Reproducibility of Reduced Pressure Test Results in Testing of Liquid Aluminum Gas Levels

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Abstract—Reduced pressure test has been widely used to check gas content of liquid aluminium prior to casting. It is a simple and a cheap test in comparison to the existing high-cost equipments. However, the reproducibility and reliability of the test results purely depends on the equipment maintenance and the user. Therefore in this study, the test results obtained from 2024 and 7075 alloys were analyzed and typical errors that could be generated from the RPT has been summarised.

Keywords—aluminium, casting, porosity, reduced pressure test, quality

I. INTRODUCTION

There are three important features that define aluminium metal quality: control of trace elements, reduction of dissolved gas, and removal of non-metallic inclusions. Oxide particles and films are often the most common inclusions observed within aluminium melts. The oxides arrive in the melt right from the start of melting. They arrive as oxide skins on the surface of the material to be melted. When melted in a crucible furnace, or other type of bath of molten metal, as each piece of solid charge is submerged and melts, its surface oxide floats free and becomes suspended in the melt. Such films are finally found as complete, massive, film-like or dross-like inclusions in finished castings [1].

The majority of light metals and alloys in their molten condition are inclined to considerable adsorption of gases. The gases absorbed by the surface of the metal are capable of diffusing into the metal in the atomic state [2]. While oxygen and nitrogen form chemical compounds on the surface of the liquid metal, hydrogen appears as the principal gas that can be taken into solution in the bulk liquid.

The main source for hydrogen results from the dissociation of water vapour. Fluxes, crucibles, refractories and charge materials all usually contain some moisture which will add hydrogen to the melt. Water vapour may be readily found in the atmosphere, especially on hot and humid days. The reactions involved are:

\[ 2\, \text{Al} + 3\, \text{H}_2\text{O} \rightarrow \text{Al}_2\text{O}_3 + 3\, \text{H}_2 \]  \hspace{1cm} (1)

\[ \frac{1}{2}\, \text{H}_2 (\text{gas}) \leftarrow \text{H} \text{ (in Al)} \]  \hspace{1cm} (2)

Figure 1: Solubility of hydrogen in aluminum [3]

As seen in Figure 1, the solubility of hydrogen in pure aluminium decreases with decreasing temperature [3]. This decreased solubility of hydrogen in the solid phase can result in the precipitation of hydrogen gas, which may cause porosity. However such precipitation requires suitable conditions, of course, otherwise the hydrogen is forced to remain in solution, in a supersaturated state.

The presence of these defects, as well as gas or shrinkage porosity formed during solidification, can make properties unpredictable and significantly affect the mechanical properties of aluminium castings [4-9].

Since the dissolution of hydrogen gas in liquid aluminium has been assumed to be a significant issue for the production of high quality castings, a test is required to check the quality of the melt prior to casting to ensure that best properties would be achieved. There exits many methods to measure the hydrogen content of the melt. Most of these techniques are complex, delicate, expensive and slow.
The standard reduced pressure test (RPT) appears to be able to provide an indication of gas level. It involves the solidification of two small samples of melt, one at atmospheric pressure, and the other under a partial vacuum. A comparison of the densities of the samples is then used to give a numerical indication of gas content.

Although RPT is a simple test, it has sensitive areas many of which may depend on the user. Therefore in this work, a series of tests were carried out to investigate and discuss the reliability of RPT test results.

II. EXPERIMENTAL WORK

Approximately 3 kg of 7075 and 2024 was melt separately in a resistance furnace at 750°C. The melting time was found to be around two to three hours. Once the whole charge was in liquid state, the temperature was measured with K-type thermocouple. Sample collection for RPT was started when the melt temperature was 730°C. Fourteen RPT samples were collected within an hour. Bifilm index was measured for the comparison of test results. The dimension of the RPT steel mould is given in Figure 2.

Figure 2: RPT mould dimension

III. RESULTS

The surface of the RPT samples of 2024 and 7075 are shown in Figure 3 and 4.

Figure 3: (a) Surface of the first and (b) last RPT samples of 2024

The cross sections of the RPT samples are given in Figure 5 and 6.

Figure 4: (a) Surface of the first and (b) last RPT samples of 7075

Figure 5: Cross sections of (a) first two and (b) last two RPT samples of 2024

Figure 6: Cross sections of (a) first two and (b) last two RPT samples of 7075

The Bifilm Index change of all the samples collected is given as a time-line in Figure 7 and 8 for 2004 and 7075.
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Figure 7: Bifilm index change of 2024

Figure 8: Bifilm index change of 7075

The average Bifilm Index of the samples is summarised in Figure 9.

Figure 9: Comparison of Bifilm Index change of the alloys after correction

IV. DISCUSSION

Reduced pressure test is one of the simplest and cheapest ways of determining the melt quality of aluminium alloys. In addition, it is relatively quick. It does not require any consumable products or any sort of expensive high technology electronic devices. Approximately 100 g of a sample is led to solidify under vacuum. The pore formation is enhanced by the vacuum and thus the density of the sample decreases accordingly. The usual analysis is therefore made by measuring the density of the samples [10]. More typically, the surface of sample is examined visually. If the surface is not sink or flat and it is risen and inflated instead, this would be the indication of high gas level. An alternative way would be to cut the sample in half and visually inspect the cross section for pore morphology and distribution.

It is important to note that there are several parameters that may influence the formation of these pores. They are summarized as follows:

Sample pouring temperature:
Increasing the temperature increases gas absorption and the solubility of hydrogen in the liquid. Therefore in this study, the melt temperature was kept constant at 730°C.

Chamber pressure:
Chamber pressure is the most significant factors since reducing the pressure increases the pore formation. As the vacuum level is increased for example from 1000 mbar to 10 mbar, the driving force for pore formation is enhanced 10 times. Thus, the selection of the working pressure is vital. For examples, if RPT machine is not equipped with a pressure regulator, the standard vacuum level can reach around 5 mbar. In this case, the pores will burst from the surface, because the vacuum is too low which makes the test unreliable. On the other hand, at lower vacuum levels, for example 200 mbar, the driving force for pore expansion becomes insufficient. Then the sample surface will look flat and possibly no pores will be observed on the cross section. This will result in under-estimation of the test.

Dispinar [11, 12] had shown that 100 mbar was the optimum pressure to be used in RPT tests for reliable and consistent results. Therefore in this study, the vacuum level was constantly checked and controlled to be kept at 100 mbar.

It is also important to note that pressure needs to be applied to the chamber house to make sure that the vacuum is reached as quickly as possible. It has to be stable and there should be no leakage during the test.

Melt gas content:
The general acceptance of the theoretical linear relationship between the density of a RPT sample and the gas content of the melt was discussed in detail by Dispinar [11-14]. Since hydrogen – the only soluble gas in liquid aluminium - cannot nucleate either homogeneously or heterogeneously in the absence of bifilms [1], there would be no pores observed even when the samples were solidified under vacuum.
It is important to address this issue because of the recognition that hydrogen is only a contributor in the formation of porosity, but not the major source. Bifilms are the initiators. Therefore Bifilm Index is used to assess melt quality from the RPT samples [11].

Mould type:

Solidification time is an important parameter for the pore formation. When it is fast, the structure is finer and the diffusion of hydrogen becomes hindered and difficult. In addition, bifilms cannot find the time to unfurl to assist pore formation. Particularly when a steel mould is used in the RPT, one has to consider these parameters. Thus, it is recommended that the mould has to be preheated prior to test for reliable results. As can be seen in Figure 8, Bifilm Indices of the first four samples are quite low for both alloys. This can also be seen in Figures 3 to 6.

The top surfaces of the first samples are almost flat (Fig 3a and Fig 4a). As seen in the cross section of these samples (Fig 5a and 6a), there are no pores observed. This results in low Bifilm Index. When user in foundry sees this type of a sample, he might simply think that hydrogen and bifilms together.

Bifilm Index results become reproducible after fourth sample.

V. CONCLUSION

Reduced pressure test is a simple, robust, low cost and relatively quick test which can assess the effect of both detrimental defects: hydrogen and bifilms together.

Bifilm Index is a discriminating parameter that can be used to quantify aluminum melt quality.

The chamber pressure has to be controlled constantly and the optimum pressure is needed to be 100 mbar.

Bifilm Index results become reproducible after fourth sample.

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