Battling the Elusive Lustrous Carbon Defect

This article examines new methods for lustrous carbon defect elimination and offers several solutions, including venting and vacuum exhausting of mold gases during pouring.

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The growth in both phenolic urethane coldbox and nobake binders since 1970 has been phenomenal.

In 1971, only 2.7 million lb of coldbox and nobake phenolic urethanes were consumed by the U.S. foundry industry. In 2001, estimated worldwide use is more then 300 million lb.

However, shortly after the introduction of coldbox phenolic urethane binders, casting defects described as severely wrinkled surface defects were reported by some users. The technical literature of the time contained little information regarding the elimination of these defects, soon to be known as "lustrous carbon." Slow, turbulent filling and low-pouring temperatures were reported to aggravate this defect formation.

Lustrous carbon defects almost always occurred when using binders that evolved large quantities of carbonaceous decomposition products during the filling of the mold by molten metal. However, such carbonaceous residue can be beneficial when present in lesser amounts, as they provide a reducing atmosphere that minimizes oxidation at the mold-metal interface and generally improves casting surface finish and peel.

In steel castings, particularly those with thick sections, pockmarking may appear on casting surfaces. In high-alloy steels, such as stainless and nickel-base alloys, appreciable amounts of undesirable surface porosity and carbon pickup might occur. Lustrous carbon defects also have become one of the major problems in lost foam castings.

This article will profile how lustrous carbon forms and analyze different casting variables to find the best way to stop this defect from occurring.

Lustrous Carbon Formation

Laps and Wrinkles-Iron Castings—Lustrous carbon defects begin to form as molten metal enters the mold cavity, causing thermal degradation of the binder, which produces hydrocarbon gases. The hydrocarbon rich vapor subsequently re-condenses as pyrolytic graphite deposits in films or sheets on the mold-cavity surface.

These films can roll up to substantial thickness. If not dissolved in the metal or oxidized, solidification can proceed against the accumulation of carbon films, giving rise to the characteristic surface wrinkling associated with lustrous carbon defects. Examination of these casting surfaces indicates a strong tendency for defects to form along the edges of the first stream of molten metal that enters the mold cavity. Defects also tend to form in the ingate areas, as well as the sides and cope surfaces.

Under more severe pouring conditions, such as when using gating systems that produce turbulent flow and can cause cold shuts, lustrous carbon films can be flushed into the body of the casting or become sandwiched between two merging streams of molten metal (Fig. 1). In severe cases, a laminating effect can occur that also might result in surface blistering. If the molten iron does not dissolve these films, they will prevent the welding of the merging

To determine the effect of pouring time on defect formation, pouring times were varied from 15-39 sec by modifying the sprue choke area. Castings were poured at 2500F (1371C).
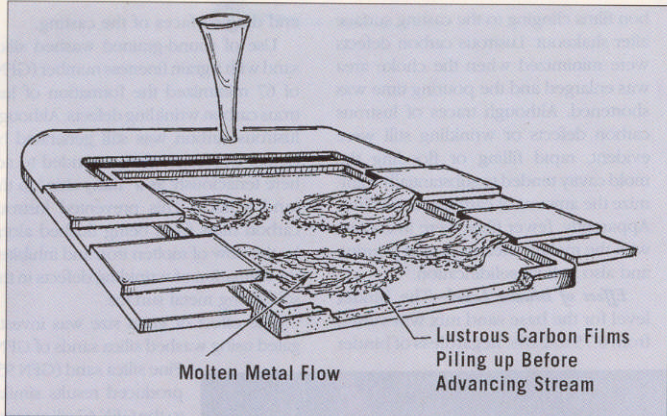
Fig. 1. This diagram of the molten metal flow pattern in the test casting shows lustrous carbon films piling up before the advancing stream.

streams of solidifying metal, often resulting in casting leakers.

It should be noted that the lustrous carbon forming tendencies of chemical binders are only harmful if large amounts of carbon films form and are subsequently dislodged from the mold-metal interface during pouring. If the lustrous carbon films are not dislodged, lustrous carbon formation may well be beneficial since casting surface finish will be improved.

Experimental Procedure

The experimental program used to identify the key causes of lustrous carbon defects was divided into two phases:
1. The development of a suitable test casting configuration with the capability to produce lustrous carbon defects;
2. The delineation of coremaking and metal-processing variables that have

an effect on lustrous carbon defects.

Gray Iron—The plate test casting was selected because it provides a large surface area-to-volume ratio that is exposed to radiant heating during the filling process. The configuration also provides a large surface for examination of defects and, therefore, information regarding the effects of metal flow patterns.

Steel—To simulate heavy section castings, a "scab block" test casting was used. The casting is 6 in. wide, 6 in. long and 5 in. high.

Molding Materials and Additives

All sand mixes were prepared in a small batch mixer by adding the phenolic resin component (Part 1) and catalyst to the sand and then mixing for 2 min.. Next, the appropriate amount of polymeric isocyanate was added

and mixed for an additional 2 min. (Part 2). The prepared mix was immediately hand-tucked into the test patterns with strip times averaging 5 min. Coldbox mixes were cured with triethylamine. Molds were aged overnight before pouring. The furan nobake and the ester cured phenolic nobake binders were prepared in a similar manner; catalyst or co-reactant was first added to sand and mixed for 2 minutes, then the resin was added and mixed for an additional 2 min. before being discharged into the test pattern.

Since a reducing atmosphere within the mold cavity appears to promote lustrous carbon formation, sand additives were selected to minimize or change the mold atmosphere to one promoting oxidizing conditions. The materials selected included carbonates, nitrates, borates, sulfates and several metal oxides, each of which is capable of providing an oxidizing atmosphere under equilibrium conditions at the pouring temperatures employed.

Each casting was carefully examined upon shakeout and general conditions of the cope, drag and side surfaces, shakeout behavior and extent of lustrous carbon surface deposits and wrinkling extent were recorded. Castings exhibiting severe defects were sectioned and metallographically examined. A surface defect rating system was developed to assess relative lustrous carbon form tendencies.

Test Results

Effect of Pouring Temperature—Lustrous carbon deposits and surface defects were not present on castings poured at temperatures of 2700F (1482
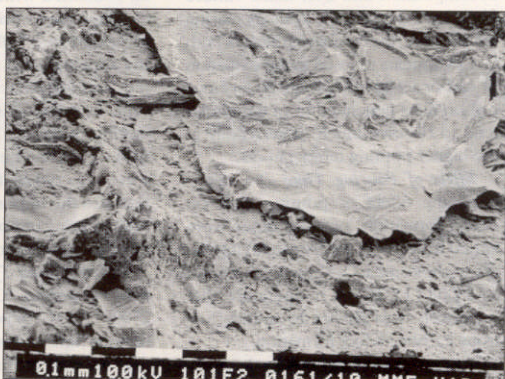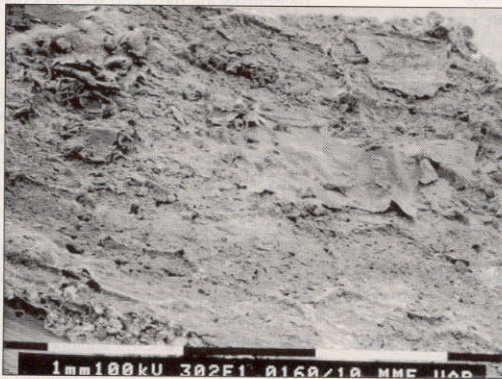

Fig. 2. Lustrous carbon forming tendencies of chemical binders (above) are only harmful if large amounts of carbon films form and are subsequently dislodged from the mold-metal interface during pouring.

or higher. Decreasing the pouring temperature increased the amount of shiny sheets of carbonaceous films and deposits that adhered to the castings during shakeout. These surfaces contained numerous areas of wrinkling that increased both in extent and severity with decreasing pouring temperature. Examples of shiny, sooty lustrous carbon films found clinging to casting surfaces are illustrated in Fig. 2.

Although the degree of surface wrinkling for any given casting temperature was not always consistent, deposits of shiny, silvery-black carbon always were present when low pouring temperatures were used in the casting tests. Pouring temperatures of 2350F (1288C) and lower produced mis-run castings. While the extent and severity of surface wrinkling was reduced on a major portion of the casting surfaces, the casting surfaces became severely wrinkled as solidification proceeded against the accumulation of lustrous carbon films at the end of the mis-run test castings.

The elimination of lustrous carbon by using high pouring temperatures can be attributed to several reactions occurring at the mold-metal interface. High pouring temperature increases both the amount and rate of formation of an iron-oxide skin during pouring. Because the reaction rate between carbonaceous films from binder decomposition and iron oxide surface films becomes greater with increasing temperature, the combined effect of both factors appears to result in the oxidation of carbonaceous by-products. Lustrous carbon films generated from the binder tend to dissolve much more readily at the higher pouring temperatures.

Effect of Pouring Time—To determine the effect of pouring time on defect formation, pouring times were varied from 15-39 sec by modifying the sprue choke area. Castings were poured at 2500F (1371C), a temperature that previously was shown to induce lustrous carbon defect formation.

Castings with long pouring times exhibited severe cold shutting with considerable amounts of shiny, lustrous carbon films clinging to the casting surface after shakeout. Lustrous carbon defects were minimized when the choke area was enlarged and the pouring time was shortened. Although traces of lustrous carbon defects or wrinkling still were evident, rapid filling or flooding the mold cavity tended to substantially minimize the amount of carbonaceous films. Apparently, fewer films were in contact with the molten streams during pouring and also at final solidification.

Effect of Binder Level—The binder level for the base sand mix was varied from 0.75 to 2.0%. Regardless of binder

Fig. 3. Using a vacuum to assist in removing carbon laden decomposition products from the mold cavity improved the surface finish, though test castings still showed a very shiny, silvery surface with moderate deposits of lustrous carbon.

level used, shiny films of lustrous carbon adhered to the test castings at shakeout when test pieces were poured at 2500F (1371C). Test casting surfaces all contained wrinkling.

When the pouring temperature was increased to 2700F (1482C), test casting appearance at shakeout was excellent and carbonaceous films were absent, as were wrinkle defects on the casting surfaces. Test castings made using extreme binder levels of 3.0% were also defect free. This further illustrates the importance of employing high pouring temperatures for lustrous carbon elimination.

Effect of Sand Type on Lustrous Carbon Formation—Castings poured at 2500F (1371C) or below contained continuous films of lustrous carbon adhering to the casting surfaces upon shakeout. Lustrous carbon wrinkling defects were present on both the cope

and drag surfaces of the casting.

Use of round-grained washed silica sand with a grain fineness number (GFN) of 67 minimized the formation of lustrous carbon wrinkling defects. Although lustrous carbon was still generated by binder decomposition, it tended to adhere tenaciously as a "filmy skin" to the sand surface. This prevented lustrous carbon films from being flushed along by the flow of molten iron and inhibited the formation of wrinkling defects in the solidifying metal surface.

The effect of grain size was investigated using washed silica sands of GFN. Fine silica sand (GFN 95) produced results similar to the GFN 67 silica sand. The lustrous carbon films that formed adhered to the sand, with minimal wrinkling defects observed on the casting. The coarser silica sand (GFN 26) exhibited extensive surface penetration. Lustrous carbon sheets also were present in the penetrated layer, but again, few wrinkling defects were observed.

These results indicate that while sand grain size has little effect on the formation of lustrous carbon defects, sand grain geometry seems to have an effect on reducing lustrous carbon wrinkling. Lustrous carbon films seemed to preferentially form a continuous and tightly bonded film with round grained sand—the lustrous carbon films remained at the mold-metal interface and were not dislodged by molten metal flow.

Elimination of Lustrous Carbon Defects

Effect of Sand Additives—Numerous compounds were evaluated as additives to change the reducing atmosphere in the mold cavity to an oxidizing atmosphere at low pouring temperatures. They included metal oxides, sulfates, borates, carbonates and nitrates.

Hematite (red iron oxide Fe_2O_3) and yellow ochre were the only additives that completely eliminated lustrous carbon film formation and surface wrinkling. However, a 2.0% addition level was required for complete elimination of lustrous carbon films and surface defects. Magnetite, which contains only
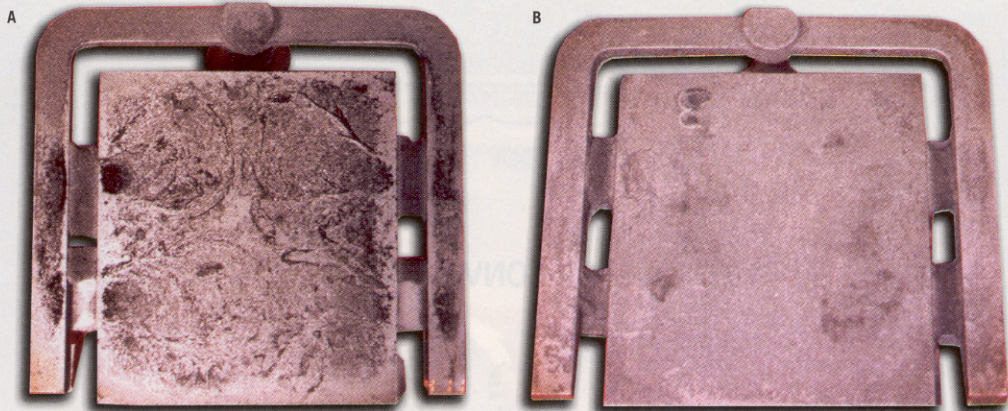
The first casting (a) illustrates severe lustrous carbon formation, while another casting (b) shows no signs of lustrous carbon.

a few weight percent less oxygen than hematite, was not as effective in eliminating lustrous carbon when used in either powdered or coarser forms.

Although additions of iron or sodium sulfates reduced the severity of lustrous carbon formation, use of aluminum sulfate was more effective. Additions of red iron oxide up to 1.5% resulted in only a minor decrease in tensile strength, but the larger additions of 2.0% produced a moderate 70-80 lb per sq. in. decrease in strength. Yellow ochre performed similarly. Aluminum sulfate additions at the 1% level produced little or no change in tensile properties.

Effect of Venting—To study the effect of extracting carbon-rich gases from the mold cavity during pouring operations, a series of test castings were poured in which both venting and the application of a positive vacuum were applied to test molds (Fig. 3). In non-vented molds, relatively heavy deposits of lustrous carbon adhered to the test casting at shakeout. General surface finish also was poor, though only minor surface wrinkling was observed.

Venting of test molds by drilling 30 vents, each with a diameter of 0.35 in., reduced the amount of lustrous carbon deposits on test castings. General surface finish improved only marginally, and minor evidence of surface wrinkling still was apparent. Using a vacuum to assist in removing carbon laden decomposition products from the mold cavity improved the surface finish somewhat, though test castings still showed a shiny, silvery surface with moderate deposits of lustrous carbon.

Effect of Mold Coatings—A number of coatings were formulated to promote oxidizing conditions at the mold-metal interface in an attempt to minimize lustrous carbon formation. Manganese dioxide, zinc oxide and yellow ochre coatings did not eliminate lustrous carbon defects and resulted in deterioration of the casting surface finish. Burn-on was particularly heavy with the manganese dioxide wash. Hydrocarbon gases and residues generated from the binder decomposition during pouring diffuse through the permeable coating, still allowing lustrous carbon defects to occur.

Effect of Core Binders—Thin-section steel castings made with phenolic urethane nobake binders exhibited slightly pockmarked surfaces. Furan nobakes and phenolic ester binder systems did not show any evidence of surface porosity. The best surface finish was obtained with the phenolic ester system, which had a surface finish of 120-200 RMS.

The addition of 2.0% Fe_2O_3 had a significant effect on eliminating the surface pockmarking associated with phenolic urethane nobake binders. After the addition of iron oxide, the surface finish improved to 300 RMS. Similar additions of black-iron oxide (2.0% Fe_3O_4) were not sufficient to prevent surface pockmarking.

Recommendations

The experimental results and the proposed mechanism of lustrous carbon formation suggest several techniques that can be employed to minimize or eliminate defects in casting operations. The best method for eliminating lustrous carbon is the employment of proper gating techniques. Accordingly, the following undesirable features should be eliminated from gating design:

- long, thin gates that enhance large metal temperature losses;
- rapid mold filling times;
- designs that maximize pouring time and/or turbulence.

In foundry operations where gating already is optimized or cannot be altered due to other limitations, other techniques may be used. If possible, pouring temperatures should be increased to approximately 2700F (1482C) unless metallurgical considerations, such as increased tendency for chill, structure limitations or casting soundness, prohibit the use of high pouring temperatures. Secondly, the employment of suitable oxidizing additions to the sand mix, such as a minimum of 2.0% Fe_2O_3 should eliminate or greatly minimize lustrous carbon problems.

With recent concerns about the environment, foundries can now use new phenolic urethane binders formulated with biodiesel solvents that decrease carbon and increase oxygen to provide vastly reduced lustrous carbon levels. *MC*

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For More Information

Visit www.moderncasting.com to read the report that this article was based on, **"Formation & Control of Lustrous Carbon Defects in Iron and Steel Castings,"** R.L. Naro, 2002 AFS Transactions, 02-154.