MALLEABLE IRON MICROSTRUCTURES EFFECT AND CAUSE

REPORT OF AFS MALLEABLE DIVISION
CONTROLLED ANNEALING COMMITTEE

In response to an expressed need, the Controlled Annealing Committee 6D of the American Foundrymen's Society has combined in an effort to set forth such the basic microstructures commonly found in malleable iron metallurgy as well as some of the abnormal structures arising from known causes.

The literature contains an abundance of records and reports covering special phases of the technology, but no recent effort has been made to collect and present the normal structures in a single paper. The committee believes that such a collection will serve a purpose useful to both malleable founders and engineers associated with the use of malleable iron castings. If the understanding of the basic metallurgy involved in the annealing of malleable iron is thereby promoted, the committee feels that its efforts will have been well rewarded.

This report contains illustrations of various microstructures encountered in the respective committee member's companies. An attempt has been made to explain the causes which produced the effects shown in the photomicrographs. It is hoped that this will stimulate interest in and bring forth some discussion of malleable iron metallurgy.

Figures 1A and 1B show a typical ferritic malleable microstructure at ×100 and ×500. Note the complete absence of residual pearlite or cementite and the random distribution of MnS (light gray particles). There may or may not be a preferred orientation of temper carbon nodules. Such a pattern results from the decomposition of the dendritic primary carbide taking place on preferred planes. The nodule shape as shown in Fig. 1B is similar to that of a cockle-burr. Essentially, it is not spheroidal.

Figure 2 (A, B, C, D) illustrates four types of acceptable rims. Figure 2A shows the complete absence of pearlite. Nodules are within 0.010 in. at the surface. Figure 2B shows a discontinuous pearlitic rim approximately 0.007 in. in thickness underlaying a ferritic rim of about the same thickness. Note that in Figs. 2A and 2B the nodule shape, size, and distribution are similar.

Figure 2C shows a heavier pearlitic rim of approximately 0.015 in. underlaying a ferritic skin of approximately 0.007 in. Note that the ferritic outer layer is approximately the same thickness as that shown in Fig. 2B. However, the nodules are larger in size, more sprawling, and fewer in number. The presence of a patch of core pearlite as well as the entire retarding effect results from an increased demodulizing tendency or increased heating rate during the anneal.

Figure 2D shows a continuous pearlitic rim with no ferritic skin. Such a structure usually indicates an excessive reducing atmosphere.

In the four illustrations of Fig. 2, the basic chemistry and overall annealing cycle is the same. The effects result entirely from variations in control of atmosphere and rate of heating.

Figures 3A and 3B show the microstructures at the surface of similar castings illustrating the effects of differences in atmosphere control on demodulizing tendency.

Figure 4A shows the microstructure of an oxidized surface. Note the non-uniform surface and increased depth of penetration. Figure 4B shows oxidation of an internal shrink.

Figure 5 shows the microstructure of a mottled rim sometimes referred to as "inverse chill" and is a precipitation of flake graphite during freezing. This effect is generated in the mold and does not result from variations in annealing or atmosphere control.

Figure 6A shows the microstructure of a spreading nodule. Note that the size and sprawahness of the nodules increase simultaneously. Figure 6B shows the microstructure of a normal compact nodule.

Figure 7 shows an example of high nodule count. This generally is considered excessive with a tendency toward lower mechanical properties.

Figure 8 shows an example of low nodule count. Such a condition frequently results in poor surface finish in rough machining.

Figures 9A through 9F illustrate the effect of increasing boron addition on nodule size and distribution. As increasing amounts of boron are added, nodule count increases and the shape compacts. In the higher concentration a preferred dendritic orientation occurs which is generally regarded as unfavorable in its effect on mechanical properties. This series was performed on the same basic iron.

Figure 10 shows the structure resulting from incom-
Fig. 1 A and B—Typical ferritic microstructures. Residual pearlite or cementite are completely absent. Light gray particles are MnS.

Fig. 2 A, B, C, D—Four types of acceptable rims. A—Complete absence of pearlite. B—Discontinuous pearlitic rim. C—Heavier pearlitic rim of approx. 0.007 in. D—Continuous pearlitic rim with no ferritic skin.
Fig. 2—Continued

C—Nital Etch, ×100.

D—Nital etch, ×100.

Fig. 3 A and B—Microstructures at the surfaces of similar castings illustrating effects of differences in atmosphere control on denodulizing tendency.
Fig. 4 A and B—A—Microstructure of an oxidized surface, with non-uniform surface and increased depth of penetration. B—Oxidation of an internal shrink.

Fig. 5—Microstructure of a mottled rim (also called "inverse chill") as a result of precipitation of flake graphite during freezing. Nital etch. X100.
A—Nital etch. X100.

Fig. 6 A and B—A shows microstructure of a sprawling nodule. B shows microstructure of a normal compact nodule.

Fig. 7—This photomicrograph shows an example of high nodule count. Nital etch. X100.

Fig. 8—An example of low nodule count is shown in this photomicrograph. Nital etch. X100.
Fig. 9—(A through F)—Photomicrographs illustrating effects of increasing boron additions on nodule size and distribution. As increasing amounts of boron are added, nodule count increases and the shape compact.

Complete first stage of annealing. Remnants of massive primary carbide are the significant indicators of this condition.

Figure 11 shows incomplete second-stage annealing. In this particular case, low carbon in the iron (2.15 per cent) resulted in heavy residual pearlite in the core structure. This condition would be difficult to pick up by means of hardness test due to the soft ferritic skin. This casting tested 149 Bhn.

Figure 12 illustrates incomplete first- and second-stage annealing. Note the presence of primary carbide, coarse pearlite, and a sprawling nodule shape. This effect is caused by nonstandard chemical analysis of the iron.

Figure 13A shows the occurrence of shrinkage in hard iron. Note the characteristic dendritic pattern of the primary carbide. The general resistance of shrink areas to normal annealing is illustrated in Fig. 13B, as shown by the presence of residual pearlite. Residual carbide may also be present. Shrinkage is fundamentally a feeding problem and does not result from variations of heat treatment.
Fig. 10—Structure resulting from incomplete first-stage annealing. Nital etch. X300.

Fig. 11—An example of structure resulting from incomplete second-stage annealing. Nital etch. X100.

Fig. 12—Structure resulting from incomplete first-stage and second-stage annealing. Primary carbide, coarse pearlite and a sprawling nodule shape are shown. Nital etch. X300.
Fig. 13 A and B—A shows the occurrence of shrinkage in hard iron. B—General resistance of shrink areas to normal annealing is shown by presence of residual pearlite.

Fig. 14 A and B—Phenomenon of mottle in hard iron (A), and in annealed iron (B).
Fig. 15 A and B—These photomicrographs illustrate the effect of low manganese on the resulting annealed structure.

Fig. 16—This photomicrograph shows a hard iron crack. The crack tends to follow the interface between primary carbides and pearlite. Nital etch. $\times 500$. 
Fig. 17—The photomicrograph shows a crack in hard iron which aligns itself to voids having the appearance of shrinkage. Nital etch. X100.

Fig. 18—Illustration of a "so-called" crack which does not show the continuous separation of metal. Unetched. X100.

A—Nital etch. X100.

B—Nital etch. X100.

Fig. 19 A and B—Effects of preheating hard iron 5 hr at 700°F. A—Normal microstructure without preheat treatment. B—Increased nodule formation resulting from addition of pre-anneal treatment.
Figures 14A and 14B illustrate the phenomenon of mottle in hard iron (Fig. 14A) and in annealed iron (Fig. 14B). Mottle is the precipitation of flake carbon on freezing in the mold and its presence does not relate to heat treatment. Because of its depletion of combined carbon in hard iron, the structure surrounding the mottle frequently does not respond completely to normal heat treatment, as shown in Fig. 14B. Islands of residual cementite are clearly evident in the etched structure. Mottle is always injurious to the mechanical properties of the casting.

Figures 15A and 15B illustrate the effect of low manganese on the resulting annealed structure. The carbides appear quite coarse, and result from inadequate second-stage annealing since the primary carbides have been completely dissolved. Manganese content is 0.33 per cent and the sulfur is 0.128 per cent. An increase in the manganese to 0.38 per cent would have permitted a normal annealing response.

Figure 16 shows a hard iron crack. Note the tendency of the crack to follow the interface between the primary carbides and pearlite. This crack extended less than 1/32-in. and was apparently caused by high internal stress in the casting.

Figure 17 shows a crack in the hard iron which aligns itself with voids having the appearance of shrinkage. There is a pronounced tendency for the crack to align itself in the orientation of the dendritic cementite pattern.

Figure 18 illustrates a so-called "crack" which does not show the continuous separation of metal. Such defects are noticed in fluorescent-penetrant inspection. Along the "crack" interface, nodule count is extremely high. This condition is presumed to have been caused by the high internal stresses which produced the crack.

Figures 19A and 19B show the effects of preheating hard iron 5 hr at 700 F. The chemical analysis and heat treating cycles of both specimens are identical. Figure 19A shows the normal microstructure without preheat treatment, Figure 19B shows the increased nodule formation resulting from the addition of the pre-heat treatment.

CONCLUSIONS

The illustrations contained herein are not intended as standards, but may be used as guides. They are representative of good normal practice, with some metallurgical defects included.

No attempt has been made to answer involved specialized problems in any phase of malleable iron heat treatment.

As originally indicated, no claims are made for this collection of photomicrographs to be a complete treatise on all of the metallurgical troubles which can beset the malleable iron foundry. Of course, troubles may always arise in any foundry from peculiarities of behavior of individual pieces of production and control equipment. In general, we have tried to avoid consideration of the type of structure resulting from "freak" conditions occurring in a single plant.

Ferritic malleable iron is an established engineering material of well-known properties and application. It has characteristic edge structures and core structures. These we have shown with the variations and explanations for the variations. Some of the variations are significant, some inconsequential. It is exactly on this difference that the focal point of this paper rests.

To those not too familiar with the details of manufacture of malleable iron, the structures shown in this presentation may act as a guide. They are not intended as standards but are representative of what may happen in normal practice. They do show some of the defects which may develop when the processing goes out of metallurgical control.