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# Observation of Hot Tearing in Sr-B Modified A356 Alloy

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## Abstract

In this work, T-shaped mould design was used to generate hot spot and the effect of Sr and B on the hot tearing susceptibility of A356 was investigated. The die temperature was kept at 250°C and the pouring was carried out at 740°C. The amount of Sr and B additions were 30 and 10 ppm, respectively. One of the most important defects that may exist in cast aluminium is the presence of bifilms. Bifilms can form by the surface turbulence of liquid metal. During such an action, two unbonded surfaces of oxides fold over each other which act as a crack. Therefore, this defect cause many problems in the cast part. In this work, it was found that bifilms have significant effect over the hot tearing of A356 alloy. When the alloy solidifies directionally, the structure consists of elongated dendritic structure. In the absence of equiaxed dendrites, the growing tips of the dendrites pushed the bifilms to open up and unravel. Thus, leading to enlarged surface of oxide to become more harmful. In this case, it was found that these bifilms initiate hot tearing.

**Keywords:** A356, Casting, Melt quality, Grain refinement, Hot tearing

## 1. Introduction

Hot tearing occurs towards the end of the solidification at high solid fractions [1]. Volumetric shrinkage causes the alloy to contract that can easily generate either a stress or a strain that would force the metal to form a crack. Depending on the level of these forces, the cast part may completely be separated into two pieces. Eskin and Katgerman [1] has summarised the mechanisms and conditions of the hot tearing phenomena in his work called “quest for new hot tearing criteria”.

Rappaz et al. [2] introduced a model based on the deformation rate and suggested that as long as cavitation (i.e. porosity) is not formed, the material is susceptible to hot tearing when the critical deformation rate was achieved. Thermal gradient is one of the major factor that decreases the deformation rate. It is a well-known fact that the existing of a hot spot in a cast part would

likely to tear due to the high thermal gradient. Stangelad et al. [3] studied the effect of cooling rate and looked into the solid fraction levels. The behaviour of dendritic solidification was described by means of the onset contraction of solid fraction. Experimental findings were correlated with the model for A356 alloy and in Sr modified alloy, critical solid fraction was found to be around 0.9. Alloying element addition together with degassing of A356 decreases pore formation [4-9]. Hamdi et al. [10, 11] worked with direct chill cast aluminium alloys and proposed a model that calculated the viscoelastic properties in the mushy zone.

There are also several mould designs in the literature where the susceptibility of hot tearing tendency in aluminium alloys are studied. Li [12] has done an extensive work that covers a wide literature survey. One of these designs contain a long runner bar connected by a T junction at the end where a thermal gradient region is generated. The main idea is to generate a hot spot and the remaining solidified part will create uniaxial force to tear the

liquid to cause a crack. However, the results show that hot tearing does not always occur under same conditions and it is quite random. In all of these studies, the effect of melt quality was not evaluated. Bifilms are known to be the most important defects that may exist in aluminium melts [13]. Campbell [13] suggested that separation of liquid phase is difficult due to the requirement of high hydrostatic tensions. In the presence of a defect (i.e. bifilm), this phenomena can be assisted. Therefore the motivation behind this work was to see the effect of bifilms on the hot tearing tendency of Sr and B modified A356 alloy.

## 2. Experimental Work

In this work, A356 alloy was modified by Sr and B and permanent moulds were used to investigate the hot tearing tendency. 20 kg of charge was melted in a resistance furnace at 750 °C. Permanent moulds were heated up to 150 °C. After degassing of the melt with Ar for 15 minutes, 30 ppm Sr and 10 ppm B was added. The hydrogen content of the melt was measured by AISPEK to be 0.11

from the present study. The mould used in the tests is given in Figure 1.



Fig. 1. The picture of cast parts from T-mould

The composition of the alloy used in the experiments is given in Table 1. The alloy was a primary alloy obtained from a primary foundry plant in Turkey.

Table 1.

Chemical composition of A356 alloy

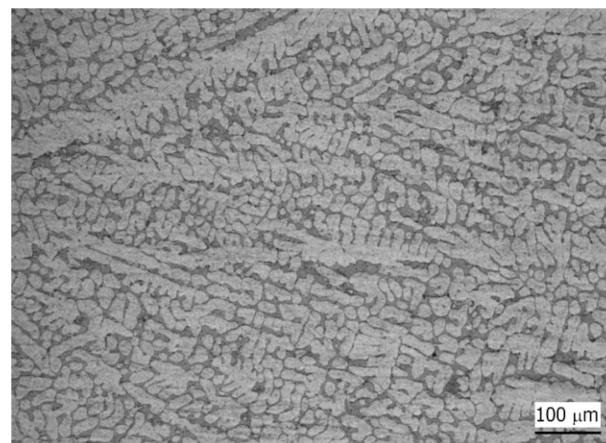
Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
6.80	0.19	0.003	0.001	0.30	0.011	0.108	Rem.

## 3. Results and Discussion

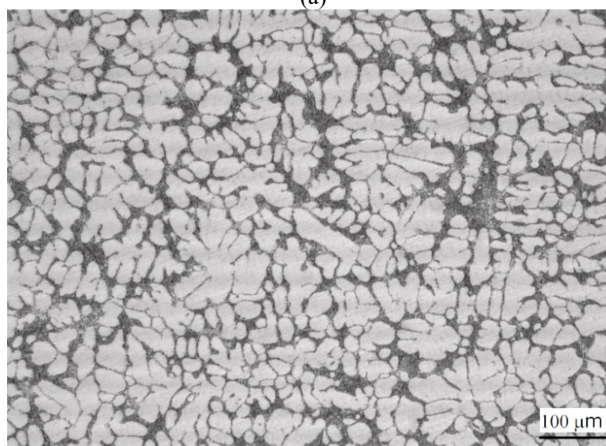
When the first casting was made, the sample was taken out of the mould and after 3 minutes, the second casting was made and so on. Only in the first test, hot tearing was observed. In the second and third casting, there were no hot tear. It was found that when the mould temperature was at 150 °C, the thermal gradient was so high that the microstructure consisted of columnar dendritic structure (Figure 2). However, when the following castings were made, when the mould temperature was slightly

increased. Thus, the resulting cooling rate was lowered and therefore, more homogeneous globular dendritic structure was observed (Figure 2b). Campbell [14] have shown that bifilm can be harmful when they are opened. This unravelling of bifilms can be caused by several mechanisms as follows:

- Pushing action of growing dendrites, particularly columnar growth
- Coarse grain size
- Slower cooling
- Nucleation of intermetallic phases on bifilms



(a)



(b)

Fig. 2. Microstructure of (a) casting with hot tearing, and (b) without hot tearing

Rapid cooling is one of the best means of retarding the opening of bifilms. Therefore, during grain refinement, feedability is enhanced which generates a metallosstatic pressure to keep bifilms in their convoluted structure. When it comes to the formation of porosity or tearing in the liquid metal, again, high pressures are required. As Dispinar et al [15-20] have shown, porosity can only be formed in the presence of bifilms. Thus, hot tearing can also be only initiated by the unravelling of bifilms. In this work, when the microstructure was columnar, the bifilms were pushed by the growing tip and they were easily unravelled (Figure 3). Thus, the

surface area of the bifilm can enlarge and lead to the deterioration of the properties. On the other hand, with the finer structure, due to the heterogeneous nucleation by grain refiners, the bifilms may not find the time to open up and stay in the compacted form which is less harmful.

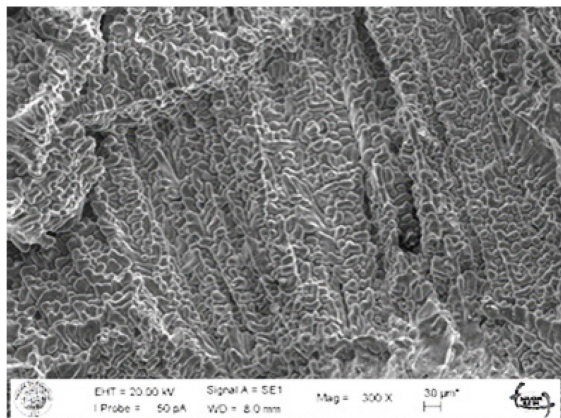


Fig. 3. SEM image of the hot tear region

Campbell [13] suggested that in the absence of bifilms, the shrinkage could only be compensated by the surface sink. It is important to note that there was an apparent sinking of the surface at the hot spot region of the 2nd and 3rd castings (Figure 4). In this work, precisely the same phenomena was observed. As can be seen in the simulation results in Figure 5, the mould filling is quite turbulent in the T-junction and any bifilm carried through the melt and located at that particular point can initiate hot tearing.

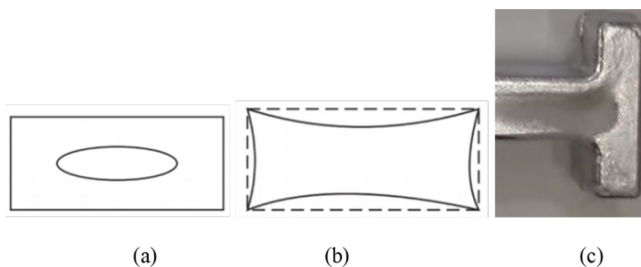


Fig. 4. (a) pore formation, (b) surface sink in the absence of pore, (c) surface sink on the hot spot region of A356

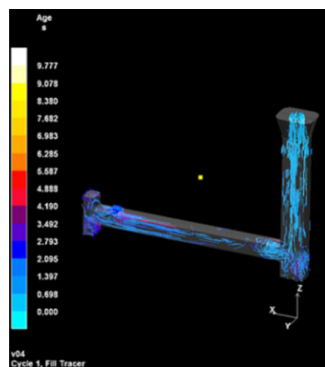


Fig. 5. Mould filling

## 4. Conclusions

When the alloy solidifies directionally, the structure consists of columnar dendritic structure. Tips of the dendrites pushes the bifilms to unravel. Thus, leading to enlarged surface of oxide to become more harmful. In this work, it was found that in the presence of bifilms, hot tearing can be initiated regardless of the alloy content. Thus, hot tearing tendency is melt quality dependent.

The microstructure is important for hot tearing as it determines the unravelling of the bifilms.

The positioning of the bifilm in the cast part as it is carried out from the melt though the cast part plays an important role. Thus, mould filling and runner design determines the quality and hot tearing susceptibility of the cast product.

A356 can hot tear in the presence of a bifilm.

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