Cast Iron Microstructure Anomalies and Their Causes

Cast Iron Quality Control Committee 5J Report
Principle Author:
G.M. Goodrich
Bodycote Taussig, Inc.
Skokie, Illinois

INTRODUCTION

For the past eight years, The American Foundrymen's Society's Cast Iron Division, Quality Control Committee has collected examples of microstructures that are considered anomalies, or unusual with respect to normal cast iron production. Not only the Cast Iron Quality Control Committee 5J but other committees, including the Cast Iron Molten Metal Processing Committee, the Gray Iron Research Committee and the Ductile Iron Research Committee, have contributed. The purpose for this report is to present these anomalies, with the understanding of their causes, so that other foundrymen can benefit from the learning experience.

Many of these anomalies, individually, have already been published as "Cast Facts" articles in *Modern Casting* magazine. The rate of collection and publication of these individual stories has slowed somewhat in recent months, and the number of anomalies being received by the Committee has significantly dropped. As a consequence, it has been decided that the time has come to present this collection of anomalies for publication in *AFS Transactions* as a historical documentation for future reference.

These anomalies have been divided into three basic categories: anomalies associated with solidification; anomalies associated with cooling after solidification and heat treatment; and the catch-all category, "other" anomalies.

ANOMALIES ASSOCIATED WITH SOLIDIFICATION

Faulty Inoculation

Foundrymen depend on two key processing steps to achieve the desired microstructure of ductile cast iron. If the process fails, a number of other types of graphite may develop, causing structural imperfections.

The first step introduces a *nodulizing agent*, such as magnesium, which creates the condition for the graphite to precipitate and grow in a nodular shape. If insufficient Mg is added, or if the molten metal is held for an extended period after the Mg has been added, the graphite will not precipitate in a round shape.

Figures 1 and 2 show unacceptable graphite nodularity that was identified in the cover plate for a floor-level utility box in a major convention center. The designated material for this cover was ASTM A536-80, Grade 65-45-12 ductile cast iron.

The second critical processing step is to add an *inoculant.* The inoculant is usually a ferrosilicon that contains small amounts of calcium and/or aluminum and/or other special-purpose elements. The principal purpose of the inoculant is to prevent chill. More specifically, the inoculant enhances graphite nucleation, preventing the formation of primary carbides.

Using the covers from the floor-level utility boxes as examples, Figs. 3, 4 and 5 illustrate the presence of primary carbides in a ferritic structure and in structures that contain both ferrite and pearlite. These utility box covers failed immediately after installation, due to the movement of heavy equipment across them. The ductile iron covers that met the A536-80 requirements for 65-45-12 ductile iron grade performed acceptably without failure.

The presence of the degenerate graphite illustrated in Figs. 1 and 2 impairs mechanical properties. The presence of primary carbides in the structure can also reduce mechanical properties. In both instances, the ductility, as measured by the percent elongation, is most dramatically reduced. The observed structures can be the consequence of *fade.*

Fade occurs when the effects of Mg treatment and inoculation decrease with time. If the molten metal is held for an extended period after Mg treatment and inoculation, both degenerate graphite and primary carbides can occur in the structure. Another possibility for the observed structures could be high sulfur-base iron contaminated with deleterious trace elements.

Note: All photos were reduced to 75% for publication.

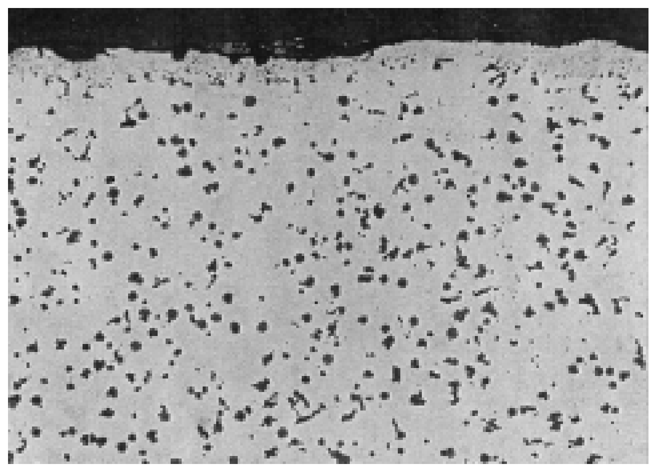

Fig. 1. Poor ductile iron nodularity caused this utility cover plate to fail; (100X, unetched).

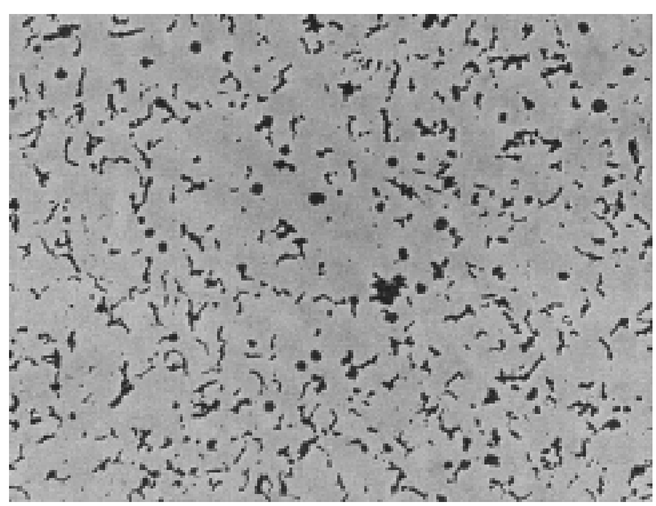

Fig. 2. Photomicrograph of ductile iron shows unfavorable graphite nodule formation; (100X, unetched).

Note: All photos were reduced to 75% for publication.

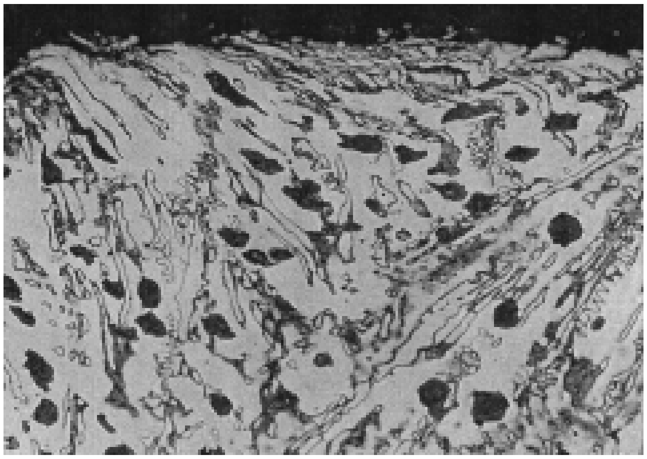

Fig. 3. Ductile iron microstructure is illustrated at a fracture site. Note pearlite (dark constituents) and ferrite (white constituents). White platelets are primary carbides resulting from inadequate inoculation or inoculant fade; (400X, nital etch).

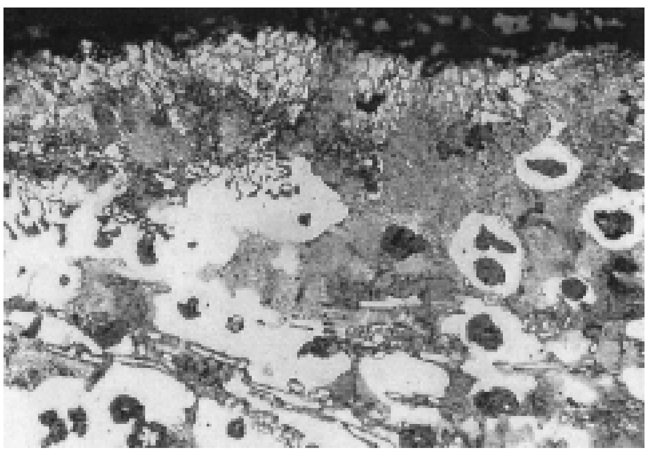

Fig. 4. Ductile iron microstructure shows flake surface graphite and nonspheroidal graphite. Dark matrix is pearlite; white is ferrite. Primary carbide is evidenced by blocky white structures occurring in pearlite and ferrite; (400X, nital etch).

Figures 4 and 5 also reveal a third kind of ductile iron anomaly. In some instances, the graphite structure at the surface of ductile iron castings is *flake graphite,* more commonly associated with gray iron. Flake graphite structures at the surface can occur in ductile iron as the consequence of surface reactions with contaminants in the sand, usually sulfur.

This structure can become even more pronounced, depending on the Mg content in the iron versus the contaminant level in the sand. High contaminant and/or low Mg produce relatively more flakes.

Primary Carbides in Ductile Cast Iron

Ductile cast iron is particularly prone to the formation of primary carbides during solidification. A primary reason for this susceptibility is that the graphite forms into a spherical shape, which is the lowest surface area-to-volume ratio for the graphite. The limited surface area available for graphite precipitation, during solidification, increases the carbide-forming tendency. In addition, the principle element added for the nodulizing treatment is Mg, a known carbide stabilizer.

Another factor is that the S content in ductile iron is purposely lowered to less than 0.02%, to facilitate the formation of spherical graphite nodules. Therefore, inoculation is crucial to successfully cast ductile iron without carbides. Even after effective inoculation, fade can occur and result in the formation of primary carbides. Figures 6, 7 and 8 are three different examples of primary carbides in a ferritic ductile iron. Figures 9, 10, 11 and 12 show four different examples of primary carbides in a pearlitic ductile iron.

These carbides have several names, including ledeburite, chill, primary carbide, Fe_3C, iron carbide cementite, white iron and hard iron.

The principle step in controlling the occurrence of primary carbides in ductile iron calls for close attention to detail concerning inoculation and fade time. The effects of inoculation fade with time and, therefore, processing time within the foundry should be closely controlled. In many instances, modern-day foundries have utilized late-stream inoculation or mold inoculation to counteract effects of fade.

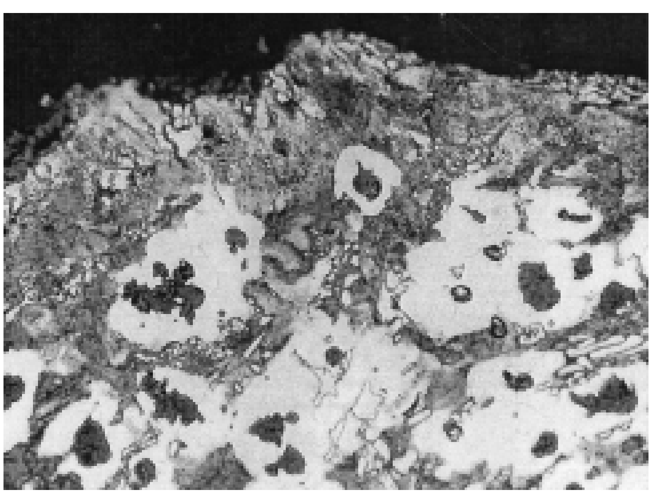

Fig. 5. Ductile iron microstructure illustrates poor graphite nodularity in matrix of pearlite (dark constituent) and ferrite (white regions surrounding graphite). Small, angular, white particles in matrix are primary carbides; (400X, nital etch).

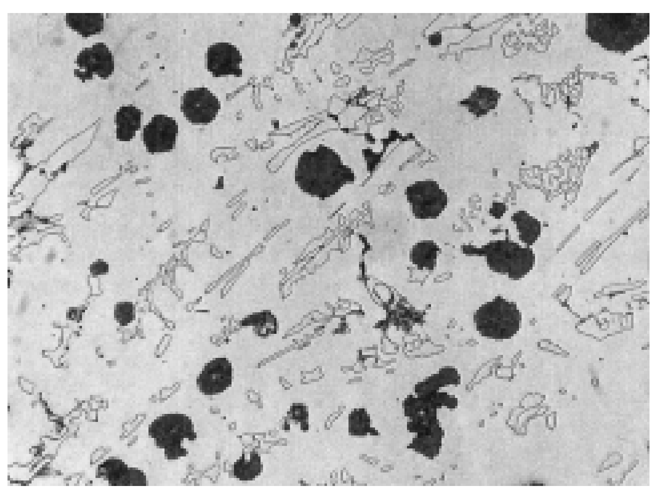

Fig. 6. Ductile iron photomicrograph with a ferritic matrix containing primary carbides. Predominant white matrix structure is ferrite; white angular constituents with ferrite are primary carbides; (400X, nital etch).

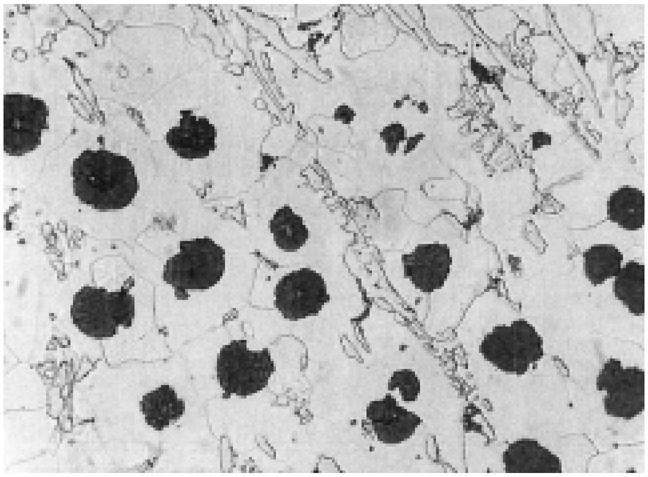

Fig. 7. Ductile iron photomicrograph with a ferritic matrix containing primary carbides. Predominant white matrix structure is ferrite; white angular constituents within ferrite are primary carbides; (400X, nital etch).

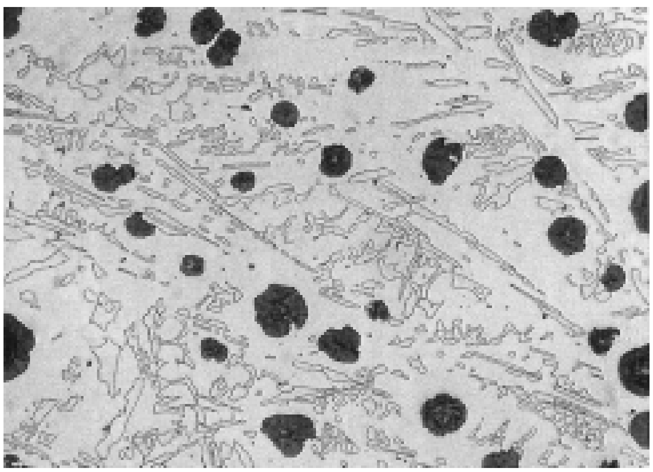

Fig. 8. Ductile iron photomicrograph with a ferritic matrix containing primary carbides. Predominant white matrix structure is ferrite; white angular constituents within ferrite are primary carbides; (400X, nital etch).

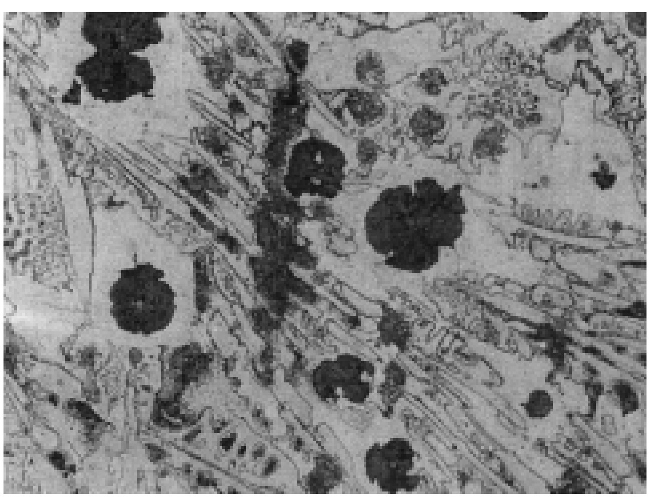

Fig. 9. Ductile iron photomicrograph illustrating primary carbides in a pearlitic ductile iron. Matrix is predominantly pearlite. The white angular constituents within pearlite are primary carbides; (400X, nital etch).

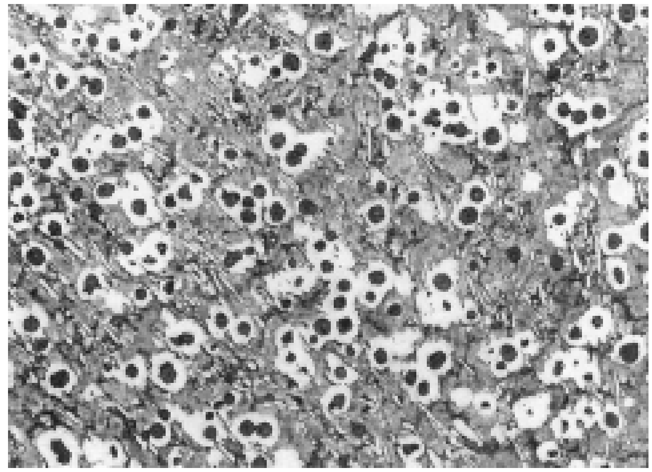

Fig. 10. Ductile iron photomicrograph illustrating primary carbides in a pearlitic ductile iron. Matrix is predominantly pearlite. The white angular constituents within pearlite are primary carbides; (200X, nital etch).

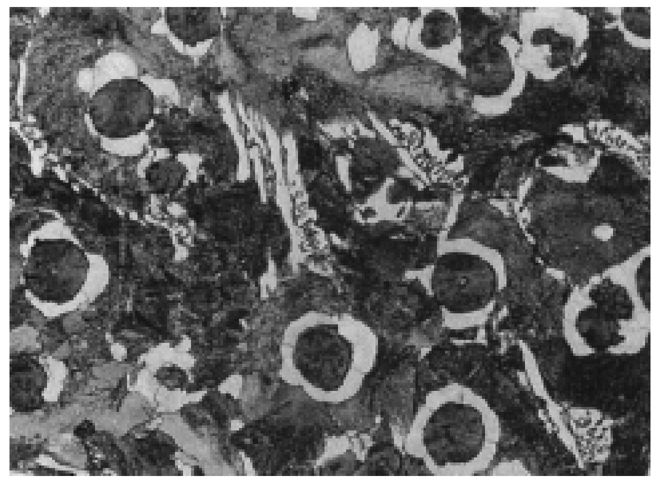

Fig. 11. Ductile iron photomicrograph illustrating primary carbides in a pearlitic ductile iron. Matrix is predominantly pearlite. The white angular constituents within pearlite are primary carbides; (400X, nital etch).

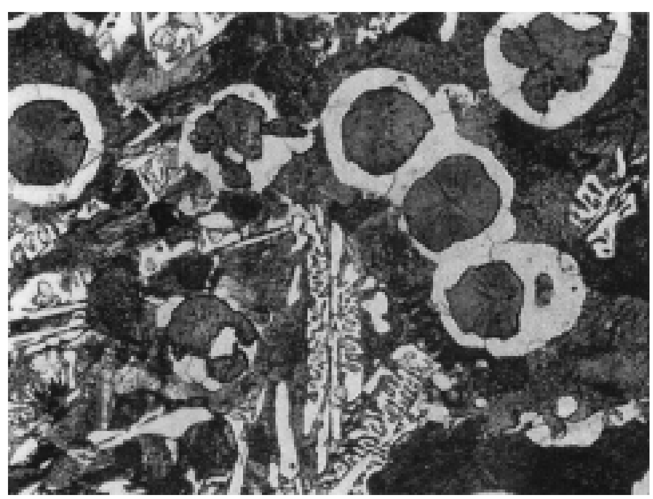

Fig. 12. Ductile iron microstructure illustrating primary carbides in a pearlitic ductile iron. Matrix is predominantly pearlite. The white angular constituents within pearlite are primary carbides; (400X, nital etch).

In addition to the inoculating effects and fade effects, some contaminants can cause primary carbides. In ductile iron, chromium is particularly noted for the formation of stable primary carbides that are not easily removed with heat treatment and are not easily removed with proper inoculation. Hydrogen is also noted for causing primary carbides. In this instance, however, the primary carbides can occur in the last iron to solidify because of H segregation to the liquid during solidification. When this occurs, a particular carbide form results, known as inverse chill. Figure 13 shows an example.

Primary Carbides and Steadite in Gray Cast Iron

Two microstructure constituents in gray cast iron can cause hard spots, which aggravate machinists. These two constituents are iron carbides and iron phosphides. Figures 14 and 15 show a typical example of iron carbides, and Figs. 16 and 17 show a typical example of iron phosphides.

Note: All photos were reduced to 75% for publication.

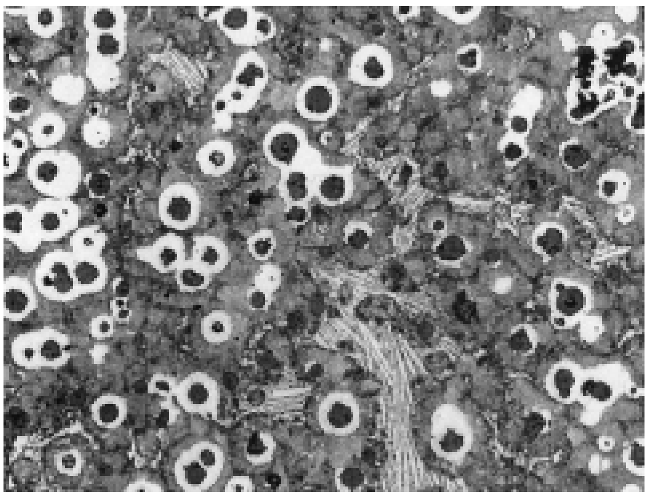

Fig. 13. Ductile iron microstructure illustrating inverse chill primary carbides in a pearlitic ductile iron. Needle-like carbides toward middle bottom of photograph are inverse chill; (200X, nital etch).

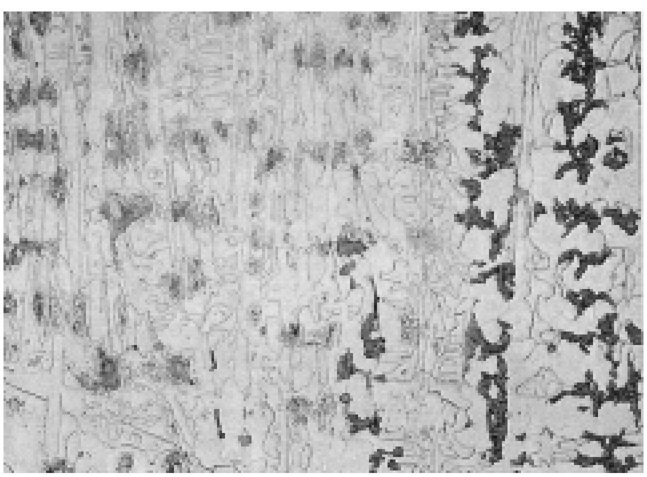

Fig. 14. Photomicrograph showing primary carbides in gray cast iron with a predominantly ferrite matrix. Black constituent at right is graphite that appears to have precipitated after solidification; (100X, nital etch).

Fig. 15. Photomicrograph showing primary carbides (white constituent) in a predominantly pearlitic gray iron matrix; (400X, nital etch).

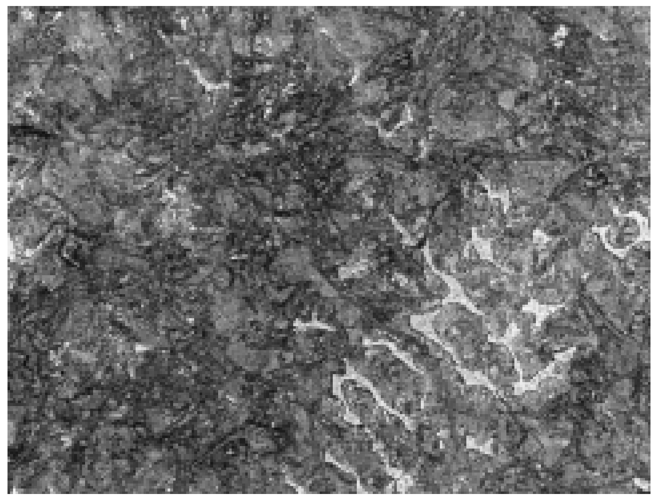

Fig. 16. Photomicrograph showing steadite in a predominantly pearlitic gray cast iron; (200X, nital etch).

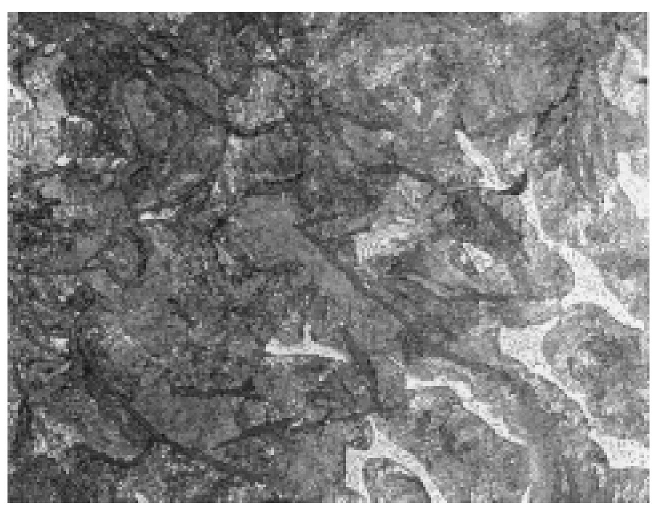

Fig. 17. Photomicrograph showing same area seen at lower magnification in Fig. 16 to illustrate “pepper marks” within steadite plate constituent; (400X, nital etch).

As indicated previously, iron carbide has several names. The machinists have appropriately applied several other unprintable names. Iron phosphide is more commonly known as steadite. Both of these constituents are eutectic phases between iron and carbon, and iron and phosphorus, respectively. Because they are eutectic, they are the last to solidify. The solidification temperature for iron carbide is 2066F (1130C). For iron phosphide, the solidification temperature is 1920F (1049C).

When these two eutectics combine, a tertiary iron-carbon-phosphorus eutectic, with a still lower melting point, will occur in the microstructure. An example of this combined eutectic structure is shown in Figs. 18 and 19. Although the melting point for this constituent is not published, it is believed to be lower than the melting points for the individual eutectics.

Since these eutectics are the last to solidify, they can be present in the cast iron structure as liquid surrounded by solid, and can be drawn from thin sections to feed thick sections. The consequence can be microscopic shrinkage voids in thin sections. These voids have a shape that is similar to the carbide and steadite constituents that would be found in the structure. Figures 20–23 show an example of the microscopic voids that form from drawing the liquid eutectic phases from thin sections.

Fig. 20. Photomicrograph showing presence of a "shrinkage" void in a thin section at upper right; (200X, unetched condition).

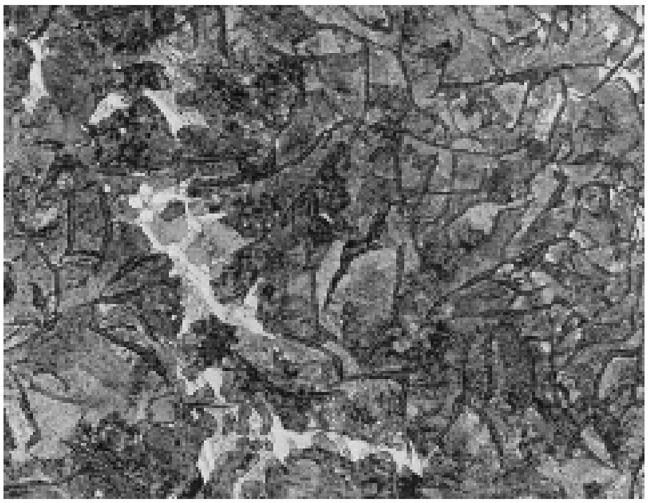

Fig. 18. Photomicrograph showing tertiary iron/carbon/phosphorus eutectic in a predominantly pearlite matrix gray cast iron; (400X, nital etch).

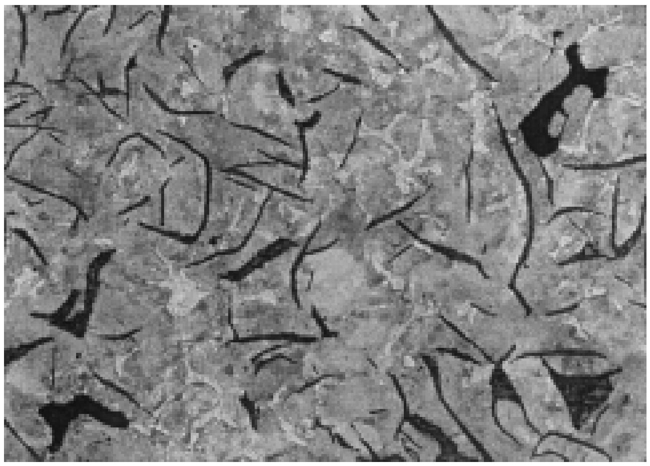

Fig. 21. Photomicrograph showing same area seen unetched in Fig. 20 to further illustrate nature of matrix associated with void. Matrix is predominantly pearlite; white constituent is steadite; (200X, nital etch).

Fig. 19. Photomicrograph showing tertiary iron/carbon/phosphorus eutectic in a pearlite matrix gray cast iron; (1000X, nital etch).

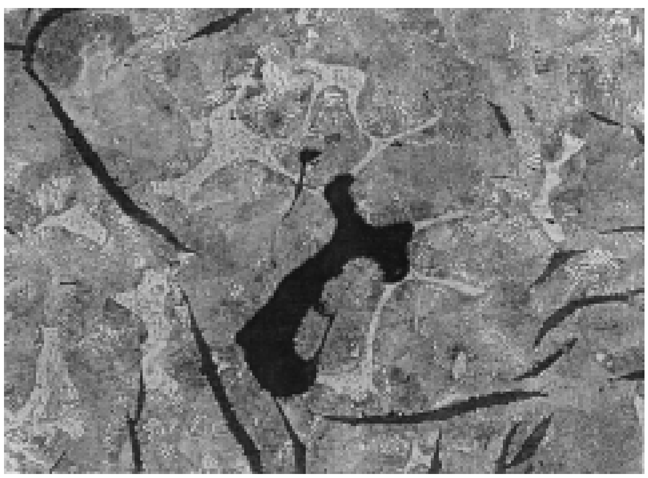

Fig. 22. Photomicrograph showing same void seen at lower magnification in Fig. 22. Note how void appears to be associated with steadite phase that is present in structure; (400X, nital etch).

Note: All photos were reduced to 75% for publication.

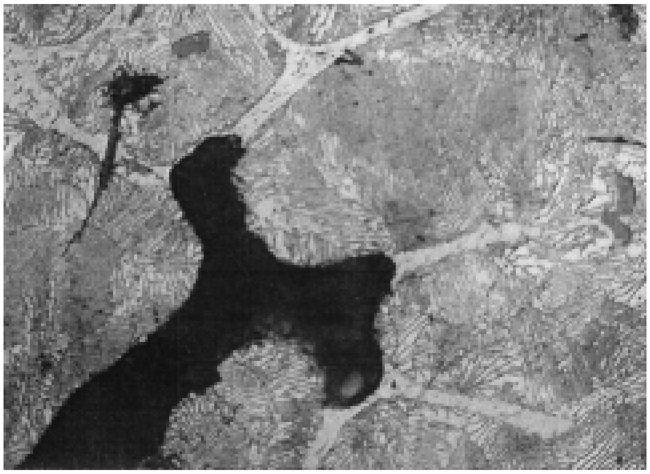

Fig. 23. Photograph showing same area seen at lower magnification in Figs. 21 and 22 to further illustrate how void that appeared as "shrinkage" in Fig. 20 is actually the absence of steadite; (1000X, nital etch).

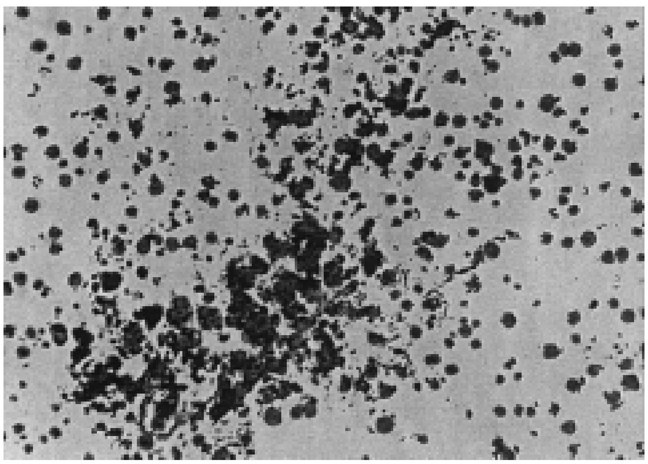

Fig. 24. Ductile iron microstructure with a dross type defect. This dross defect results from a reaction between magnesium dissolved in iron and oxygen in surrounding air; (100X, unetched condition).

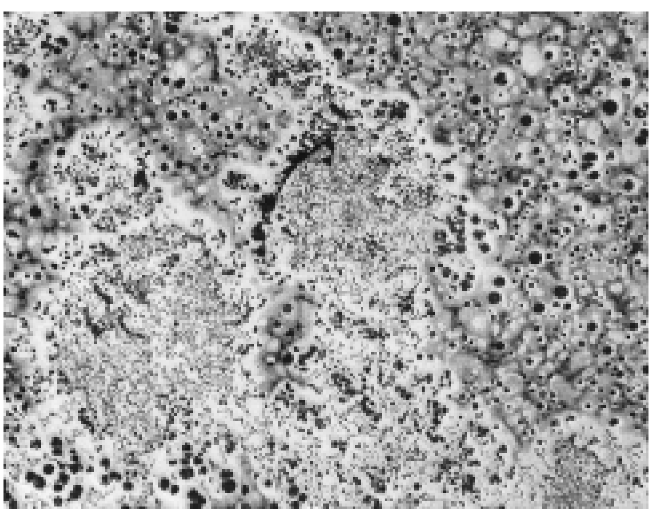

Fig. 25. Photomicrograph illustrating a dross defect in ductile iron. Dark constituent is pearlite; white constituent is ferrite. Note that ferrite concentrates with dross structure; (50X, nital etch).

As with ductile iron, inoculation in gray cast iron is primarily used to control the occurrence of primary carbides. Ladle inoculation, mold inoculation, late stream inoculation or a combination of the various inoculation techniques have all proven effective. Control of tramp elements that are known carbide stabilizers, such as chromium, vanadium and molybdenum, and other less common elements in gray cast iron, such as antimony, tellurium and hydrogen, are also essential.

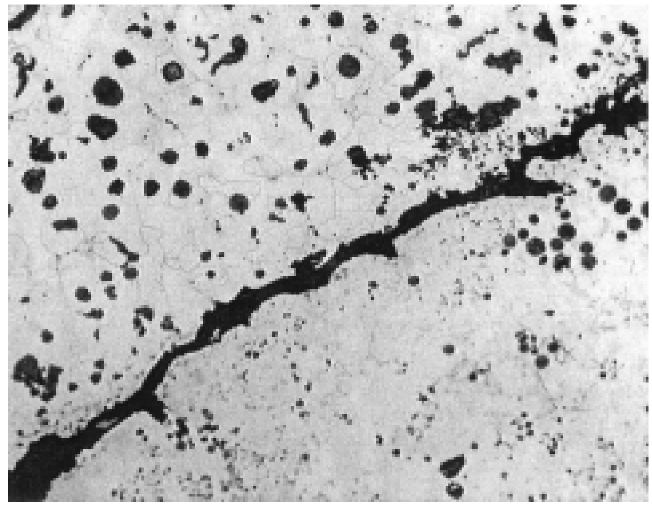

Fig. 26. Photomicrograph illustrating a line of demarkation between a "normal" structure and a partially dissolved inoculant area (200X, unetched condition) (see Figs. 27 and 28).

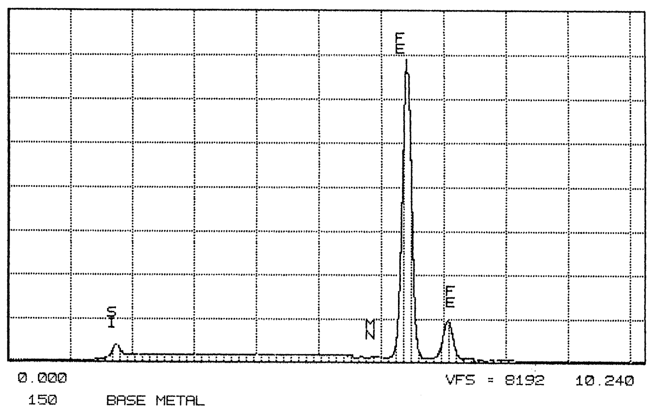

Fig. 27. Spectrum of elements representing base metal in Fig. 26.

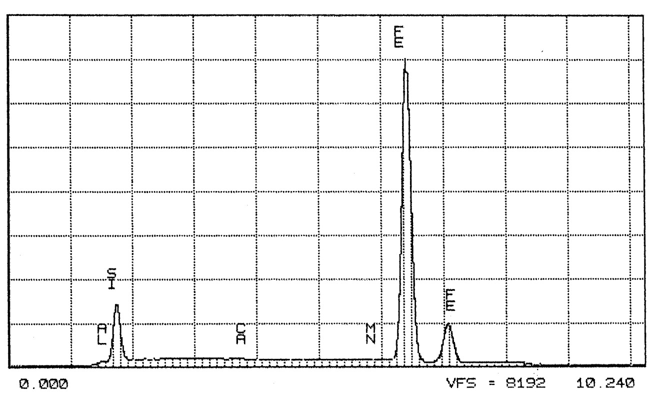

Fig. 28. Spectrum of elements representing partially dissolved inoculant in Fig. 26.

Dross in Ductile Iron

The addition of Mg to cast iron is an essential processing step for manufacturing ductile iron. Magnesium, however, is a very reactive element. As a consequence, ductile iron has a higher tendency to form slag than does gray iron or malleable iron. The reaction products that result are often called *dross.* The presence of Mg in molten iron also causes the iron to generate slag, almost continuously. Ductile iron pourers often complain that ductile iron "makes slag" while it is sitting in the ladle. This dross is the result of the Mg dissolved in the iron reacting with oxygen. As a consequence, a good slagging practice must be exercised when pouring ductile iron.

Since molten ductile iron "makes slag," an undesired microconstituent that can occur is dross. Figure 24 shows an example of the graphite structure associated with dross that has occurred in the casting. When etched, the area associated with the dross will often have a ferritic structure, as shown in Fig. 25. The occurrence of dross in a casting can be the consequence of poor slagging practices. When slag enters the mold cavity during pouring, the dross-type structure shown in Figs. 24 and 25 can occur.

These dross-type structures can also occur, even though slag-free metal was poured. Keeping in mind that ductile iron "makes slag," any time the iron experiences turbulent flow in the mold, a reaction can occur between the Mg in the iron and the oxygen in the surrounding environment. This reaction can form dross, even in the mold. Dross defects such as this can occur, for example, in castings with knife gates. Dross can also be generated in the runner system when fluid dynamics causes turbulent flow conditions to exist. Dross-type structures can also be present if the metal is poured too cold.

Sometimes, the dross is associated with undissolved or partially dissolved inoculant. Figure 26 shows an example. In this instance, the structure on one side of a demarkation line from the dross will have a normal silicon level, whereas the structure on the opposite side will have a high Si level. Energy dispersive x-ray (EDX) spectrographic analysis has been helpful in identifying this type of dross defect. Figures 27 and 28 show a typical example of analysis in the normal structure vs. analysis in the dross region.

ANOMALIES RESULTING FROM PROCESSING AFTER SOLIDIFICATION

Widmanstätten Graphite

Widmanstätten graphite can occur in cast iron as the result of lead contamination. Other elements are also known to cause this problem. Lead levels as low as 0.005% have been known to create the Widmanstätten graphite. Widmanstätten graphite occurs after solidification with the precipitation of carbon atoms on crystallographic planes creating a spiky appearance to existing graphite flakes. If the condition becomes significant, the precipitation onto crystallographic planes can occur, aside from the primary graphite flakes, creating hatch marks in the structure. Figures 29–31 show Widmanstätten graphite in the *unetched* structure and Figs. 32–34 show the Widmanstätten graphite in an *etched* structure.

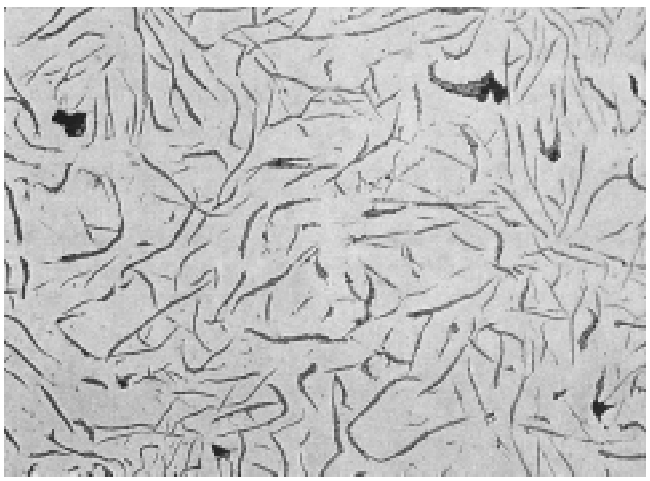

Fig. 29. Photomicrograph showing a "normal" graphite structure; (100X, unetched condition).

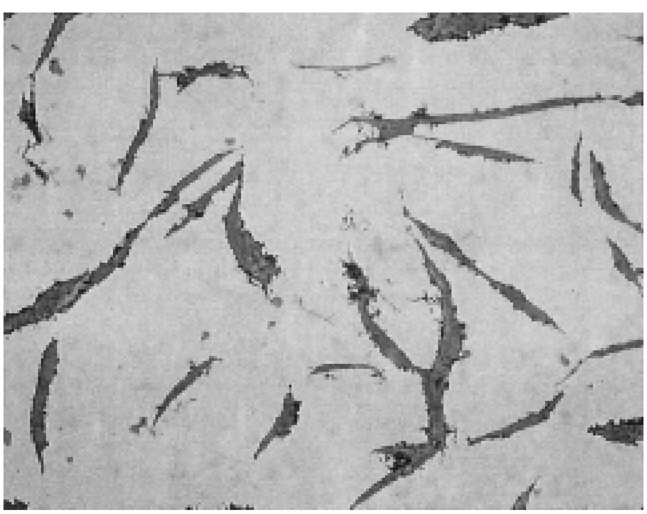

Fig. 30 Photomicrograph showing same area seen at lower magnification in Fig. 29. Note that graphite appears "fuzzy." Also note that other graphite forms have precipitated within regions between flakes; (400X, unetched condition).

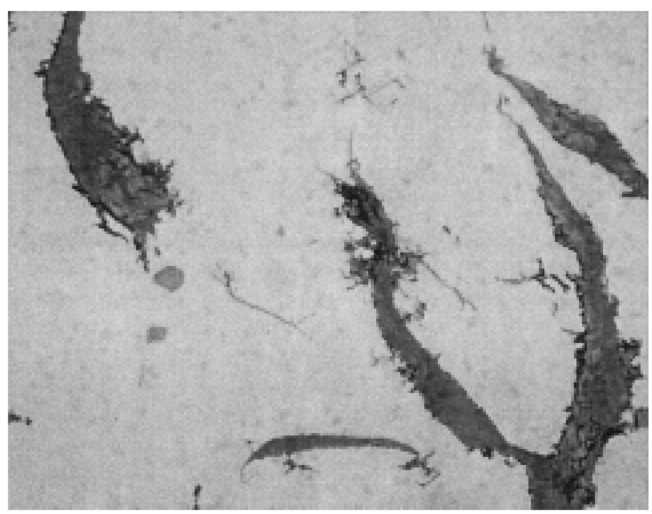

Fig. 31. Photomicrograph showing same area seen at lower magnification in Figs. 29 and 30. Note that "fuzzy" graphite is consequence of small fingers of graphite growing on sides of graphite flakes. Also note graphite forms with thin graphite forms in between graphite flakes toward middle and middle top; (1000X, unetched condition).

Note: All photos were reduced to 75% for publication.

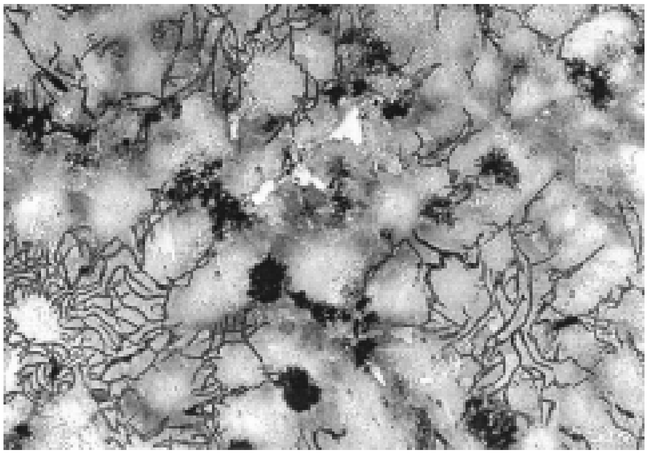

Fig. 32. Photomicrograph showing a pearlitic gray cast iron with Widmanstätten graphite. This area is shown at progressively higher magnifications in Figs. 33 and 34; (100X, nital etch).

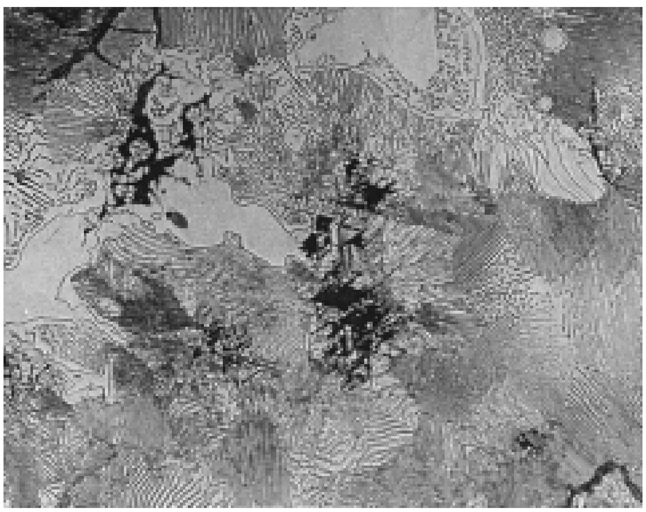

Fig. 33. Photomicrograph showing same area seen at lower magnification in Fig. 32 to illustrate Widmanstätten form of graphite. Note that graphite has precipitated at angles representative of crystallographic planes; (400X, nital etch).

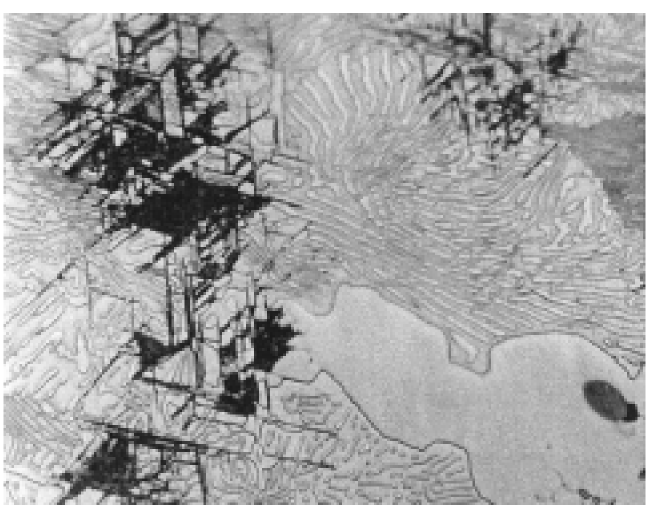

Fig. 34. Photomicrograph showing same area seen at lower magnification in Figs. 32 and 33 to further illustrate graphite precipitated on crystallographic planes; (1000X, nital etch).

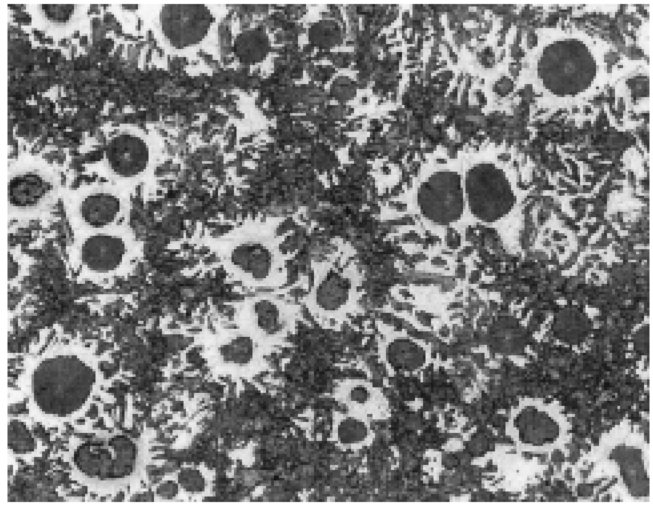

Fig. 35. Photomicrograph of ductile cast iron. This structure was intended to be normalized (100% pearlite); (200X, nital etch).

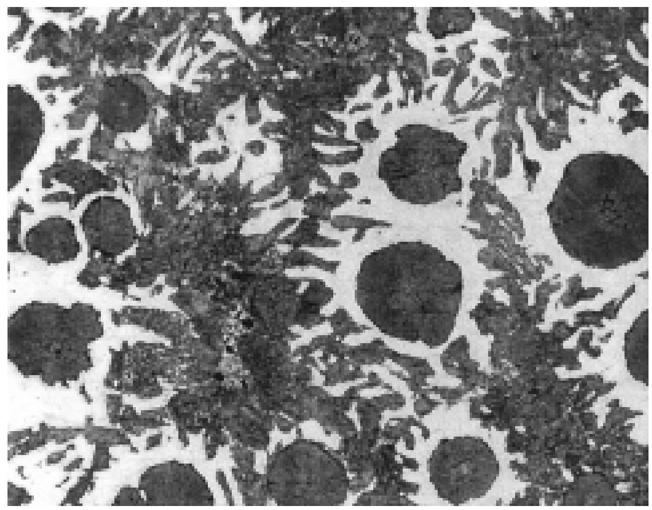

Fig. 36. Photomicrograph of same area shown at lower magnification in Fig. 35. This structure was intended to be annealed (100% ferrite); (400X, nital etch).

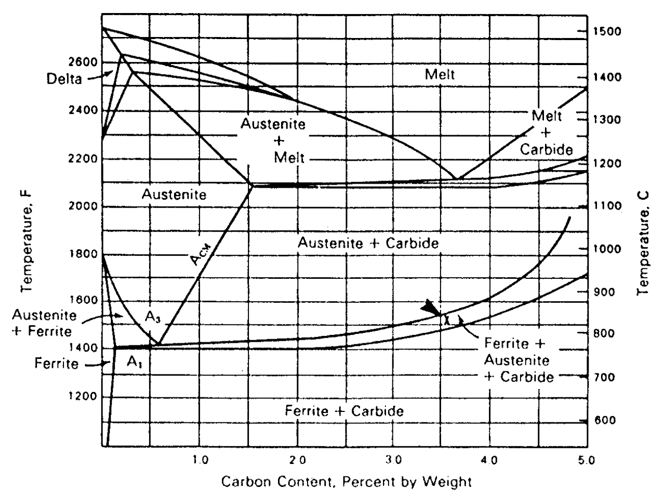

Fig. 37. Shown is iron-iron carbide-silicon ternary diagram sectioned at 2% silicon. "At the tip of the arrow head, X" shows austenitizing temperature reached, in three-phase region indicated by arrow, in two castings examined. Reprinted from "Iron Casting Handbook," American Cast Metals Association.

Often, this graphite structure is associated with phosphorus-rich steadite regions. Research[1,2] has shown that this graphite type can be controlled with the addition of rare earth elements, primarily cerium. As a consequence, the condition does not often occur in ductile cast iron because of the presence of rare earth elements in the treatment alloy. If the condition is occurring in gray cast iron, it can be controlled by eliminating the lead. However, inoculation with a cerium-bearing inoculant can also reduce the effect.

The presence of this graphite form greatly reduces the mechanical properties of the resulting iron. For example, a normal Class 30 gray iron, having a Pb concentration of 0.05% without the benefit of Ce or other rare earths, can actually have a tensile strength of less than 15,000 psi because of the presence of Widmanstätten graphite form. This graphite form will become Type F in the soon-to-be-published revised ASTM specification A247.

Unusual Ferrite Microstructure in Heat-Treated Ductile Iron

Analyzing microstructures can sometimes be confusing. For example, the two microstructures shown in Figs. 35 and 36 contain pearlite (the dark constituent), ferrite (the white constituent) and nodular graphite. All of these constituents are normally expected for ductile iron microstructures. However, the shapes and the constituents as shown in these photomicrographs are not normal. Both structures resulted from heat treatment. The structure was the consequence of a normalizing heat treatment intended to produce 100% pearlite. As these structures clearly show, the goal was not achieved.

Ductile iron is in a family of metals called cast iron, which has three principal elements: iron, carbon and silicon. The fact that Si is present is often forgotten. At certain temperatures, this element allows austenite, ferrite and carbides to exist in equilibrium as a three-phase field. The presence of this field can cause difficulties, particularly during heat treatment.

To normalize or anneal ductile cast iron, the casting must be heated to a high enough temperature for the matrix to become completely austenite. In the two examples, the austenitizing temperature reached the three-phase region, indicated by the arrow in the phase diagram in Fig. 37.

As a consequence, the austenite that was present transformed to the desired pearlite or ferrite constituent. However, the ferrite or pearlite that was present in the structure, but was not transformed, remained intact as the sample was cooled. The structures shown in the photomicrographs reflect both the transformed constituents and the untransformed constituents. The untransformed constituents are the cause of the unusual shapes in the photomicrographs.

Retained Austenite in Gray and Ductile Iron

Cast irons that are quenched and tempered to form martensite can have unusual microconstituents. In addition to the expected martensite, an unexpected white constituent in the structure can occur. This white constituent is shown in Figs. 38 and 39 for ductile iron and in Figs. 40 and 41 for gray iron. The constituent is *retained austenite.*

Carbon can stabilize austenite and, since cast irons are hypereutectoid, the austenitizing temperature can affect the amount of carbon dissolved in the austenite, prior to quenching. As the temperature increases above the eutectoid reaction, the amount of carbon dissolved in the austenite increases. When this iron is quenched, some of the high carbon austenite is retained, leaving a mixed structure of martensite and austenite. More specifically, this is a mixed structure of martensite and high carbon austenite.

To prevent retained austenite from occurring in quenched martensitic cast iron structures, the temperature from which the iron is quenched should be lowered to a temperature immediately above the eutectoid. The correct temperature may require trial and error to establish it for individual irons. The reason is that the eutectoid temperature varies significantly, as a function of Si, and no single temperature for gray iron or for ductile iron can be stated. Nickel also stabilizes austenite. As Ni content increases, so does the tendency for retained austenite.

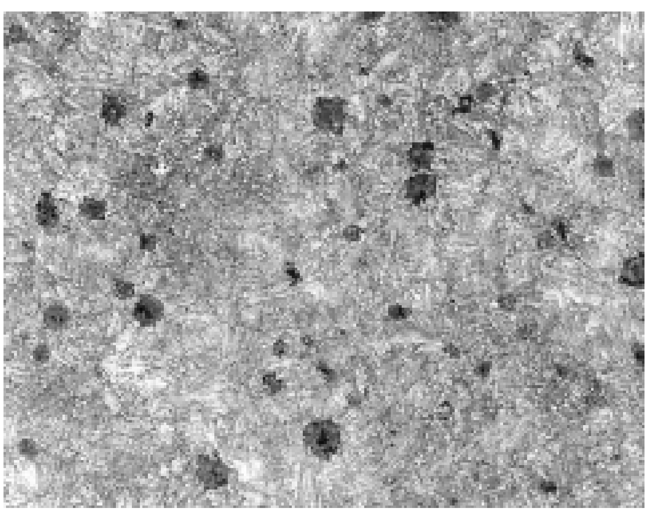

Fig. 38. Photomicrograph illustrating retained austenite in a martensitic ductile cast iron. Small angular white constituents (arrows) in matrix are retained austenite; remainder of matrix is martensite; (200X, nital etch).

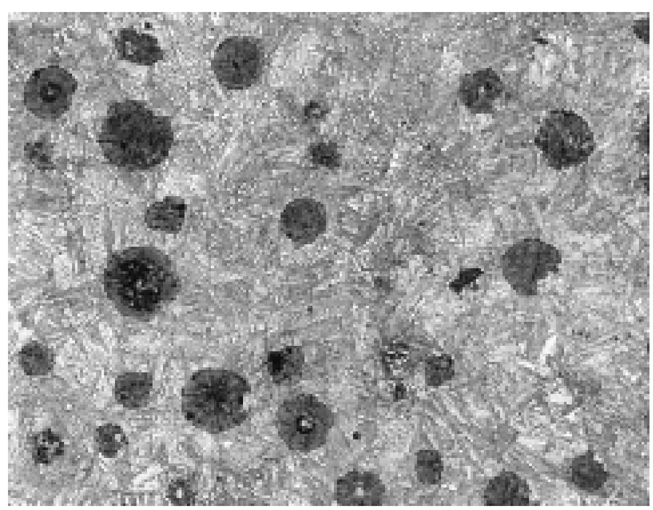

Fig. 39. Photomicrograph illustrating retained austenite in a martensitic ductile cast iron. Small angular white constituents (arrows) in matrix are retained austenite; matrix is martensite; (400X, nital etch).

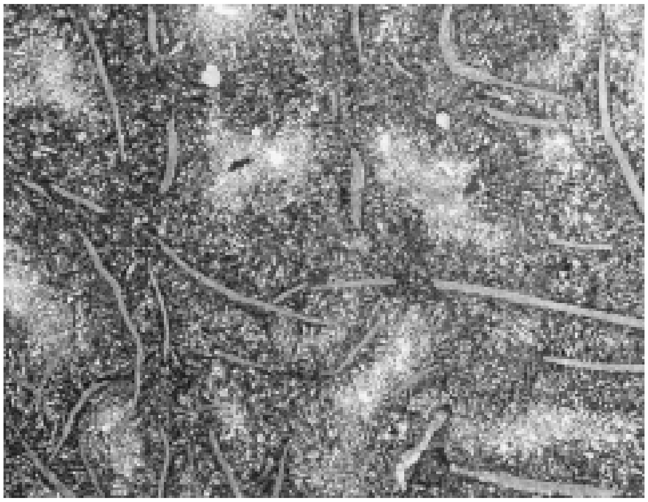

Fig. 40. Photomicrograph illustrating retained austenite in a martensitic gray cast iron. White angular constituent in structure is retained austenite; remainder of matrix is martensite; (400X, nital etch).

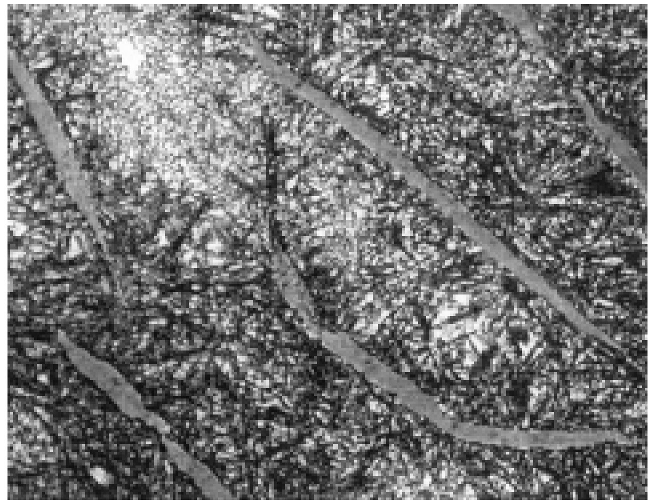

Fig. 41. Photomicrograph illustrating retained austenite in a martensitic gray cast iron. White angular constituent is retained austenite; remainder of matrix is martensite; (1000X, nital etch).

OTHER ANOMALIES

Microstructure Anomalies That Affect Ductile Iron Properties

The microstructure of ductile iron plays a vital role in affecting the mechanical properties of the final casting. To illustrate this vital role and how to determine the cause of failure, an example of a foundry's experience with a certain casting is provided.

In this example, the customer desired a ductile iron grade of 80-55-06 per ASTM 536. This grade is an as-cast pearlitic ductile iron with a minimum ultimate tensile strength of 80,000 psi, a minimum yield strength with 0.2% offset of 55,000 psi and a minimum 6% elongation.

Inconsistencies

The customer, who regularly purchased the casting, was confused about the inconsistencies with the test results in different heats.

Problem 1: The castings failed to meet the elongation requirement, exhibiting only 3% maximum elongation.

Problem 2: The castings failed to meet the yield strength requirement, with only a 50,000 psi at 0.2% offset.

Problem 3: The castings failed to meet the yield strength and the elongation requirements.

Metallographic evaluation of the microstructures revealed the reasons for these inconsistencies.

In Problem 1, the microstructure at the tensile fractured surface had a required graphite nodularity (greater than 80%) and pearlite content (greater than 50%), but the structure had a high incidence of intercellular carbides (Fig. 42). As shown in Fig. 43, EDX spectrographic analysis revealed these carbides were high in titanium, vanadium, molybdenum and niobium. These carbides significantly detracted from the ability of the casting to meet the elongation requirements.

In Problem 2, the microstructure had acceptable nodularity, but the ferrite content was excessive. Figure 44 shows that the ferrite content was about 70% of the matrix. For this grade, the matrix should be in excess of 50% pearlite. Excessively high ferrite content detracts from the yield strength.

In Problem 3, the microstructure exhibited an acceptable pearlite content (Fig. 45), but the graphite nodularity (Fig. 46) was not acceptable. Poor nodularity negatively affects both the yield strength and elongation.

Correcting the Problem

Correcting these problems required different approaches. For Problem 1 (failing to meet the elongation requirement), closer scrutiny of the charge material was required to minimize the influx of tramp elements.

For Problem 2 (failing to meet the yield strength requirement), either an increase in the amount of pearlite stabilizers was required or the foundry needed to shake out the castings at a temperature hot enough to force rapid cooling from "red heat."

For Problem 3 (failing to meet both yield strength and elongation requirements), the magnesium/cerium content was not adequate as the result of fade or ineffective treatment.

Lustrous Carbon Defects in Cast Iron[3–5]

Lustrous carbon defects generally appear on the surface or just under the surface formed by the cope mold or top of the core. This defect often appears as adherent, shiny, "wrinkled" deposits of carbon, and is also known as resin, kish or a soot defect. It can be found on castings made in urethane-bonded sands, shell molds, (expandable polystyrene) EPS molds or green sand molds. Lustrous carbon is caused by high levels of volatile gases trapped at the mold or core surface. The volatile gases are released as the organic binders (especially urethane-based cold-set and shell mold systems) break down during the pouring process, releasing the hydrocarbons.

In lesser amounts, the carbonaceous material provides a reducing atmosphere in the mold, which minimizes casting surface oxidation and improves casting surface quality or *peel*. It is often removed from the casting surface by casting cleaning operations. As the level of these volatile gases increases, the severity of the defect increases and the lustrous carbon folds into solidifying metal, causing unacceptable cold shuts and laps.

Figures 47–50 show a typical example of a lustrous carbon defect. Figures 47 and 49 illustrate the depth of the discontinuities and their microstructural differences. Figures 48 and 50 illustrate a lap defect resulting from folding the graphite layer into the metal.

The frequency and severity of the defect can be reduced and controlled by the following means:

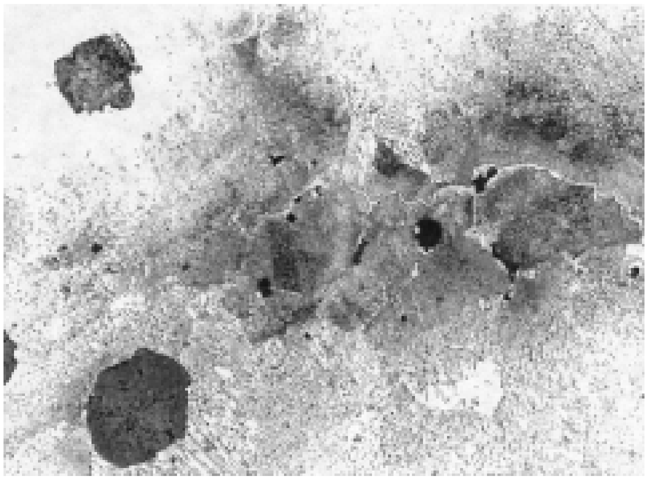

Fig. 42. Photomicrograph showing high incidence of intercellular carbides in casting. See Fig. 43 for composition of carbides; (400X, nital etch).

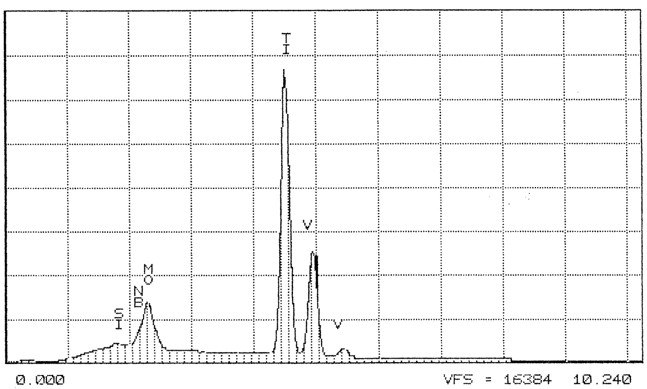

Fig. 43. Spectrum of elements representing intercellular carbides in Fig. 42.

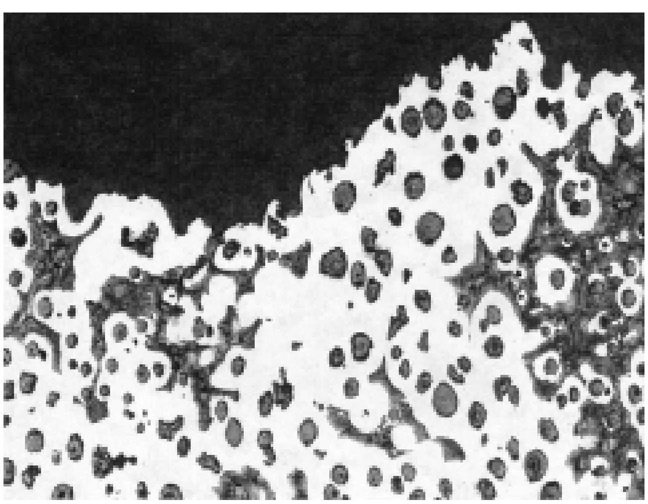

Fig. 44. At 100X, this casting is 70% ferrite (white area) and only 30% pearlite—20% below its specified pearlitic minimum.

- Lowering the binder content, especially the isocyanate component in urethane bonded systems.
- Increasing the mold and core mechanical venting and permeability.
- Increasing the pouring temperature.
- Reducing the fill time and pouring turbulence.
- Applying a low-carbon coating to the core and/or mold coating.
- Adding 0.5%–1.0% oxidizing materials, such as iron oxide, to the core sand.

Unusual Hard Spots

The use of tin as a pearlite stabilizer is well established.[6–9] Tin has been a popular alloy addition because it does not promote chill, is effective in stabilizing pearlite on the skin of the casting and has a predictable, 100% recovery. Tin decreases the sensitivity of the casting to variations in shakeout time. However, excess Sn, especially in the presence of high S, can cause serious problems.

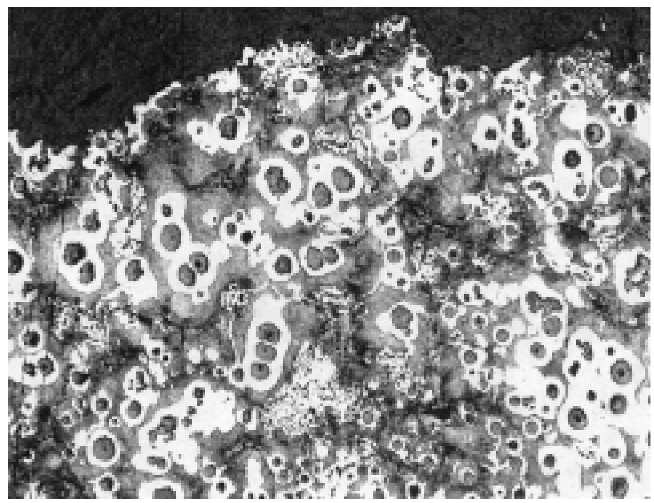

Fig. 45. At 100X, casting's pearlitic content is acceptable (80%).

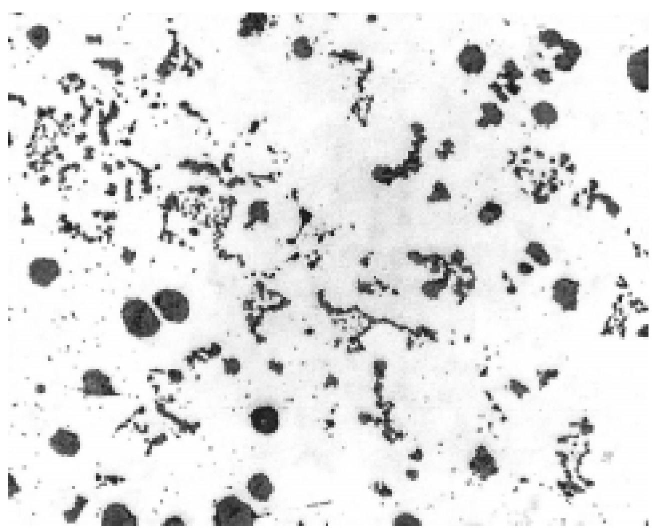

Fig. 46. At 100X, this photomicrograph shows microstructure's low graphite nodularity.

Vern Patterson, in Foote Foundry Facts, No. 18, describes a situation where a buildup of Sn to levels of 0.15% resulted in castings cracking in service. There was no observable change in microstructure, tensile strength or hardness. The only quantifiable change was the increase of Sn from the desired 0.10% max up to 0.15%, as the returns were run back through the system over a period of time, without any adjustment for the buildup of Sn in the system. The Sn level was reduced to 0.10% and the breakage/cracking problems were eliminated.

Machining operations sensitive to *hard spots* quickly identify the presence of undesired constituents. Normally, these constituents are easily identified as primary carbides, intercellular alloy carbides, steadite or a tertiary iron/iron phosphide (steadite)/iron carbide. In this instance, however, the hard spots were areas of fine pearlite with relatively large ASTM type A graphite in an otherwise coarse pearlite matrix with smaller ASTM types A and D graphite. Figure 51 shows an unusual hard spot in an otherwise acceptable gray iron structure. Figures 52 and 53 compare the pearlite in the surrounding matrix with the fine pearlite in the hard spot. Energy dispersive x-ray analysis of the matrix revealed traces of Sn, Cr and S in the fine pearlite that were not present in the coarse pearlite. The results of this EDX analysis are shown in Figs. 54 and 55. The Sn content of this casting was 0.14%, Cr was 0.09% and the S content was 0.12%.

A Foreign Object

With the new mold filter technology being used today, it has been found that, occasionally, portions of the filter become entrapped in the iron. This is shown in Fig. 56. Apparently, the quality of the iron in the immediate vicinity of the filter segment can be unaffected, as can be seen by comparing Figs. 57 with 58 and 59. However, depending upon what materials might be trapped on the filter, the iron in the immediate vicinity of the filter segment could be compromised. Sometimes, cold shuts and degenerate graphite can occur, as shown in Fig. 60.

Note: All photos were reduced to 75% for publication.

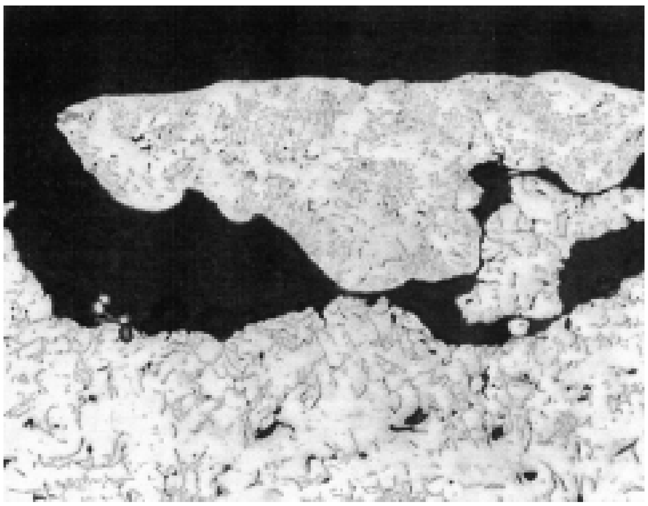

Fig. 47. Photomicrograph illustrating a cross section through one of the defective regions on casting. Note difference in graphite structure between three different "layers." These differences are characteristic of laps and cold shuts; (50X, unetched condition).

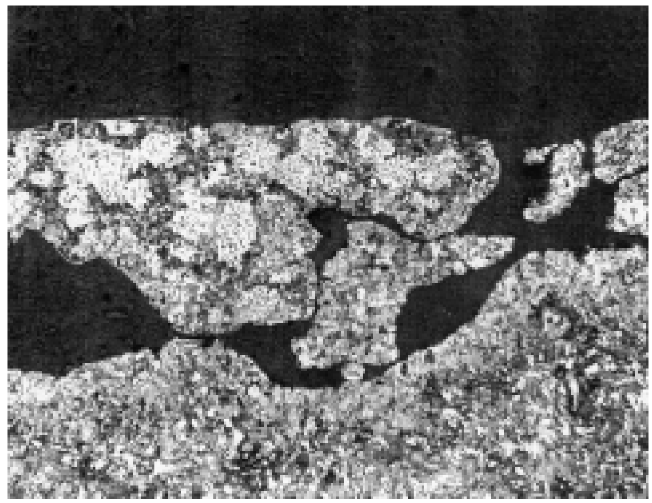

Fig. 49. Photomicrograph illustrating same area shown unetched in Fig. 46. This etched structure further exemplifies differences between individual layers; (50X, nital etch).

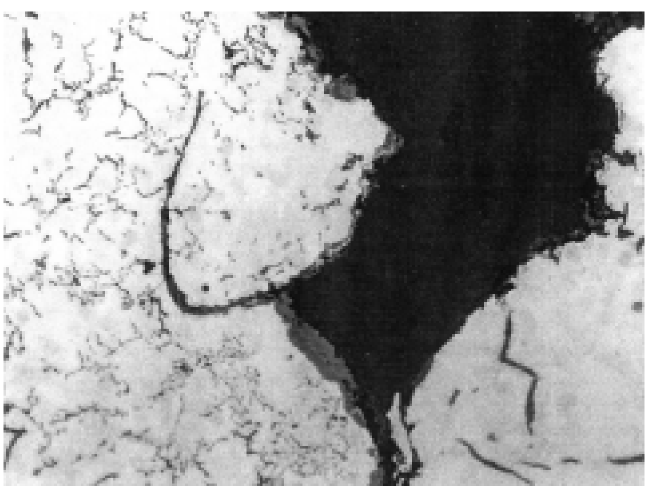

Fig. 48. Photomicrograph illustrating same area shown at lower magnification in Fig. 46. Note how graphite film at center left has been folded into metal. Also note that these individual "layers" have a graphite film liner; (400X, unetched condition).

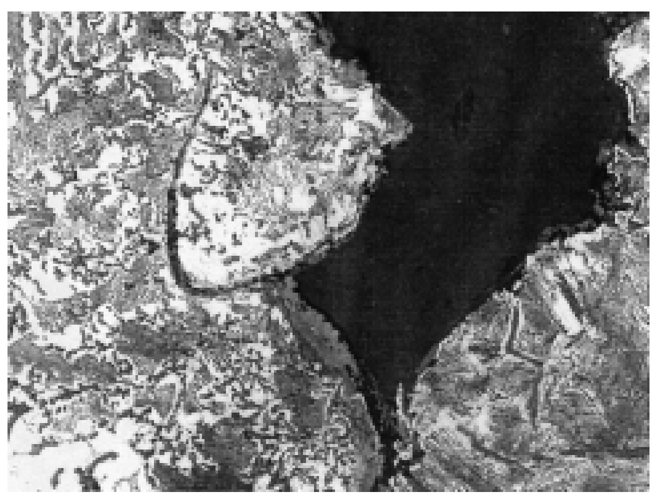

Fig. 50. Photomicrograph illustrating same area shown unetched in Fig. 47. The etched structure further exemplifies differences between two regions and graphite film that developed from lustrous-carbon defect; (400X, nital etch).

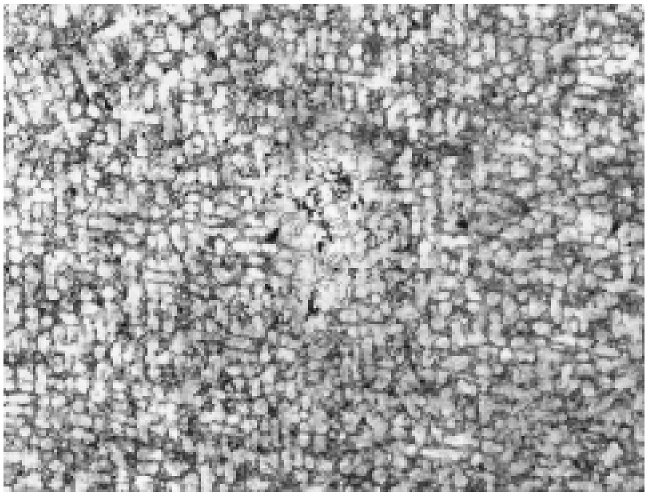

Fig. 51. Photomicrograph showing "hard spot;" (50X, nital etch).

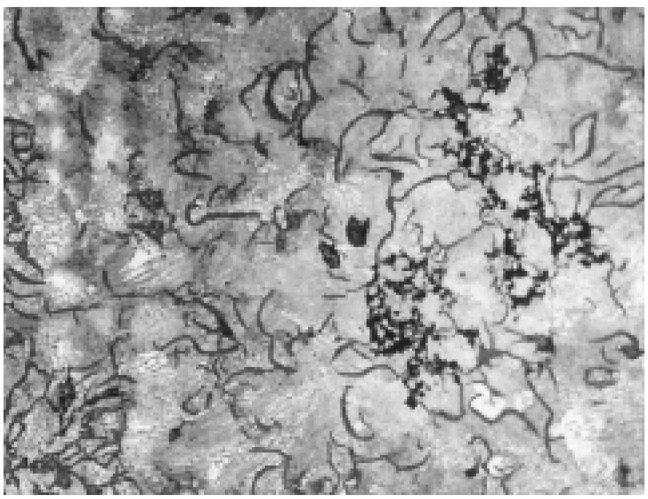

Fig. 52. Photomicrograph emphasizes fine pearlite in "hard spot" in Fig. 51. See Fig. 54 for composition of pearlite matrix in this "fine" area; (400X, nital etch).

Fig. 53. Photomicrograph emphasizing coarse pearlite matrix in Fig. 51. See Fig. 55 for composition of matrix in this coarse area; (400X, nital etch).

Nitrogen in Gray Cast Iron

The nitrogen level in gray cast iron normally has an equilibrium of 70 ppm. Occasionally, high N can occur. When the dissolved N increases, the graphite is affected, producing fat graphite, as shown in Fig. 61. Nitrogen in excess of 150 ppm can generate the type of graphite that is shown in Fig. 61. Nitrogen is generally controlled with the use of Ti. Ordinarily, at high N content, if Ti is present, the graphite structure will be normal (Fig. 58).

Calcium in Gray Cast Iron

The calcium content in gray cast iron can increase locally, beyond trace levels approaching 0.5%, with some inoculants that have failed to completely dissolve. Calcium is a graphite nodulizing agent, although it is rarely used for this purpose. The microstructure anomaly that occurs with high Ca in gray cast iron is an occasional spheroidal graphite particle. Figure 62 shows an example.

CONCLUSIONS AND COMMENTS

Tons of cast iron are produced with normal cast iron microstructures. This article is not intended to detract from those castings produced with acceptable quality. Occasionally, foundrymen encounter unusual microstructure anomalies that are not ordinarily associated with their good foundry practice.

This article is intended to provide some insight in detecting the cause for these microstructure anomalies. It is not intended to be a total glossary of all possible anomalies. Therefore, the Cast Iron Division, Quality Control Committee invites anyone who has anomalies to submit them for consideration.

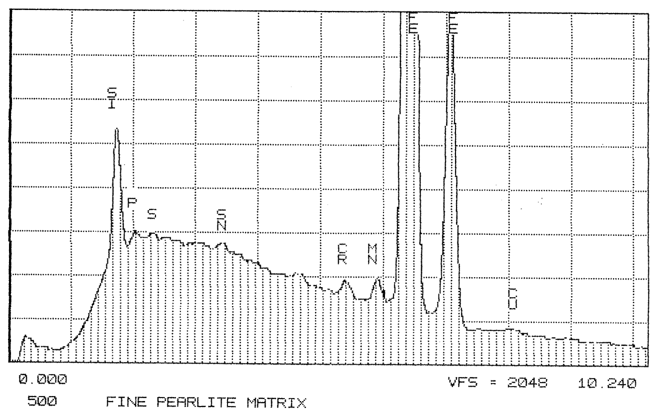

Fig. 54. Spectrum of elements representing fine pearlite in Fig. 52.

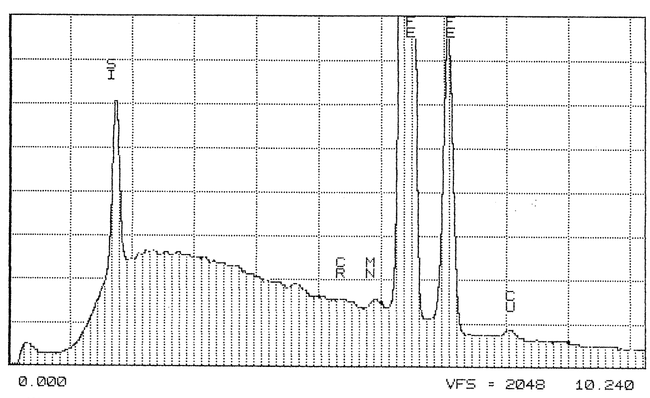

Fig. 55. Spectrum of elements representing coarse pearlite in Fig. 53.

It is our conclusion that, as foundry technology develops, more and different anomalies can be encountered. Any information that we can generate, which will be beneficial in identifying and eliminating unusual microstructures or anomalies, can do nothing but benefit the foundry industry in their efforts to produce quality products.

ACKNOWLEDGMENTS

The Cast Iron, Quality Control Committee respectfully acknowledges each and every member who has contributed examples of anomalies for consideration. In particular, the Committee wishes to recognize B. Henning from Miller and Company, Bodycote Taussig, Inc. for their willingness to provide microstructure preparation and photographs, and to *Modern Casting* magazine for their willingness to publish many of these anomalies as they were developed throughout the years.

REFERENCES

1. "Influence of Lead-Contaminated Charge Materials on the Structure and Mechanical Properties of Gray Iron Melted in a Vertical Channel Induction Furnace," N.K. Datta, *AFS Transactions,* 1981, vol 89, pp 547-552.
2. "Trace Elements in Gray Iron," C.E. Bates and J.F. Wallace, *AFS Transactions*, 1966, vol 74, pp 513 -523.
3. "Lustrous-Carbon Defects in Castings," *BCIRA Broadsheet 222.*
4. "Lustrous-Defective," *BCIRA Forecast*, Oct 1984.
5. "Formation and Control of Lustrous Carbon Surface Defects," R.L Naro, R.D., Tenaglia, *AFS Transactions*, 1971, vol 79, pp 65-74.
6. *BCIRA Broadsheet No. 45.*
7. "Recent Developments in Tin-Alloyed Cast Iron," Chatterjee, S. et al., *Castings*, pp 16, 18, 20-21, 24, 27, Sep-Oct 1976.
8. "Pearlite Stabilization in Cast Irons, B.V. Kovacs, *AFS Transactions*, vol 88, pp 79-96, 1980.
9. "Tin as a Promoter for Pearlitic Iron Castings" S. Karpel, *Tin and Its Uses*, No. 156, pp 8-11, 1988.

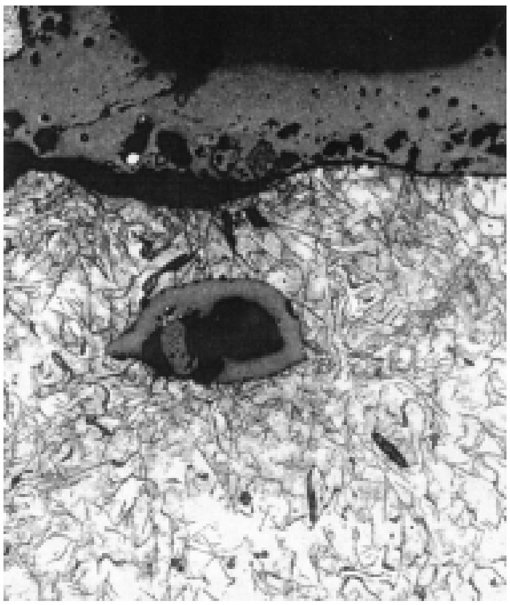

Fig. 56. Photomicrograph showing a cross section where a filter segment was trapped in microstructure; (50X, nital etch).

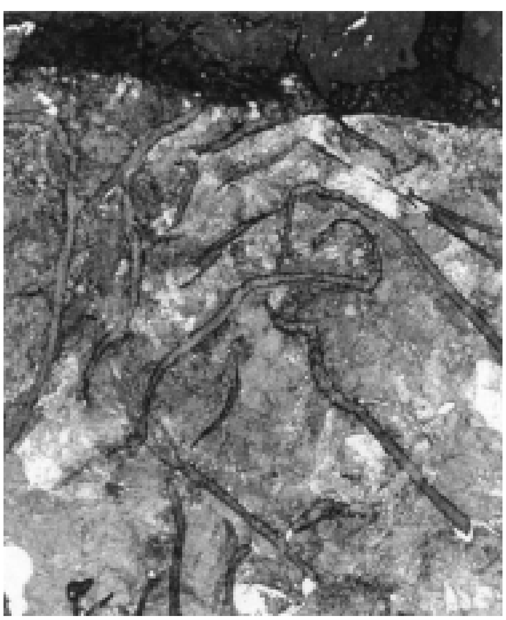

Fig. 57. Photomicrograph showing same area seen at lower magnification in Fig. 56. This photograph illustrates that no ill effects have occurred with respect to microstructure quality; (400X, nital etch).

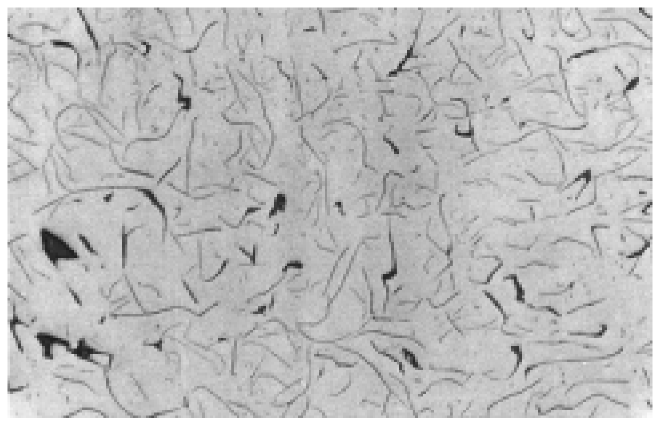

Fig. 58. Photomicrograph showing graphite structure of casting, away from defect; (100X, unetched condition).

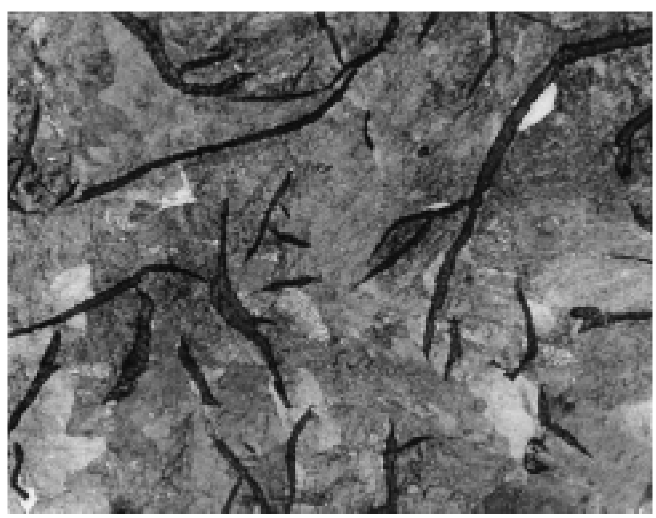

Fig. 59. Photomicrograph showing etched structure of casting, away from filter segment. Compare this structure with that shown in Fig. 56 near filter segment; (400X, nital etch).

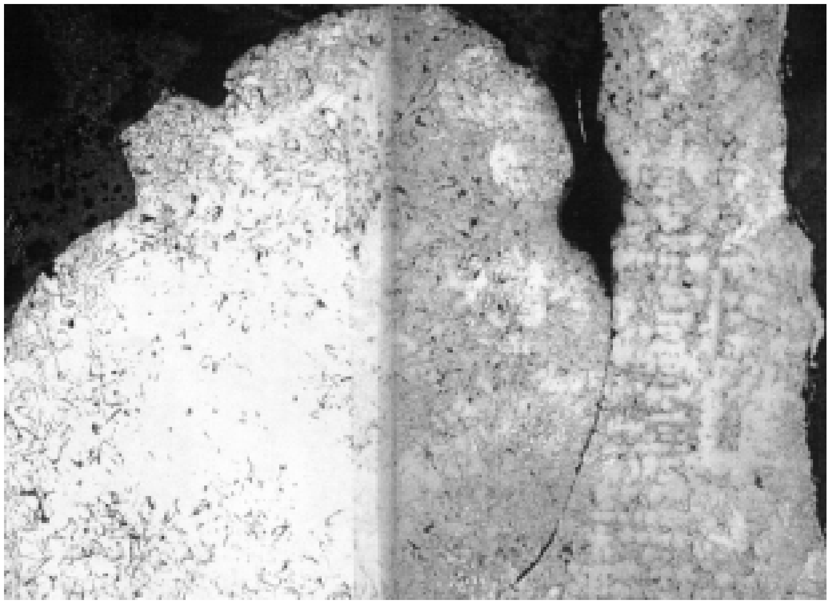

Fig. 60. Photomicrograph showing quality of cast iron in vicinity of a filter segment where casting has sustained a cold shut and degenerate graphite; (50X, unetched condition).

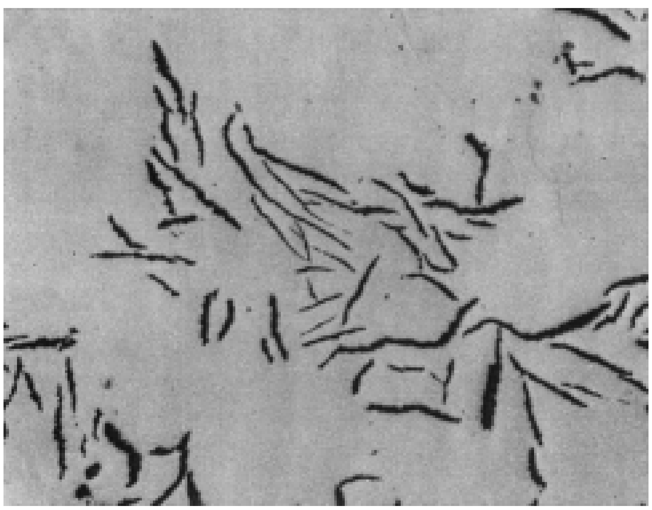

Fig. 61. Photomicrograph illustrating "fat" graphite morphology associated with gray cast iron when nitrogen content becomes excessive (greater than 150 ppm); (100X, unetched condition).

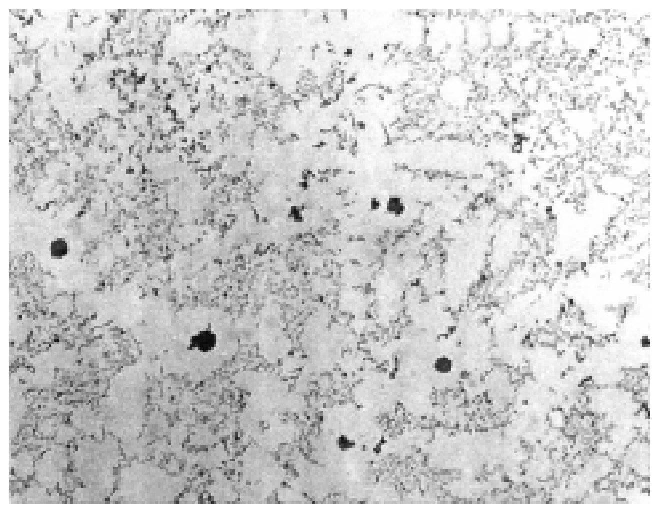

Fig. 62. Photomicrograph showing spheroidal graphite in a gray iron casting; (400X, unetched condition)

Note: All photos were reduced to 75% for publication.