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**CLEAN FERROUS CASTING TECHNOLOGY
RESEARCH**

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ABSTRACT

This annual report covers work performed in the second year of research on Clean Ferrous Casting Technology Research. Significant progress was made in establishing pouring practices which avoid re-oxidation of steel during pouring; application of revised pouring practices have led to reduced inclusion levels in commercially poured steel castings.

CLEAN CAST STEEL TECHNOLOGY

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EXECUTIVE SUMMARY

In 1981, the Steel Founders' Society Quality Task Force identified oxide macroinclusions as the number one customer complaint when machining steel castings. In 1991, SFSA technical committees again identified clean steel as a major competitive need for the steel casting industry.

In response to customer needs for more machinable castings, the Steel Founders' Society established a program to determine if some practical approaches could be devised to improve metal cleanliness.

The overall objective of this program is to enhance the competitiveness of the U.S. metal casting industry by performing research that leads to production of higher quality castings at a commercially competitive price, while at the same time meeting all of the environmental and safety regulations.

The objective of this project is to demonstrate technologies that can deliver clean steel from the furnace to the casting cavity. A number of candidate technologies will be evaluated.

The tasks in the project are outlined as follows:

1. Modeling pouring of steel to understand turbulence, fluid flow, and reoxidation during pouring.
2. Conducting casting trials with the casting weights up to 250 pounds using conventional lip pour ladles.
3. Conducting casting trials with casting weights over 500 lbs using stream shrouding.
4. Conducting casting trials using special techniques, such as vacuum-assisted pouring.
5. Developing a data base on cleanliness and defects in steel castings using samples provided by participating steel foundries.
6. Transferring the technology being developed to the U.S. steel casting industry through meetings, seminars, and technical papers.

The focus of research and process evaluation in the past year has been on water modeling of different methods of pouring metal to find methods that minimize air entrainment, conducting plant trials to evaluate commercially available filters for their ability to minimize debris in castings and organizing additional plant trials to evaluate shrouded pouring and heat-to-heat effects on metal cleanliness.

The significant accomplishments of the past year are summarized as follows:

Conventional Lip Pour Casting Trials Of Castings Less Than 250 Pounds

1. A casting trial was conducted to evaluate the effectiveness of filtration on reducing the weld repair time on a 41 lb. casting.
2. Filtration reduced weld repair time by approximately 90% compared to conventionally poured castings.
3. Filtration of the castings resulted in a net savings of \$16 per casting.

Stream Shrouding During Pouring Of Castings Weighing Over 250 Pounds

4. A casting trial was conducted to evaluate the effectiveness of shrouding the pouring stream and purging the mold with inert gas on reducing oxide macroinclusions.
5. No benefit of gas shrouding or mold purging was observed in this trial.
6. In sections removed from selected castings, gas defects were observed.
7. Little or no oxide macroinclusions were observed in any of the sections.
8. Better control of the gas flow rate may improve the effectiveness of gas shrouding.
9. A trial was conducted to evaluate the effectiveness of mechanical shrouding on reducing oxide macroinclusions.
10. The shroud did seal and prime.
11. Mechanical shrouding of the pouring stream and the use of a filter/riser sleeve improved casting cleanliness by about 50% compared to the conventionally poured castings.
12. Mechanical shrouding of the stream produced x-ray ratings that ranged from low to very high.
13. During pouring, it was observed that a steel shell had solidified on the shroud and was impacting the side of the mold during pouring. This may have introduced molding sand into the mold.
14. Defects removed from selected shrouded test plates indicated molding sand as the primary constituent. Defects removed from conventionally poured test plates indicated reoxidation products and molding sand.
15. Trials evaluating the source of heat to heat quality variations have been started at three foundries.
16. Three other foundries have expressed a strong interest in joining the trial.

17. Trends to date indicate that metal chemistry show a strong influence on heat quality.

Special Pouring Arrangements

18. A quadrant pour ladle has been fabricated and installed at a participating foundry.

19. Preliminary trials have been conducted with the ladle. A formal trial has been planned and will be executed before the end of the project.

Data Base On Casting Defects

20. Over forty steel defects have been collected and examined. The results will be presented at the SFSA Technical and Operating Conference in November.

Technology Transfer

21. Three sponsors meetings have been held in Birmingham, Chicago, and Fort Worth, TX. Six presentations will be made at the SFSA Technical and Operating Conference in November.

Conventional Lip Pour Casting Trials Of Castings Less Than 250 Lbs.

A casting trial was conducted to determine the effectiveness of filtration on reducing weld repair and machine shop time on a carbon steel transmission casting. This particular casting required a considerable amount of inclusion removal and weld repair time. It was thought that the use of ceramic filters would remove the inclusion material from the metal stream in the gating system.

The pour weight of the casting was 41 lbs. The pouring ladle was a 500 lb teapot with a 70% alumina breastplate and spout. The molds were green sand with bonded sand cores and a shell downsprue. There was one casting per mold. All castings were poured from the same heat. Filters from two manufacturers were used in the trial and were identified as Filter #1 and Filter #2. Both filters were three inches in diameter by one inch thick reticulated partially stabilized zirconia. A total of sixty castings were poured: twenty with the standard gating system, twenty with Filter #1, and twenty with Filter #2.

The filters were mounted in the bottom of a riser and the filtered molds were poured using the riser as a gating system. Pouring time for the standard gating system ranged from 3-5 seconds, from 4-7 seconds for both Filter #1 and Filter #2. The effectiveness of the filters were rated by the amount of time needed to weld repair the castings.

Filtered molds poured with a metal temperature of less than 2920 F typically had problems with filter priming and mold filling. A minimum of 2920 F was needed to ensure that the mold filled. After the castings were weld repaired and sent through the machine shop, it was calculated that the filtered castings had a weld repair time about 90% less compared to the unfiltered castings. This resulted in a net savings of \$16 per casting. The foundry is currently incorporating the filter system into the gating system for use on a production basis.

STREAM SHROUDING DURING POURING OF CASTINGS WEIGHING OVER 250 LB

Pouring metal from a ladle, especially a bottom pour ladle, will expose the metal to atmospheric oxygen. Oxygen will react with steel to form reoxidation products which have been shown to compose a large portion of the defects observed in carbon and low alloy steel castings. (1) Bottom pour ladles have the disadvantage of a high metallostatic head pressure compared to teapot/lip ladles. This head pressure produces a high metal stream velocity exiting the ladle which can entrain large amounts of air. (2) Steel mills have for years shrouded their pouring streams to protect the metal from oxygen for this very reason.

The purpose of these trials was to evaluate the effectiveness of two techniques in protecting the pouring stream in a foundry environment and improving casting quality. The technique in the first trial used either an inert gas to blanket the metal stream or to purge the mold of oxygen before pouring or a combination of the two. The technique in the second trial used a mechanical shroud attached to the bottom of the ladle similar to the pouring practice in steel mills.

Procedure

Gas Shrouding and Mold Inerting Trial

The gas shrouding and mold inerting trial was conducted at Foundry A. The 8630 steel was melted in a six ton acid electric arc furnace and the ladle was a 1700 lb bottom pour lined with zircon sand. The casting used in the trial was a bracket with a pour weight of about 338 lbs. The shroud was eight inches in diameter and the metal skirt extended approximately seven inches. Two diffusers were used to disperse liquid argon inside the skirt. Two 1/2" wide viewing slits were machined in the skirt to allow observation of the stream during pouring. Mold inerting was also conducted as a part of this trial. About 150 cc of liquid argon was poured down the downsprue approximately 45 - 60 seconds before the mold was poured.

Prior to conducting the trial, a test was performed to determine the effectiveness of the argon purge. An oxygen sensor was placed in a mold, and 150 cc of liquid argon poured in the downsprue. After approximately 30 seconds, the oxygen level in the mold dropped to less than 1% and remained less than 1% for at least three minutes.

A full factorial experimental matrix was designed to evaluate both gas shrouding of the stream and inerting of the mold. Two heats were poured due to the number of molds needed to complete the matrix. The pouring order for each heat was randomized to eliminate any bias caused by head height variations in the ladle. There were four different conditions: standard practice, mold inerting only, gas shrouding only, and a combination of mold inerting and gas shrouding. Six molds were poured from each heat for each condition. A total of forty-eight castings were poured in the trial. Metal cleanliness was rated by weld repair time at the foundry. Historical weld repair data was also available for this casting to allow comparison to the trial data.

Mechanical Shrouding Trial

The mechanical shrouding trial was conducted at Foundry B. The 1025 steel was melted in a five ton acid electric arc furnace. Green sand molds were made using the SFSA test plate pattern used in previous casting trials. The ladle was a 2500 lb bottom pour. A fused silica shroud was attached to the bottom pour ladle with clamps and a pliable gasket was used to make

a seal with the bottom of the ladle. The SFSA test plate riser was modified to allow the shroud to be lowered to the bottom of the mold.

Two problems have been associated with mechanical shrouding in past experiments. (3) One problem involves making the shroud removable and still obtaining a good seal with the bottom of the ladle. Any leak will aspirate air during the pour. A combination of a pliable gasket to seal the shroud and an inert gas cover around the seal appears to have worked in a previous trial at Pelton. The second problem involves dealing with the additional metal velocity caused by the shroud. Two different methods were used to reduce the metal velocity as it entered the mold. The first method placed a ceramic filter at the bottom of the riser to absorb the impact of the metal at the start of pour. The second method was to use a filter/riser combination such as the FOSECO Stelpur to reduce the velocity of the metal.

Ten molds were poured under three different conditions: standard gating, shrouding with a filter placed in the bottom of the riser to reduce the impact of the metal, and shrouding and pouring the metal into the Stelpur riser/filter. Casting quality was determined by radiograph as well as by a visual rating of the surface of the casting.

Results

Gas Shrouding/Mold Inerting

An Analysis of Variance was run on the data to determine the effect of gas shrouding/mold inerting on casting quality. Figure 1 illustrates the effect of mold condition on welding time. Weld times on castings from the shrouded or purged molds were not statistically different from the weld times for the castings poured using conventional methods. In two cases, weld repair times for castings poured in the shrouded or purged molds were considerably worse. The historical weld time for these casting was about 18 minutes which is lower than the average weld time for the conventional castings from this heat. This is an indication that another factor overwhelmed any beneficial effect of shrouding. The effect of mold condition on weld repair time for the second heat is illustrated in Figure 2. Again, there was no statistical difference between the four groups. There was uniformly less weld repair time for all of the castings from this heat. The wider variation in casting quality for the purged or shrouded molds may indicate a loss of process control.

A plot of the weld repair times for the conventionally poured castings from both heats is illustrated in Figure 3. There was clearly a reduction of variation in casting quality in Heat 2 compared to Heat 1.

Liquid argon was observed dripping into the mold during pouring in the shrouding trial. Possibly argon gas was being trapped in the castings and increasing the weld repair times. The

Figure 1. Effect of Mold Condition on Weld Time. (Heat #1)

Figure 2. Effect of Mold Condition on Weld Time. (Heat #2)

Figure 3. Effect of Heat Number on Weld Time.

foundry observed that some of the worst defects in the castings appeared to be gas holes. Three castings were selected and a section of defect removed for examination. The defects appeared to be caused by gas trapped in the casting. Little or no indication of solid inclusion material was observed in these castings.

No benefit in casting quality from shrouding or purging was seen in this trial. However, this may have been caused by argon being entrapped in the casting. Too much argon could have been used to shroud the mold and produced gas defects in the shrouded castings and resulted in higher weld repair times. A change in diffusers to produce more gas instead of liquid argon may eliminate the gas defects. There were no oxide macroinclusions observed in the castings examined which indicates that the metal was protected from atmospheric oxygen.

Mechanical Shrouding Trial

ANOVA results on the x-ray rating and the two surface visual ratings are given in Table 1. A statistical difference was observed between the three pouring conditions. The effect of pouring condition on casting quality as measured by X-ray rating is illustrated in Figure 4. The castings poured with the shroud with the filter/riser combination had the best casting quality with an average x-ray rating of about 2. The conventionally poured castings and the shroud with filter splash plate casting were statistically similar. However, the shrouded castings obtained ratings which were as good as the shroud/filter in some cases and in some cases worse than the conventionally poured castings. Figures 5 and 6 illustrate the effect of pouring condition on casting quality as measured by a visual rating of the casting surface. The results were similar to the x-ray results with the shroud/filter combination producing the best castings followed by the shroud and conventionally poured castings.

A steel buildup was observed to form on the shroud during pouring. This buildup in conjunction with the difficulty in holding the ladle steady when lowering into the riser caused the shroud to contact the side of the riser. Sand may have been dropped into the mold during pouring. Examination of the castings did not reveal any erosion.

Three conventionally poured castings and three shrouded castings were selected and sample defects were removed from the plates. Defects removed from the shrouded test plates were primarily composed of silica sand grains. This supports the theory that molding sand was introduced into the mold upon pouring and was washed into the casting. Typical sample defects from the conventionally poured test plates were composed of a mixture of reoxidation products and silica sand grains.

The decrease in pouring time for the shrouded castings indicates that the shroud did in fact seal. The two higher pouring times were either throttled or opened and closed repeatedly. The shroud with the Stelpur filter consistently produced the highest casting quality compared to

Table 1.
ANOVA Results For Shrugging Trial.

Source	Sum of Squares	Degrees of Freedom	Significance
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X-Ray Rating as Dependent Variable

Between Groups	70.34	2	99
Within Groups	47.64	21	
Total	118	23	

Visual Rating (ig) as Dependent Variable

Between Groups	59.8	2	99
Within Groups	83.15	21	
Total	143	23	

Visual Rating (jag) as Dependent Variable

Between Groups	77.96	2	99
Within Groups	127.18	21	
Total	205.2	23	

Figure 4. Casting Quality Measured By X-ray Rating .