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The Effect of Holding Time and Solidification Rate on Porosity of A356

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ABSTRACT: *During casting of aluminum alloys, the final microstructure and mechanical properties are strongly affected by the ambient atmosphere. The liquid aluminum reacts with water vapour to form aluminum oxide on the surface and hydrogen is dissolved in the melt. The intrusion of these defects into the cast part will result in degradation of the properties. Excess hydrogen is typically removed by degassing operations. Considering the density difference of liquid and oxide, holding of the liquid for a certain period of time is assumed to be the solution for the removal of oxides. However, the possible change in the morphology of the oxide structure (thin or thick film) has been disregarded. Therefore, in this work, two different charges of A356 alloy was melt at 750^oC in a resistance furnace and held for 3 hours. One of the melts were left untreated, and the other was degassed. Hydrogen level was measured by AlSPEK. At certain time intervals (30 and 120 minute), samples were collected for melt quality change by using reduced pressure tests. A mould that consisted of various thickness was used to cast parts in order to check the porosity distribution at different cooling rates.*

Keywords: *Casting, Al alloys, Degassing, Holding time, Porosity, Bifilm index*

I. INTRODUCTION

Al-Si alloys exhibit good corrosion resistance, cast ability, high thermal and electrical conductivity. In addition, aluminum alloys are famous for having high strength and low density ratios. Therefore, typical application areas are found to be in automotive and aerospace industries [1-5]. Due to this critical uses, it is important that high quality castings are produced.

Hydrogen is known to be the only soluble gas in liquid aluminum [6]. The source of hydrogen is the moisture which can be present in the ambient atmosphere in the cast floor, crucibles, charges and refractories. As the temperature of the melt is decreased (i.e. solidification), the solubility of hydrogen decreases. And thus, it is believed that porosity is formed by hydrogen since the dissolved hydrogen has the tendency to produce hydrogen gas [7-8]. On the other hand, the turbulence of the liquid metal during transfer or uncontrolled filling may generate a defect known as bifilms [9]. These folded oxide skins act as a crack which can easily open up to form porosity during solidification contraction [10]. These defects can deteriorate the mechanical properties significantly [7].

Since presence of porosity results in lowered properties, it is important that it should be kept to the mininum and if possible, there should be no pores in the final product [6]. One of the simplest way to reduce porosity is to increase the solidification rate. Faster cooling leads to better properties, not just due to the lowered porosity, but also, the grain size gets smaller and finer; and thus, mechanical properties increase [11].

In this work, a step mould design was used to obtain different cooling rates and A356 alloy was cast to investigate the correlation between dendrite size and porosity. In addition, bifilm index was measured and the effect of melt quality was also evaluated.

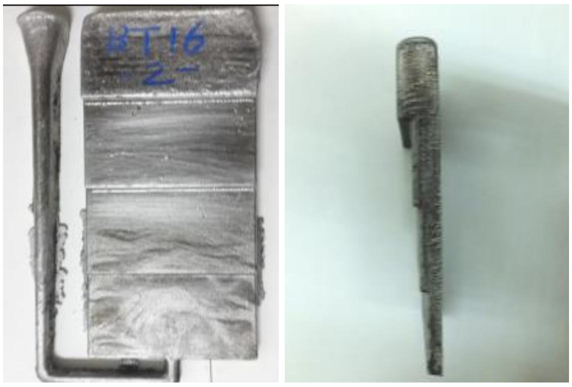
II. EXPERIMENTAL WORK

The chemical composition of the A356 alloy used in the experiments is given in Table 1.

Table 1.A356 composition

Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
6,60	0,20	0,02	0,03	0,30	0,04	0,14	Rem.

The melting procedure was carried out in a resistance furnace at 750°C. Once the charge was completely melted, the liquid melt was led to settle for 30 and 120 minutes and samples were collected at these time intervals. Reduced Pressure Test (RPT) was used to quantify the melt quality by using bifilm index. The step mould was designed have the thinnest section at the bottom and the thickest section at the top. The mould cavity was filled from a high sprue followed by upward (countergravity) casting so that no turbulence would occur during filling. A sample of one of the cast parts is given in Figure 1. The dimension of plates are 50x100 and thickness was varying from 10 mm to 30 mm.



a b

Figure 1. a) front, and b) side view of the cast part

Each thickness was cut and microstructural analysis was carried out. Archimedes principle was used to measure density of each sections. Secondary dendrite arms spacing (SDAS), porosity size, shape and distribution were measured using an image analysis software.

III. RESULTS AND DISCUSSION

The cast part consisted of four plates with different thicknesses. For statistical purposes, 3 samples were produced for each parameter A representative micrographof these castings are given here as seen in Fig 2 and 3.

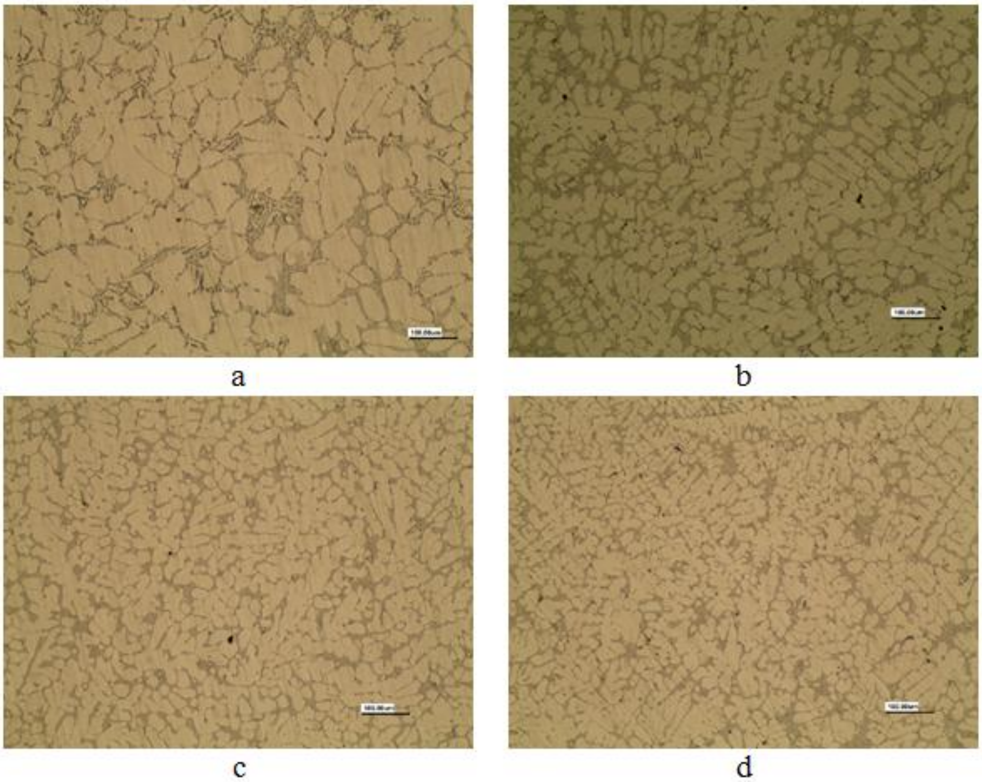


Figure 2. Microstructure of various sections a) 30 mm, b) 20 mm, c) 15 mm, d) 10 mm cast at 30 minutes of holding

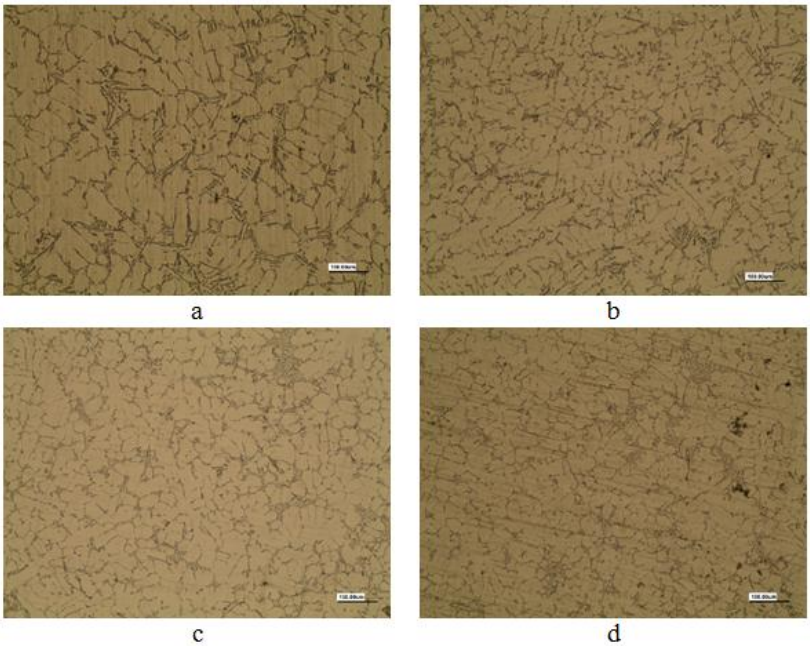


Figure 3. Microstructure of various sections a) 30 mm, b) 20 mm, c) 15 mm, d) 10 mm cast at 120 minutes of holding

Figure 4 shows the SDAS measurements taken from the different thicknesses cast at various holding times. It can be seen that as the section thickness decreases, SDAS decreased. This result was not affected by the holding time. For both 30 minute and 120 minutes of holding, SDAS was always decreased with decreased section thickness. In other words, as cooling rate was increased, SDAS was decreased.

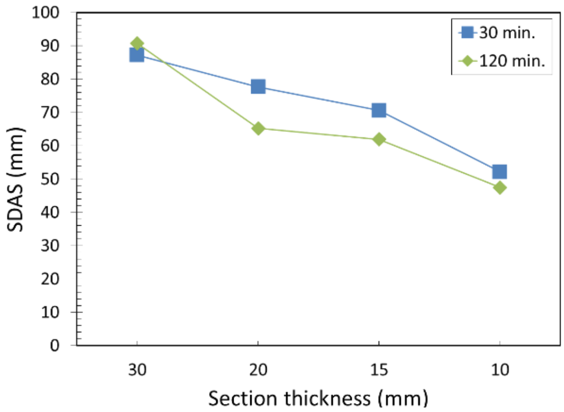


Figure 4. SDAS change with section thickness and holding times

Figure 5shows the density measurements of each sections with regard to the holding times.

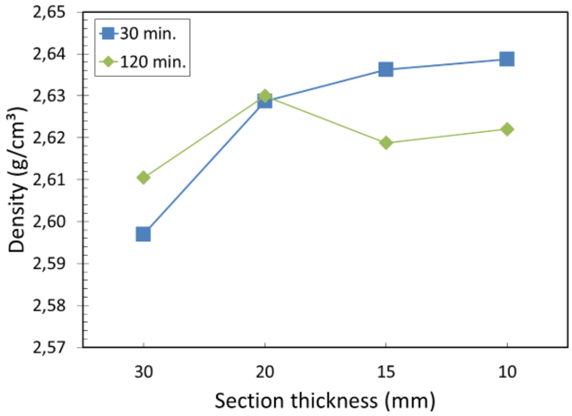


Figure 5. Density change with section thickness at various holding times

As seen in Figure 5, porosity was majorly affected by the cooling rate. As section thickness was increased (i.e. slow cooling), porosity was increased. However, there is no significant effect of holding time over the porosity levels. For 20 mm section thickness, there appears to be no effect of holding time on volumetric porosity. The density remained unchanged around 2630 kg/m^3. For the samples analyzed at 15 mm section thickness, the density was decreased (i.e. porosity was increased) as the holding time was increased. Similarly, 10 mm section thickness seems to have the highest density which indicates that the porosity was lowest amongst the cast part.

It is understandable and explainable that 30 mm section must have the lowest density, since there was no feeders used, this region of the cast part would act as the feeder and therefore have the highest level of porosity. This effect can also explain the fact that the density of 20 mm sectioned samples were constant and unchanged with the holding time due to the feeding effect of 30 mm section. Similarly, the thinnest section (10 mm), was located at the bottom of the cast part which had the highest metallostatic pressure acting on it. Therefore, highest density (i.e. lowest porosity) was found at this section of the cast part. As a result, all the defects were occurring between 10 and 15 mm sections, since the solidification shrinkage, feeding, fluidity and permeability of the liquid above would have the most dominant effect in these regions. Therefore, 15 mm section has the most scattered results.

Figure 6 shows the correlation between average pore area and number of pores. It can be seen that there are no certain relationship between the number of pores and pore area. There are big and few pores and sometimes there are a lot of small pores. The distribution suggests that the size and distribution of pores are not homogeneous throughout the section of the cast part.

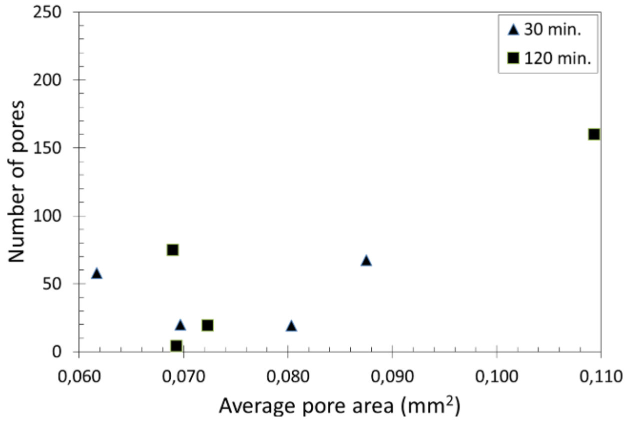


Figure 6. The correlation between average pore area and number of pores

Figure 7 shows the relationship between section thickness and total pore area at different holding times of the melt. It can be clearly seen that as the section thickness increases and holding time increases, total pore area increases.

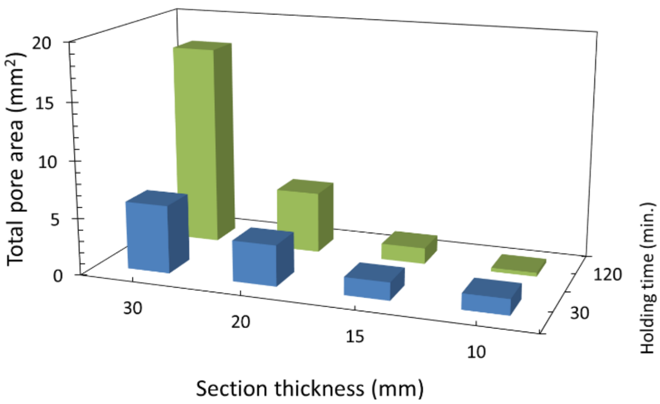


Figure 7. Total pore area change with section thickness at different holding times

Bifilm index measurements were made for each of the melt that were held at different holding times. The results were calculated to be 105 and 109 mm for 30 and 120 minutes of holding. This increase in bifilm index with increased holding time is attributed to the fact that oxidation rate was increased with increased holding at 750^{o}C for long times. The comparison of pore length with bifilm index and section thickness is given in Figure 8. It can be seen that in general, as the bifilm index was increased, the length of pores were increased.

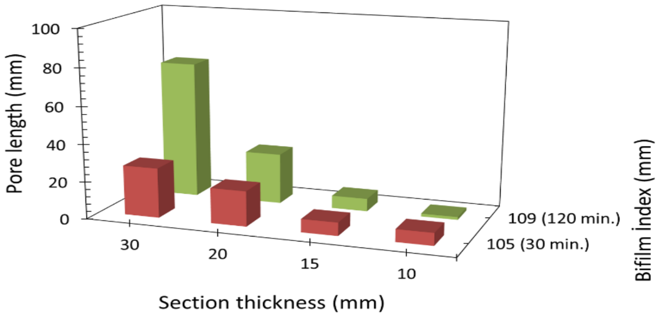


Figure 8. Pore length change with bifilm index and section thickness

Similar findings were found for the number of pores. As bifilm index was increased, the number of pores were increased (Fig 9). The reason for low number of pores at the thinnest section is based on the fact that as the solidification rate increases, bifilms do not find the time to unravel and form porosity. In addition, considering the metallostatic head above this section, the highest pressure was exerted to 10 mm section which resulted in impeding of opening of bifilms to form porosity. Therefore, bifilms may still be present but they are not observed as pores since they were not opened.

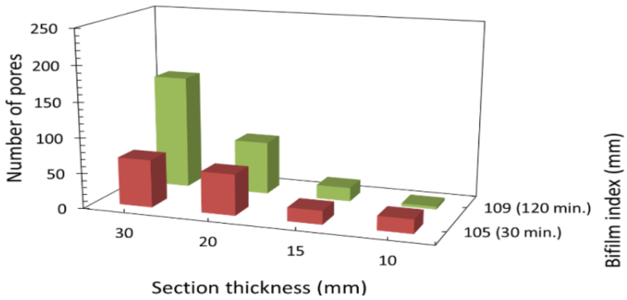


Figure 9. Number of pores change with bifilm index and section thickness

IV. CONCLUSIONS

As the holding of the melt is increased, the quality of the melt decreased significantly resulting in higher porosity. Cooling rate has effect over the pore size and distribution, but not due to hydrogen evolution, simply due to the unravelling mechanism of bifilms. There is good correlation between number of pores and bifilm index. The size of the pores (i.e. pore area) is only related with the opening of bifilms. If enough time is given, the pores can grow to larger sizes. On the other hand, faster cooling will delaythe unravelling of bifilm and lead to less pore formation.

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