Controlling Cast Iron Gas Defects

Charge materials chemistry, melting practices and molten metal handling procedures are root causes, but defects can be avoided.

AFS Cast Iron Molten Metal Processing Committee (5-L)
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Cast iron gas defects generally result from faulty charge materials or careless melting and handling practices. Evident as pinholes, blowholes or fissures, they are generated, alone or in combination with other gases, by the excessive formation of hydrogen (H₂), nitrogen (N₂), carbon monoxide (CO) and possibly oxygen (O₂) gases.

Pinholes account for a significant portion of the scrap losses by commercial foundries. Castings lost to scrap due to pinholes are approximately 50% greater in ductile iron than gray iron. Caused mainly by hydrogen or nitrogen induced during the melting process, they can be prevented by the magnesium (Mg) treatment process. They also may result from mold atmosphere pickup.

Hydrogen pinholes are round or egg-shaped. Usually occurring just below the casting surface, they are associated with wet sand and have a smooth interior with a crystalline graphite coating. The microstructure in the area of an H₂ pinhole often consists of a ferritic ring containing vermicular or flake graphite. Nitrogen pinholes in ductile iron can be spherical with visually dull interior linings. Discriminating between the two is difficult.

Blowholes are entrapped or retained gas bubbles formed as solidification begins and contain a gas whose pressure is greater than that of the surrounding metal. Blowholes are also caused by CO developed in a slag reaction with precipitated graphite.

Fissures are irregular openings in the metal. Single fissures, rather than several small interconnected ones, are associated with melt chemistry or melting practices. Fissures can be caused by either H₂ or N₂.

There is a great deal unknown about the origination of gases and their interaction with molten iron, but research and experience have provided an understanding of and many solutions to gas defects.

Hydrogen Defects

Hydrogen gas defects in cast iron appear most commonly as pinholes, blowholes and fissures, but it is possible for iron to contain an appreciable amount of H₂ and have no defects.

Pinholes occur just below the surface of the casting and often are visible only after removing a casting's surface. They are spherical or flat-shaped gas bubbles 1/32-1/8 in. in diameter with shiny, graphite-coated cavities surrounded by graphite-free iron. Occasionally, the pinhole cavity will contain a shot of exuded metal but never any nonmetallic inclusion.

Pinholes can also be formed by N₂, CO and sometimes, indirectly, by dress.

Thus, it is necessary to classify pinholes by cause. There is no good correlation between hydrogen pickup or the hydrogen content of an iron and pinhole formation. There does, however, appear to be enough evidence to say that hydrogen content is a factor. Evidence shows that hydrogen pickup from damp ladles and launders can intensify the pinhole defect.

Pinholes, too, can be related to a metal/mold reaction. The increased gas content in a base iron, then, would be expected to lower the threshold facilitating the formation of H₂ and N₂ pinholes.

The presence of aluminum (Al) in iron will promote H₂ pinholes. It is suggested that moisture from the green sand mold reacts with the Al in the iron to form aluminum oxide (Al₂O₃) and H₂. When an Al-bearing iron solidifies in air, it does not tend to produce pinholes. If the same iron were to solidify in contact with a green sand mold, surface pinholes would probably result. Hydrogen pinholes are also the result of interactions in the mold between organic materials and hot metal.

There is some inconsistency among metallurgists as to the level of Al that will cause pinholes. It seems that below a certain level (possibly 0.03% Al), pinhole formation is not a problem. When this Al threshold is crossed, the incidence and severity of the pinholes in-

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Fig. 1. The solubility of N in a low carbon melt is a function of time, eventually reaching an equilibrium.

Fig. 2. The number of times returns and high carbon scrap have been remelted also affects the absorption rate and the volume of N solubility.

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creases at an even higher Al threshold content (possibly 0.2% Al and above), H2 pinholes cease to be a problem. Other studies have held that Al content in the 0.005–0.02% range is harmful.

Aluminum in an iron melt comes from many sources such as Al attachments to ferrous charge materials like engine blocks and pistons. Significant Al is usually present in inoculating ferrosilicon (0.7–4.0% Al) and in magnesium ferrosilicon (0.6–1.2% Al) treatment alloys.

Ferrosilicon used in the charge makeup can also contribute to a higher Al residual (0.05–1.5% Al in FeSi is typical), although low Al grades are available. It is difficult to produce ductile iron and stay below the suggested 0.01% Al level, though pinholes are not always produced due to Al presence. Other interactions may determine the defect formation.

A metal treatment can lower the Al in an iron. Aluminum content and pinhole severity may be reduced by the use of an oxygen lance or by plunging iron ore pellets into the melt, but, in practice, this latter technique is seldom used.

Magnesium levels and treatment conditions have an influence on the hydrogen level and the resulting pinhole severity. For Mg levels up to 0.1% (high for ductile iron), hydrogen content increases with no pinhole increase. With Mg levels over 0.1%, H2 will increase and pinhole formation will decrease. Utilizing an NiMg alloy reduces pinholing compared to an MgFeSi alloy due to the lower Al input. Studies show that superheated iron treated with an Mg alloy at a lower temperature will produce more pinholes than when treated at the higher temperature.

Cast iron alloying elements, often in minute quantities, can affect pinhole formation. High C content, up to the eutectic composition, favors pinhole formation in ductile iron. Above the eutectic composition, pinholing subsides.

Studies have shown that late additions of tellurium (Te) in the range of 0.002–0.003% and bismuth (Bi) at 0.004–0.10% help decrease pinholes in gray iron. It is also known that pinholes occur in gray iron with over 0.01% Te, 0.048% titanium (Ti) and 0.15% S. However, some of these elements can induce other defects.

As noted, pinholes are formed by the interaction of hot metal and the mold, but can be reduced by lowering the amount of water in the green molding sand. Seacoal, pitch and/or other volatile carbonaceous mold additives will reduce H2 pinholes. "Mold barriers" formed with sodium silicate washes and additives, such as iron oxide (Fe2O3), are reported to be successful in reducing pinholes.

Blowholes are iron casting defects attributed to H2. Although other gases are usually involved, blowholes are bubbles of entrapped or retained gas formed during solidification. These cavities, or blowholes, contain a gas whose pressure is greater than that exerted by the atmosphere and the surrounding metal.

Inconclusive studies have not proved that specific amounts of gases in the metal result in a corresponding severity of blowholes. It is unlikely that a dangerous gas level can predict defect severity. Gas content depends on the alloy as well as foundry practices and the relative levels of all gases.

A gas defect study conducted with pure iron resulted in only a few blowholes. However, when a foreign particle or substance was added to a molten iron specimen, many bubbles formed.

Fissure-type defects can be caused by H2 or N2. If this defect is present in iron melted in a cupola foundry iron, it is probably due to N2. Iron steel or scrap contains about 70–100 ppm of N2, but the opportunity for N2 absorption during subsequent remelting is potentially greater in a low-carbon ferrous melt. The presence of a continuous graphite film indicates that the defect is caused by H2, but it is difficult to distinguish between fissures caused by either gas.

If H2 is believed to be the cause of the defect, the Al content should be measured and reduced if too high because Al promotes H2 pickup in iron. Sources of water vapor, such as furnace and ladle refractory linings, should be eliminated.

**Nitrogen**

The solubility of nitrogen in cast iron depends on furnace temperature and Si and C contents. Unlike other solidification systems, Ni is more soluble in austenite than the liquid iron. Nitrogen contents are less likely to exceed the solubility limits at high carbon equivalent values. The shift in N levels due to a change in solubility conditions generally occurs slowly as shown in Fig. 1 and 2.

Farquhar's Table 1 illustrates typical N levels observed in commercially produced irons.

The nitrogen content of an iron is usually expressed as the total N content, meaning uncombined N dissolved in the iron as well as various particles of N compounds suspended in the iron. Allowing the iron to sit would provide time for these "nitride particles" to float out of the melt, although they are small and their flotation is slow.

The solubility of (uncombined) N2 at 1 atm pressure in pure iron is approximately 200 ppm. The addition of C and Si lowers this solubility; Mg, Cr, and Va raise the solubility and Ni has very little effect (Fig. 3). Higher temperatures raise gas solubility in molten iron.

Various carbon-raising additives can significantly increase N2 in the melt. Listed in Table 2 are the various properties for some common C additives.

Pig iron, foundry returns and scrap steel are significant sources of N. Foundry returns, and particularly pig iron, usually will not be high in N due to their already high C and Si contents. Steel scrap, with N at 30–150 ppm, can contain higher levels of N than iron and can accommodate more N during melting due to lower C content.

Table 3 illustrates the N content of a melt compared to the percent of steel scrap in a charge for cupola-melted iron. The higher N level may...
be due more to the higher melting temperature of a steel charge and higher N and C contents when steel is substituted for iron in the charge.

Alloy additions from ferroalloys normally are not an N source, but alloy data sheets should be checked because some ferroalloys intentionally contain appreciable levels of N.

Melting methods will have an effect upon the N level in the melt (as shown in Table 4) for malleable iron production.

The cupola would be expected to produce a high N iron. The high temperature inside the cupula shaft, high steel scrap charge, exposure to coke and a high air volume (wind) would serve to raise the N content.

Arc melting conditions illustrate this high N content. Arc furnace charges normally are composed of high steel scrap and carbon raiser material with the potential for carrying a high N content to the melt. The electric arc has a high ionizing potential and extremely high, localized metal temperatures. The solubility of N in iron increases as the temperature rises and acid slag conditions in the furnace retard the N metal content; higher N levels result in a basic slag practice. High S and carbon boil during melting inhibit N absorption.

Induction furnaces produce the lowest N-level irons and, though they receive high steel scrap charges, liquid bath holding time is long and the stirring action vigorous. These circumstances allow the N to reach an equilibrium level.

In a cupola charge, Ti is useful in neutralizing the N effect by adding Ti-bearing pig iron or ferrotitanium, titanium-containing inoculants or ilmenite (FeTiO₃) or rutile (TiO₂) minerals. Treating iron with Mg to produce ductile iron reduces N levels because the vigorous gas evolution of the Mg treatment will carry N from the melt and make N levels in treated ductile iron less than in its base iron.

### Table 4. Effects of Melting Methods on Nitrogen Levels

<table>
<thead>
<tr>
<th>Method</th>
<th>Primary Melter</th>
<th>Basic Melter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (ppm)</td>
<td>50-100 ppm</td>
<td>110-140 ppm</td>
</tr>
<tr>
<td>PRODUCTION TIME</td>
<td>50-80</td>
<td>80-120</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>75-110</td>
<td>95-125</td>
</tr>
</tbody>
</table>

### Oxygen

It is difficult to omit O₂ even though it is not believed to be the gas that actually forms a defect. Oxygen is chemically reactive and oxidation-reduction reactions are believed to contribute to the creation of gas defects.

Certain melting conditions can be associated with increasing the O₂ content in iron, such as overblowing a cupola or rusty charge materials.

The addition of deoxidizing or reactive elements (Al, Ti, Si, C, Mg, etc.) will reduce the soluble O₂ content in iron.

The total O₂ content of cast iron is reported to be between 5-250 ppm and the soluble O₂ content up to 15 ppm. Treating ductile base iron with an Mg and Si inoculation can lower the soluble O₂. Three factors—Si, C and temperature—influence the amount of dissolved O₂ in cast iron. At temperatures below the inversion temperature (about 2372°F), O₂ levels are controlled more by Si than C. The major process variable, however, seems to be temperature as evidenced by the small changes in C or Si in cast iron production.

Dissolved gases in cast iron and the defects they cause are complex. Measurement is difficult. H₂ is particularly difficult to sample because of the rapid diffusion of the gas from the sample and the need to send the sample to a remote laboratory.

In summation, one ASF Cast Iron Division member cautioned that "the role of gases as the cause of casting defects should be studied for relationships to the chemical and physical reactions in progress rather than for relationships to some specific percentages (of a gas) present at any given moment of sampling." ▼

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### Bibliography


"Pinholes Formed by Hydrogen Gas During Solidification," BCIRA Broadsheet, No. 7.


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**Editor's Note:** A caption in Part 1 of this series was in error. See correction on p 76.

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