POROSITY, INCLUSIONS AND PINHOLES IN MALLEABLE CASTINGS

By C. A. Sanders

ABSTRACT

An approach to the porosity, inclusions and pinhole problem in the malleable foundry is put forth. Inclusions are recognized too slightly as having a direct relationship toward the creation of pinhole porosity. Hot sand and brittle sand, in the author’s opinion, are the most common sources of inclusions that may create pinhole porosity in production malleable foundries. Hot sands are believed to create a chain of reactions which become difficult to control. Other reasons for porosity or pinholes in malleable castings are those of improper melting practices. Also, mold wall movement tends to aggravate a surface pinhole condition.

MALLEABLE SCRAP CAUSES

There is no concrete agreement concerning porosity in malleable metal. Removing undesirable gases in malleable metal is a problem so complicated, and attached to so many theories, that one may easily develop strong arguments to support individual claims. Porosity is one continual difference of opinion supported by little evidence which has been proved on this foundry scrap problem. No single remedy works universally for all foundries. Many foundries do not have a standard definition concerning this scrap defect. Sand technicians have always carried a principal share of the blame, perhaps more than other departments.

Pinholes and gas porosity are not always associated with inclusions (Fig. 1). The inspection of the pinhole, or gas hole, is most important or they may incorrectly be identified as to cause. Inclusions may cause as many pinholes as entrapped gas.

In many malleable foundries inclusion porosity is linked with the scrap defect known as “dirt.” The author is strongly against this nomenclature, as “dirt” generally indicates an inclusion (Fig. 2). If the inclusion cannot be identified properly, how can it be corrected? The inclusion must be slag, sand, refractory, carbides, sulfides, nitrides or dross from the products of combustion or oxidation, etc.; the word “dirt” must not be used in foundry nomenclature.

Since there are so many direct and indirect causes contributing to pinhole porosity, it is incorrect for one to make a positive statement that it is principally caused from a sand condition, or metal condition or by a specific department. There are too many cases in which the accuser of the sand department ends up the guilty party.

Usually, porosity originates from a collection of incorrectly applied practices, or incorrectly applied fundamental foundry laws. Even though slightly defective castings may be salvaged, the expenditure of time and materials to do so affects foundry profits. There is a series of combinations which may cause porosity, such as hot sands causing brittle sands which promote inclusions which develop pinholes.

It has been claimed that the number of operating factors that create porosity or gas defects usually is in excess of six. If an operation was constantly in error only 10 per cent, at the end of ten operations there could be a 100 per cent source of error.

It is often wise to invite service engineers to the foundry when difficulty arises, to determine whether

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or not the condition may be pointed toward sand, metal, ladles, melting practices or to other variables.

Many debates have been heard where the discussion of nonmetallic inclusions in oxidized metal was the issue. Surface oxides on the liquid metal must be trapped or skimmed, otherwise scrap may result (Figs. 3a and 3b). Metal furnace refractories erode easily under thermo-chemical activity, temperature, pressure and abrasion. The malleable foundryman is faced with the same problem as the steel foundry.

A new name is on the horizon, “ceroxides.” These so-called ceroxides are thought to be products of combustion, and are low eutectic slags generally created during the deoxidizing period.

**CERMETS**

It has been found that certain pinhole fractures are associated with carbides and sulfide formations. In most cases the segregated areas are definitely dendritic, but tiny inclusions can also be seen at the base of the pinhole.

Numerous malleable castings have been studied that show manganese sulfide particles associated with stringy slag at the bottom of pinhole craters.

When the manganese sulfide inclusions are seen, the sulfur content is generally in excess of 11 points. Most malleable foundries use the formula for manganese content as twice the sulfur content plus 15 points. As the sulfur advances, so does the ferro-manganese alloy addition.

Many of the dark blemishes shown at higher magnification at the bottom of some dendritic fractures in malleable castings appear to be manganese sulfide inclusions associated with thin, stringy slag. The author has previously termed these “cermets.” Some malleable foundries have stated that they now define this as a slag condition, and not a pinhole gas defect.

Only by severe choking and gating the metal can this condition be eliminated. In some cases, the author has observed choking the malleable metal as little as 1 lb poured per sec to eliminate such surface inclusions.

**DEFINITIONS**

Experts have tried to define separately pinholes, porosity and gas defects.

Porosity is most generally associated with the internal wall structure of the casting. It may be caused by gas or steam passing through the metal, which may be accompanied by inclusions of nonmetallic material or dross (Fig. 4). Porosity may appear as a rounded cavity or as a dendritic structure; it is easy to confuse with metal shrinkage.

When the surface of a casting is pitted with small holes it is known as “pinhole porosity.” Surface pinholing may indicate that the sub-surface metal may contain larger porosity or gas-hole areas (Fig. 5).

Gas holes are usually rounded cavities which appear spherical, flattened or elongated (Fig. 6). They vary in size and even in color, and are usually formed as smooth depressions rather than irregular surfaces.

Some investigators claim there are “evolution pinholes,” which result when gas is dissolved in the metal and released because of lack of solubility with decreasing temperatures. They claim that “reaction pinholes” are caused by particles other than metal which form gas within the metal casting (Fig. 7).

Inclusions are recognized too slightly as having a direct relationship toward the creation of pinhole po-
Fig. 5 — Surface pinholing may also indicate sub-surface enlarged porosity areas. Only by destructive testing can the areas be studied clearly and identification made properly.

Fig. 6 — Many gas holes appear as cavities which may be spherical, flattened, or elongated, and may vary in size and color. By conversion of water to steam, if a sand technician immediately tests sand at this stage, the laboratory temperature may show only 120°F, or perhaps less. The result is that as the sample is handled excess air is present; therefore, further cooling of the sample occurs which is not the exact condition of the sand when molded.

Hot sand is believed to be the chief influencing factor in pinhole porosity, setting into motion a chain of reactions that becomes too difficult to control, hence porosity and pinholes can occur.

Hot sands generally occur from lack of proper sand storage, and this is where the defect begins. To overcome hot sands, the foundry technician may use excess water or air to reduce the temperature (Table). Molding sands insulate themselves; therefore, it is common to find sands returning to the muller at temperatures exceeding 350°F. These sands consume gallons of water to reduce the temperature. If excess air is applied at the muller, the foundry has a chance of avoiding this defect. If there is not enough air to drive the steam from the saturated molding sand, an epidemic of pinholes can develop.

When excess water is applied to hot sand, the temperature is generally reduced to approximately 212°F.

Fig. 7 — This pinhole may be called a "reaction pinhole," which may be caused from sand or other inclusions.

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**TABLE — PROPERTIES OF MOLDING SAND**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Molding Sand Temperature</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Room Temp.</td>
</tr>
<tr>
<td>Green Properties</td>
<td></td>
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<tr>
<td>Moisture content, %/wt.</td>
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<td>Density, grams, 2 in. spec.</td>
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<tr>
<td>Permeability number</td>
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<td>Mold hardness at 3 rams</td>
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<td>Compression strength, psi</td>
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<td>Deformation, in./in.</td>
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<tr>
<td>Dried and Fired Properties</td>
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</tr>
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<td>Day compression strength, psi</td>
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</tr>
<tr>
<td>Hot compression strength, psi</td>
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<td>at 1650°F</td>
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<td>at 1850°F</td>
<td>100</td>
</tr>
<tr>
<td>at 2000°F</td>
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</table>
Every foundryman has heard of "free moisture" and "combined moisture," but where there is an excess of water associated with an excess of bond there is always a danger of increasing the combined water. The combined water becomes an integral part of the bonded sand grain. If these fine bonded sand grains become dislodged and spall, they carry a considerable amount of mechanically combined water. When these grains are heated and converted to steam, the water expands 1600 times its own volume. The combined water then becomes a direct source for hydrogen and the chain reaction develops.

Hot sands develop faster in malleable foundries than gray iron foundries, since twice as much metal is poured by malleable foundries than gray iron per ton of salable castings, and the temperature of pouring is much higher. Management soon pays for hours of excess cleaning time, grinding time and excess labor due to this direct hot sand problem.

Scrap always increases when hot sands prevail with short mulling time. The author has seen scrap jump from a morning low of 3 per cent to as much as 57 per cent scrap in the afternoon due to the heating of the sands when it becomes unsatisfactory to mold.

Ignoring excess scrap, high cleaning costs and rougher castings due to hot sands, management may be compelled to increase the use of corn flour where hot sands have created brittle sands in order to make it workable. The author has visited foundries that increased the addition of corn flour approximately one ton per day because of hot sand mixtures. Consider these additional corn flour costs at $125.00 per day, then how many days are required before that foundry has spent enough money to have purchased a cooling device, a second or third muller or additional storage bins?

It is quite probable that foundries with hot sands and short mulling cycles are required to use more cellulose products, bond additions and fine additions, with perhaps a second or third bonding agent to consume the large amounts of water necessary to overcome hot sands. This further enhances brittle, crumbly sands at elevated temperatures.

**Hot Sand Effect**

Brittle sands are most generally caused by hot sands. The excess water required in cooling hot sands is normally free water, unless an addition of cellulose is added to soak up these larger additions of cooling water. Excess additions of cellulose help control the excess cooling water (Fig. 9). As the sands tend to cool, the cellulose makes a more brittle sand mixture. As the sand mixture becomes more brittle it calls for more bond material, whether it be fire clay, bentonite or bond of any type. With the increased addition of bond, soon the end of the line has been reached as far as additions to the sand mixture can be made.

In many cases, when excess bond has been added to overcome brittle sands, it becomes necessary to shorten the mulling time to some extent, otherwise the sands would become stiff and lack flowability.

If metal tonnage increases slightly then the only remaining solution towards furnishing sand promptly to the molders is by further shortening the mulling cycle.

Brittle sands are unstable at elevated temperatures. When metal enters the molds heat shock occurs, causing brittle sands to break and curl at the edges on the metal flow lines. Where this breaking and curling of the thin sand layer occurs, it will appear as a rattail or buckle on the casting (Fig. 10). The danger of this breaking and curling of unstable sands is the gathering of loose and free sand grains which mix with the metal as the mold is being poured. For this reason it is best to learn where flow lines of the metal occur over the face of the mold, and to disperse the gating system to avoid this phenomenon.

Malleable foundries with these problems would be better off perhaps if they added naturally bonded sand to maintain proper temper and bond. The naturally bonded sands do not require increased mulling as they possess some strength when added to the sand mixture. It is the author's opinion that naturally bonded sand added to hot sand, or brittle sands, is a better choice than to attempt to add a fire clay or bentonite and still shorten the mulling time.
When there is a large addition of core sand entering the system, so much bond is required to maintain strength that naturally bonded sands may be best for maintaining properties. It is not believed possible to rebind core sand entering the system without a sufficient mulling cycle. It is the author's opinion that unless a fire clay or bentonite is properly mulled into the system, more harm can be done than is recognized.

Hot, brittle sands are dangerous to each foundry that tries to force them to work by such efforts as described. At first, one claims a hidden success, then after some months an apology is usually made, and the fault is always pointed towards a particular raw material in the sand system. This is a regrettable error.

As larger castings or increased melting capacity occurs, the hot sand problem magnifies. Soon the mulling time is so shortened that it becomes only a mixing cycle where any bond would do the job (Fig. 11). The bond available to the foundry would probably work best. Under these circumstances all economies must be forgotten.

**Bonding Material**

There are cases where a certain bonding material has worked satisfactorily at a given foundry for as long as 10 or 12 years. Yet, after this foundry has grown in production and is confronted with hot sands, pinhole porosity or other gas defects, it wishes to blame the bond for the defect. Or, it may not be the bond accused but it may be the pig iron, the alloy, etc. The direct reasons, hot sands and short mulling time, are rarely accused.

Many foundries actually delight in stating that they have worked hot sands for years and have made them work. They state, "If they have worked in the past, why not in the future?" The medical profession has the answer to that one. Many people may live around a contagious disease for years and never catch it, but there is always a first time for this eventuality. Why take the chance?

As closer tolerances and improved casting finish are demanded by the customer, these hot sands will be corrected by the foundry. When machine shop scrap becomes out of reason due to under-surface porosity, the foundry may lose the pattern shortly.

One foundry that had molding sands so hot that molders were compelled to use gloves to handle flasks and patterns claimed they had no difficulty at these temperatures except for short periods at a time. They did not consider the amount of scrap being lost daily because of these hot sands. When it becomes necessary to heat patterns in order to get proper draws, sands are too hot to work.

The author has seen cases where hot sands have been so difficult to draw from the pattern that excess liquid parting was added. Consequently, these hot sands soaked up the parting as rapidly as it was applied (Fig. 12). One can recognize how much volatile gases were present at the mold-metal interface when the hot metal ran into the mold. Excess use of liquid parting is always dangerous, particularly when there are puddles in the various contours of the pattern. Hot molding sand picks up this liquid, and soaks it up even more completely when these hot sands carry excess additions of cellulose and bond materials. Excess volatility is dangerous to good melting practice, and is a regular source of hydrogen gas porosity.

Here lies the confusion of mallcable pinholes in most cases. Foundries will continue to resist the use of facings to overcome hot sands, but when facings become necessary the added cost will be accepted. They...
Management has lost track of why synthetic sands first entered the foundry industry; it was to maintain control and economy, and this involved the purchase of mulling equipment. If mulling capacity is too short to do the job, it is the author’s opinion that management is paying the bill for excessive additives which normally would purchase mulling capacity and proper cooling and aerating equipment several times per year.

Management seems too inclined to want to purchase raw materials to add to hot sands to overcome their lack of workability rather than go directly to the source to overcome the problem. No doubt management shall continue to pay the bill for such scrap, but this bill when accepted is more likely to be lost or covered by other costs. Hot sands create a chain of reactions which become difficult to control.

There are many other reasons for porosity, or pinholes in malleable castings, particularly those of improper melting practices.

**MALLEABLE MELTING CONTROL**

Much of the surface pinhole porosity in malleable castings are termed “spears” or “spikes” due to their appearance (Fig. 13). Graphitic hot tears appear on the surface when this pinhole porosity condition exists.

This condition may occur in either a duplex operation or with a cold melt furnace. Larry Emery, Chief Met., Marion Malleable Iron Works, Marion, Ind., states that “the cold melt foundries which melt-down charges very high in graphitic carbon run into pinhole defects quite frequently.” Usually they incorrectly diagnose the cause of the difficulty as being sand. Only recently further detailed information has been accumulated to counter these claims. Many malleable heats from cold melt furnaces have not been properly super-heated and refined; thus the solidification temperature of the metal is changed (Fig. 14).

A slow rate of solidification permits gases which become entrapped in the casting to evolve. Nucleation is greater in malleable iron which is not properly refined, and pinholes may more often be present (Fig. 15). These pinholes are rounded in shape and have an oxidized surface. They may occur in clusters just below the surface skin of the casting.

**Duplex Foundries**

The duplex foundries encounter a similar problem if a proper oxidation loss is not maintained in both the cupola and air furnace. If a desired amount of oxidation does not occur, the pinhole defects may be predominant (Fig. 16). The defect shows immediately on vertical sidewalls of heavy sections near ingate and riser areas. The responsible mechanics is the lowering of the solidification temperature, permitting the gases that are dissolved in the metal to come out of solution and become entrapped under the skin of the casting. In some cases the gas does get to the surface of the casting, and is entrapped at the mold-metal interface.

A good example of the above is in the casting of ductile iron. Solidification temperature is greatly re-
duced, and at these lower temperatures the gases present in the metal begin to work out of solution and may be entrapped on the surface of the casting (Fig. 17).

In an experiment reducing the sulfur content of a malleable metal, by reducing the sulfur to less than 0.05 per cent, with soda ash, a considerable amount of pinholes developed. This was identified as a loss of temperature combined with excessive gas content in the metal.

In melting malleable iron, whether it is in a cold melt furnace or a duplex operation, it is important to maintain a minimum amount of oxidation loss. Reducing atmospheres in air furnace practice possibly are common faults in creating pinhole porosity.

Excessive additions of ferromanganese or ferrosilicon to white iron is a method of creating pinholes. If excessive additions reduce the solidification temperature of the metal being cast, pinhole porosity thus can be produced. The composition of the base metal in many cases is on the border line of producing pinhole porosity. If there is insufficient oxidation when the metal is being held in a reducing atmosphere, pinhole porosity may be magnified (Fig. 18).

Any addition of ferro-alloys that tends to reduce the solidification temperature at the point at which poured should always be seriously considered, and must be viewed as a possible source of pinhole porosity. Atmosphere control in superheated or refining furnaces is now possible. The foundry continuous gas analyser records the combustion conditions in the superheat furnace. It is an important part of good melting practice to control the amount of combustibles in the furnace, as well as the introduction of excessive oxygen.

A practice that can easily influence pinholes is one that makes use of a reducing slag cover on the bath of malleable metal. It is important to keep the bath free from slag while the cupola is in operation, that is, if it is a duplexing operation. If the heat is prolonged, and it becomes necessary to use a cover slag, the degree of iron oxide in the slag must be kept to a predetermined level.

Many examinations of malleable pinholes at 250 × and 500 ×, unetched and etched with 10 per cent am-

![Fig. 16 — Small surface pinholes where the gas does not reach the surface before solidification occurs.](image)

![Fig. 17 — It is always difficult to analyze a surface pinhole. Inclusions must be magnified at least 40 X to be identified properly. If no inclusions are present, the condition may then be due to melting practices.](image)

![Fig. 18 — A typical surface inclusion which has been termed "pinholes." It may be an inclusion or may be gas which has occurred from the inclusion.](image)

![Fig. 19 — The area adjacent the pinholes is pearlitic. A filigree network of oxides containing primary carbides directly surrounds the pinhole cavities. There are some entrapped manganese sulfide inclusions, but not in all cases. The retention of carbides is due to the porosity and oxides. Manganese sulfide is not prominent or thought to be the cause of the pinhole.](image)
monium persulfate, have revealed networks of oxides containing primary carbides directly surrounding the complete pinhole area (Fig. 19). In most cases there are areas of pearlite surrounding the oxide network. In some pinhole cavities small amounts of entrapped manganese sulfide inclusions can be detected, but not in all cases. Some pinholes appear to be associated with a complicated manganese sulfide and iron sulfide compound, which also have a network of "slag bond" at the surface of the pinhole. These the author has referred to as "cermet inclusions."

A duplex operator stated that it is better to pass from the cupola with a higher carbon rather than a lower carbon content, thus reducing the carbon content in the air furnace rather than at the cupola. For example, he states it is better to come from the cupola at 2.80 per cent carbon, than 2.60 per cent carbon if a 2.50 per cent is the end point. In the air furnace the 2.80 per cent carbon may be reduced to approximately 2.50 per cent carbon, whereas the 2.60 per cent cupola iron is already too close to the 2.50 per cent which may force a practice of holding the heat with a reducing slag.

This synthetic slag used to block the heat is dangerous, and if a too reducing furnace atmosphere develops more centers of nucleation, primary graphite may be present. This is primary graphite that causes the carbon rings on certain malleable castings, and these hot tear areas may also show the black spears or spikes common with certain types of pinholing.

**MOLD MOVEMENT POSSIBILITY**

Many times a gray iron or malleable casting may be oversize and overweight. This may encourage "apparent shrinkage." These surface segregated areas definitely appear dendritic (Fig. 20). The formation of carbide needles at the fractures may be due to hot spots on the surface created by this mold movement. Furthermore, the mold movement may tend to encourage hot tearing, which may further result in a dendritic structure.

Any movement of the mold tends to aggravate a surface pinhole condition, and certain malleable foundries are now aware that seacoal seems to minimize this unusual mold movement.

**REFERENCES**


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