

Slim the Slag in Your Iron

Three causes of slag-related defects in ductile iron castings are well documented. A third more critical cause often has been overlooked.

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For safety reasons, certain casting applications demand ductile iron castings with no surface defects resulting from slag in the melt. The treated iron and the role of magnesium and process temperature in producing these defects have been well documented. However, more severe forms of slag can be associated with pre-existing oxidation of the base iron.

Metallographic evidence has been shown to support this additional cause of slag. In this article, the origin of this type of slag defect is explored, and suggestions for its prevention are offered.

The Accepted Causes

Slag, a non-metallic film-type inclusion, represents a major concern for both metalcasters and clients, as it affects surface quality and in turn favors the initiation of cracks. Technical literature supported by industrial practice suggests that slag in cast iron results from three basic factors: magnesium treatment, re-oxidation (which takes place thereafter) and turbulence during mold filling.

During magnesium treatment, the amount and type of reaction products depend on the chemistry of the base melt, treatment temperature and master alloy composition. Acid cupolas generate more slag rich in manganese sulfides, which is easily identifiable (Fig.1). Electric or rotary melting generates less complex slag with the predominant film type being magnesium silicate inclusions (enstatite and forsterite) (Fig.2).

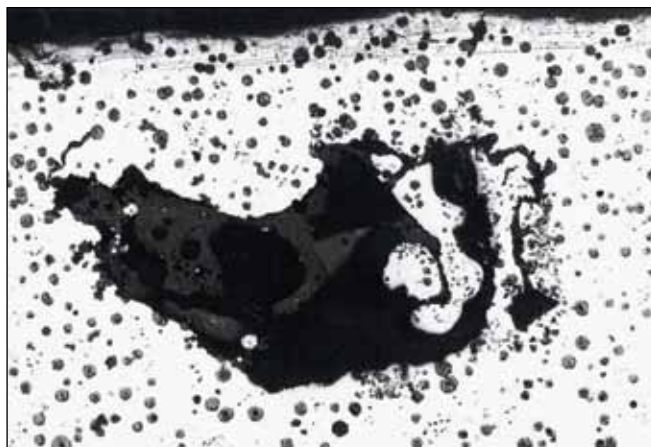


Fig. 1. Shown is typical slag associated with cupola melting after treatment. (Photo courtesy SKW Trostberg, Germany)

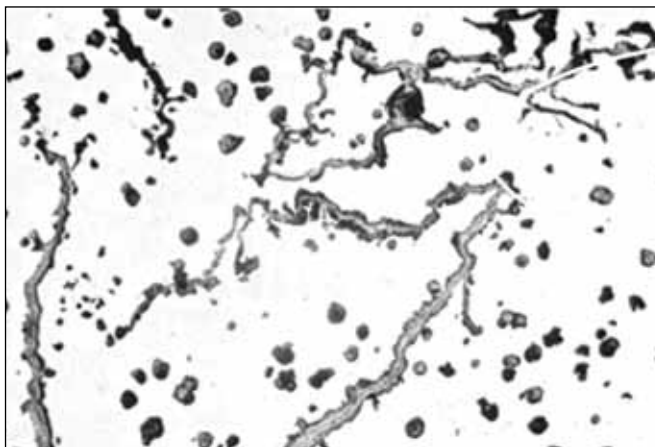


Fig. 2. Shown is typical slag associated with electric melting. (Photo courtesy Rio Tinto Iron & Titanium)



Fig. 3. The surface imperfections in this crankshaft are aligned to the flow path from right to left due to excessive metal speed at the riser gate.

During cooling in the liquid state, magnesium oxidizes in a predetermined way, depending on temperature. At relatively high temperatures, it generates a slag film, and at low temperatures, it makes solid slag containing higher amounts of silica.

Traditional master alloys contain relatively low levels of magnesium (<10%), as compared to those used with the wire technique, where the content of the element exceeds 20%. This allows lowering the rates of addition and potentially reducing the amount of slag, though it will depend on powder formulation. Moreover, it is generally assumed that the higher the magnesium content, the higher the amount of magnesium oxide, which should then increase the consistency of the slag. But this is not always true.

Re-oxidation of magnesium takes place after treatment and continues as temperature decreases. Re-oxidation also occurs during mold filling, when the gating system favors high velocities and thus metal spraying (Fig.3). Low temperatures enhance this phenomenon.

Another Source of Slag

The formation of magnesium silicate inclusions in ductile iron after treatment appears unavoidable. The amount generated can be high or low depending on the influence of the factors listed above. Still, these inclusions rarely provoke rejection of heavy castings, since they are currently confined to a surface layer that can be eliminated through machining. The true concern is what is acknowl-

edged as heavy slag, which penetrates deep into the casting skin and whose origin is related to a previous state of heavy oxidation of the base melt.

If subjected to extended holding at relatively low temperatures

(<2,480F [1,360C]), slag in an iron melt undergoes changes in composition as it becomes enriched in iron oxide. This is a well known fact in gray iron, where manganese oxide also plays an additive role. Both of these oxides reduce the melting point of the silica-rich slag and favor the formation of film-type inclusions, which react vigorously with the carbon in the melt, generating carbon monoxide gas holes. The continuous use of dirty ladles can lead to the same result. This defect is not qualified as slag, as it is uncommon.

Although magnesium is a well known deoxidizer, during treatment it cannot eliminate all the iron oxide present in the slag because of the short time available. Consequently, after treatment, slag will contain magnesium silicates rich in iron oxide, which will increase its aggressive tendency.

This situation worsens in conditions of turbulence during mold filling, leading to the presence of false cold laps due to further iron oxide enrichment as a consequence of surface oxidation (Fig.4). Low pouring temperatures (<2,410F [1,320C]) exacerbate the



Fig. 4. Shown are false cold laps due to further iron oxide enrichment as a consequence of surface oxidation

phenomenon, although it is not the main culprit.

The phrase “oxidation state of the melt” may sound ambiguous to some metalcasters, as a way to measure it does not exist. Analysis of oxygen has been shown to be of limited value in cast iron. As the melt and the slag stay in symbiosis, it is much easier and less costly to observe the state of the slag based on the fact that the amount of iron oxide will condition its consistency (Fig.5).

A highly-oxidized slag will display a clear color with a fluid texture. At temperatures above 2,660F (1,460C), its presence could pass unnoticed, as it subtly covers the bath surface, giving the sensation during tapping of being at a lower temperature than measured (Fig. 6a). The slag easily accompanies the iron during tapping despite any attempt to skim it off. It will remain so after treatment, regardless of the type of alloy used (Fig.6b).

The opposite is true for a high melting point slag. This displays a dark color with a good consistency that facilitates both furnace and ladle skimming (Fig.7a). It remains consistent after treatment (Fig.7b).

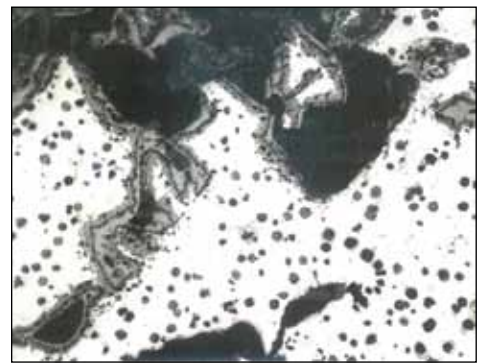


Fig. 5. Heavy surface oxidation is apparent in this casting, as well as the microscopic appearance of iron oxide rich inclusions

Cure and Remedies

Holding metal for long periods of time and using dirty ladles can favor the generation of heavy slag problems. These conditions are likely in the production of heavy castings on a non-continuous basis. To prevent such an occurrence, it is necessary to act on the base iron in order to correct an excessive state of oxidation evidenced by the color and overall fluidity of the furnace slag.

One method is to modify the slag chemistry so that silica prevails. This can be achieved by additions of new silica sand on the order of 0.5% of the metallic charge or during the superheating stage, coupled with strong agitation for several minutes. This practice was employed in the melt shown in Fig. 6a. Fig. 7a shows the melt after the technique was performed. This was the solution to a problem involving low elongation in tensile specimens taken from castings plagued with non-metallic inclusions.



Fig. 6. At left, fluid slag is shown on the melting furnace at 1,480C before treatment. At right, the same melt is shown after treatment with high magnesium (80%) cored wire.



Fig. 7. At left, high melting point slag is shown before treatment after addition of 0.5% of silica sand. Even if the tapping temperature was similar, the liquid iron appears brighter than in Fig.9a. At right, the same melt is shown just after treatment with high magnesium (80%) cored wire.

Another remedy requires the addition of slag conditioner prior to magnesium treatment. Good results can be obtained with small additions (0.05%). However, these products require the metalcaster to incur an additional cost and may not be available everywhere.

Regular and steady additions of ferrosilicon or silicon carbide during melting also are possible cures, but

apart from cost considerations, they are not always practicable because of limitations in chemistry.

Parallel measures should be undertaken to devise an adequate gating system to prevent metal spraying and turbulence during mold filling.

Last but not least, since the melt and the slag stay in symbiosis, the modification of the latter will bring benefits to the former, as an excess of oxygen in

the melt affects nucleation and in turn reduces self-feeding capacity.

Some uncommon situations exist, but any metalcasting facility producing castings with high quality demands should exercise an adequate surveillance of the melt through the observation of the slag consistency, following where necessary the suggestions given in this paper. This approach can be extended to gray iron melts, as well. **MC**