

Characterization of surface fish-eye casting defect

Caracterização do defeito superficial de fundição do tipo olho de peixe

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Resumo

O defeito de olho de peixe é geralmente observado em ferros fundidos nodulares. O mecanismo de formação desses defeitos não é totalmente compreendido e muito pouco tem sido publicado a esse respeito. Esse trabalho investiga o efeito de diferentes luvas na formação do defeito olho de peixe. Luvas exotérmicas e isolantes, com diferentes concentrações de flúor, foram trituradas e misturadas com areia a verde. A mistura foi usada como areia de faceamento dos moldes de fundição. A caracterização morfológica e química do defeito foi realizada por microscopia óptica (MO) e microscopia eletrônica de varredura com microanálise química por dispersão de raios X (MEV/EDS). Os resultados de EDS mostraram elevadas concentrações de alumínio e flúor na região do defeito.

Palavras-chave: Ferros fundidos nodulares, defeitos superficiais, olho de peixe, luvas exotérmicas.

Abstract

Fish-eye defects are usually observed in the surface of ductile iron casting. Their formation mechanism is not fully understood and very little has been published concerning the subject. This paper investigates the sleeve material effect on fish-eye defect formation in ductile cast irons. Unburnt exothermic and insulating sleeves with different fluorine concentrations have been crushed and mixed in with green sand. These mixtures have been used as facing sands for the casting molds. The morphological and chemical characterization of the fish-eye defects have been performed by light optical microscopy (LOM) and scanning electron microscopy with energy-dispersive spectroscopy (SEM/EDS). Experimental results suggest that surface fish-eye defects on ductile cast irons are caused by the buildup of fluorine-containing sleeve materials in the molding sand.

Keywords: *Ductile cast iron, surface defect, fish-eye, exothermic sleeves.*

1. Introduction

Metallurgical defects in ductile iron can be quite costly to foundries, not only because the elements have to be partly remade or rectified, but due to the unfortunate fact that many defects are not revealed until after the expensive machining stage (Aufderheide, 1998). Common defects observed in ductile iron castings may be divided into two basic categories, i.e.: i) those related to the nodule shape and size, such as compacted graphite structures, exploded and chunky graphite, graphite floatation, spiky graphite and nodule alignment; and ii) those related to inclusions/discontinuities within the matrix, such as flake graphite surfaces, slag inclusions, carbides and gases. Care through raw materials selection, good process control during melting stage and proper metal handling procedures constitute effective methods for defect prevention. (Masoumi, 2005; Tiedje, 2010).

A casting set usually consists of a mold, gating system, pouring cup, riser, cores, and other components such as exothermic and/or insulating sleeves. To produce a metal casting, metal is poured into the pouring cup and passes through the gating system to the mold and cores

where it solidifies. Metal from the riser fills the voids in the casting when the metal contracts during solidification. Thus, the metal from the riser needs to remain in a liquid state for a longer period of time, so it can provide metal to the casting as it cools and solidifies (Källbom, 2005; Masoumi, 2005). Sleeves are used to surround or encapsulate the riser and other parts of the casting assembly in order to keep the molten metal in the riser as hot as possible, maintaining it in liquid state for a longer period of time. In order to serve their function, sleeves have exothermic or insulating properties. Exothermic sleeves function by liberating heat, providing part or all of the specific heat requirements of the riser and so reducing the molten metal temperature loss. Ductile iron castings have unique riser requirements compared to the feeding of other metals. The volume changes in the casting are not a simple contraction as metal solidifies. For example, when the graphite nodules are formed, the metal actually expands, which can push metal back into the riser and gating system if these are not properly designed (Källbom, 2005). This, along with the metal subsequent contraction during cooling, creates

a strong demand on the riser feeding capabilities, which is usually achieved by using suitable exothermic and/or insulating sleeves (Showman, 2001).

Before the widening use of exothermic sleeves, fish-eye defects were only occasionally seen in green-sand foundries when some excessive amount of clay had been present in sand. With the growing usage of exothermic riser sleeves, the presence of fish-eye defects has increased. Typical exothermic sleeve formulations contain aluminum as a combustible, metal oxides and/or nitrates as oxidizers, besides fluorine containing compounds as fluxing agents. These agents reduce the time taken by the exothermic sleeve to ignite and improve the propagation of the exothermic reaction. However, high fluorine levels in the sleeve could cause fish-eye defects in ductile iron castings when the green sand is contaminated with fluorine-containing sleeve materials (Aufderheide, 1998; Showman, 2001).

This paper presents the results obtained after casting tests using four different types of crushed unburnt sleeve materials mixed in with green sand. A detailed characterization of a fish-eye defect is also presented.

2. Experimental procedures

The tests presented in this work have been performed at Schulz S.A. company, located in Joinville city, Brazil. A mold assembly for a ductile iron piece (Figure 1) has been chosen for the experiments. Four different sleeves have been used in this study, i.e.: S1) a high-fluorine exothermic sleeve; S2) a low-fluorine exothermic sleeve; S3) a low-fluorine insulating sleeve; and S4) a non-fluorine exothermic sleeve. The analyzed amounts (wt.-%) of aluminum, fluorine and sulfur in the sleeves are displayed in Table 1. The unburnt

sleeves have been crushed and mixed in with green sand in a laboratory mixer, following the same parameters used in the casting practice. The mixtures have been used as facing sand for the casting tests, as depicted in Figure 1.

The alloy used in present investigation was a ferritic-pearlitic ductile iron (FE-5007), whose nominal chemical composition is given in Table 2. Melts have been prepared in a 12-ton, basic-lined induction furnace. Pouring temperatures were monitored through an immersed

thermocouple and has varied between 1385°C-1410°C for all castings. Each casting was carefully examined upon shake-out. Visual surface casting inspection has been followed by macroscopic examination using light optical microscopy (LOM) technique. Morphological and chemical characterization of a surface fish-eye defect was carried out in a SSX-550 model Shimadzu scanning electron microscope (SEM) equipped with an energy-dispersive spectroscopy (EDS) system, operating at 20 kV in the secondary electron mode.

| Element | S1 | S2 | S3 | S4 |
|----------|-------|-------|-------|-------|
| Aluminum | 16.98 | 18.69 | 17.06 | 13.65 |
| Fluorine | 0.737 | 0.378 | 0.377 | N/A |
| Sulfur | 0.89 | 1.24 | 1.56 | 1.54 |

Table 1
Chemical composition of exothermic (S1, S2, S4) and insulating (S3) sleeves (wt.-%).

| C | Si | Mn | P | S | Mg | Al |
|-----------|---------|-------|-------|-------|-------------|---------|
| 3.55-3.65 | 2.1-2.3 | < 0.3 | < 0.6 | < 0.2 | 0.028-0.045 | < 0.015 |

Table 2
Nominal chemical composition of FE-5007 ductile iron (wt.-%).

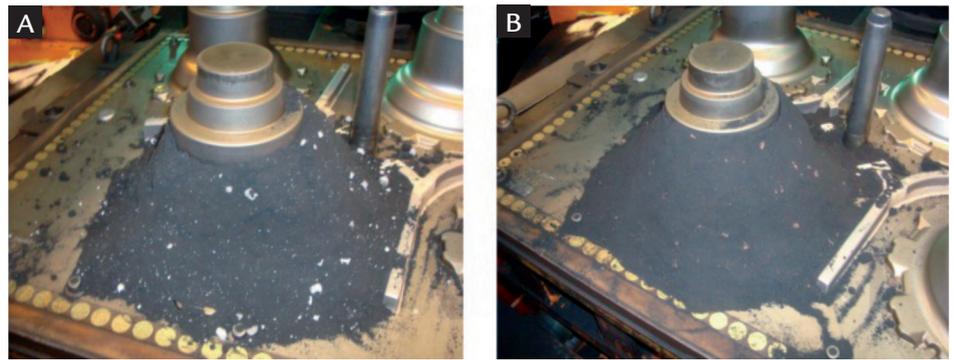


Figure 1

Mold assembly showing examples of facing sands contaminated with crushed unburnt exothermic sleeves: (A) S1-sleeve, high-fluorine. (B) S2-sleeve, low-fluorine.

3. Results and discussion

Macroscopic examination

Experiments showed that the fluorine presence in the exothermic or insulating sleeve formulations contribute to the formation of surface fish-eye defects. Typical distributions of these defects can be seen in Figures 2(A) to 2(C), corresponding to S1, S2 and S3 sleeves. These macrographs show the extent of defects with increasing fluorine content in the sleeves. However, when the fluorine-containing sleeves are replaced by a non-fluorine sleeve (S4), no fish-eye defects were produced, as shown in Figure 2(D).

Aufderheide and co-workers (Auf-

derheide, 1998) reported similar results using five different contaminants, including cryolite and crushed unburnt and burnt riser exothermic and insulating sleeves. However, these authors have placed the contaminants directly on the pattern surface during the casting tests, instead of being mixed with the foundry sand. This procedure does not correspond to that performed in casting practice.

During the casting shakeout the mold sand is crushed and mixed in with riser burnt sleeves. This contaminated sand returns to the closed sand system and initiates a new preparation cycle,

renewing additives and receiving water, in order to acquire the properties of foundry sand. The silica sand is highly hygroscopic and absorbs water during the addition cycle. When the molten metal is poured at high temperatures a metal-mold reaction takes place, dissociating hydrogen from free-water absorbed by the mold sand. Hydrogen tends to migrate towards the monoxide carbon bubbles nucleated on the mold surface, leading to the formation of a fish-eye defect. Further details concerning this mechanism will be discussed ahead.

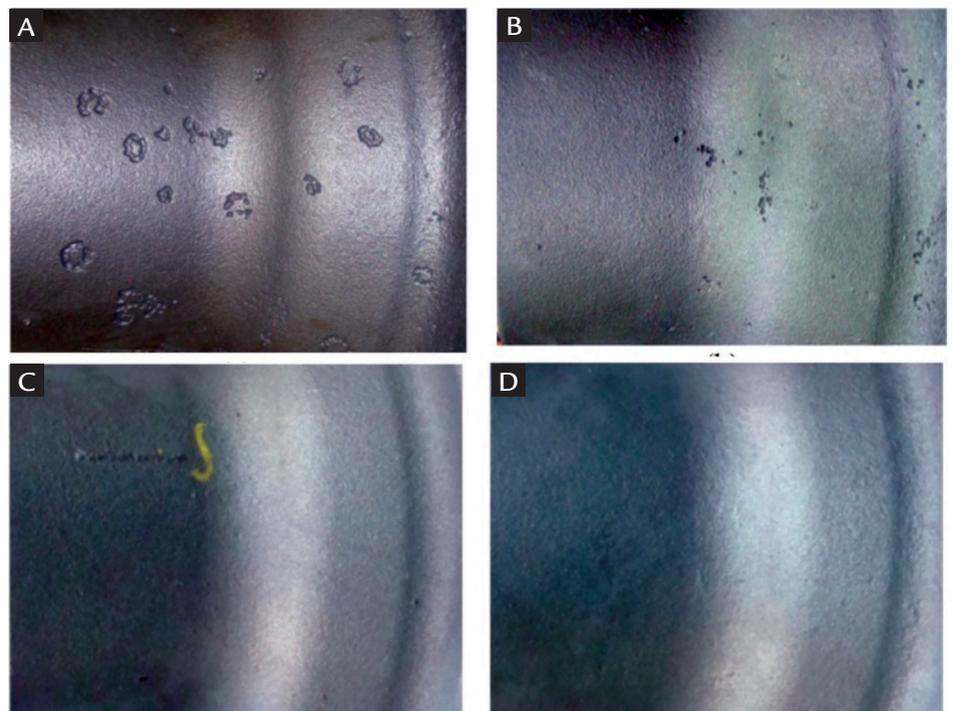


Figure 2

Casting surfaces resulting from facing sands contaminated with: (A) S1 high-fluorine exothermic sleeve. (B) S2 low-fluorine exothermic sleeve. (C) S3 low-fluorine insulating sleeve. (D) S4 non-fluorine exothermic sleeve.

Microscopic examination

A closer inspection of a surface fish-eye defect has been carried out by scanning electron microscopy (SEM). Figure 3 shows typical morphologies

observed nearby and inside the defect. The same regions have been analyzed by EDS technique and the results are displayed in Table 3. SEM examination

revealed the presence of several oxidized areas (Figure 3A); most often located in cavities vicinity (point A). Figures 3(B) to 3(D) clearly show the progressive con-

centration of metal-mold reaction products located in the border and inside the defect. The presence of higher amounts of fluorine is noticeable in these regions (points B and C of Table 3), confirming that surface fish-eye defect is associated with fluorine contamination.

In addition to high fluorine concentrations, EDS results of Table 3 also show smaller amounts of sodium, magnesium, aluminum and sulfur, as well as residual levels of other elements such as calcium, potassium and chlorine. Some of these compounds are derived from aluminum dross, which is a by-product of aluminum manufacture. In the manufacturing process of

exothermic sleeves the aluminum dross is intimately mixed with fluorine and melted with aluminum, besides other oxidizable metals such as magnesium and silicon. Therefore, it provides a very efficient, fast igniting, and good propagating exothermic reaction. Exothermic sleeves containing aluminum dross, fine aluminum powder, potassium nitrate, and iron oxide are particularly efficient as riser sleeves in the casting of ductile iron (Showman, 2001).

Concentration profiles based on EDS results in Table 3 are presented in Figure 4, depicting higher concentrations of fluorine within the defect, as well as the variations in carbon and aluminum

concentrations. Despite the limitations in carbon quantification by EDS, results have shown that the concentration of this element reduces towards the defect, suggesting a nucleating mechanism of gas bubbles by carbon oxidation. Both the hydrogen dissolved in liquid metal as the one resulting from free-water dissociation migrate to the monoxide carbon bubbles, increasing the size of gas porosities. Further details of this mechanism are reported elsewhere (OHNAKA, 2008). The aluminum concentration behaves similarly to the carbon. The smaller amounts of aluminum inside the defect suggest the occurrence of an intense aluminothermic reaction.

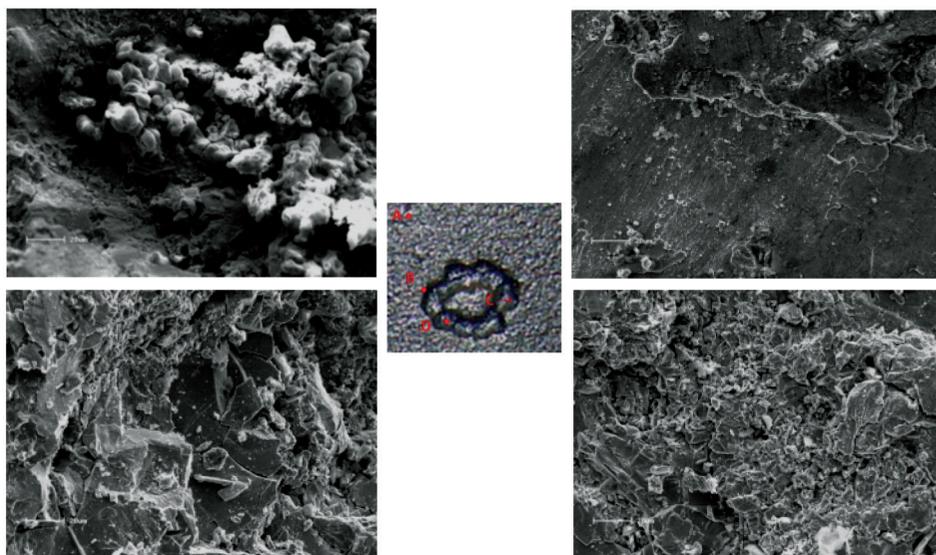


Figure 3 Set of SEM micrographs depicting different morphologies nearby and inside a surface fish-eye defect (central image indicates the analyzed points).

| Elements | A | B | C | D |
|----------|---------|---------|---------|---------|
| C | 7.235 | 3.984 | 3.751 | 4.298 |
| O | 24.687 | 35.893 | 33.373 | 33.475 |
| F | 5.789 | 8.974 | 9.148 | 5.401 |
| Na | 0.633 | 0.360 | 0.337 | 0.262 |
| Mg | 0.239 | 0.129 | 0.127 | 0.107 |
| Al | 1.328 | 0.072 | 0.176 | 0.139 |
| Si | 6.686 | 1.938 | 3.311 | 3.996 |
| S | 0.000 | 0.762 | 0.000 | 0.486 |
| Cl | 0.510 | 0.146 | 0.043 | 0.083 |
| K | 0.235 | 0.123 | 0.182 | 0.126 |
| Ca | 0.169 | 0.140 | 0.040 | 0.000 |
| Mn | 0.710 | 0.240 | 0.200 | 0.274 |
| Fe | balance | balance | balance | balance |

Table 3 EDS results for the analyzed points showed in Figure 3 (wt.-%).

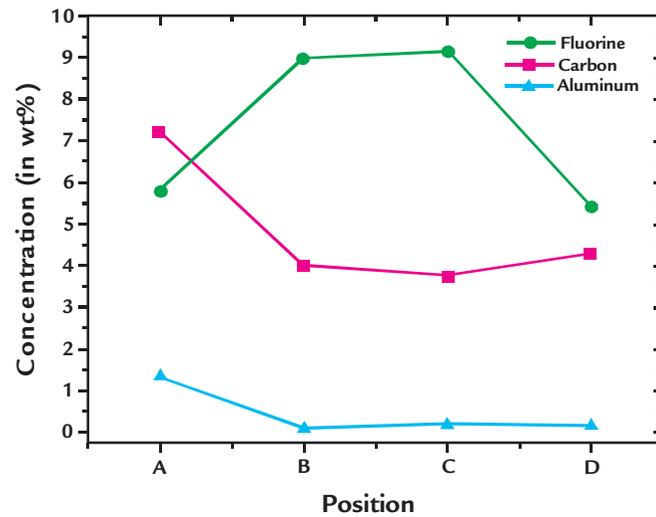


Figure 4
Concentration profiles of
fluorine, carbon and aluminum.

4. Conclusions

Experimental results suggest that surface fish-eye defects on ductile cast irons are caused by the buildup of fluorine-containing sleeve materials in molding sand. This surface defect appears as result-

ing of an aluminothermic-type reaction, enhanced by the free-water absorbed by the foundry sand. EDS results have shown high amounts of fluorine in the defect region, besides aluminum small concen-

trations. Good foundry practice recommends replacing the fluorine-containing sleeves by non-fluorine ones, as well as reducing the sand contamination with sleeve materials.

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6. References

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