

Common Metallurgical Defects in Grey Cast Irons

Causes and Cures

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Abstract

Whilst most foundries today recognise the types of defect found in grey cast irons, an appreciation of the causes and therefore cures is not always apparent.

This paper will examine some of the common metallurgical defects, which have been found during examination of rejected castings in Elkem's Research Centre in Norway.

Gas defects are particularly difficult to categorise and particular attention is paid to hydrogen, nitrogen and carbon monoxide gas holes.

Other defect types examined include shrinkage, flake compaction, Widmanstätten graphite and the commonly seen ferritic rim.

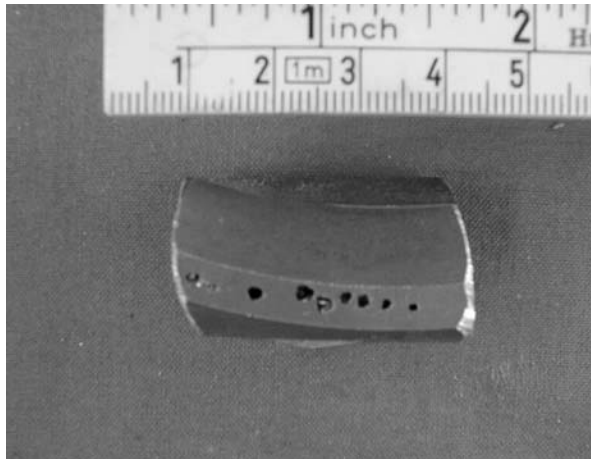
Introduction

Metallurgical defects, whilst normally a small part of a foundry's defect casting percentage, can be time consuming and expensive to classify and hence remedy. In this paper, some of the more common defects are described based on case studies from Elkem's Research Centre. In the examination of any defect, good metallographic facilities are necessary to provide sufficient detail to avoid mistakes in the correct identification of the defect, particularly when gas is suspected as the problem. Other defects, such as Widmanstätten graphite, may require high magnifications to be able to see the problem.

Hydrogen Pinholes

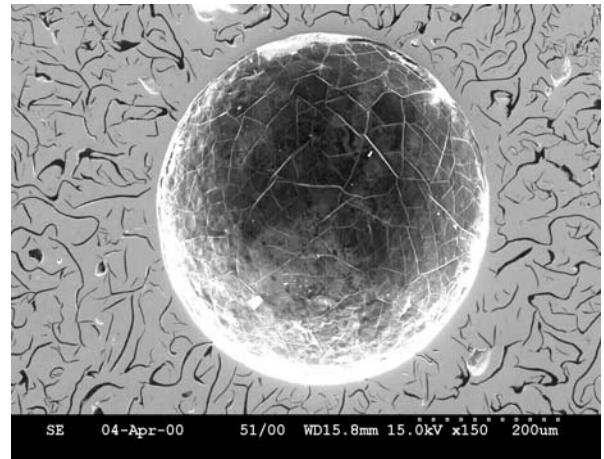
These may be considered to be one of the most expensive defects as they are not normally revealed until after machining. They can be found both in grey and ductile irons and tend to appear as small spherical holes just beneath the casting surface. The inner surface of the hole will have a continuous graphite lining and hence appear to be black and shiny on examination. This precipitation of graphite onto the surface results in a graphite depleted area around the hydrogen gas hole as shown in Figure 1.

Hydrogen pinholes can be caused by several factors, either alone or in combination. Most commonly, high levels of aluminium or titanium in the base iron causes a reaction with moisture from the greensand, damp tools or wet refractories. Other sources of moisture could be damp or oily charge materials (including rust), a build up of dead clay in the sand system which will tend to retain moisture or the use of old cores, which have picked up moisture from humid atmospheres.



Example of hydrogen porosity revealed on machining.

Figure 1. Hydrogen pinhole.



Close-up of hydrogen pinhole revealing inner graphite lining.

Pinholes may be prevented, or the occurrence reduced, by restricting the aluminium content of the base metal below 200ppm and minimising the titanium content. Careful control of steel scrap, avoidance of CG iron returns (if made using Ti) and elimination of enamelled scrap will help in this respect. Some pig irons can also contain titanium.

Care should be taken to fully dry refractory patches and coated tools before use and sufficient new sand added to the moulding system to prevent build up of dead clay. Moisture in the system should preferably be below 3%. Cores and water-based coatings should be fully cured and dry before the metal is poured into the mould.

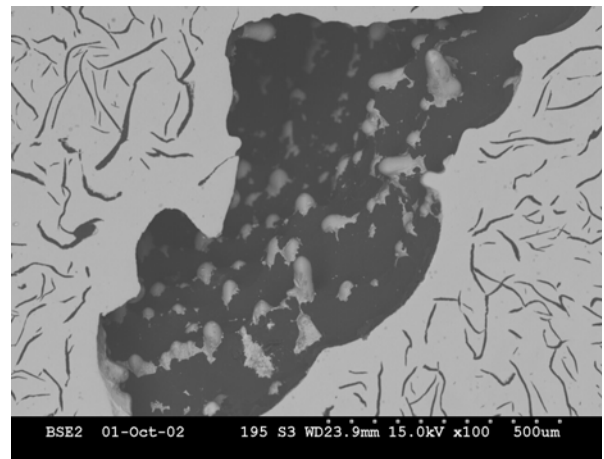
Increasing metal pouring temperatures and carbon equivalents have also been noted to reduce the incidence of this particular defect.

Nitrogen Blowholes



Example of Nitrogen porosity defect in grey iron revealed on machining.

Figure 2. Nitrogen Blowholes



Close-up of defect showing flake depleted rim.

Nitrogen blowholes may be either a surface defect or a sub-surface occurrence. The example shown in figure 2 was only revealed on machining, thus being detected at the most expensive post-foundry finishing operation. Blowholes appear more frequently in medium to heavy section thicknesses and are often adjacent to resin bonded core or mould materials. The holes, or fissures, are normally irregular in shape (as opposed to the more spherical hydrogen holes) and are perpendicular to the casting surface, protruding some millimetres into the casting. The

inner surface of the hole has a continuous or dis-continuous graphite lining coupled with the subsequent decarburisation in the immediate surrounding matrix. This is clearly seen in figure 2. Also seen in this figure are dendrites, which have grown into the hole. On occasions, the graphite flakes are seen to have become shorter and thicker, this being a typical sign of high nitrogen.

Nitrogen fissures are caused simply by excess nitrogen in the system. In cupola melted grey irons, this comes from high proportions of steel scrap in the charge which require high levels of coke, whereas in induction melting, poor quality, high nitrogen containing carburiser is normally the cause. The use of some resins in the production of cores or moulds can also lead to nitrogen pick up locally within the casting, particularly at a potential hot spot.

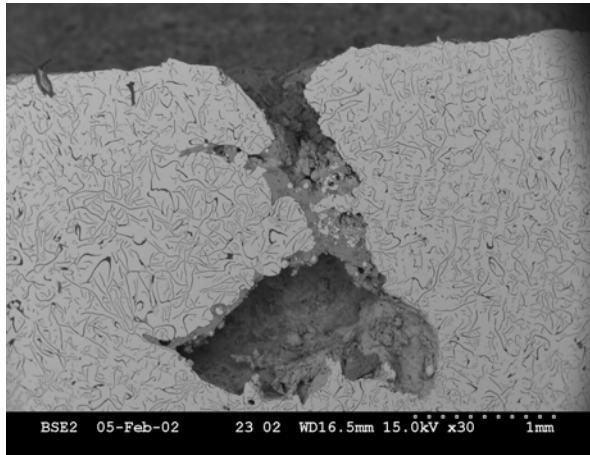
Restricting the dissolved nitrogen content to 80 ppm in medium to heavy sections and 120ppm in thin, uncured sections will normally not give nitrogen blowhole problems. In addition, careful selection of raw materials will also help reduce the potential for blowhole problems. Titanium and zirconium are known to neutralise the effects of nitrogen by producing carbo-nitrides, however care should be taken when using titanium as this can then promote hydrogen pinholes in the presence of aluminium and moisture as previously discussed. Increases in pouring temperature and carbon equivalent are also known to reduce the incidence of nitrogen defects.

Often, it is very difficult to distinguish between hydrogen and nitrogen gas defects. Analysis of a defect sample may show that the control parameters for both elements are within limits, yet a gas hole, characteristic of hydrogen or nitrogen, will appear. In such cases, it is likely that there is a synergistic effect where the elements have combined to form the hole. Here, a full examination of the causes for both gases needs to be undertaken with tighter controls put in place.

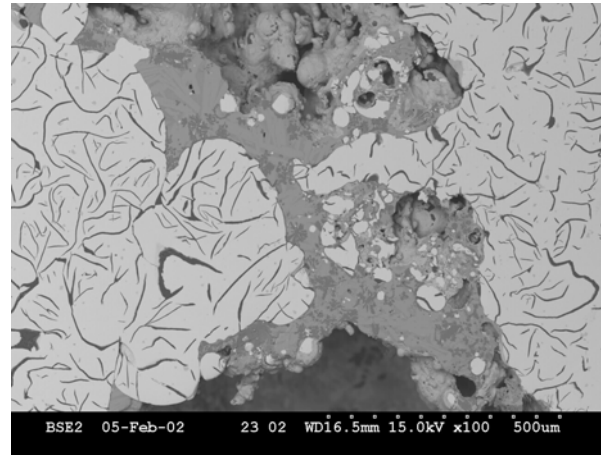
Carbon Monoxide Blowhole

The third of the common gas defects is the carbon monoxide blowhole. Figure 3 shows an example of this type of defect, which can normally be seen as a surface blow.

The carbon monoxide blow can appear as a hole a few millimetres across, as in the illustration here, or in large castings the hole can be large enough to put a fist into. Normally seen in conjunction with slag and clouds of manganese sulphides, it is also possible to see dendrites protruding from the inner surfaces of the hole.

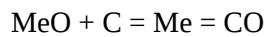


Example of surface slag blowhole in grey iron.
Figure 3. Carbon monoxide blowhole.



Close-up of defect showing slag cluster.

The most common cause of this problem is the failure to totally empty ladles between taps. This results in a lowering of the overall metal temperature and a build up of cold manganese sulphide/oxide rich slags. Eventually, the point is reached where a metal/slag reaction takes place as;



The defect may also be attributed to excess manganese and/or sulphur in the system. These should be balanced according to the equation:

$$\% \text{Mn} = \% \text{S} + 0.3$$

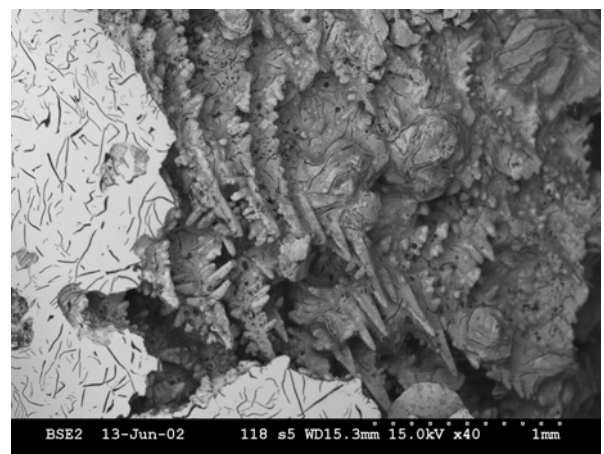
Carbon monoxide blowholes can normally be eliminated by ensuring a complete emptying of ladles between taps, operating with clean ladles and preventing slag build up on the refractory. Increasing metal temperature can also help.

Shrinkage



Overview of the position of the shrinkage. The defect was revealed after machining and was located in the centre of the casting section with T-shape.

Figure 4. Example of a hot-spot shrinkage defect.



Close-up of the shrinkage showing dendrites and metallic surface.

The example shown in Figure 4 is a typical shrinkage defect, typically the surface of the shrinkage hole will show dendrites, but without any graphitic lining as would be seen in a gas related defect. In the case illustrated, the shrinkage appears at the thermal centre of the casting and the cause was attributed to the sharp radii and to poor metal flow design. Soft sand in the vicinity of the defect may have been a contributory factor in this case.

Indeed, the majority of shrinkage defects found in the industry today may be attributed to a soft spot in the moulding sand. Otherwise there are many causes of shrinkage;

- Thicker sections of a casting that are not properly fed or have inadequate runner/gate designs
- Low carbon or carbon equivalent irons are more prone to shrinkage due to a lack of low density graphite being precipitated and not providing an “expansion” effect to counter the natural solidification shrinkage
- Insufficient clamping or weighting of the mould can lead to lifting
- Under-inoculation or over-inoculation both increase the potential for shrinkage, the former due to the lack of precipitated graphite, the later produces too many eutectic cells which can result in porosity between the cells.
- High phosphorous contents, in excess of 0.1% tend to promote shrinkage, as does excessive pouring temperatures

Inter-cellular Carbides

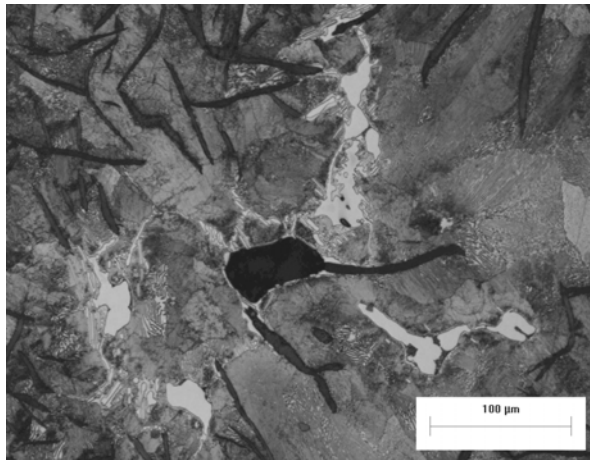


Figure 5. Example of grain boundary carbides

Today's industry has to cope with decreases in the quality of affordable steel scrap. Often, the trace element content of the steel is higher than has been found previously and there is a resulting increase in the incidence of inter-cellular carbides. These are particularly noted in thicker section castings where the slow solidification time allows for segregation and a build up in the concentration of deleterious elements, such as molybdenum, vanadium, manganese, chromium and titanium.

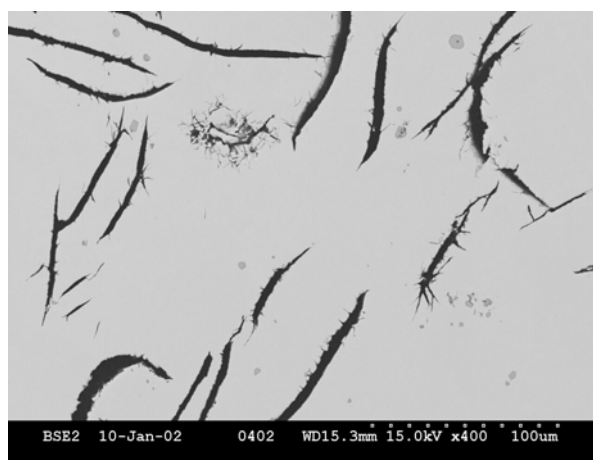
In some cases, increased or more powerful inoculation will help to disperse the carbide promoting elements and thus avoid the formation of carbides. However, it must be noted that the effects of trace elements, such as those noted above, is cumulative and not individual to the particular elements. Further, some carbide forms, for example Mo and Cr cannot be removed by subsequent heat treatment.

Avoidance of grain boundary carbides is achieved by careful control of raw materials, particularly steel scrap and by optimising the inoculant addition. Increases in carbon equivalent may also help to disperse the undesirable elements.

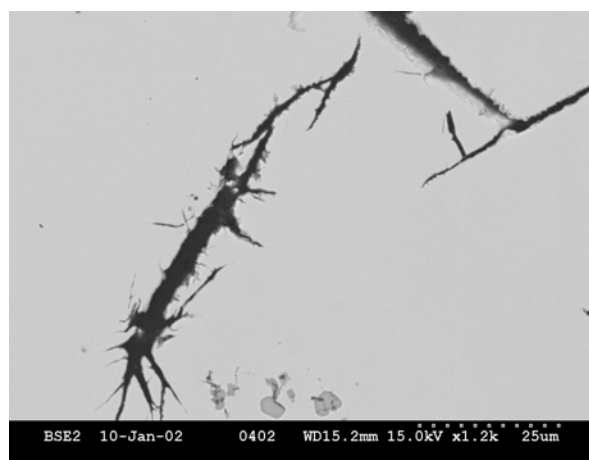
Widmanstätten Graphite.

Figure 6 shows a classical example of Widmanstätten graphite. This effect, sometimes referred to as “spiky graphite” is found when levels of the trace elements lead, bismuth or antimony become too high.

Antimony will promote Widmanstätten graphite in the presence of hydrogen, particularly in heavier section castings, as will bismuth. The usual cause of this defect is the presence of lead, a 0.0005% addition is likely to cause Widmanstätten graphite forms.



Overview of the graphite structure.



Close-up of one of the graphite lamellas.

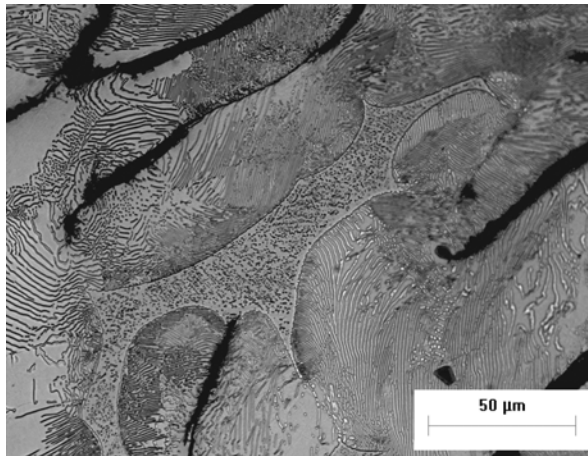
Figure 6. Example of Widmanstätten graphite.

The normal sources of lead are free cutting steels, old painted scrap, vitreous enamelled scrap,terne plate or contamination of the melt with white metals. Melting petrol engines from the days of leaded petrol can also be a source of lead contamination.

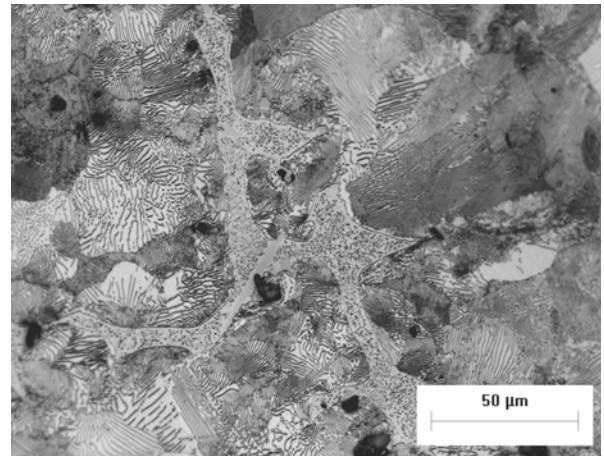
Widmanstätten graphite has a catastrophic effect on the mechanical properties of the iron, the spikes on the graphite flakes acting as points of weakness to reduce tensile strength values dramatically. The problems with lead tend to arise in induction melted irons as the lead stays within the bath, but is rarely seen in cupola melted metal as the lead disappears up the stack.

Once lead has appeared in grey iron, there is no real cure except to use a rare earth containing inoculant/preconditioner to try to scavenge the lead from the iron.

Steadite



Steadite in thick section.



Steadite in thin section.

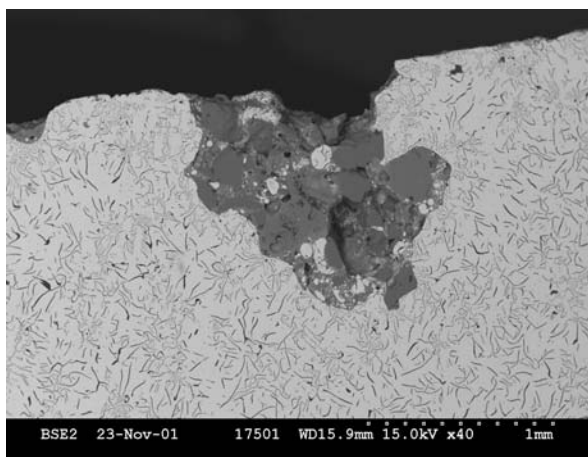
Figure 7. Steadite in grey iron

Steadite, more commonly known as the phosphide eutectic, is really a precipitation of iron phosphides. Normally this is not regarded as a defect unless excess phosphorus enters the system and clusters are detected at the grain boundaries.

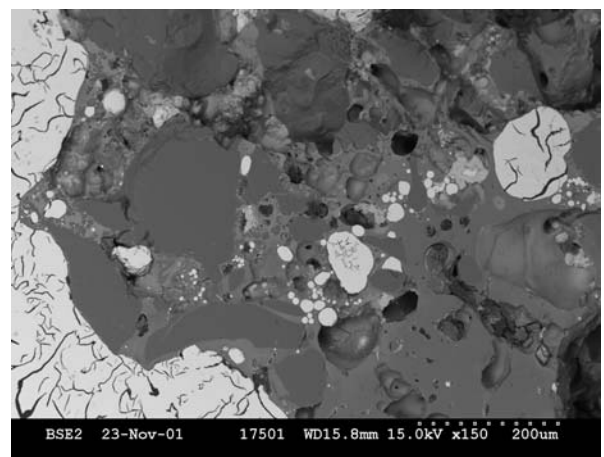
Phosphorus has the benefits in iron of increasing fluidity and wear resistance when present in the right amounts. Less than 0.04% may lead to metal penetration and finning, whilst levels of 0.1% and above can lead to the formation of a network of steadite at grain boundaries with subsequent problems of shrinkage and embrittlement. Some irons are deliberately produced with higher phosphorous levels where fluidity is a big issue, radiator castings, stove plates and some electrical casings for example.

The cure for excess steadite, apart from reducing the levels of phosphorous, is to disperse the phosphorous within the casting by improving inoculation or to increase the solidification rate. Care should be taken in the selection of scrap to avoid domestic heating castings and analysis should be made of the pig iron as some brands contain higher levels of phosphorous.

Slag



Example of grey iron slag inclusion cluster.
Figure 8. Example of slag inclusions



Close-up of slag cluster showing various phases.

Slag inclusions may be found both at the surface of the casting, as illustrated here, or within the body of the casting. They are recognisable as having no decarburisation associated with them and the slag usually seems to have several different phases within the particle.

Slag defects are caused by inadequate slag removal during the melting and pouring phase or by a build up of slag in the pouring ladle or receiver – see also the section on the carbon monoxide blowhole. Slag traps or filters built into the running system often help with the removal of slag, but do not help with the root cause of slag build up and are no substitute for good metal cleaning practise. Slag may also be formed if there is excessive turbulence in the running system or metal is poured from some height. Examination of the runner design or time spent watching the ladle operator's practise is well spent.

Sand inclusions

The final defect examined in this paper is concerned with sand. As seen in Figure 9, sand can be distinguished from slag in that it has a single phase and the sand grains are relatively regular in shape.

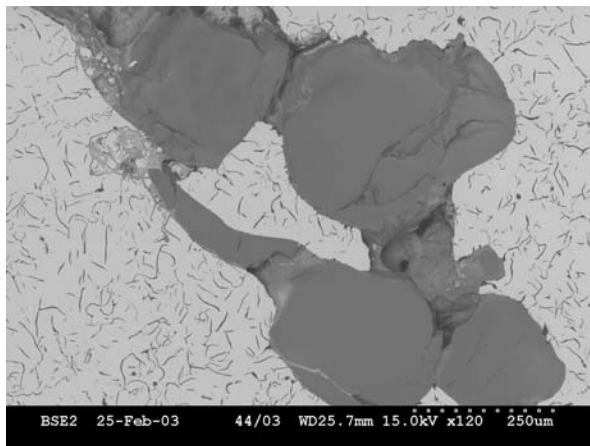


Figure 9. Sand grain inclusions

Sand is normally generated within the mould, loose sand around the downsprue or erosion of sand if the metal is dropping a large distance onto sand at the bottom of the sprue. Sharp corners are also a common cause of sand erosion. Care should be taken to blow loose sand from the mould during the assembly of the mould and frequent examination of pattern plates in horizontal moulding machines should be made to ensure that nothing is sticking to the plate.

As with slag inclusions, avoidance of excess turbulence when pouring will help to avoid subsequent problems.

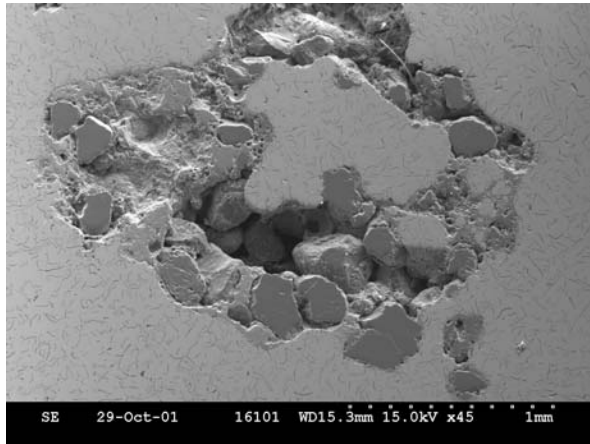


Figure 10. Sand grains enveloped in slag

On frequent occasions, sand grains have been noted within an envelope of slag, as in Figure 10. Viscous slags coming from the melting/pouring processes can drag sand grains from even a well bonded surface, emphasising the importance of good metal preparation prior to casting

Summary

Castings with defects very often have to be scrapped. This is a major cost for the foundry, both in terms of productivity and, often, reputation. Defects that have slipped through inspection have the highest value as they may not be discovered until they reach the machining stage or, even worse, the end user.

Systematic logging of defects may seem time consuming, but is a worthwhile exercise so that the most serious problem can be addressed as the priority. Many foundries spend inordinate amounts of time and money addressing minor issues while not focussing resources on the major defects. Good maintenance, raw material selection and careful metal handling are the three key criteria in defect control.

It may be seen throughout this paper that composition and inoculation may be used to control several defects. Careful consideration of these factors can have significant financial benefit for the foundry.