Casting is one of the most economical methods of mass production and gravity casting is the simplest way of doing so. The critical and the crucial concern is the falling of the liquid by gravity which may lead to porosity if it is uncontrolled [1]. This case is particularly significant when working with oxide forming alloys such as aluminium. During an uncontrolled filling of a mould, entrapped air and folded oxides skins may be introduced into melt which forms detrimental defects known as bifilms [1]. Thus, a need for a counter-gravity filling had emerged. For this purpose, low pressure casting method has been developed. In this process, the melt is contained in a closed furnace and a riser tube is placed between the melt and the mould that is placed above the furnace. Pressure is applied to the surface of the melt and the melt rises through the tube to fill the mould cavity.

LPDC method clearly eliminates the intrusion of entrained defects (i.e. bifilms), simply because the filing velocity can be adjusted to 0.5 m/s which is the critical velocity below which no turbulence is observed [1]. In addition, the need for pouring basin and runners (as in the case of gravity casting) are also eliminated which leads to a better yield. Bonollo [2] has compared and summarised the technical and economical differences of this casting method in detail.

This paper presents some of the observations made during the low pressure die casting of A356 about porosity formation and its relationship with metal quality.

2. Experimental Procedure

The experimental setup used in the casting trials is schematically shown in Figure 1.

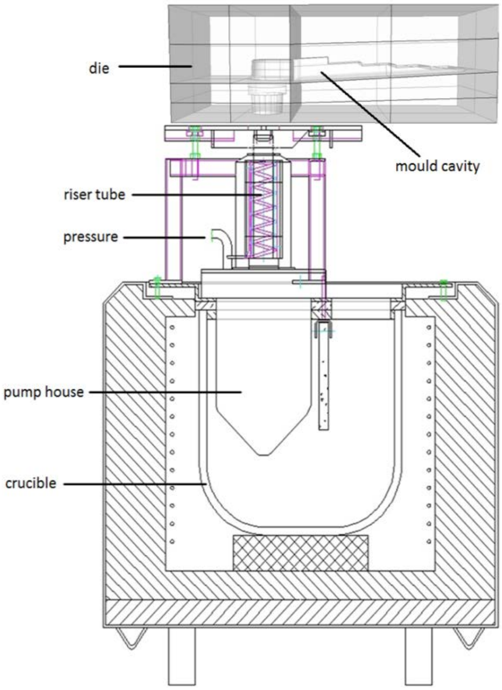


Fig. 1. Schematic drawing of the experimental setup of LPDC unit

As seen in Figure 1, the unit consists of a resistance furnace where SiC crucible with 150 kg of A356 charge is melted at 750^{o}C. An air-tight pump housing (made from non-porous alumina) is placed inside the main crucible which is submerged into the melt. The capacity of the pump housing is approximately 15 kg. A pressure is applied into the pump housing using dry air with an initial of 0.025 MPa followed by 0.033 MPa 7 seconds later. A riser tube is used to deliver the melt upwards into the die cavity.

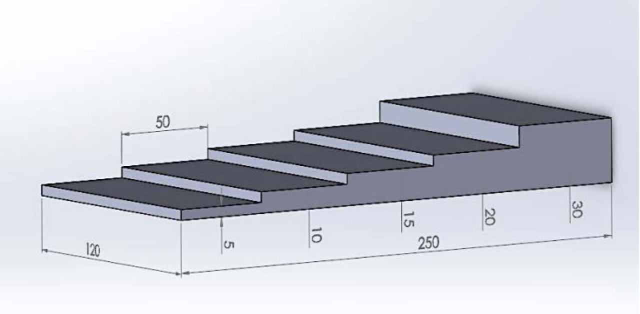


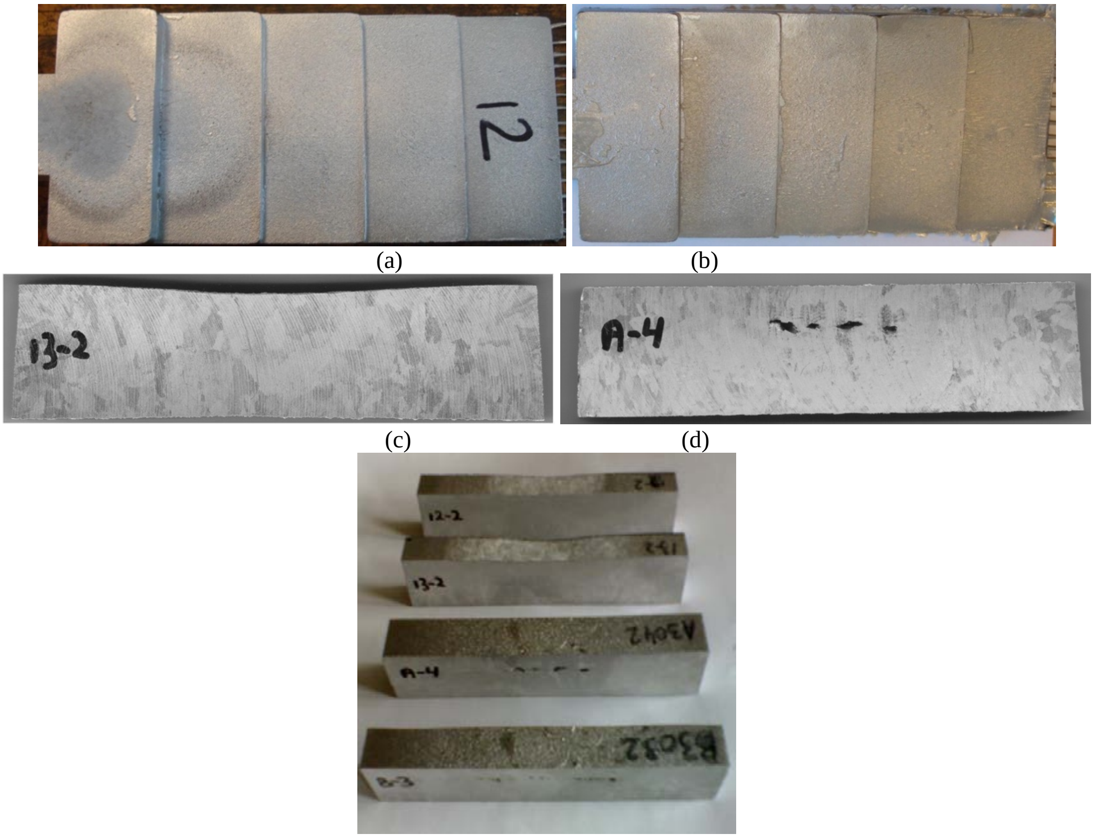
Fig. 2. Dimension of the mould used in the casting trials

The die consisted of 5 steps with 5, 10, 15, 20 and 30 mm thicknesses and 120 mm x 50 mm (Figure 2). The two halves of the dies (QRO90 tool steel) were coated (FOSECO DYCOAT) and the total thickness of the coating was measured to be between 200 - 250 µm. Calorific oil was pumped through the channels inside the dies and it was kept at 320°C. Throughout the casting trials, reduced pressure test samples were collected for bifilm index measurements [3]. The only variable in the tests was the holding time of the liquid and the duration between the collected samples.

3. Results and Discussion

The low pressure die casting unit used in this work was not a typical design where a pressure was applied over the whole melt surface in the casting furnace. Instead, a “pump housing” was used as shown in Fig 1. The use of this equipment has many advantages such as the elimination of the need to seal or leak-proof the whole casting furnace. In addition, the design allows the ability to treat the melt. The only disadvantage of the system could be reported as the need for the frequent addition of charge to the furnace in order to constantly level the melt inside the pump housing.

The cast parts and their cross sections are given in Figure 3.



(a) (b)

(c) (d)

(e)

Fig. 3. Step mould castings
(a) surface sink at the thickest section, (b) flat surface with no sink on the thickest section,
(c) cross-section of ‘a’, (d) cross-section of ‘b’, (e) general overview

Bifilm index change of the melt during the period of the casting trials is given in Figure 4. The data in Figure 4 represents the averages where the standard deviation is also given. It can be clearly seen that the bifilm index is increasing significantly from Day 1 to Day 63. It is important to note that the scatter of the results s also increasing. This indicates that the size, number and structure of bifilms are changing. Raiszadeh [4-12] has carried out an extensive work where a bubble was trapped in the liquid aluminum. The change in the volume of the bubble with regard to the oxidation of the bifilm due to the air consumed between the folded films was recorded. It was reported that the air was consumed to further oxidize the bifilm and given the time, the remaining nitrogen was also consumed to form AlN.

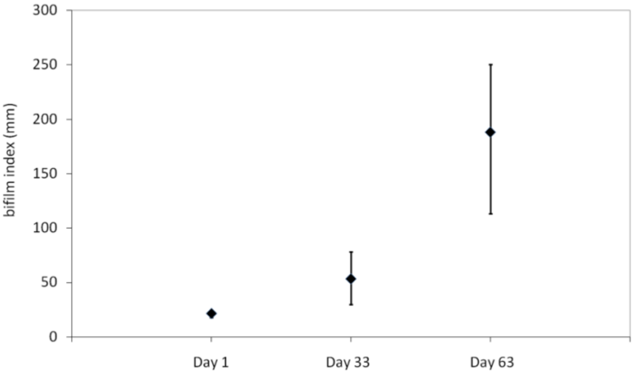


Fig. 4. Bifilm index change of A356 with time

SEM images were taken from the inside of the pores and thick oxides were observed as seen in Figure 5. In a typical “gas porosity”, it is expected that fully dendritic structure is seen. However, as can be seen in SEM images, all pores have flat and rough surfaces which is an indication of oxide presence. Fragments of oxides can be seen in Figure 5 a and b. A dendrite appears to have broken through the oxide layer in Figure 5 c. On the other hand, in Figure 5d, a complete thick oxide is seen that covers the whole surface of the pore.

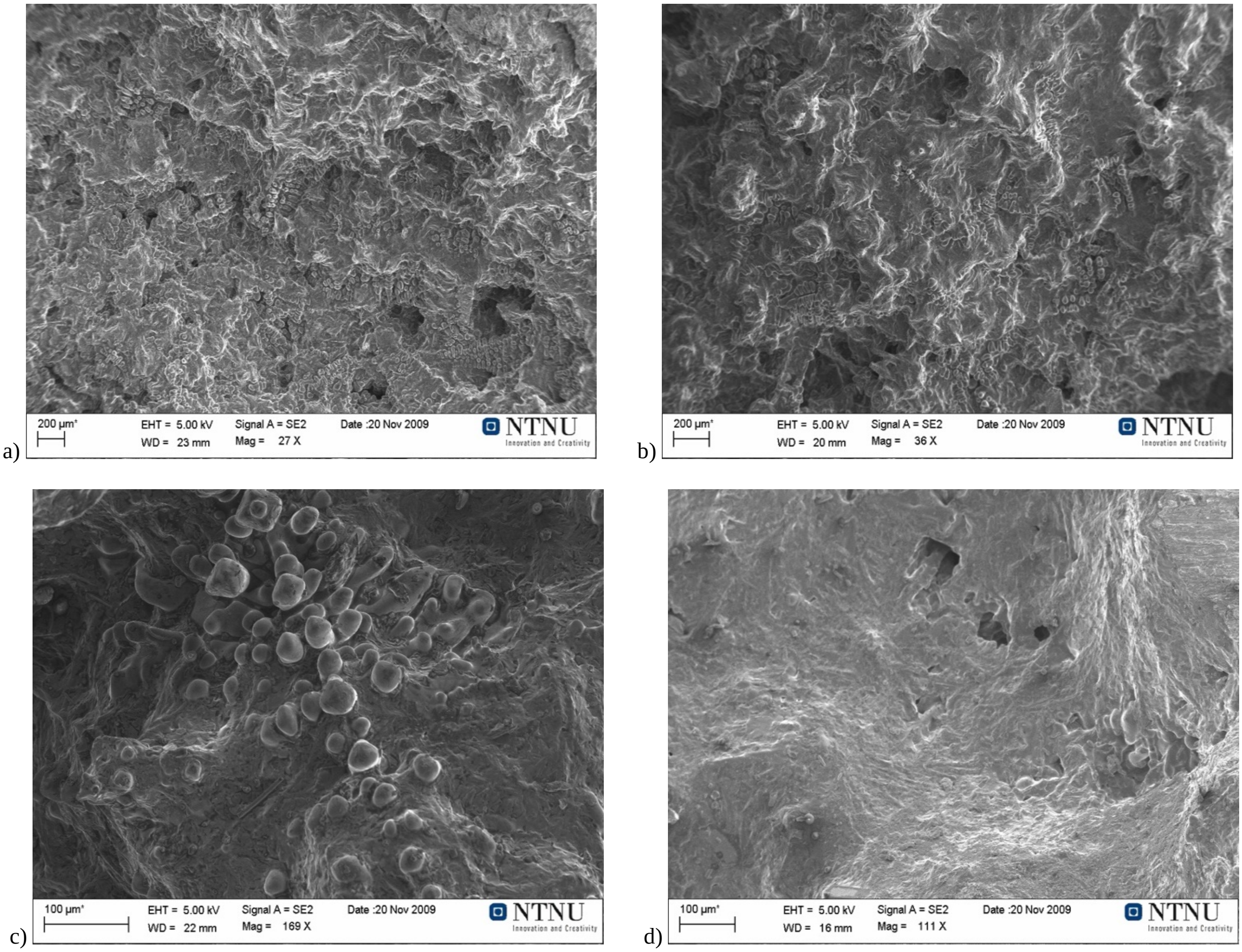


Fig. 5. SEM images taken inside the pores

The experiments were carried out with A356 which was cast into a step mould. When the castings were taken out of the die, a surface sink was observed in the thickest section of the cast part (Fig 3). The first assumption was the possible existence of a leakage in the system. If the pressure was not applied well enough; the filling would not be complete. Thus, the system was checked thoroughly. The pressure gauges were checked; bolts and nuts were screwed tightly once again and then the casting trials were continued. Surprisingly, the same results were found.

To remedy this problem, the duration of the pressure was increased from 30 seconds to 80 seconds with 10 second increments. Alternatively, the pressure was increased from 0.025 to 0.045 MPa. Nevertheless, the problem of the surface sink at the thickest section was not solved.

During these trials, the melt in the furnace was kept inside the crucible and it was not emptied. This holding period was approximately 2 months. As the cast samples were collected, new ingot was added every time.

It was observed that the surface sink on the thickest section of the cast part was no longer apparent. When the samples were sectioned and analysed, it was found that there was a large pore at the centre of the thickest sections (Fig 3). On the other hand, the castings with the surface sink had no porosity at all (Fig 3).

Due to the design of the system (Fig 1), the level of the melt inside the pump housing has to be the kept same with the level of the melt in the crucible. For this reason, after few castings, the same weight of metal was charged into the furnace. Regrettably, this had led to the intrusion of surface oxide (Fig 6) which increased the bifilm index of the melt (Fig 4).

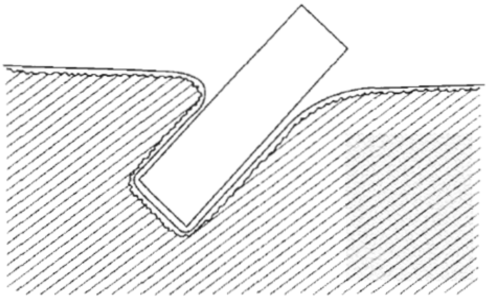


Fig. 6. Submerging of surface oxide [1]

Over the last decade, many researchers focused on the modelling of porosity in aluminium castings. Since hydrogen has low solubility in the solid, the rejection of hydrogen from the solidification front and its interaction with the solidification shrinkage has been considered as the major source for porosity. However, most of the models failed to predict both the quantity and the location of the pores when compared with the experimental findings. Stefanescu [13] has summarised a review of these simulations.

Zhu [14] proposed a microporosity simulation module for 356 and concluded that their model fits perfectly with the experimental results and claims that the errors in the model are related with hydrogen diffusion in the bulk. Merlin [15] predicted the shrinkage porosity in their model. Zhang [16] developed a 3D model for LPDC. Although they were able optimise the casting procedure, they claimed that the prediction of macro/micro porosity was not straightforward. Therefore Zhang [17] concluded the necessity of the challenge that more fundamental work was required to correlate and integrate the relationship between defects and metal quality.

Campbell [18-19] had shown that homogeneous nucleation of pores was difficult and a non-nucleation process was required for pore formation (whether gas or shrinkage). He also suggested that if there were no more liquid left to feed the shrinkage; then the solidified metal would contract to compensate for it, making a surface sink [20]. Thus, the non-nucleation process for porosity inside aluminium and its alloys has to be simply aided by bifilms [21, 22]. Several works [23-26] were also reported that show the correlation between bifilms and porosity formation.

The experimental findings in this work supported Campbell [1] and Tiryakioglu [27-29] approaches. In the clean melt, where bifilm index was 20 mm (Fig 4), the thick section of the step casting revealed no porosity and had a surface sink (Fig 3). Once the folded oxides were introduced into the melt that acted as the source for ‘growth’ of the pores, the castings began to suffer from central porosity.

4. Conclusion

In this work, the low pressure die casting method was used to cast samples using A356 alloy. During the experiments, a correlation was found between porosity and metal quality. In the absence of pore nucleant, the solidified metal would compensate the inadequate feeding by simple contraction. Pore formation was enhanced and pronounced by the presence of surface entrained defects: i.e. bifilms.

Acknowledgment

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