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Quality Evaluation of Remelted A356 Scraps

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Abstract

A356 is one of the widely used aluminium casting alloy that has been used in both sand and die casting processes. Large amounts of scrap metal can be generated from the runner systems and feeders. In addition, chips are generated in the machined parts. The surface area with regard to weight of chips is so high that it makes these scraps difficult to melt. Although there are several techniques evolved to remedy this problem, yet the problem lies in the quality of the recycled raw material. Since recycling of these scrap is quite important due to the advantages like energy saving and cost reduction in the final product, in this work, the recycling efficiency and casting quality were investigated. Three types of charges were prepared for casting: %100 primary ingot, %100 scrap aluminium and fifty-fifty scrap aluminium and primary ingot mixture were used. Melt quality was determined by calculating bifilm index by using reduced pressure test. Tensile test samples were produced by casting both from sand and die moulds. Relationship between bifilm index and tensile strength were determined as an indication of correlation of melt quality. It was found that untreated chips decrease the casting quality significantly. Therefore, prior to charging the chips into the furnace for melting, a series of cleaning processes has to be used in order to achieve good quality products.

Keywords: Bifilm index, Melt quality, Scrap, Recycle, Mechanical properties

1. Introduction

The foundry industry has always focused on factors affecting the properties of aluminium and its alloys. Most of the work was based on porosity and its effect over the mechanical properties. Therefore, many researchers investigated the formation of pores during casting [1-6]. The main source of porosity in aluminium castings was blamed to be hydrogen which has a high solubility in liquid but very low in solid. Thus, it is proposed that the rejected hydrogen from the growing dendrites is accumulated between the secondary arms to nucleate and form porosity. On the other hand, Campbell et al. [7-10] have shown the effects of surface entrained defects (i.e. bifilms) and their relation with porosity.

Bifilm which can be formed during the turbulent flow or transfer of the melt in a casting process can be found in the final microstructure and reduce the service life of cast part. Therefore, controlling the quality of the cast part begins with quality of melt. The starting materials bifilm content has to be as low as possible.

Dispinar [11-19] has carried out an extensive study to be able to numerically measure the quality of a melt and proposed an index called bifilm index [16].

If bifilm are trapped by surface turbulence during the casting process, they become crumpled and smaller in size. When the sizes are between 0.1-1.0 mm diameter, bifilms are quite dangerous. They can be in the form of a straight crack and freeze in the cast part as a big crack in the microstructure. However, they may increase their harmful effect 10 times when they start to unravel. There are several mechanisms that can open (unravel) bifilms to form a crack [2];

(i) precipitation of the hydrogen into the air layer between the films,
(ii) shrinkage (effect of reducing pressure on films),
(iii) precipitates between iron (beta phase form) and other metals (intermetallic),
(iv) coarse grain size

It is “known” that hydrogen porosity, shrinkage porosity, iron levels and coarse grain size reduces ductility. However, these so-called sources are actually all initiated by bifilms. Therefore, its neither hydrogen, nor shrinkage or the iron level, but the unravelling or stretching of the folded bifilms that causes a decrease in ductility [12, 14, 19-21]. Therefore, bifilms are the most important factor to control the mechanical properties of cast part. The simplest way of quantifying bifilms in the melt is the use of solidification test under vacuum. The sectioned surface of the samples can be processed by image analysis software to measure the maximum length of pores as an indication of total oxide length; i.e. bifilm index [16]:

$$Bifilm\ Index = \sum (Pore\ Length) = L_b$$

This index is a value measured in millimetres and it is simple and can be easily in the industry as an evaluation of melt quality.
Dispinar et al. [30] and Kvithyld et al. [31] had studied the recycling efficiency of coated sheets and concluded that the removal of the surface contaminations increased the yield to around 97% prior to melting.
Hatayama et al. [22] discuss the Material Flow Analysis (MFA) techniques to predict the scrap sorting and recycling potential of aluminium and its alloys. It was concluded that the primary alloy usage could be lowered as much as 25%. Modaresi and Muller [23] predicts that by 2050, the energy saving potential is around 43-240 TWh/year if all the aluminum alloys are recycled from vehicles. However, it was indicated that the difficulties in refining process of scrap leads to the strategies where primary alloy supply is prefered. Similar calculations were also made by Cullen [24] and Lovik et al. [25]. Gaustad et al. [26] has reviewed the techniques of removing unwanted elements and general recycling issues. Lately, recycling by hot extrusion pressing has been very popular [26-29].
In this work, the recycled melt quality was measured by bifilm index and its correlation with the mechanical properties were determined.

2. Experimental study

Primary ingot and turnings of aluminium alloy A356 from a wheel producer were used in the tests. The chemical composition of A356 aluminium alloy are given in Table 1.

Table. 1.
The chemical composition of A356 aluminium alloy

Si	Mg	Cu	Fe	Mn	Ti	Al
7.13	0.389	0.023	0.135	0.002	0.114	Rem.

In the experimental work, three different combinations of charge material were used:

i) 100% primary ingot,
ii) 50% primary ingot + 50% chip
iii) 100% chip

The ingot and chips used in the study is shown in Figure 1.

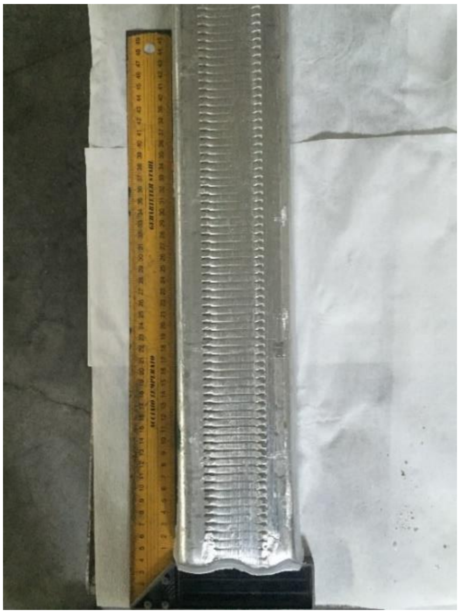
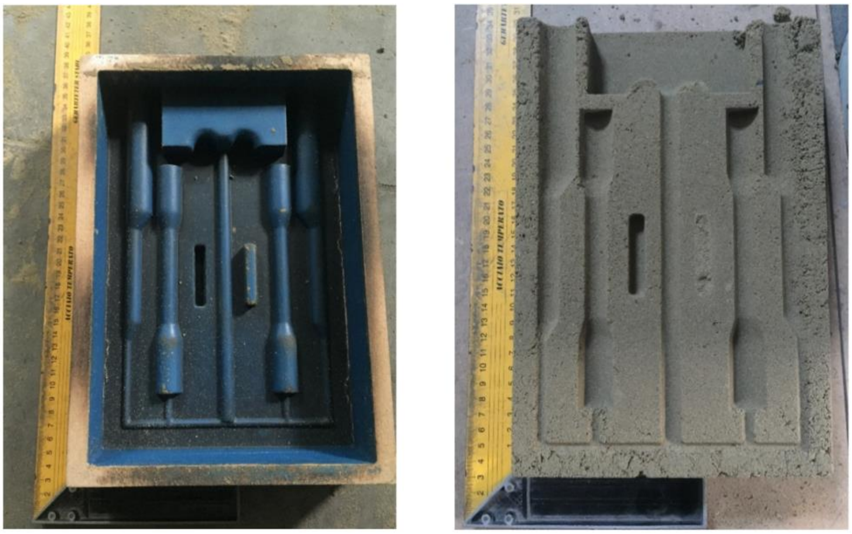
a)  b) 

Fig. 1. (a) primary ingot (b) chips

20 kg silica sand, 1 kg of bentonite and 0.66 kg water were mixed with the help of sand mixer machine and moulds were produced as seen in Figure 2.



(a) (b)

Fig. 2. The two bar (a) pattern and (b) sand mould

Melting process was made with 50 kW induction furnace. A charge of 4 kg was prepared in each casting process. In order to achieve 50-50% mixture, 2 kg of primary ingot and 2 kg of chip were used. The casting temperature in each of the tests were kept constant as 740 °C. Melt temperature was measured continuously by K-type thermocouple. Reduced Pressure Test (RPT) samples were taken at certain time intervals and simultaneously two tensile test bars were cast. The mould used in RPT tests has conical geometry wit base diameter of 40 mm, 20 mm height and 70 mm top diameter. RPT samples were then sectioned (Fig 3) and SigmaScanPro software was used to measure bifilm index. Mohr-Federhaff 10-ton tensile machine was used to examine the tensile strength of the materials used in this work by ASTM E-8-00 standards. The diameter of the tensile test bars was 12 mm in neck and 20 mm in grips with 75 mm length for the extensometer grips (Fig 2).

3. Results and discussion

The cross section of the reduced pressure test samples is given in Figure 3. As can be clearly seen (Fig 3c), the primary alloy has almost no visible pores. On the other hand, as the chip ratio was increased, there was a significant increase in both the number and the size of the pores.

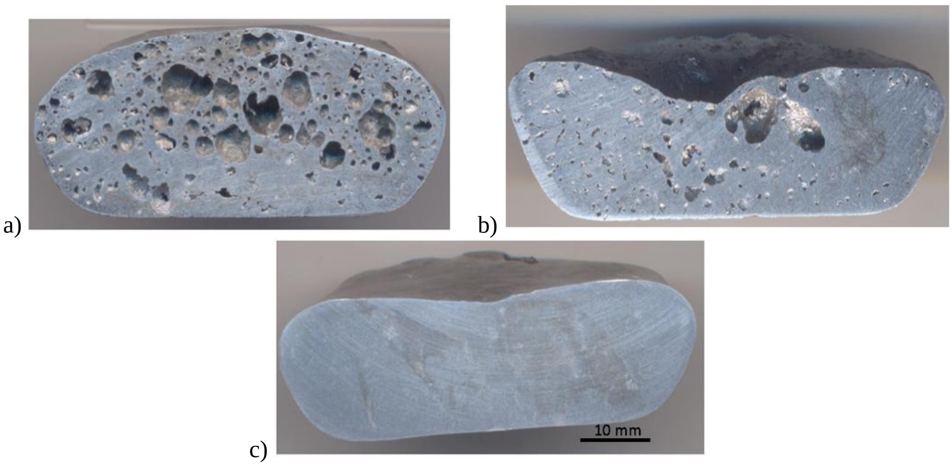


Fig. 3. RPT samples collected from the melt for conditions:
(a) %100 chip (b) %50 primary ingot - %50 chip (c) %100 primary ingot

Figure 4 is show a comparative chart which has different cast melt conditions and Bifilm Index. As can be seen from this graph that 100% primary ingot which has a 5.8 mm bifilm index is the cleanest melt and 100% chip which has 221.5 mm bifilm index is the lowest quality melt. 50-50% mixture melt has a bifilm index of 95 mm. One of the important observations was the increase of scatter of results as the content of the chips (i.e. scrap) was increased (Fig 4). Dispinar et al. [16-18] had suggested in their earlier work that higher the scatter of the bifilm index incidated higher population of bifilms in the melt. The surface area to weight ratio of chips are so high (Fig 1b). It is well known that one of the most important features of the aluminium alloy is its protective oxide on the surface. Thus, as the chips were melted, the surfaces of the chips that were in contact with each other (Fig 1b) has automatically been introduced into the melt as bifilms. This is the main reason why the number and the sizes of pores are so scattered in the cross section of RPT samples in Fig 3 a and b.

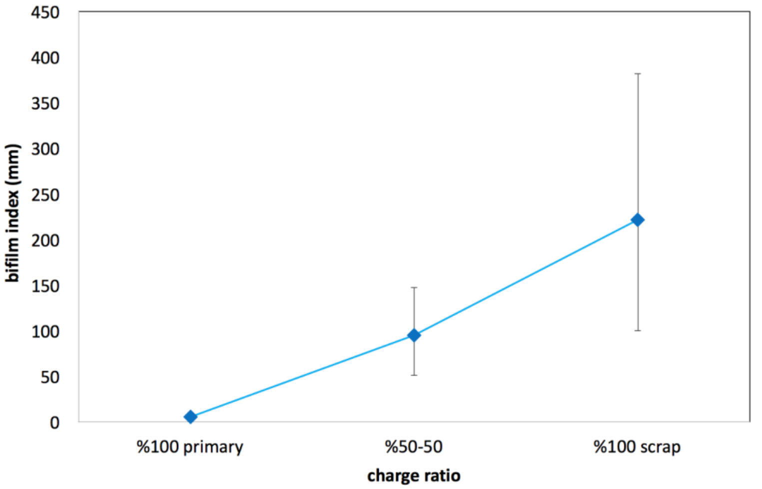


Fig. 4. Bifilm index of different charges

Figure 5 shows the bubble diagram of the mechanical test results. It can be seen that the scatter of the test results (i.e. bubble size) were almost similar in all conditions. The primary alloy properties were the highest amongst the conditions tested in this work: it lies on the right top corner of the plot which indicates that the ultimate tensile strength and the elongation at fracture was the highest.

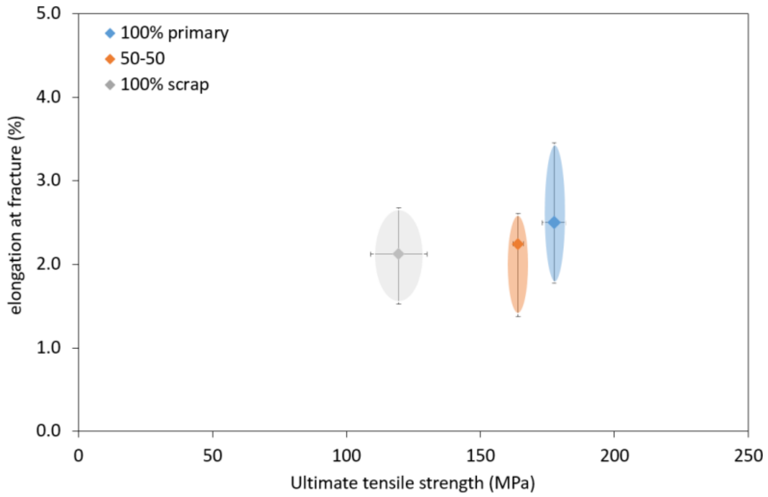
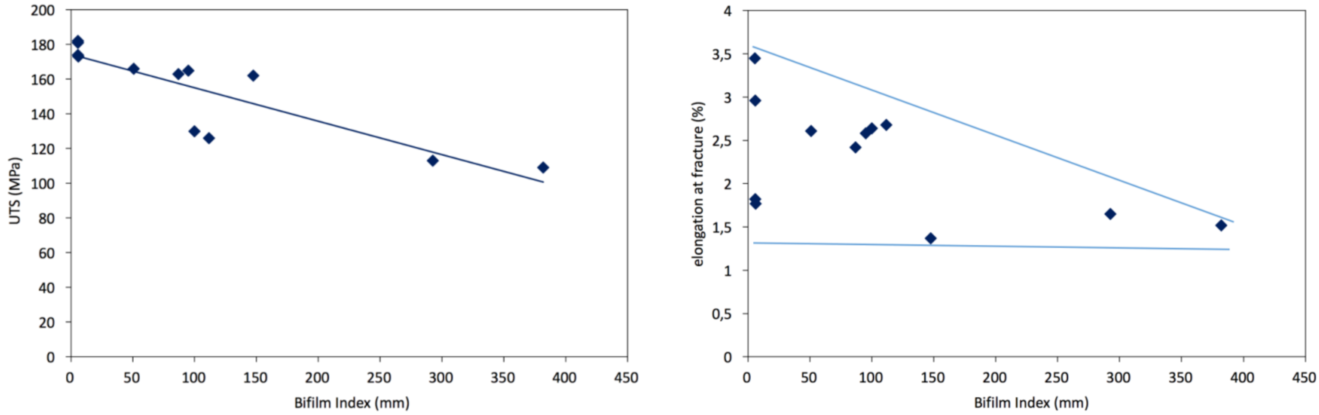


Fig. 5. Bubble diagram of the tensile test results

When tensile properties of all three conditions are compared, there was an interesting observation. As seen in the bubble diagram in Fig 5, as the scrap ratio was increased, ultimate tensile strength decreased (the x-axis values). However, elongation at fracture values for 100% scrap and 50-50% mixture appears to be very close around 2.3%. This relationship was also evaluated by means of using bifilm index as seen in Figure 6. Ultimate tensile strength was decreasing linearly with increased bifilm index. Thus, it can be concluded that as the quality of the melt is lowered, the mechanical properties decrease. Yusuf [29] had found similar results. It was found that the strength of the recycled samples was decreased. Ludwig et al. [6] found that there was an average of 10% decrease in the mechanical properties with the increased oxide content where oxides were both measured by bifilm index and PoDFA.



a) b)

Fig. 6. The correlation between mechanical properties with bifilm index (a) UTS, (b) elongation at fracture

As seen in Figure 6a, the correlation between bifilm index and tensile strength is close to linear. It can be easily concluded that as the bifilm index was increased UTS was decreased. On the other hand, this was not the case with the elongation at fracture values. When the maximum and the minimum values are connected as straight lines, the bottom values form a horizontal line and the top values form a linear line (Figure 6b). And this result appears as the bifilm index is increased, elongation at fracture values certainly decrease. However, when the bifilm index is low (i.e. high quality melt), it does not necessarily mean that the toughness will be high, too. Campbell [2] had shown the effect of reduction in area by the presence of a defect and how it would effect the elongation at fracture in Figure 7. In the same analogy, considering a bifilm with a size of 1 mm, its orientation with reference to the tensile axis has to play an important role for the determination of the elongation at facture. If it lies parallel with the tensile axis, the elongation at fracture might be high. On the contrary, the positioning of the same size bifilm perpendicular to the axis has to decrease the elongation at fracture at a relatively lower value. Dispinar [12-14] had found similar results. It can be concluded that as the bifilm index was increased (low quality melt): the higher the population of these defect, the most likely the material will fail easily.

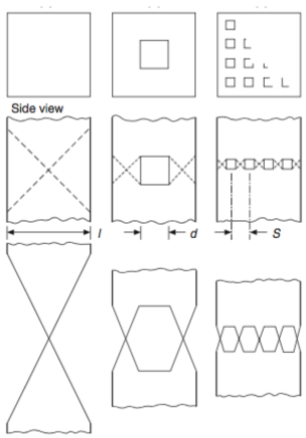


Fig. 7. Simple ductile failure model [2]

Hatayama [22] proposed that primary aluminium requirement can be reduced by 25% by correct scrap sorting. In this work, the basis for the achievement of high quality casting from scraps has been investigated. Thus, it is expected that this ratio can even be extended to higher levels by proper measurement of the melt quality.

4. Conclusions

1. Reduced pressure test can quantitatively give an indication of the melt quality of aluminium alloys by using bifilm index.
2. There is a linear relationship between mechanical properties and bifilm index.
3. As the scrap ratio in the melt is increased, the quality decreases linearly.
4. Quality of the melt can be increased by controlled treatment of the scrap and proper cleaning process prior to charging.

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