Casting Clean Steel

"Clean steel" is the latest buzzword in the steel foundry sector, with good reason. A group of melting, refining and flow control practices, clean steel technology can help steel foundries meet more stringent customer requirements.

Paul M. Bratower/Associate Editor

Like other segments of the foundry industry, steel castings producers are feeling the pinch of customer requirements for better properties and improved performance in their cast components. To help meet these needs, the 41st Technical and Operating Conference of the Steel Founders’ Society of America (SFSA), held Nov 14-16, 1997 in Schaumburg, IL, focused on clean steel technologies and control of steel casting defects.

Clean Steel Technology

Clean steel technology generally refers to a group of melting, refining and flow control practices, most of which have been or are being adapted from existing steel mill technologies to the steel foundry industry.

According to Dr. John M. Svoboda, vice president technology, SFSA, clean steel, as specified by the customer, can include any or all of the following:
- low sulfur content;
- low phosphorus content;
- low oxygen content;
- low hydrogen content;
- low nitrogen content;
- minimum number of microinclusions;
- minimum number of macroinclusions.

Desulfurization

The trend toward lower maximum sulfur levels has continued, from 0.060% to 0.025% or lower, Svoboda said, as applications of castings in hostile environments and use of cast grades of high strength low alloy steels continue to grow.

Traditionally, double slag basic melting provided desulfurization, but steel foundries are benefiting in many ways from the newer, ladle refining methods. In addition to desulfurization, deoxidation, degassing and alloying can also be carried out in secondary vessels, freeing up electric arc furnaces for efficient remelting of less expensive high sulfur scrap.

Over the past several years, SFSA members have evaluated several ladle desulfurization processes, including ladle slag, ladle slag with argon stirring, powder injection and calcium wire injection. "The process most directly applicable to existing foundry environments was the ladle slag with stirring technique," Svoboda noted.

"Sulfur level reductions from the 0.030-0.035% range to the 0.010-0.014% range were routinely achieved," Svoboda reported. "Tensile elongation and reduction of area and Charpy V-Notch properties were significantly improved. Hot tearing defects were substantially reduced."

High speed photograph of ladle-to-tundish molten steel stream illustrates triening and stream break-up, causing reoxidation of the stream. "Oxygen pickup by molten steel from air is extremely rapid," commented Dr. Iain Sommerville.

Inclusion Control

As mentioned, clean steel production also requires control of nonmetallic inclusions. The major types of inclusions—oxides, sulfides, carbides and nitrides—are harmful to the strength, formability, toughness, strain aging, hardenability and other properties of steel. In the words of Dr. Iain Sommerville, Univ of Toronto, their formation should be minimized or their removal maximized.

Sommerville’s paper, "Inclusions: Formation, Detection and Control," co-authored with Steve Dawson, Univ of Toronto, was part of the SFSA Lecture Series, "Troubleshooting the Steel Casting Process," a short course in steel casting defects which took place during this year’s T&O conference.

Of all inclusion types, research has shown that oxides are the most abundant, potentially comprising up to 95% of the total inclusion count. Oxide inclusions are formed during deoxidation procedures and by reoxidation of the molten steel. The oxide inclusions formed by reoxidation are generally larger and more numerous, often causing serious defects in steel castings. In one recent project cited by Sommerville, reoxidation accounted for over 80% of the macroinclusions in carbon and low alloy steel castings.
Reoxidation of steel streams occurs directly as it falls through air during transfer or pouring of the molten steel. Also, the metal in the receiving pool can be oxidized by air entrained by the stream.

According to Sommerville, reoxidation is particularly undesirable due to its potential to form inclusions very late in the casting process, between the ladle and tundish and in the mold immediately prior to solidification. "With this in mind," he comments, "it becomes evident that reoxidation during the final transfer operation has the potential to nullify all of the steps taken previously to produce a clean steel."

Both Sommerville and George Vingas, Cermacon, Inc., discussed compaction, protection and control of the stream during molten metal transfer, pouring and flow through the gating system as keys to minimizing reoxidation of the melt. Compaction refers to lowering the turbulence of the stream so that it is less likely to flare and disintegrate, reducing the amount of air entrained in the stream.

Both speakers agreed that nozzle design is important in overcoming these deficiencies in bottom pouring. The design of the nozzle influences swirling tendencies in the flow. Vingas described the development of a bottom pour nozzle which produces a laminar flow and is not prone to flaring as the nozzle is throttled and which is resistant to slag buildup.

Steam protection, which involves shielding the stream from the atmosphere during transfer and pouring is also important. Various designs for producing a curtain of inert gas around the stream have been used, as have solid, ceramic shrouds. According to Sommerville, "Neither approach is completely satisfactory on its own and for the highest steel cleanliness ratings, a combination of both is required, in which inert gas is introduced into the ceramic shroud."

Flow control in the gating system is also important. Gating designs should reduce turbulence in order to avoid reoxidation through contact with and erosion of mold and refractory materials. According to Vingas, a ceramic tile gating system is used with large steel sand castings to avoid erosion. One ceramic gating insert has been developed which incorporates a spiral gate which traps inclusions before they reach the mold cavity.

Gas Defect Control
Problems with gases cause a large percentage of casting defects and Svoboda discussed the formation of many types of gas defects and their remedies.

Blowholes and pinholes are among the most common gas defects. They appear as smooth-walled spherical cavities which can appear in any area of the casting, often not contacting the casting surface. Endogenous gas holes (defects having internal origin) can be caused by release during solidification of gases dissolved in the metal bath and in the case of steel often occur from the formation of carbon monoxide.

Gases arising from excessive moisture in cores or molds, or from the liberation of gas from core binders, additives or coatings cause exogenous blowholes and pinholes (defects having external origin).

Improved venting and permeability, adequate curing of nobake molds, adequate control of sand moisture levels and reduction in amounts of binders and additives are some suggestions Svoboda provided to control exogenous blowhole defects.

Adequate deoxidation, avoidance of reoxidation and reduction of hydrogen and nitrogen contents are some steps Svoboda recommended to remedy endogenous blowhole defects. Other gas related defects he discussed are surface and subsurface pinholes and conchoidal or rock-candy fractures.

Controlling Common Defects

Hot Tearing—"Hot tears probably still represent the most widespread and troublesome source of linear surface discontinuities in the steel foundry," said Dr. W. J. Jackson, a consultant who retired in 1986 after 32 years with SCRABA. He added that their elimination, "is essential in providing cost-effective production of castings. Hot tears occur during the final stages of solidification or immediately after.

According to Jackson, hot tears occur when hot spots have formed at section changes or junctions where the design has caused stress, and thermal contraction of the casting is hindered. "If the casting contracts freely or the casting is of uniform section and without hot spots, hot tearing is unlikely to occur."

Erosion—Erosion defects have received greater attention in recent years and a large number of researchers agree on the mechanism of their formation. Matt J. Granlund, Foundry Systems Control, said, "Investigators agree that the expansion of the silica grain is the main factor in all mechanisms proposed for the formation of rittals, buckles and scabs." Casting design, pattern design, flask equipment, gating system design and mold and core sand composition and density are the major variables that can cause erosion defects.

Burn-on and Burn-In—These are defects characterized by a layer of sand grains and oxides bonded to the casting surface. Their difference is generally...
a matter of degree of severity, said Svoboda. These defects are generally caused by a mold/metal reaction which forms a salt-like, an iron silicate which penetrates between the sand grains, causing the bonding of sand to the casting surface. Jackson commented that oxidizable elements such as carbon, silicon and manganese will reduce the oxygen available for iron oxidation, retarding the formation of a salt-like layer.

Penetration—Penetration consists of an interlocking mass of sand grains and metal tightly bonded to the casting surface, Svoboda said. It is more prevalent at hot spots and in heavy section areas or transition zones from thin to heavy metal sections. The most common type of penetration occurs when liquid metal enters the voids between the sand grains due to pressure and/or capillary forces.

Therefore, much of this penetration cannot be eliminated by reducing the size of the voids between the sand grains. This can be accomplished by using a liner sand or a mixture of grain sizes to fill in the voids. Ramming the sand harder to achieve a higher density and using core and mold coatings are other solutions.

Shrinkage Porosity—"Unsoundness arising from metal shrinkage has been a severe problem with steel castings almost as long as steel castings have been made," asserted Ronald W. Ruddle, Caststeel Technology Associates, Inc. Cavities formed at section junctions and hot spots and centerline shrinkage are both common in low carbon steels. In alloy and high carbon steels, shrinkage tends to be dispersed and microshrinkage also forms.

Normally, low carbon steel castings freeze progressively toward the center of the section. Shrinkage is basically prevented with feeding practices that ensure directional solidification toward the heat centers. "Directional solidification means that there also exists a component of freezing direction toward the heat center and attached riser," Ruddie said. He pointed to optimum riser size and location and the use of chills as the principal tools for the proper feeding of steel castings.

Microalloyed Cast Steels

Two presentations covered the research and development of microalloyed cast steels. R. Voigt, Univ of Kansas, delivered preliminary results from the first year of a three year SFSA sponsored study of microalloyed cast steels. Increased demands for low cost, moderately strong steel castings with good toughness and weldability point to many potential applications for microalloyed steels.

According to Voigt, "Excellent toughness and weldability are achieved by lowering the carbon content and strength is maintained by adding small amounts of vanadium and/or niobium that result in precipitation strengthening upon heat treatment."

"Initial heat treatment studies have shown that the properties of a C-Mn-Mo-V-Nb microalloyed steel depend strongly on the austenitizing temperature for both quenched and tempered and normalized and tempered treatments," Voigt said. "High austenitizing temperatures increase the re-solution of microalloys into the austenite and increase the hardness (strength) after tempering. Impact toughness, however, decreases with increasing austenitizing temperatures and is very dependent on tempering time."

Work to develop cast grades of microalloyed steels by SFSA and KO Steel Castings, Inc was presented by Daniel E. Dutcher. Typical compositions consist of a C-Mn-Mo steel with additions of vanadium and/or niobium at levels under about 0.10%.

Up to about 0.10% vanadium was shown to be effective as a secondary hardening agent in normalized and tempered steels as well as quenched and tempered steels. Also, intercritical heat treatment was found to enhance impact resistance, though at a loss of strength.

Foundry Operations

Other speakers at the T&O included James Dvorak, Mercury Marine, who discussed his foundry's experience in the investment casting of austenitic stainless steel alloys; John Simon, Dofasco Inc, who reported on the use of SPC to reduce shot consumption, blast cycle time and defects on a shotblast machine; and Terrance D. Oertwig, Rockwell International, St. Joseph, MO, who described a joint statistical program between foundry and machine shop to improve cutting tool cost and efficiency.

Tom Prucha, CMI Cast Parts, informed conference attendees about the properties of austempered ductile iron, noting its competitiveness with certain grades of steel in terms of ductility and toughness. Bob Shepherd, Harrison Steel Castings Co and Fred Squire, Pfizer Inc, reported on improved steel pourability and cleanliness achieved with calcium wire injection.

The microstructure of a microalloyed cast steel is shown at 1900X, by scanning electron microscope. The effect of cooling rate from the austenitizing temperature on the final quenched and tempered microstructure is visible. According to Dr. R. Voigt, air cooling causes a fine ferrite/pearlite microstructure. Fine vanadium and niobium carbide precipitates add hardness to the alloy but cannot be observed, even at this high magnification.