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7 Ways to Avoid Shrinkage Defects

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Examine your metallurgy, tooling and molding practices to improve the quality of your castings.

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Several factors in ductile iron melting and pouring can be controlled to maximize yield and reduce shrinkage. Whether dealing with a problem part or a need to improve current yields, these methods can help reduce shrinkage defects and lead to more consistent casting quality.

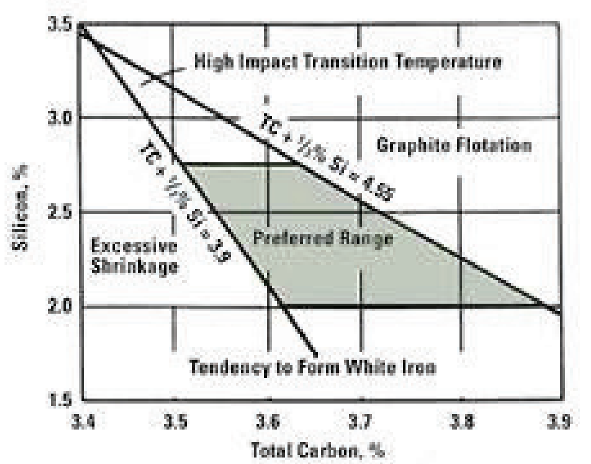

Fig. 1. Use this chart to determine the preferred carbon equivalent in your ductile iron.

1. Maximize the Graphite Precipitation Expansion Effect Without Nodule Flotation

One of the first steps in avoiding shrinkage problems in ductile iron melting is to select a suitable carbon equivalent (CE) that avoids the flotation of graphite nodules leading to shrinkage. The chart in Figure 1 advises the total carbon plus one-third silicon should not exceed 4.55. The diagram was developed as a general rule for sections varying from 0.5 in. to 1.5 in. For very thin sections, such as in manifolds, the CE may be higher. For thicker sections, it must be lower to avoid nodule flotation and an increased risk of shrinkage. When carbon precipitates from liquid iron during freezing, an expansion effect occurs. Shrinkage will be minimized at the highest possible carbon content, where the iron freezes in the eutectic mode, just below the content where primary graphite precipitates and nodule flotation occurs.

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The British Cast Iron Research Association, as part of a research project for the American Foundry Society, produced a table providing the maximum carbon for various silicon values to avoid flotation of graphite nodules for various section thicknesses of different shapes (Table 1).

2. **Table 1. Maximum % Carbon to Avoid Nodule Flotation**

	Section Size of sample (mm)			
Square Bars (mm)	20	30	50	80
Volume-to-surface area ratios (mm) (Modulii)	4.79	7.06	11.34	17.23
Cooling rate thickness in large plates (mm)	10	15	23	35
Cylindrical section diameters (mm)**	19	28	45	70
% Silicon*	MAX. % Carbon to Avoid Nodule Flotation for 2,550F Pouring Temperature			
1.8	4.00	3.96	3.88	3.76
2.2	3.90	3.86	3.78	3.65
2.6	3.80	3.76	3.67	3.55
3.0	3.69	3.65	3.57	3.45
3.4	3.69	3.65	3.57	3.45
3.8	3.49	3.45	3.36	3.24
4.2	3.38	3.34	3.26	3.13
4.6	3.28	3.23	3.16	3.03
5.0	3.18	3.13	3.05	2.93

Carbon contents should be decreased by 0.05% for each 90F (50C) increase in pouring temperature.
**Silicon contents must include additions made in magnesium treatment and inoculation.*
***Plus lengths greater than 5x the diameter.*

Table 1. Maximum % Carbon to Avoid Nodule Flotation

Time the Carbon Precipitation Expansion Effect Correctly

Generally, shrinkage is reduced as the carbon percentage increases, provided that freezing involves simultaneous precipitation and graphite growth contained within austenite shells. If the percent carbon becomes too high and primary graphite starts the solidification process, a great deal of the expansion effect available from graphite precipitation is consumed early during freezing. The rapid precipitation of graphite as it floats in the liquid metal can result in insufficient graphite expansion effect during the later stages of freezing, within the last isolated pools of iron to freeze.

Figure 2 shows plots of the maximum carbon equivalent data for square bars, flate plates and modulii, with three curves shown for three silicon levels. The lines have been extended to the CE eutectic of 4.3. This shows all thicker sections that must be at or below 4.3% CE to avoid primary graphite precipitation, nodule flotation and higher shrinkage.

Carbon precipitation as graphite nodules is required at the start of freezing to ensure the carbon does not take the iron carbide form as edge chill. Too much early graphite precipitation must be avoided, or too little graphite precipitation will occur during the end of freezing, when the gating system and risers can no longer deliver more liquid to compensate for contraction.

Higher silicon leads directly to higher nodule count, more ferrite and early carbon precipitation. To minimize shrinkage, the CE should be on target with the maximum carbon content and the minimum silicon content. Enough silicon should be used to avoid carbides and strengthen the ferrite to meet properties but not excessively more. Too much silicon can lead to excessive initial expansion effect with too little occurring in the last iron to freeze. Normally excessive nodule count that leads to shrinkage has a structure where the nodule size appears identical throughout, as all the nodules started forming early during freezing (Fig. 3).

Excessive inoculant addition rate or the use of bismuth to increase nodule count can lead to high nodule counts with uniform sizes. High nodule counts can be useful to turn off shrinkage, but only if a wide nodule size distribution can be produced. This implies graphite precipitation proceeds at a steadier pace from the start to the end of freezing and not too fast during the first part of freezing.

Magnesium content also should be controlled. Enough magnesium should be used to produce good nodules, but an excess of magnesium can lead to slag defects or spiky graphite formation, in addition to shrinkage problems.

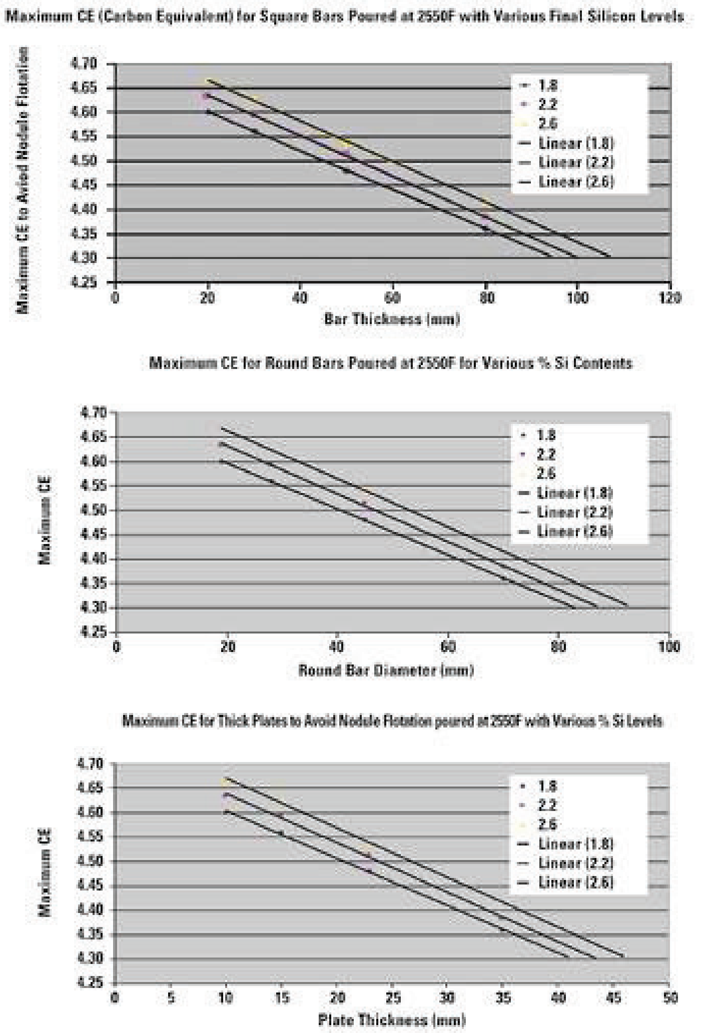

Fig. 2. These charts show the maximum CE to avoid nodule flotation for square bars, modulii and flat plate sections for three silicon levels poured at 2,550F. The curves are extended to show the section thicknesses where the CE must be eutectic or slightly below.

3. Keep Base Sulfur Content Consistent

The base sulfur content of iron can have a large impact on nodule count and size distribution. For very thin castings prone to carbides, some metalcasting facilities will intentionally operate with a higher base sulfur. These nodules appear to be similar in size and may lead to shrinkage problems if the nodule count becomes too high, especially in heavier sections. For reproducible nodule count, the base sulfur content must be uniform from one treatment to the next. Large variations in the base sulfur, such as when converting between gray and ductile iron, could lead to variable nodule counts and nodule size distributions and shrinkage propensity.

4. Avoid Long Hold Periods

As base iron is held,

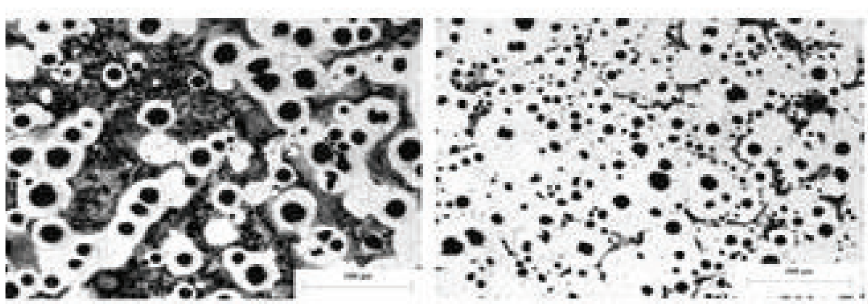

Fig. 3. Higher silicon leads directly to higher nodule count, more ferrite and more early carbon precipitation. Keep the percent silicon steady at the minimum level, using just enough to avoid carbides.

carbon is lost and the state of nucleation changes over time. After holding for 30 minutes at tapping temperature, the subsequently magnesium-treated and inoculated iron will become slightly more shrinkage prone and strongly more carbide prone. Ladle and stream inoculation may not eliminate the carbides. This effect was observed in a metalcasting facility using medium frequency furnaces, with one furnace melting and the other furnace delivering iron for tundish treatments. Six tundish treatments were made over one hour to drain the furnace, before switching to the next furnace. As a consequence, the first three treatments were conducted as desired and the last three treatments produced carbides within the structure, despite the use of powerful, continuous stream inoculation with high potency inoculants.

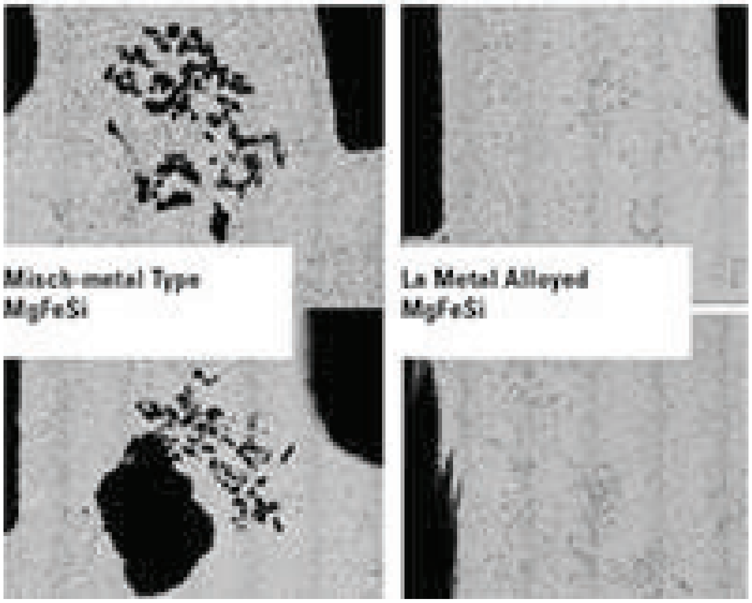

Fig. 4. Reduced shrinkage is observed in the MgFeSi alloy treated with lanthanum (right) vs. mischmetal.

The casting facility learned some of the lost nucleation effect could be restored by adding crystalline graphite to the iron while replacing carbon losses during holding, but that one hundred percent graphite electrode turnings were reported to be the best type of carbon replacement material to eliminate the carbide tendency.

The rate of loss in carbon and nucleation effect from holding base iron is believed to be different for various holding furnaces and temperatures.

Holding magnesium-treated iron can induce shrinkage. After 25 to 30 minutes of holding iron in an autopour without any freshly treated iron additions, the state of nucleation changes and it becomes shrinkage prone. This change can be detected using thermal analysis. The effect can be corrected by additions of proprietary sulfur and oxygen-coated inoculant.

5. Use Special Nodulizers to Avoid Shrinkage

Historically, MgFeSi alloys have been alloyed with rare earth metals, which are used to neutralize tramp element effects to avoid edge carbides at low pouring temperatures and to optimize nodule count. For many years, mischmetal was the most common type of rare earth metal added. Special alloys have been developed that use pure lanthanum rather than the mixture of rare earth elements. An optimized amount of lanthanum results in a high nodule count with a different nodule size distribution. The number of large, early forming nodules decreases slightly, and the number of medium and smaller nodules increases, which is an indication that graphite precipitation has been steadier through freezing, with more expansion effect during the latter stages of freezing.

In a comparison of MgFeSi alloys using the traditional mischmetal and MgFeSi alloy using lanthanum, the ductile iron using lanthanum provided a structure with fewer large nodules and a high population of medium and small nodules. Figure 4 shows gross shrinkage in the iron treated with mischmetal and none in the iron treated with lanthanum. Conserving the expansion effect by saving some carbon precipitation to the latter stages of freezing has a profound effect on shrinkage. A minimized tendency of iron to shrink can be somewhat correlated with a wide nodule size distribution, highly skewed to the finer sizes. This also can be achieved using a proprietary inoculant containing sulfur and oxygen compounds.

Fig. 5. Holes drilled into cores become chill pins when the mold is filled with iron (left). Clusters of chill pins cast inside the part force those areas to freeze sooner so they are shrinkage-free.

6. Increase Freezing Rate Rather Than Risering

Flow and solidification simulation software is useful to predict where shrinkage is likely to occur in castings. At that point, metalcasters have the choice to add risering to feed more liquid iron to the spot where shrinkage is predicted or somehow make that part of the casting freeze more quickly with chilling techniques. In large castings, producing structures with high nodule counts and high nodularity can be a struggle. In these situations, using chilling to avoid shrinkage is useful because it also provides an improvement in the structure. Risers may make the structure worse by prolonging the freezing time and reduce the iron yield.

Heavy shrink-prone areas can be chilled in a number of ways. Figure 5 shows holes drilled into the cores and the subsequent cooling pins cast during mold filling. These iron pins serve as radiators to transfer heat from the casting into the sand more rapidly, to avoid shrinkage in those areas. In some cases, pins or fins can be added to a pattern. If they can’t be included automatically with patterns or coreboxes, they can be drilled into the pattern and then removed from the casting during or after cleaning.

Fig. 6. A metal spring inserted into the core to produce a cylinder head casting serves to provide a high surface chilling device (left). A sectioned cylinder head reveals the remnants of a spring that did not totally melt but fused to the surrounding iron.

In Figure 6, a coiled spring is used to rapidly freeze a section of a casting prone to shrinkage. The greater surface area of a spring can chill the iron more rapidly than a straight wire or bolt. In some cases, a hole is drilled through the center of the area where the spring is located, and in other cases, the spring is machined entirely out. In both cases, the drilled surface must not reveal shrinkage voids of any size.

Chills also may be embedded into a core as it is produced in order to provide chilling of the iron. The metal chills do not melt into the casting but extract heat more quickly from the shrinkage-prone sections of the casting. Metal chills must have clean, dry surfaces and often are coated with a ceramic wash.

In Figure 7, bolts were formed as “ram-up” type inserts set into the pattern before creating the mold section to accelerate freezing in a green sand mold.

7. Produce Uniformly Strong, Rigid Molds

Ductile iron can be produced without risers if molds are suitably strong. This normally means using a nobake rather than a green sand mold. Green sand molds must be as strong as possible to avoid shrinkage induced by wall movement. This means attention must be paid to sand properties and molding machine maintenance. For example, valve wear on impact machines can result in weaker molds. Methods to maintain mold strength when the pattern has deep pockets should be considered, including adequate venting of air expelled during impact compaction.

Fig. 7. Two bolts are formed into a large green sand mold as ram-up inserts to force faster solidification into the area.

This article is based on “Avoiding Shrinkage Defects and Maximizing Yield in Ductile Iron” published in the 2012 AFS Proceedings.

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