

A Review of Common Metallurgical Defects in Ductile Cast Iron

Causes and Cures

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Abstract

The objective of this paper is to provide an overview of some of the most common metallurgical defects found in the production of ductile cast iron today. The examples shown have all been determined during the examination of samples in Elkem's Research facility in Norway.

Whilst many foundries recognise the defects, an appreciation of the possible causes, and therefore cures, is not always apparent. The causes and cures for the different problems are examined in the paper. Emphasis is made on shrinkage problems, probably the most common problem seen by Elkem's team of service engineers around the world.

Introduction

Metallurgical defects in ductile iron can be very costly to the foundry, not only because the part has to be remade or rectified, but due to the unfortunate fact that many defects are not revealed until after the expensive machining stage. Care in the selection of raw materials, good process control in the melting stage and proper metal handling procedures will go a long way to the prevention of defects.

Further, a routine for logging and recording of defect occurrences will reveal which are the major problem areas, allowing for a systematic elimination of the defects.

This paper will examine the most common defects, starting with shrinkage. Deterioration of affordable steel scrap qualities, use of incorrect inoculants and nodularisers plus the pressures to get castings out of the door as fast as possible has led to an increase in the incidences of shrink/porosity related cases seen by Elkem's team of technical service engineers. Indeed, the ductile iron foundry, which truthfully claims not to have shrinkage concerns is the exception to the rule.

Other common defects may be divided into two basic categories:

- Those related to nodule shape and size, such as compacted graphite structures, exploded and chunky graphite, graphite floatation, spiky graphite and nodule alignment.
- Those related to inclusions/abnormalities within the matrix, such as flake graphite surfaces, slag inclusions, carbides and gas.

These problem areas are described to aid recognition of the defect and causes are discussed together with possible cures.

Shrinkage Control

Figure 1 shows a typical sub-surface shrinkage defect. There are many causes of shrinkage in ductile iron, experience globally has shown that about 50% of shrinkage defects are related to sand systems, feeding and gating. The other 50% may be attributed to metallurgical factors such as carbon equivalent, temperature, inoculation or high magnesium residuals.

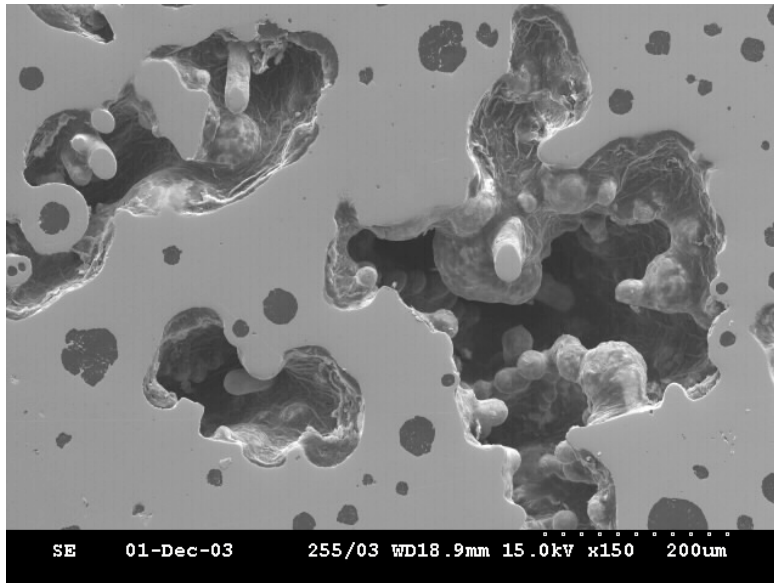


Figure 1: Typical sub-surface shrinkage defect with dendrite arms partly covered with graphite sticking out.

When a shrink or porosity is detected in a casting, there are several immediate and simple steps that can be taken to identify the cause of the problem. Firstly, the geometry of the casting should be examined to determine whether the location of the defect is close to a sharp radius or a potential hot spot. At the same time, the sand in the region of the shrink should be examined to look for any soft spots. Sand integrity accounts for a high proportion of shrinkage defects and a worn seal on the moulding machine, for example, resulting in a lower sand compaction can often be the cause of an unexplained sudden outbreak of shrinkage.

The second avenue of investigation should be the gating / runner designs and the feeding of the casting. Whilst many foundries have computer aided design systems, patterns are often altered slightly over the years at shop floor level and can be significantly different from the original design. Also, changes to the feeder specification can lead to different burn characteristics and metal solidification patterns. This can affect the amounts of feed metal available to different parts of the casting.

Metallurgically, there are many factors that can affect the shrinkage tendency. Figure 2 shows the relationship between magnesium and shrinkage.

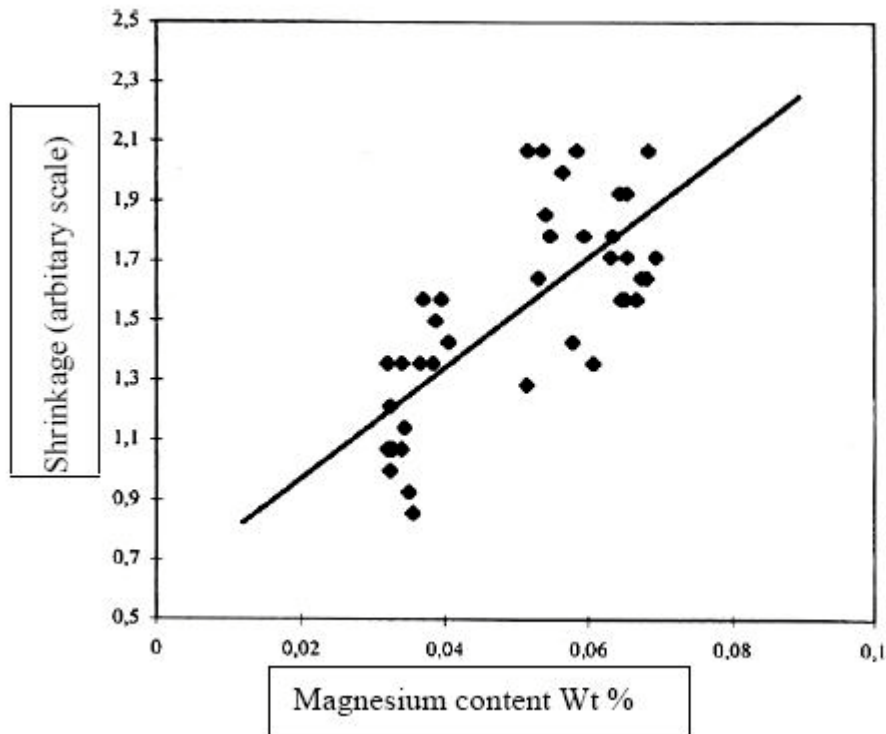


Figure 2: Effect of magnesium content on shrinkage

Magnesium, apart from being one of the most powerful carbide stabilisers, has a marked effect on the shrinkage tendency of ductile irons. Foundries operating at the higher end of the magnesium range, 0.05% or above, will find that the iron is more prone to shrink than foundries operating at lower, but very acceptable, levels, say 0.035-0.04%.

Both under-inoculation and over-inoculation can cause shrinkage. In the case of under-inoculation, not enough dissolved carbon is precipitated as graphite. Graphite nodules have a far lower density than the matrix and to precipitate the low density, high volume graphite has an overall expansion effect, which helps to counter the natural tendency of the iron to shrink. With over-inoculation, too many nucleation points are active early in the solidification, resulting in an early expansion and sometimes large mould wall movements. Later in the solidification, when feeders become inactive and contraction takes place, there is no graphite coming out from solution to counteract the contraction and the result is shrinkage between the eutectic cells.

In many foundries, the microstructure shows even sized nodules (accounting for the fact that the section cuts through nodules in 2-dimensions). Many foundrymen still consider this to be a good structure, even though the iron is prone to shrinkage. Nodularisers and specialist inoculants are available these days, which help to counter shrinkage by giving a skewed nodule distribution. These structures are shown in figure 3.

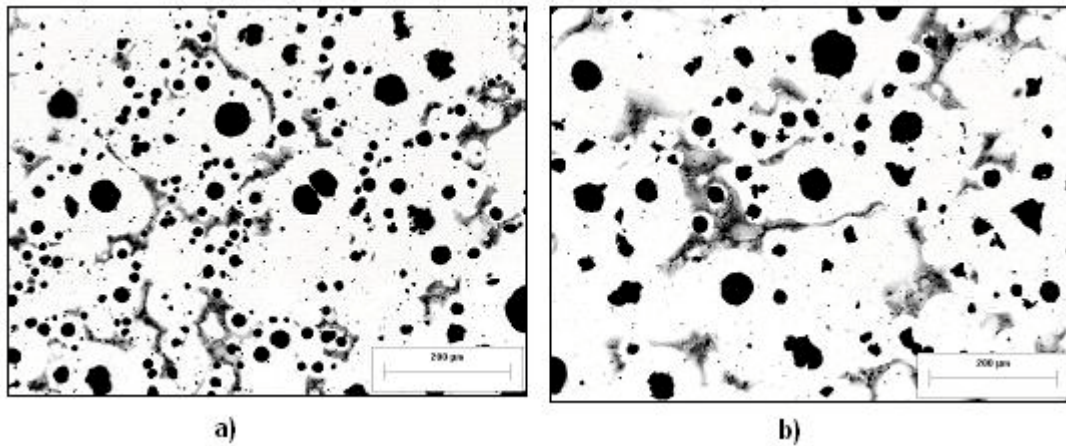


Figure 3: The same base iron treated with two different nodularisers resulting in a) Skewed nodule distribution b) Unskewed nodule distribution

A skewed nodule distribution indicates that some nodules are being created late in the solidification process and the drawing of graphite from solution at this stage is a very effective way to counter shrink. Most inoculants act almost instantaneously and this gives the even nodule size effect. Once the potency of the inoculant has gone, then there is no driver to create nodules late in the solidification and shrinkage can be the result. More recently, nodularisers have been developed by Elkem that have the same effect of producing the skewed and shrink reducing nodule distribution curve.

A low carbon equivalent, or metal that has been held for some time at temperature, due to a mechanical breakdown, for example, is also prone to shrinkage. In these cases, the inherent nuclei within the melt will be low and some preconditioning may be necessary to achieve a good level of nucleation.

Compacted Graphite within the structure.

Figure 4 shows a good example of compacted graphite in the structure. There are several causes of this, the most common being that the nodularisation process has partly failed. Incorrect weighing of the nodulariser or the use of the wrong nodulariser are possible reasons for the failure, although a long holding time in the ladle or excessive temperatures can be contributory factors.

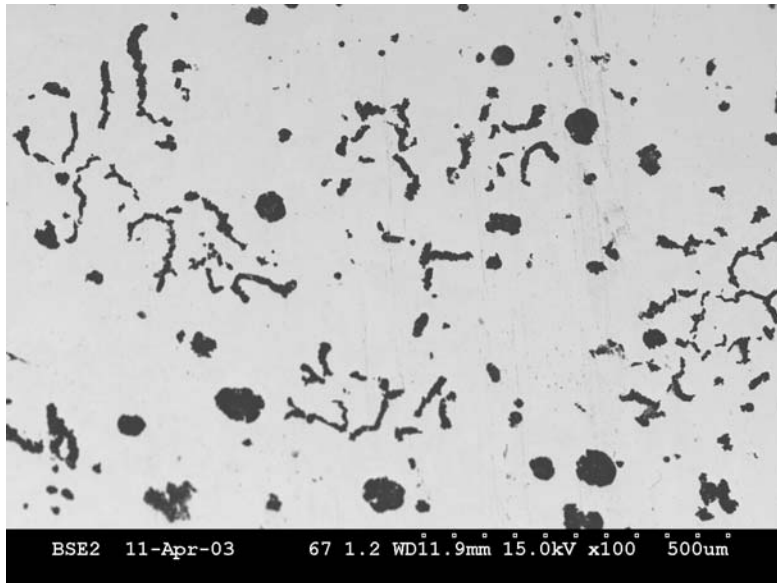


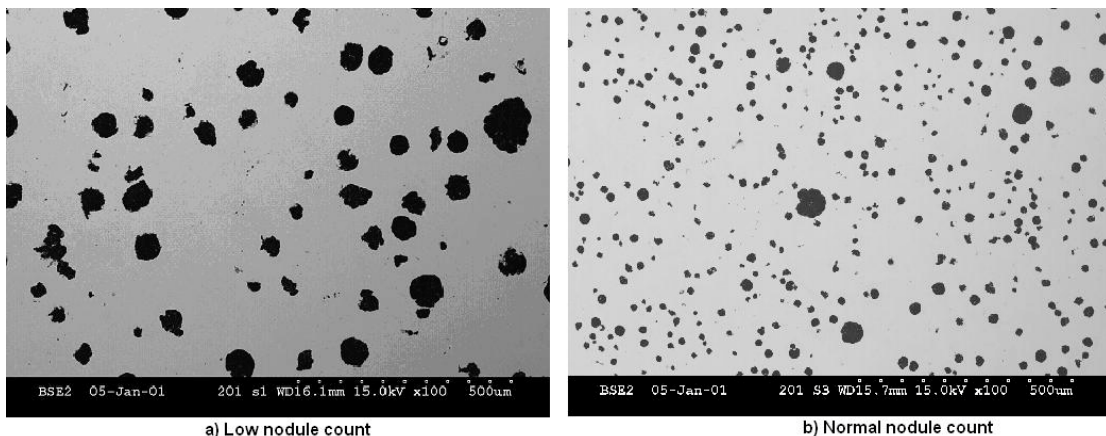
Figure 4: Sample with compacted graphite present in the matrix due to partly failed nodularisation process.

Another cause of CG particles in the matrix is an incorrect sulphur level in the base iron. Many foundries melt both grey and ductile charges and segregation of returns is essential. During the nodularisation process, the first reactions that take place are a desulphurisation and deoxidation, these elements combining preferentially with the magnesium. The base sulphur level must be accounted for in the calculation of MgFeSi charge weight.

A note of caution here with regard to the addition of the MgFeSi to the ladle or treatment vessel. To add the MgFeSi early to a hot ladle and then hold the ladle for several minutes until the moulding line calls for metal is bad practise as the alloy will be burning or oxidising in the bottom of the ladle during this time. Higher and more consistent recoveries can easily be achieved by adding the alloy just before tap from the furnace.

Low Nodule Count

As the compacted graphite mentioned above may commonly be attributed to the nodulariser, then low nodule counts tend to be a function of the inoculant. Figure 5 shows a low count compared to the foundry's normal practise. Avoiding long holding times in the furnace and prolonged pouring time post-inoculation will help to achieve consistent nodule counts, as will improving the responsiveness of the iron via preconditioning. The use of a specialist powerful inoculant will give the most consistent results.



a) Low nodule count

b) Normal nodule count

Figure 5: Two casting with the same metal treatment resulting in a) low nodule count due to long pouring time and b) normal nodule count with normal practise.

Exploded graphite

Figure 6 shows exploded graphite within the structure. Characteristically, exploded graphite looks exactly as the name might suggest that the graphite has been blown apart. Most MgFeSi alloys contain some rare earth metals, cerium, lanthanum, neodymium, praeosodium etc and these are beneficial in that they neutralise the effects of some detrimental tramp elements such as lead, bismuth, antimony, titanium etc.. Rare earth elements are also nodularisers and aid the effects of the magnesium. In excess, however, rare earths can cause exploded graphite. This is more especially when high purity charges are used which are low in tramp elements. Exploded graphite is normally found in thicker section castings with slow cooling rates or at very high carbon equivalent levels.

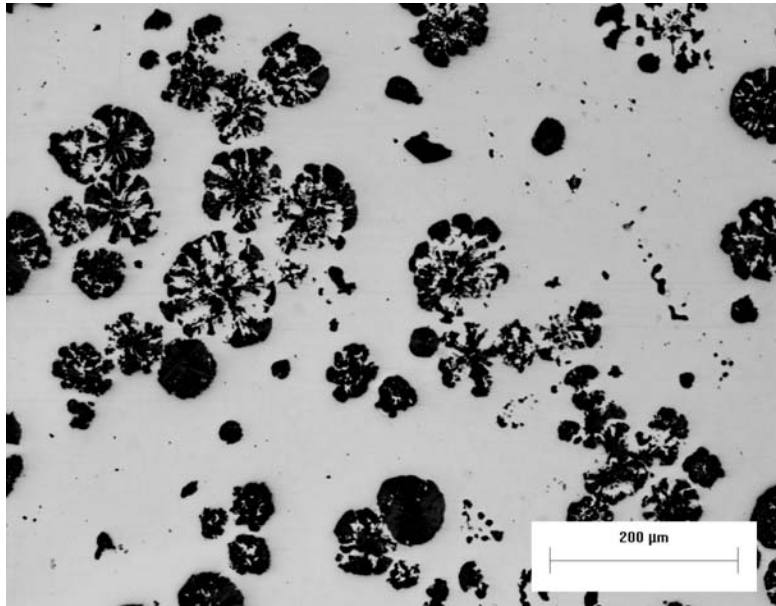


Figure 6: Sample with exploded graphite present due to excess concentration of rare earth metals.

Care should be taken when using induction melting as rare earths can be cumulative in the iron. They tend to have very high melting points and do not volatilise, although some will be oxidised and come out in the slag. This is important to note if a low/zero RE containing nodulariser is substituted to eliminate the problem as it may take time to dilute the residual RE out of the system.

Should exploded graphite occur, then examination of the rare earth sources should be made – normally the MgFeSi. Melting a virgin charge with steel scrap, pig iron and no returns will quickly show if the returns and/or the MgFeSi are the problem. Latin America and countries in the Far East tend to use high levels of rare earth in the nodulariser. Reductions in the carbon equivalent may help to reduce exploded graphite.

Chunky graphite

This is shown in Figure 7. The causes of chunky graphite are exactly the same as for exploded graphite with the addition that the defect is also found in thinner casting sections and is not as sensitive to the carbon equivalent as exploded graphite.

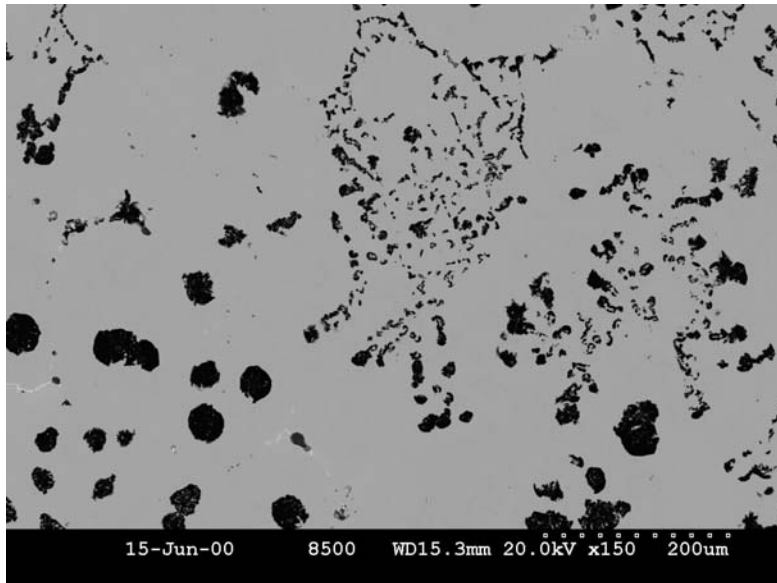


Figure 7: Sample with chunky graphite present due to excess concentration of rare earth metals.

Graphite floatation

This is caused when large, low density graphite nodules are formed during the solidification of thick section or otherwise slow cooling castings. The nodules, being of a lower density than the matrix, tend to float towards the surface of the casting and thus can have a negative effect on the mechanical properties (and surface finish) in that region.

A reduction in the carbon equivalent will help to control this, as will a reduction in the pouring temperature or increasing the cooling rate of the casting by the use of chills. The inoculation system should also be examined, as it is likely that the large graphite nodules have been formed very early during the solidification process and an inoculant, which will generate more, smaller nodules, could be an advantage. An example of graphite floatation is shown in Figure 8.

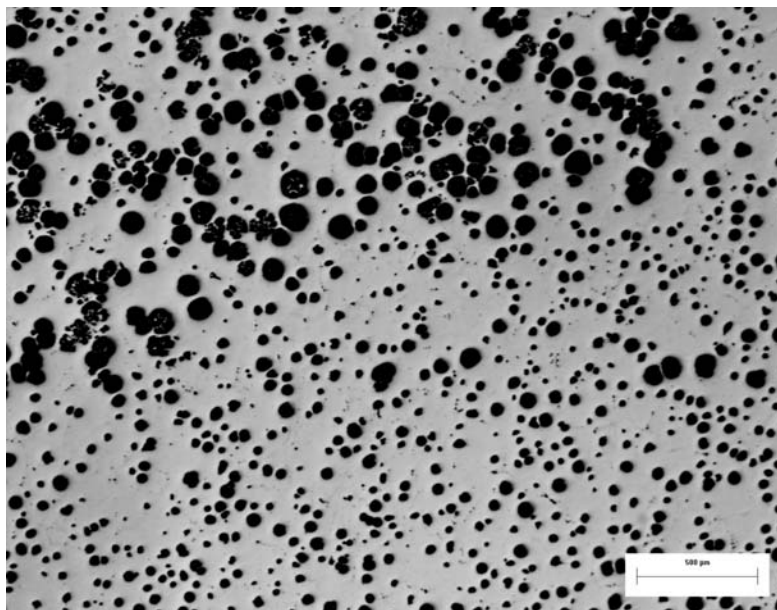


Figure 8: Sample with graphite floatation present due to high carbon equivalent.

Nodule Alignment

Figure 9 shows a classic case of nodule alignment, not too many examples as clear as this have been seen coming through our laboratory. This is caused by large dendrites growing during the solidification with the nodules being precipitated between the dendrite arms. Thus the nodules appear to be aligned. Whilst not normally a serious problem, this can have detrimental effects on such properties as tensile strength or impact resistance.

The normal causes are low carbon equivalent where not enough graphite is precipitated during the cooling, under inoculation or too high a pouring temperature.

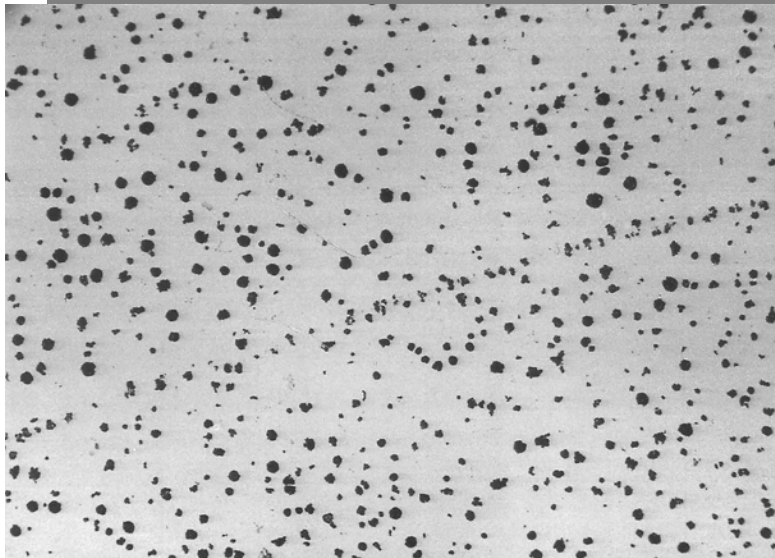


Figure 9: Sample with nodule alignment caused by large dendrites growing during the solidification with the nodules being precipitated between the dendrite arms.

Spiky Graphite

The occurrence of spiky graphite in ductile iron is rare provided that the nodulariser used contains a small amount of rare earths. Normally, the rare earth metals neutralise such elements as lead, bismuth, titanium and antimony, as discussed in the section on exploded graphite, however the use of a rare earth-free nodulariser where traces of the deleterious elements are present results in spiky graphite. This is most commonly found in converter iron where the separate additions of RE have been left out by human error.

The effect of spiky graphite is a dramatic reduction in the mechanical properties of the iron, the spikes provide points of weakness in the structure. Figure 10 shows a typical example of spiky graphite. The only cure for this type of defect is the addition of rare earths with the nodulariser.

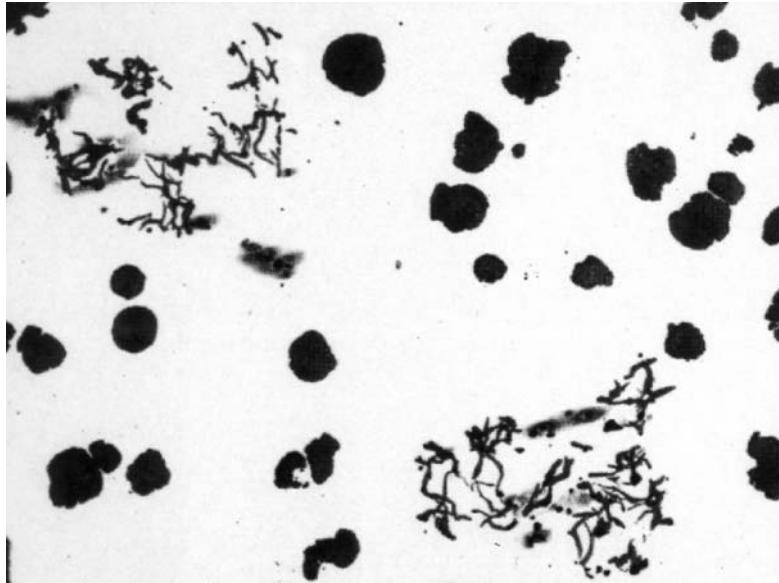


Figure 10 Sample with spiky graphite present in the matrix due to too elevated level of Pb.

Flake Graphite on the Casting Surface

This is commonly seen in foundries, however many ignore the flake graphite on the surface as it forms part of the machining allowance. The defect is illustrated in Figure 11 and clearly shows the thin layer of flake graphite adjacent to the mould. This is found mainly in greensand systems and is caused by a build up of sulphur in the sand, which reacts with the magnesium in the iron to form magnesium sulphides and effectively de-nodularise the iron. A higher Mg or Re in the nodulariser can overcome this, subject to shrinkage restrictions discussed earlier, but the most common remedy is to use an inoculant containing cerium. This has the effect of re-nodularising the iron locally.

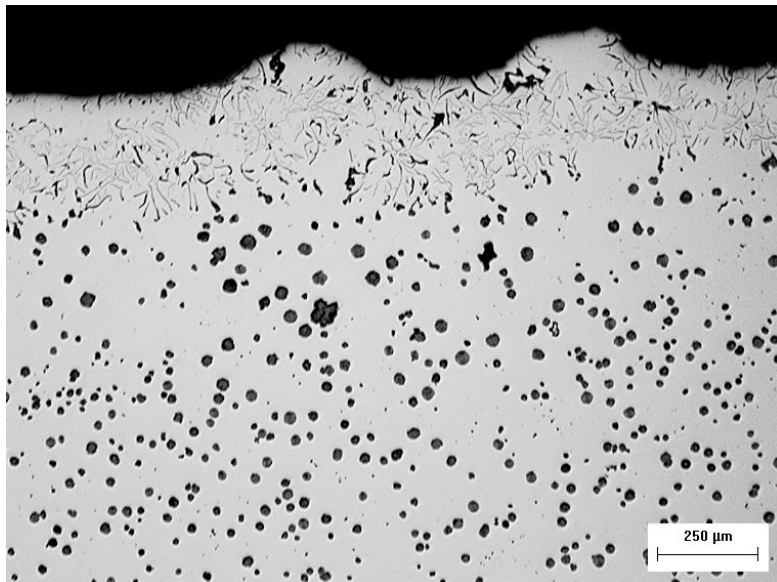


Figure 11 Sample with flake graphite on the surface of the casting due to high sulphur content in the moulding sand.

Carbides

In the production of ductile iron, it must be remembered that magnesium is one of the most powerful carbide promoters. Coupled with this, the violence of the magnesium reaction during the nodularisation process tends to destroy nuclei. For these reasons, inoculation requirements are heavier than for grey irons and under-inoculation or the use of the wrong inoculant are amongst the most common causes of chill or carbides in ductile iron.

Figure 12 shows typical carbides in a ductile iron structure. Poor inoculation is not the only cause of carbides, however, and all the potential reasons need to be explored to determine the reason behind carbide formation.

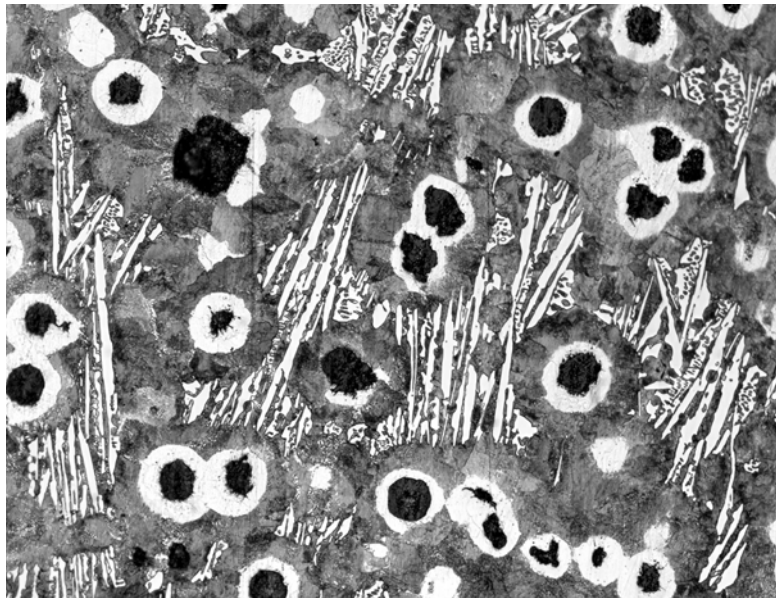


Figure 12 Sample with carbide present in the matrix due to poor inoculation

Steel scrap qualities have already been mentioned in this paper and increasing concentrations of carbide promoting elements, such as molybdenum, chromium, vanadium etc can lead to the promotion of carbides. These can be found particularly in the centre of castings or at grain boundaries, where the eutectic solidification front tends to concentrate the elements to the point where carbides form. Apart from steel scrap, use of molybdenum containing returns can be a source of undesirable carbide promoting materials.

Low carbon equivalent and high pouring temperatures may also promote carbides, particularly in thin section castings.

The cures for carbide problems usually revolve around the use of a more powerful proprietary inoculant, although nodularisers have been developed which have lower carbide promoting properties.

Summary

This paper has reviewed the most common metallurgical defects in ductile iron production. Extraneous effects, such as slag and gas have had to be omitted due to space constraints, but the elimination of these could form a paper on their own.

As shrinkage is the most prevalent problem in most ductile foundries, then focus has been made on this.

Systematic recording of defects, whether found in post casting inspection or even in post foundry operations is essential to identify the most common and the most costly problem areas. These can then be addressed in order of importance.