CLEANLINESS OF CONVENTIONALLY DEOXIDIZED AND CALCIUM TREATED LOW CARBON STEEL

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ABSTRACT

This project was conducted to compare the general cleanliness of a calcium wire treated steel to a conventionally deoxidized heat of steel. Samples of each heat were cast in a graphite mold and examined.

Both inclusions examined were principally composed of refractories and some reoxidation products. The relatively high pouring temperatures (2900-2925°F) and the use of calcium in the deoxidation practice can aggravate attack of acid refractories. Some reoxidation products were observed in the inclusion removed from Heat F-732, but the reoxidation products are a minor source of inclusion material. The oxygen concentration and number of microinclusions of the calcium treated steel was slightly lower compared to the conventionally deoxidized steel (0.005% vs. 0.0066%).

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Two heats of steel were melted in an acid refractory lined electric arc furnace. The furnace charge for the conventionally deoxidized heat (F-732) was prepared with 18,000 lbs. of steel plate. The carbon concentration was 0.38% at meltdown. Oxygen was blown into the furnace to reduce the carbon to a value of about 0.07%; the heat was blocked; and the composition adjusted. The heat was deoxidized with an addition of aluminum, Calsibar, ZrFeSi, and Ferrogen to the ladle during tapping. The metal temperature after tapping was 2904°F. The final metal contained was 0.09% C, 0.19% Mn, 0.55% Si, 0.014% P, 0.020% S, 0.06% Cr, 0.05% Ni, 0.016% Mo, and 0.056% Al.

The furnace charge for the calcium treated heat (F-914) was made up with 16,000 lbs. of plate scrap. The heat had an initial carbon concentration of 0.43% which was blown down to approximately 0.25%. After blocking and adjusting the composition, the heat was tapped into a ladle and deoxidized by plunging with aluminum. The metal temperature in the ladle was 2921°F. The heat was then treated with 0.4 lbs. of calcium wire per ton of metal. The final metal contained was 0.27% C, 0.77% Mn, 0.46% Si, 0.018% P, 0.016% S, 0.66% Cr, 0.54% Ni, 0.20% Mo, and 0.010% Al.

The ladle used in both heats was lined with heavy duty silica bricks containing 56% SiO₂ and 38% Al₂O₃ on the sidewall and 70% Al₂O₃ bricks on the bottom. A sample of steel from each heat was poured into a graphite mold to produce a bar approximately four inches in diameter and nine inches long. The purpose of pouring the bar in the graphite mold was to eliminate mold materials as a source of inclusions.
VISUAL OBSERVATIONS

Figure 1A illustrates the appearance of the inclusions found on the surface of the cast bar from the conventionally deoxidized steel. A subsurface inclusion from the calcium treated steel is illustrated in Figure 1B. Most of the inclusions in the conventionally deoxidized steel were on the bar O. D. surface and did not penetrate deeply into the bar. There were few surface inclusions on the calcium treated bar, but a large defect was observed in one cross section through the bar.

MICRO-CLEANLINESS OF THE BASE METAL

A section of metal near the defect area from each heat was mounted and polished to an 0.05 micron finish. Three areas on each section were randomly selected and examined at a magnification of 100X. The number of microinclusions present was determined and the number divided by the area examined to provide an indication of metal micro-cleanliness. Samples of each heat were also analyzed for oxygen concentration using a Leco T-36 inert fusion thermal conductivity oxygen analyzer.

Figure 2 illustrates typical areas of the base metal near the defects. The number of microinclusions present was about 110 per mm² in both castings. The number of microinclusions per unit area and the oxygen concentration in both steels is illustrated in Figure 3. The cleanliness of the calcium treated steel (Heat F-914) was slightly better than the conventionally deoxidized steel. The oxygen concentration was also slightly lower in the calcium treated heat compared to the conventionally deoxidized steel (0.005% vs. 0.0066%).
Figure 1. Photographs of surface and sub-surface macroinclusions found in a graphite mold cast steel bar. (A) Heat F-732  (B) Heat F-914
Figure 2. Micrographs of metal near defect area for (A) Heat F-732 (conventionally deoxidized) (B) Heat F-914 (calcium treated). 100X
Metal Cleanliness

Inclusions/Area (#/mm^2)

Oxygen = 0.0066%

Oxygen = 0.0050%

Heat Number

F-732

F-914

Figure 3. General metal cleanliness for Heats F-732 and F-914.
DEFECT EXAMINATION

An inclusion from each bar was saw cut out, mounted in low viscosity epoxy, ground and polished to a 0.05 micron finish. Optical micrographs were made on a Nikon inverted stage metallograph. If warranted, the polished inclusion was coated with a conductive material and examined using an ETEC Autoscan scanning electron microscope (SEM). The SEM was equipped with a Kevex energy dispersive x-ray detector (EDX) which allows the elemental concentration to be made in areas as small as 10 microns in diameter.

A micrograph of the polished cross section through an inclusion removed from Heat F-732 is illustrated in Figure 4. The solid inclusion material contained three separate phases. Figure 5 illustrates those phases at a magnification of 100X. An EDX spectrum of a dark colored particulate phase, labeled "A" in Figure 5, is illustrated in Figure 6. The particle was predominantly composed of alumina. The size, shape, and composition of this phase indicates that it originated from a refractory, probably from the 70% alumina refractory lining the bottom of the ladle.

An EDX spectrum of the light colored phase labeled "B" in Figure 5 is illustrated in Figure 7. This phase was primarily composed of alumina, silica and zirconia with traces of calcia, manganese oxide, and carbon. These elements were used in the deoxidation of the heat and indicate a reoxidation product. An EDX spectrum of the dark colored phase labeled "C" in Figure 5 is illustrated in Figure 8. It was composed of silica, alumina, and calcia with traces of titania and magnesia. This phase is a combination of reoxidation products and dissolved refractory material. The traces of carbon were from the conductive coating.
Figure 4. SEM micrographs of polished cross section through macroinclusion illustrated in Figure 1A. (Heat F-732)
Figure 5. SEM micrographs of macroinclusion at higher magnification Heat F-732. (a) 100x (b) 100x
Figure 6. EDX spectrum of dark colored particle labeled "A" in Figure 5A.
Figure 7. EDX spectrum of light colored particles labeled "B" in Figure 5A.
Figure 8. EDX spectrum of dark colored phase labeled "C" in Figure 5B.
An optical micrograph of a polished cross section through an inclusion removed from the calcium treated Heat F-914 is illustrated in Figure 9. The inclusion was large and plate-like in shape. Figure 10 illustrates a SEM micrograph of the same inclusion at higher magnification (20X). Two different phases were observed. Figure 11 illustrates those two phases at magnifications of 200X. An EDX spectrum of the phase shown in Figure 11A is illustrated in Figure 12. The phase contained alumina, with smaller amounts of magnesia, calcia, and iron. Figure 13 illustrates an EDX spectrum of the phase shown in Figure 11B. This phase was similar to the previous phase.

The size, shape, and composition of this inclusion indicate that it was refractory material eroded into the mold. It should be noted that the electric arc furnace was patched just before the calcium wire treated heat was melted. The patch material may have been the source of refractory material.

CONCLUSIONS

Both inclusions examined show indications of refractory attack and erosion into the graphite mold. The use of calcium in the deoxidation practice can aggravate attack of acid refractories. Some reoxidation products were observed in the inclusion removed from Heat F-732, but reoxidation is probably a minor source of inclusion material. The oxygen concentration and number of macroinclusions of the calcium treated steel was slightly lower than in the conventionally deoxidized steel (0.005% vs. 0.0066%).
Figure 9. Micrograph of polished cross section through the macroinclusion illustrated in Figure 1B (Heat F-914) 10X.
Figure 10. SEM micrograph of macroinclusion from Heat F-914.
Figure 11. Optical micrographs of macroinclusion from Heat F-914 (A) area "A" in Figure 10 (b) area "B" in Figure 10. (200x)
Figure 12. EDX spectrum of light colored phase illustrated in Figure 11A.
Figure 13. EDX spectrum of dark colored phase illustrated in Figure 11B.
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