It’s Time to Play, Name… That… Green Sand Casting Defect!

Foundrymen often are stumped by the origin of casting defects. To aid in the analysis, this article explores common green sand defects, their causes and possible remedies.

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Expansion Defects

Expansion defects are a family of defects that include rattails, buckles and scabs. These defects originate, in part, from the expansion of the sand gains when heated by the metal entering the mold. Silica sand expands the greatest amount when in contact with the molten metal, as compared to olivine, chromite and zircon sands, which expand less.

Beyond sand expansion, these defects also are moisture related. As molten metal runs over the surface of a green sand mold, moisture in the sand is converted to steam that permeates between the sand grains. When the steam reaches a point in the mold where the sand temperature is less than 212°F (100°C), it re-condenses, creating a wet layer. This wet layer is weaker than the normal green sand or the hot, dry sand layer directly beneath the metal. As the hot sand expands, the wet layer shears to allow the expansion. The small ridge of sand that extends into the mold cavity as a result of the expansion can create a line on the surface of the casting called a rattail (Fig. 1). This defect usually is formed on the drag portion of the casting.

In further filling of the mold cavity, the molten metal radiates heat toward the cope casting surface. The moisture on this surface vaporizes and permeates into the sand where it condenses to form the wet layer. In the same manner as in the drag portion of the mold, as the molten metal nears the cope surface of the mold, the intensity of the radiant heat increases and the sand in the dry sand layer expands. The wet layer splits or shears to accommodate this expansion.

As the metal completes the filling of the mold cavity, the sand buckles, creating a deep groove on the casting surface called a buckle (Fig. 2). Sometimes the buckle will open up, allowing the metal to run through the crack in the sand and fill the void behind the buckle to create a scab (Fig. 3).

Although the rattail is synonymous with the drag and the buckle and scab with the cope, the three expansion defects may be found on either casting surface. When foundries are faced with these defects, the following remedy progression should be applied to the sand system:

- make an addition of cellulose or cereal to the sand to provide a place for expansion to occur;
- lower the moisture content of the molding sand, which increases the overall mold strength;
- lower the pouring temperature of the metal (eliminate excess superheat), which reduces the amount of sand expansion;
- lower the temperature of the molding sand from the return sand system to increase the strength properties of the sand;

Fig. 1. RATTAIL.—Caused by expansion, it is a small ridge of sand that extends into the mold cavity and makes an impression on the casting surface.

Fig. 2. BUCKLES—Due to a weak wet layer in the mold, the sand can buckle and form a deep groove on the casting surface.
increase the clay content of the sand, especially sodium (western) bentonite, for better hot strength properties;

- improve the sand distribution to at least three screens to stagger the expansion and create a linear expansion curve;

- decrease the amount of fines in the sand. Fines tend to soak up water, increasing overall mold moisture without increasing mold strength;

- avoid over-ramming or over-squeezing the mold. This pushes the moisture closer to the mold surface, increasing the probability for defects;

- improve the sand mulling practice to create a more homogeneous sand mixture with better developed bond;

- fill the mold faster by increasing the flow rate of the gating system to leave less time for the heat to act on the sand without pressure from the metal.

Adhering Sand Defects

Adhering sand defects are common to all alloys poured in green sand and are characterized by a rough casting surface or by sand sticking to the casting surface. These defects may be found at a specific spot on the casting such as a hot spot or over the entire casting surface. Two of the most common ways these defects are produced are mechanical penetration and chemical reaction.

Mechanical Penetration—This is the penetration of metal into the mold material due to the metallostatic pressure of the molten metal. It usually is seen when the sprue height is too large. The greater the height of the metal in the mold from the top of the pouring cup to the bottom of the casting, the greater the pressure exerted on the liquid. High metal pressures force molten metal between the sand grains where the metal solidifies, holding sand on the casting surface.

Mechanical penetration also can occur where the metal impinges on the mold wall. This dynamic pressure of the metal can force it into the sand grain openings. This often occurs near the gate entrances to the casting. High metal velocities found at the gates can produce the pressure necessary to create penetration defects.

Two factors that affect mechanical penetration are the sand’s fineness and the metal pouring temperature. In general, the coarser the sand, the larger the voids between the sand grains. It takes less pressure to force metal into larger voids.

In regard to pouring temperature, when the molten metal contacts the mold surface, it quickly loses heat and a thin, solid skin forms against the mold. This skin prevents molten metal from penetrating into the voids between the sand grains. When metal is poured at higher temperatures, the extra heat in the metal diffuses into the sand, delaying the skin formation. Without the rapid formation of the skin, molten metal has more time to penetrate into the sand, creating the defect.

Chemical Reaction—In this mechanism, a reaction occurs between the liquid metal and the molding material. These reactions may produce products that act as glue, adhering the molding sand to the casting.

This reaction usually is limited to ferrous alloys (especially steel). When these alloys are exposed to a source of oxygen (O) such as air or water, the O may react with the iron (Fe) in the ferrous alloy to form iron oxide (FeO), also called wustite. Once formed, FeO can react with silica to form iron silicate or fayalite. This is a liquid at metal pouring temperature that easily wets the surface of the silica and runs between the sand grain. Fayalite then solidifies around the grains, gluing the sand onto the surface of the casting.

The defect has two different forms—burn-on and burn-in. The difference is how tight the sand is adhering to the casting surface, which is a result of how fast the silicate cools as it is being formed. Burn-on (Fig. 4) sand isn’t held as tight and usually can be removed during shotblasting. Burn-in usually requires a grinding operation to remove it, if it can be removed at all.

Remedies for sand-adhering defects include:

- reduce the moisture content of the sand because the moisture fills the space between the sand grains. When the moisture evaporates after being hit by molten metal, it then leaves open space for the metal to penetrate;

- improve mold compaction to increase density and leave less room for the metal to penetrate;

- reduce metal velocity because higher velocities create more pressure, allowing the metal to penetrate more easily;

- improve casting design and avoid metal re-entrant angles. Sharp internal corners create hot spots, which are areas where penetration is more likely occur;

- reduce the metallostatic head pressure because the higher the pressure, the easier metal can penetrate the mold wall;
• use a mold coating as a preventative barrier against the metal at the mold interface;
• add a finer sand to the mix if the GFN is too coarse for better mold compaction;
• check metal chemistry and temperature (especially in iron) to ensure proper fluidity;
• improve the mold filling with better gating to reduce velocities and avoid hot spots;
• increase carbon additives (seacoal) in the mold to create the reducing atmosphere in the mold that produces better surface finish.

Gas Defects

Gas Defects are divided into two major categories—blows (Fig. 5), which are large voids in the casting, and pinholes (Fig. 6), which are numerous small holes. For the most part, these gases can occur in castings due to two mechanisms—entrapped gas and soluble gas.

**Entrapped Gas**—Entrapped gas is derived from the thermal decomposition of mold and core materials or air and mold gas washed into the casting from the gating system. Entrapped gases are free gases that float to the top of the molten metal as the casting solidifies.

Entrapped gas from core or mold binders occurs when these organic materials degrade as they are exposed to the heat of the molten metal. The greater the amount of resin used to manufacture the cores and molds, the greater the amount of gas to be generated. Entrapped gas from the gas design occurs at the sprue or as metal flows through the downsprue, runners, and ingates. During pouring, care must be taken to ensure that the sprue remains full and gas isn’t pulled down with the metal. Also, if the poured metal undergoes excessive turbulence while flowing through the gating system, air and gas can become entrained and flushed into the casting cavity.

If an entrapped gas bubble floats to the top of the mold cavity, the gas should permeate into the molding sand before the metal can solidify around it. If the permeability is not sufficient, the gas may not have enough time to leave the metal before solidification takes place.

The force that pushes gas into the sand is the metal head pressure. If enough head pressure is not above the top of the casting, then the gas may not be expelled quick enough.

The pouring temperature also is critical in ensuring trapped gases are out of the casting. If a mold is poured too cold, the metal quickly forms a solid skin. If the gas reaches the top of the casting cavity after a skin has formed, the gas cannot permeate the solid metal skin and enter the sand.

Another consideration with entrapped gas is mold/core venting. Gas is “lazy.” It simply follows the easiest route away from where it is formed (path of least resistance). If gas is formed in the molding sand and the easiest way out is through the metal, than that is where it will go. If gas can go through the metal easier than through a core, then it will follow that route.

The venting of molds and cores provides an open path for the gases released from the decomposing mold and core materials to follow, rather than through the metal. Venting also helps in situations where low permeability is a problem.

Another factor related to venting is core print size. Smaller prints make the flow of gas through the prints difficult. Often, venting of the cores through the print area can reduce or eliminate gas defects in castings. Another aid can be core washes or coatings, which will help reduce entrapped gas defects by sealing the surface of the core, forcing the gas out through the core prints.

Although venting molds and cores can help reduce gas defects, a vent only is effective while it is open. Vents on top of the casting cavity will allow gases to escape prior to the complete filling of the cavity or possibly while the metal is in the molten state. Once the vent fills with metal, it quickly freezes off. At that point, no further removal of gas from the mold cavity can occur. This idea also applies to core print vents if the metal leaks into the print area. Sloppy fitting cores often show gas related defects.

**Soluble Gas**—This refers to gases that dissolve in molten metal. Aluminum alloys will dissolve hydrogen. Iron alloys will dissolve hydrogen and nitrogen. Copper base alloys will dissolve hydrogen and oxygen. Steel alloys will dissolve hydrogen, nitrogen and oxygen. The problem is that molten metal can hold a greater amount of gas in solution than solid metal can.

This means that large amounts of gas that may dissolve in the liquid metal during melting, pouring and mold filling will be expelled from the metal as it solidifies. During solidification, the dissolved gases will precipitate into tiny bubbles of gas, forming pinholes in the casting.

Pinholes also may result from soluble gases near the casting surface. High sand moisture and combustible levels in the mold may lead to the formation of these defects. As with entrapped gas, increasing sand permeability and mold and core venting can reduce these problems.

Remedies for gas related defects include:
- reduce the combustible level of the sand because combustibles create gas during pouring;
- reduce the moisture content of the sand because moisture means more steam (gas);
- increase the sand permeability to allow the gases to escape through the mold;
- with entrapped gases, increase the metal pouring temperature to increase metal fluid life, which provides entrapped gases more time to escape the mold and/or metal;
- with soluble gases, reduce the pouring temperature to reduce the chance for gases to be dissolved in the metal;
- vent molds and cores to provide the gases a “highway” to escape through;
- fill the mold quickly but quietly to avoid turbulence and entrained oxides. Also, the quicker a mold fills, the less time allowed for gases to form;
• reduce the binder level of cores to reduce the gas-producing materials in the mold;
• use a mold or core coating to prevent gases from escaping into the molten metal.

**Weak Sand Defects**

Two sand properties relate to weak sand defects—low green strength and low hot strength.

**Low Green Compressive Strength**—Tear-ups, stickers, drops and crush are defects resulting from low green sand strength. This strength is affected primarily by the type of clay used, the amount of clay used and the moisture content of the sand.

If sand does not have sufficient green strength, the mold may tear up when the pattern is stripped. Loose sand also may result, leading to inclusions in the casting.

Stickers (Fig. 7) are defects resulting from the molding sand sticking to the pattern as it is drawn from the mold. The molten metal then forms the sticker defect when it fills the mold cavity. While stickers also may be blamed on tooling that lacks the proper draft angle or has improper use of mold release agents, many problems occur when sand with a low green tensile strength is used.

Crush is a defect that occurs when two mold surfaces fit together poorly. If the sand is not strong enough, one mating surface may give-in or crush. Loose sand from crushes often leads to sand inclusions in other parts of the casting.

In general, increasing the percentage of clay in the sand increases its green compressive strength. This is true for clay levels up to 12%. Calcium (southern) bentonite develops higher green strength than equal amounts of sodium bentonite, so adding clay for green strength problems is a logical choice.

To improve sand green strength, foundries can:
• increase calcium bentonite levels in the mold to increase mold green strength;
• introduce better mulling practices to allow for better and more consistent distribution of clays, sand and other additives throughout the mold;
• reduce the moisture level in the sand. Excess moisture weakens the mold.

**Low Hot Strength**—This is the strength of the sand during and just after pouring, and is a common cause of defects for iron and steel foundries where higher metal temperatures are required. The defects that occur due to this problem are swell, erosion and run outs.

Swell refers to swollen, oversized castings that result when the mold wall is not capable of holding the casting’s shape while the molten metal is in the mold. Swell occurs when the mold wall is pushed back due to the head pressure on the metal. Although this may occur with an inadequately rammed mold with low sand compactability, swell typically occurs when the sand hot compressive strength is too low.

Mold erosion (also called cuts or washes) can be caused by sand with a low hot compressive strength. Erosion (Fig. 8) is excess metal on the casting surface at places where high metal velocity exists, such as at the front of a gate. Without sufficient hot strength, high metal velocity washes the mold material away, leaving an erosion scab. The loosened sand may be found as inclusions in other parts of the casting. Besides increasing the hot strength, reducing ingate metal velocities also solves this problem.

Run out (Fig. 9) describes the defect where metal leaks out of the mold at the parting line. While a majority of run outs occur due to a lack of mold weight being placed in the mold prior to pouring, a run out also can occur with low hot strength. Metal pressure on the mold may push back the weak sand at the parting line. This exposed area then lifts the cope, allowing the metal to flow freely out of the mold cavity.

Increasing the sand clay content will increase hot strength properties. The correct mix of clay is critical as sodium bentonite has higher hot strength than calcium bentonite.

Another option (which does not apply to green strength) is to increase the sand moisture, which increases hot strength. However, due to the host of other problems high moisture content causes, this is not recommended as a solution to inadequate sand hot strength.

To improve sand hot strength, foundries can:
• increase sodium bentonite levels in the mold to provide better hot strength properties;
• introduce better mulling practices for more consistent distribution of clays, sand and other additives throughout the mold;
• reduce the combustibles in the sand mix because they increase the mold moisture content and gas-producing ability, but usually do not strengthen the mold.

It is of the utmost importance that the metalcaster understand the complex relationships that exist between the components of a green sand system. While looking at the remedies suggested in this article, some of the solutions seem to contradict one another. To ensure success, sand properties should be compared to casting scrap (and to good castings), and limits should be set up to ensure that the sand system runs at a level that does not produce either defect. Controlling a sand system can be like walking a tightrope—too far one way or the other means trouble, but if you stay on the straight path (within pre-established ranges), things come out OK at the other end of the line.

For More Information

*Analysis of Casting Defects, AFS, Des Plaines, IL (1997).*
* Casting Defects Handbook, AFS, Des Plaines, IL (2000).*