BLOWHOLES FROM SLAG INCLUSIONS

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From the B.C.I.R.A. Lecture Course on Defects in Grey Iron Castings

Defects in iron castings due to gas holes may occur owing to the inclusion of slagggy materials with the liquid metal during casting. Although this foreign matter is usually called slag and the defects are known as slag holes, the intrapped material may not necessarily be a true slag such as cupola furnace slag, but can consist of a variety of dross-forming substances.

The casting defects which are the subject of this paper can exist as blowholes visible in the as-cast state, as glassy depressions in the casting surface, or they may not be revealed until the casting has been machined. Typical defects are shown in Figs. 1 and 2. In Fig. 1 some of the blowholes are breaking through the casting skin, and others were revealed by machining the pad and in Fig. 2 the blowholes are some considerable way beneath the surface.

There are three principal sources of the foreign matter which may find its way into the metal:

1. The cupola slag itself;
2. The refractories used for containing and conveying liquid metal;
3. Ladle surface slag produced by chemical action, such as oxidation at the metal surface.

All these substances will react under certain conditions with carbon to produce carbon monoxide. This gas is responsible for the blowholes.

Cupola slag—Cupola slag very rarely enters a casting owing to its rapid rise in viscosity with falling temperature. This allows it to be chilled and trapped in pouring bushes and downgates, and it can also be fairly easily removed from the ladle metal surface with a skimmer. A good cupola operator will not allow slag from the cupola to enter the ladle, and should be encouraged to maintain a few inches of gas-free metal in the cupola. Blowholes of course should be removed. The appearance of cupola slag is that of a very light, glassy mass, and can be distinguished in contrast to the dark material described above.

Ladle slag—Ladle slag is the main cause of blowholes. Ladle slag is used in the important foundry practice of purifying the metal by removing dross, and consists of any dross having been poured into the ladle. These drosses may be of many different sorts, but generally consist of a mixture of dross (that has floated to the top of the metal for some reason or other) and oxide. It is difficult to remove all the dross from the ladle, and it is usual to mix in a little milled material lining in order to assist in this.
being tapped and the linings are renewed frequently. The slightly porous nature of this type of lining assists in drying out and also absorbs some of the more fluid ladle surface oxides.

**Botting clays**—Another refractory item which tends to be overlooked is the botting clay. This is used for plugging the tap hole in a cupola and the composition of this material is very important, both from the point of view of physical properties such as plasticity and stickiness, and fusion point. The fragments of bott produced during tapping are sometimes deliberately scooped away from the launder, but more frequently they are washed into the ladle with the first rush of metal from the tap hole. A low fusion point material (some have been tested with results as low as 1170°C) produces a thin reactive liquid drop on the surface of the ladle, and this material cannot easily be skimmed off. The resulting fluid enters the mould during pouring and is very erosive, cutting into the sand channels and ingates and producing dross and gas holes. A typical microstructure of this defect is shown in Fig. 4. Various samples of botting clays in

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**Fig. 3**

Acid cupola slag under reflected light.

*Unetched. × 600.*

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Ladle and launder refractories—Refractories used in handling the metal are of more importance. The normal refractory materials used in ironfoundry are siliceous and consist of ganisters and fireclays, usually having a fusion point in excess of 1400°C. These refractories rarely cause difficulty except perhaps in drying, but provided that this is carried out conscientiously no trouble should ensue. Considerable evolution of steam will oxidize and cool the metal, however, and the resulting surface slag can be troublesome. Some ladles are lined with a naturally-bonded red sand, or a red sand milled with a little extra fireclay. This material sinters and forms quite a satisfactory lining provided that very hot metal is not
actual use, which have been fired at 1250°C, are shown in Fig. 5. The dark materials have fused and in two cases have become severely bloated due to gas evolution. At 1350°C these materials would be very liquid and gassy. The use of a refractory clay mixed with silica sand and coal dust in the approximate proportion 5:3:2 is to be recommended. Ordinary brickmaking clay, or clays from unknown sources should not be used.

Ladle surface slags—Ladle surface slags produced by oxidation and chemical action, are most important and are responsible for a high proportion of scrap castings. Blowhole defects of this type are usually revealed as sub-surface gas holes on machining, and such defects are illustrated in Fig. 6. This defect can be extremely difficult to diagnose, often being attributed to wet sand, 'gassy metal,' 'slag' and a host of other factors. If the microstructure of such a defective casting is examined in the vicinity of the gas holes, a characteristic segregation of a non-metallic

Fig. 5
Botting clay test pieces after firing at 1250°C for two hours.

Fig. 6
Sub-surface gas holes associated with manganese sulphide segregation.

Fig. 7
Manganese sulphide segregation and slag contained in gas holes. Etched in 4 per cent. picral. × 150

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**Fig. 8**
Typical manganese sulphide segregation and slag associated with sub-surface gas hole defects. Unetched. × 100.

**Fig. 9**
The centre of the casting is blocked out by an oil sand core.
Test cube.

**Fig. 10**
Machined surface of test cubes (after Tonks).

<table>
<thead>
<tr>
<th>Average pouring temperature</th>
<th>0.54</th>
<th>0.70</th>
<th>0.93</th>
<th>1.08</th>
<th>1.22</th>
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<tbody>
<tr>
<td>1345°C</td>
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<td>1285°C</td>
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<td>1210°C</td>
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Manganese content, %

Composition: T.C. 3.04%; Si 2.30%; S 0.11%; P 1.14%
compound, manganese sulphide, is always found. This is shown in Figs. 7 and 8, and it will be seen that associated with the gas holes is a complex crystalline slag.

The defect is not confined to green sand moulds, and may occur in all types of moulds. The presence of moisture, however, usually aggravates this defect.

Experimental work carried out by Tonks and observations by Cook, Jolly and Morgan, have shown that the chief contributing factor is low pouring temperature associated with high sulphur and manganese contents in the metal. Tonks used a hollow cube as a test piece, shown in Fig. 9, and studied both the composition and pouring temperature. After casting, the surface of the block was machined to reveal the sub-surface gas holes, as shown in Fig. 10. This particular set of blocks is arranged to show the effect of increasing manganese contents and falling temperatures. Sections cut at right-angles to the surface and sulphur-printed to reveal the sulphide segregation are shown in Fig. 11.

The results of these experiments showed that when the sulphur content is plotted against manganese content at any one temperature, a curve can be drawn separating sound and unsound castings. This is shown in Fig. 12. As a result of the reversible reaction

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\text{Mn} + \text{FeS} \rightarrow \text{MnS} + \text{Fe}
\]

which proceeds to the right with fall in temperature, an increase in either manganese or sulphur will cause manganese sulphide to be precipitated. The experiments also showed that the sub-surface blowhole defects arise when the casting temperature is low enough to permit some precipitation and segregation of manganese sulphide before and during pouring.

This type of defect has also recently been discussed by Dahllmann and Löhberg, and it is generally agreed amongst investigators that the formation of the blowholes involves two factors: first the reaction which could produce a gas, and second, the part played by manganese sulphide.

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Fig. 13

Structure of slag contained in manganese sulphide gas hole. Unetched x 100

Action of manganese sulphide—The reaction between the slag containing iron oxide and other oxides, and the graphite precipitated during solidification of the cast iron produces carbon monoxide gas and metallic iron, according to the simplified equation:

$$\text{FeO} + \text{C} = \text{CO} + \text{Fe}$$

The activity of carbon in liquid iron is not high enough to produce a reaction with the slag, and only a very fluid slag can be brought into intimate contact with graphite at eutectic temperatures. This very low melting point slag is produced by manganese sulphide dissolving in the iron silicate/manganese silicate oxidation slag and lowering its melting point. Thus the presence of manganese sulphide facilitates the gas-producing reaction by making the slag sufficiently fluid at the eutectic temperature.

By examination of the microstructure it should be possible to find evidence of solution of manganese sulphide in the silicate slag, and the metallic iron produced by reduction of the iron oxide. This is shown in Figs. 13, 14, 15, which indicate:

1. Segregation of manganese sulphide;
2. Presence of a complex silicate slag;
3. Blowhole surrounding this slag;
4. Solubility and precipitation of manganese sulphide in slag;
5. Formation of iron dendrites in slag.

The schematic formation of the sub-surface gas holes is shown on page 444.

The practical implications of this work are that when using irons of high sulphur content it is necessary to pour at high temperatures if gas hole defects are to be avoided. The practice of adding more manganese to "look after" the sulphur will only increase the tendency to blowhole formation, and manganese contents in excess of 0.7 per cent require
Manganese sulphide in silicate slag

Segregated manganese sulphide

Fig. 14
Manganese sulphide and silicate slag present in gas holes. Unetched. × 600.

- Cupola metal
- High temperature as tapped
- Carbon oxidizing
- Falling temperature
- Small amount of FeO, MnO and SiO₂ beginning to form on surface
- Surface easily cleaned
- Falling temperature
- Formation of Fe₂O₃ and MnO, FeO and SiO₂ crust. Skimmed off easily
- Falling temperature
- Separation of MnS. This dissolves in surface oxides and forms very fluid slag which is difficult to skim off
- Fluid slag reacts with graphite to form CO gas which causes blowholes
correspondingly low sulphur contents and high pouring temperatures.

If this type of defect occurs in a foundry, the pouring temperature should be raised, the means of reducing the sulphur content should be explored, and the manganese content should be adjusted to a level below 0.7 per cent. The metal should also be tapped into heated ladles and casting ingates should be arranged to avoid stagnant pools of metal during mould filling.

REFERENCES