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Evaluation of methods for metal cleanliness assessment in die casting

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Abstract

Faced with higher quality requirements, many die casters need to assess and monitor the cleanliness of the metals used in their operations. While several assessment methods are available, only some are considered to be feasible for die casting. This paper reports a preliminary study that evaluated three feasible assessment methods: K-Mold, mechanical testing, and porous disc filtration apparatus (PoDFA). Results indicate that each method may be used for different purposes and is suitable for different applications. The K-Mold is a quick and simple method that provides information on macro-scale inclusions. It is a good quality control tool for die casters that do not have high requirements for mechanical properties. Mechanical testing can provide both qualitative and quantitative information of the metal cleanliness. The results suggest that elongation is a more appropriate parameter. Modification of the mold to minimize shrinkage porosity is recommended. PoDFA is a good tool for identifying the major types of inclusions present in the molten metal. Modifications of the testing procedure are needed if it is to be used with different sample sizes.

Keywords: Metal cleanliness; Die casting; K-Mold; PoDFA

1. Introduction

It is a common practice in die casting industry to mix a large fraction of scrap metals to Virgin ingots. A ratio of 50/50 of scrap/ingot is often used in many plants. Since the key requirements in most die casting applications has been the dimensional accuracy and tolerances, not the mechanical properties, the presence of inclusions introduced from scrap additions has not been an issue. In addition, in most cases, the effects of porosity defects on the mechanical properties overshadow those of the inclusions. So, the die casting industry has not paid a lot of attention on the cleanliness of the metals.

However, in recent years many die casting plants are faced with higher quality requirements, so the metal cleanliness is becoming a focus in die casting operations [1]. Clean molten metals not only yield improved physical and mechanical properties, but they also provide other benefits such as better fluidity, machinability, and surface finish. In addition, cleaner metals reduce the tendency for stickers and die scoring upon removal of the castings from the dies [1].

It is, thus, important for die casters to control the metal quality used in their production. A first step is to assess the metal cleanliness for quality control and to determine whether further treatments are necessary. However, currently most die casting foundries do not have a method to assess the cleanliness of the molten metals. Although several methods being used in other foundries are available, some of them such as LiMCA and Prefil-Footprinter may be too expensive and sophisticated for die casting operations. This study's objectives are: (1) to evaluate the methods that are feasible for die casting: K-Mold, mechanical testing, and porous disc filtration apparatus (PoDFA), and (2) to test these methods in a commercial die casting operation.

2. Experimental procedures

2.1. The assessment methods

Three methods were first selected due to the availability and the ease of use and control. The description and testing procedures used in this study are given as follows.

2.1.1. K-Mold

The molten metals were cast into a notched bar permanent mold, shown in Fig. 1. The fractured surfaces were visually examined for any macro defects. The number of all inclusions was counted, and the cleanliness of the melt was quantified using the K-value, which is defined as [2]:

$$K = \frac{S}{n} \quad (1)$$

where S is the number of inclusions found in n pieces of the small sample.

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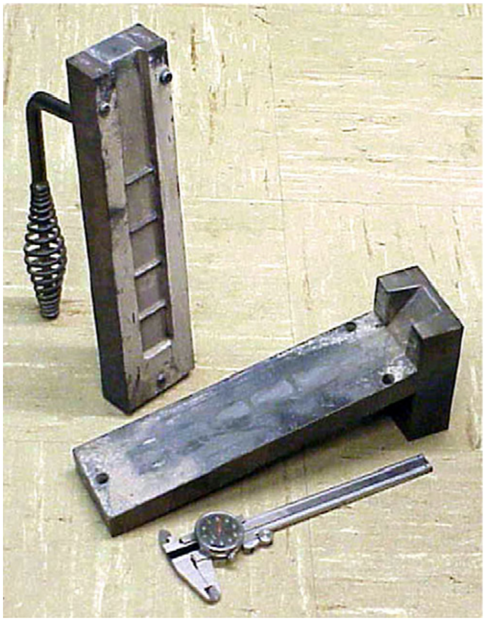

Fig. 1. The K-Mold.

2.1.2. Mechanical testing

The molten metals were cast into a test bar mold preheated to about 200 °C, see Fig. 2. Ten test bars per each metal sample were obtained. The ultimate tensile strength (UTS) and the elongation data were determined.

2.1.3. PoDFA (Porous Disc Filtration Apparatus)

Approximately 1.5 kg of the molten metals were poured into a preheated crucible which had a fine-grade test filter at the bottom, see Fig. 3. A vacuum was applied to cause the molten metal to flow through the filter. Any inclusions in the melt were then collected on the surface of the test filter. The metal cleanliness was then determined by metallographic examinations of the "cake" area. The total inclusion is given as [3]:

$$\text{Total inclusion}\ (\text{mm}^2/\text{kg}) = \frac{\text{mean measured residue area}\ (\text{mm}^2) \times \text{inclusion area fraction}}{\text{filtered metal mass}\ (\text{kg})} \quad (2)$$

Fig. 2. The test bar mold.

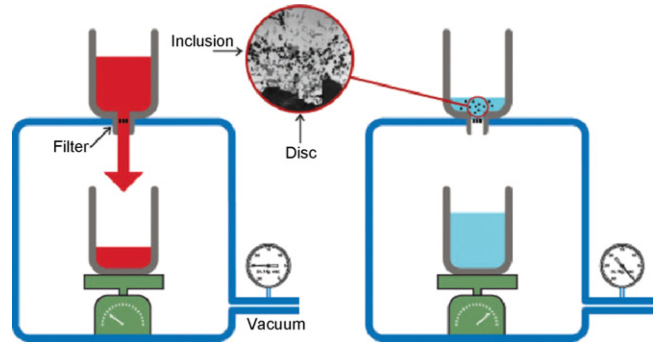

Fig. 3. The PoDFA [Courtesy of ABB].

Table 1
Types and conditions of the samples

Sample ID	Description	Quality level
Virgin	Primary ingots	"Clean"
Type I Scrap	Scrap metals: thick runners and gates	"Intermediate"
Concentrated Scrap	Scrap metals: re-used several times	"Dirty" and Unacceptable
Die Casting	From a barrel furnace at a die casting plant	"Production"

Fig. 4. The 10,000-kg barrel furnace.

2.2. The assessment procedures

Three metal samples with known cleanliness conditions were first used to establish the baseline levels for metal cleanliness. These samples include: (1) the Virgin ingots, (2) Type I Scrap metals, and (3) the Concentrated Scrap metals. Brief descriptions of the samples are given in Table 1. In these assessment tests, approximately 100 kg of the metals were melted and heated to 700 °C in an induction furnace. The molten metals were skimmed well and then assessed using the three methods.

After establishing the baseline levels, the methods were then used to assess the metal cleanliness in a commercial die casting operation. The assessments were performed at a 10,000-kg barrel furnace, which was used to melt and provide A380 alloy for several die casting machines, see Fig. 4.

3. Results and discussion

3.1. Evaluation of the methods using the baseline samples

3.1.1. K-Mold

Representative fractured surfaces and the K-values of the baseline samples are reported in Fig. 5. The Virgin, Type I Scrap,

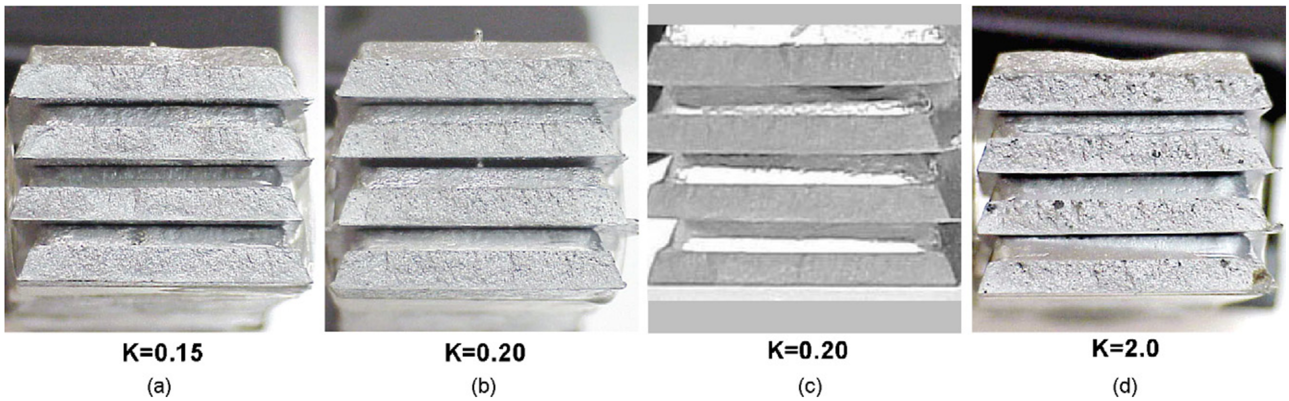

Fig. 5. Fractured surfaces and *K*-value of: (a) the Virgin, (b) Type I Scrap, (c) Die Casting and (d) the Concentrated Scrap.

and Concentrated Scrap samples have the *K*-value of 0.15, 0.20, and 2.0, respectively. Several large inclusions can be obviously observed in the Concentrated Scrap samples, Fig. 5d, but not in the other samples (Fig. 5a–c).

In practice, the molten metal with the *K*-value below 0.5 may be considered "clean" and acceptable in most applications, and with the *K*-value over 0.5, metal treatments to clean the melt are required before casting [2]. Using this criterion, the results show that both the Virgin and Type I Scrap samples are acceptably clean. It is, however, important to point out that the *K*-values only report the large inclusions, which can be clearly identified by naked eyes. The *K*-values tend to exclude the finer inclusions.

3.1.2. Mechanical testing

The ultimate tensile strength and elongation of the samples are given in Fig. 6. Virgin, Type I Scrap, and Concentrated Scrap samples have the UTS and elongation of 26.2, 23.0 and 23.5 ksi, and 2.9, 2.0 and 1.8%, respectively.

The elongation data clearly show the expected trend. However, the UTS data of the Type I Scrap and Concentrated Scrap samples show mixed results. The results suggest that the UTS obtained using this test bar mold may not be the appropriate parameter used to assess the metal cleanliness since other factors such as shrinkage porosity and solidification microstructure may affect the results. In contrast, the elongation data may be a good indicator for metal cleanliness. The elongation results show clear differences between the Virgin and the Type I Scrap samples, and the Type I Scrap and the Concentrated Scrap samples.

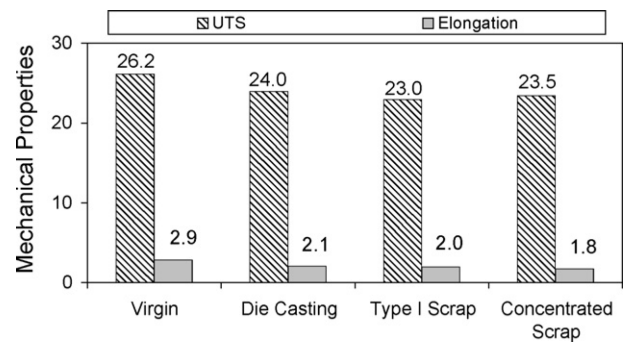

Fig. 6. UTS and elongation of the baseline samples and the Die Casting sample.

3.1.3. PoDFA

The results assessed by PoDFA are presented in Fig. 7. The total inclusions and aluminum oxide films concentrations of the Virgin, Type I Scrap and Concentrated Scrap samples are 0.98, 0.85 and 1.66 mm^2/kg, and 116, 637 and 703 #/kg, respectively. The main inclusions in the melts are dispersed magnesium or aluminum oxides, aluminum oxide films, small and large carbides and potential chloride. Fig. 8 shows representative micrographs of the PoDFA samples showing inclusions and the "cake" area.

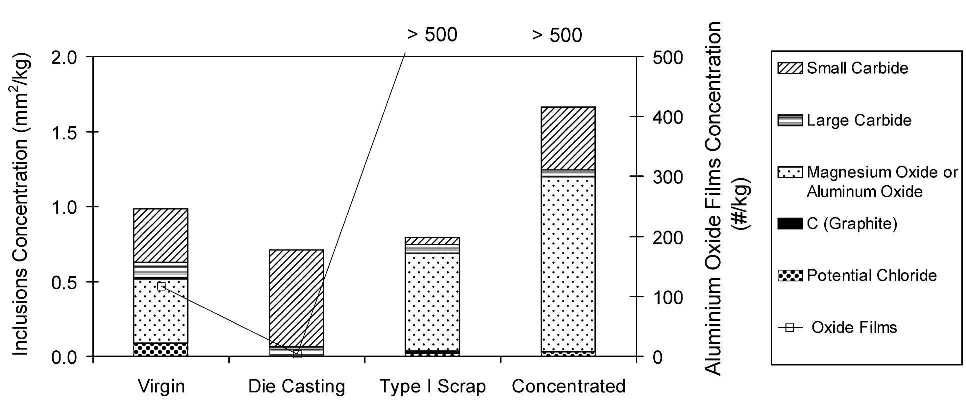

Fig. 7. PoDFA results of the baseline samples and the Die Casting sample.

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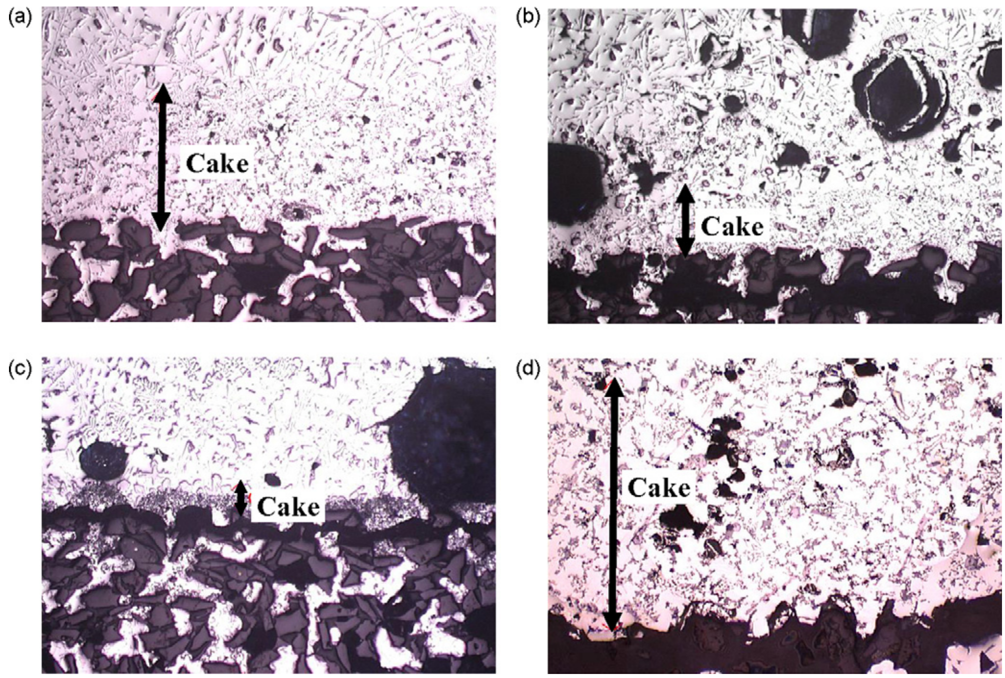

Fig. 8. Representative micrographs of the PoDFA samples showing inclusions and the "cake" area (200×): (a) Virgin, (b) Type I Scrap, (c) Die Casting, and (d) Concentrated Scrap.

The results from PoDFA shows that the Concentrated Scrap samples are the dirtiest, as expected and as reported by other methods. The PoDFA results also provide further details. The types of the inclusions are given quantitatively. This information is useful in determining the major sources of inclusions, which will allow appropriate actions to be done to resolve the problems. In this case, the oxide films may be the major sources that cause low UTS and elongation in the Type I Scrap and Concentrated Scrap metals.

3.2. Application of the methods in a die casting plant

The *K*-value, the UTS, and the elongation of the Die Casting samples are 0.20, 24.0 ksi, and 2.1%, respectively, Figs. 5–6. The *K*-value is comparable with that of the Virgin and Type I Scrap samples. Based on this K-Mold method, the results show that metal used in this die casting plant is considered clean.

The UTS and elongation of the Die Casting sample are as one would expect. Since in this die casting operation some scrap metals are mixed with Virgin ingots, the UTS and elongation values of the metal are in between the values of the Virgin and Type I Scrap samples.

The PoDFA results, Fig. 7, indicate that the metal is quite clean, with the lowest inclusions concentration and the lowest aluminum oxide films concentration. However, the PoDFA results of the Die Casting sample should not be compared directly with those from the baseline laboratory experiments since the assessment procedures are different. There are several factors that contribute to the differences. One is the fact that the Die Casting sample was obtained from a very large pool of metal (10,000 kg), instead of 100-kg melt. The amounts of oxide skins in the baseline samples are expected to be higher. Modifications of the PoDFA laboratory testing are needed before a direct comparison can be made [4].

4. Conclusions

In general, all the assessment methods show the expected trend in the metal cleanliness for both the baseline samples and the sample from a die casting operation. Each method may be used for different purposes and is suitable for different applications. The following conclusions may be derived regarding these methods:

(1) K-Mold is a quick and simple method to provide information of macro-scale inclusions. It is a good quality control tool for foundries that do not have high requirements on the mechanical properties.
(2) Mechanical testing can provide both qualitative and quantitative information of the metal cleanliness. The results suggest that the elongation data is a more appropriate parameter. Modifications of the mold to minimize shrinkage porosity, the effects of solidification microstructure, and the other factors on the properties are recommended.
(3) PoDFA is a good tool for identifying the major types of inclusions. Modifications of the testing procedures are needed if it is to be used with different sample sizes.

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