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Ultra-Refining Processes for Specialty Steelmaking
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LAMINAR BARRIER INERTING FOR SPECIALTY STEELMAKING

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ABSTRACT

In the processing of specialty steels, it is important to protect the molten metal from the ambient atmosphere. Laminar Barrier Inerting (LBI) is a patented process for providing an inert atmosphere in open-ended enclosures. It is used on induction furnaces of various sizes to reduce slag formation and atmospheric gas absorption. Laminar barriers have also been used to protect molten metal streams. Electroslag remelting (ESR) is one recent application of LBI technology. This paper will compare laminar barrier inerting to a consumable tube inerting practice in a commercial ESR. The improvement in ingot chemistry control, experienced with both inerting techniques, will be discussed.

INTRODUCTION

Molten metals react quickly with the surrounding atmosphere. Elements in the metal bath, such as silicon, aluminum, and chromium react with oxygen to form slag that is usually removed to ease further processing. Oxygen, nitrogen, and hydrogen also dissolve into the metal, requiring degassing to avoid the formation of porosity or to obtain specific mechanical properties. The removal of oxygen with deoxidants, or nitrogen with titanium or aluminum, results in the formation of oxides or nitrides. The problem of alumina inclusions from deoxidation and reactions with the atmosphere clogging the nozzles of continuous casters is well known. The oxide or nitride inclusions must also be removed to ensure clean product and good mechanical properties.

Various methods have been developed to prevent the reaction of the metal with the atmosphere. Most of these consist of some type of physical shroud and gas injection system. The shroud prevents direct contact of the atmosphere with the metal. However, these physical shrouds also limit visibility and process flexibility by limiting access to the metal. A method to protect the metal from the atmosphere while maintaining visual and physical access to the metal would be of utility.

Laminar Barrier Inerting (LBI) is Praxair's patented technology for providing inert atmospheres to open ended enclosures.[(1)] Initially developed for the soldering of electronics, it is being used to inert induction furnaces[(2)] and tundishes in the foundry, aluminum, and powdered metal industries, to inert during welding and in the protection of metal streams.

The LBI principle is simple. By creating a laminar flow of gas across an opening, a gaseous barrier is formed, preventing infiltration by the atmosphere. Methods that use simple pipes create turbulent jets, which do not do a good job of creating a barrier. The turbulent jet aspirates air into the jet. A laminar stream aspirates air very slowly, and a true barrier is formed. Oxygen contents less than 1% are typically measured in induction furnaces equipped with LBI.

The LBI concept can also be applied to metal streams. The volume above a tundish protected by

LBI is also inert.[3] This is shown in Figure 1. The LBI element is on the tundish, which is labeled B. During tap of the furnace, the oxygen content at the pouring spout (A) drops dramatically. Oxygen contents less than 5% exist without the use of a physical barrier. Access to the stream and all parts of the apparatus are maintained.

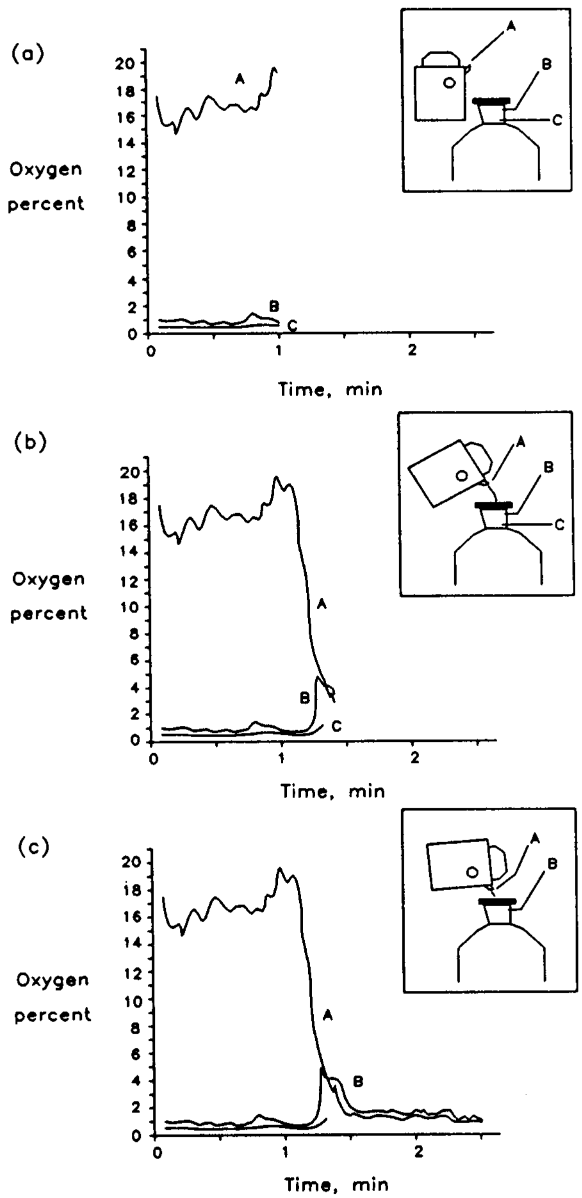

Figure 1 Oxygen Levels Around Induction Furnace Pouring Stream and in Atomizer Tundish with LBI

INERTING THE ELECTROSLAG REMELT FURNACE

The potential benefits of operating the electroslag remelt furnace with an inert atmosphere are ingots of more uniform chemistry and controlled levels of dissolved gases. With proper inerting, ESR composition control might approach that of vacuum arc remelting (VAR) without the additional vacuum machinery. An improvement in ESR ingot quality can also lead to a decrease in scrap losses through reduced end cropping.

Inerting the ESR has been tried with varying degrees of success. Improved recoveries of reactive metals resulting in more uniformity between the ingot top and bottom have been reported at headspace O_2 levels of 2.0 percent.[4] However, many inerting arrangements remain too cumbersome and/or ineffective.

Developing an inerting system to efficiently produce a consistently low level Of O_2 (<1.0 percent) in the crucible headspace was the major goal of this work. For the system to gain acceptance it could not require modifications to the crucible and it had to work with a hot or cold start practice. The need for a tight seal between the crucible and electrode holding assembly was also considered a major drawback of conventional ESR inerting. The ease in which the inerting system could be used on crucibles of varying sizes and how it integrated with a typical fume collection system was also addressed.

Two inerting systems that best fit these criteria were chosen for this evaluation. The first, LBI, was applied to electroslag remelting by placing a circular diffuser around the top edge of the crucible. The second, consumable tube inerting, is a novel technique on which there was limited background information.

Consumable tube inerting, uses a small diameter tube that runs the entire length of the electrode to introduce the purge gas at the molten slag level. The tube is progressively melted throughout the melt therefore the name, consumable tube. Both inerting techniques are illustrated in Figure 2.

During electroslag processing there are extended periods where the ability to view or access the melt is not crucial. A cover can be used to limit the

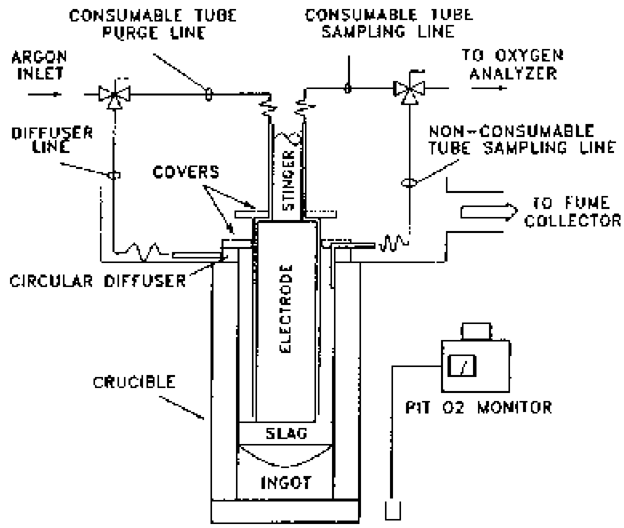

Figure 2 Schematic for ESR Inerting Test

opening at the top of the crucible during these periods. A cover should allow the reduction of inert gas flowrates and maintain an oxygen deficient atmosphere in the headspace. To simplify installation the covers were not designed to maintain a gas tight seal around the electrode as in most shroud arrangements. Covers of this type were evaluated with both inerting systems.

This paper will present the results of inerting for both methods with respect to gas consumption, metallurgical benefits, and ease of operation. Procedures to obtain representative samples of the atmosphere in the crucible headspace are introduced also.

EXPERIMENTAL PROGRAM

The test program was conducted at Teledyne Allvac's remelt facility in Monroe, NC. The experiments were carried out in two stages on a 23 t (25 ton) capacity commercial ESR furnace. In the first stage both inerting methods were tested with and without covers on an iron wash electrode. Oxygen levels were monitored throughout the melt to determine flows required to maintain a consistently low (< 1.0%) O_2 level in the crucible headspace with each technique. These optimum flow settings were used in stage two of the experiments. For these tests one melt of grade 718 alloy was processed using LBI and then another test was conducted with the consumable tube. Argon was used as the purge gas for all the tests and flows were varied between 0.26 - 52.5 Nm^3/hr (10 - 2000 SCFH) depending on inerting configuration.

The laminar barrier inerting device consisted of a fully circular diffuser built in two semi-circular sections. The diffuser was positioned on top of the ESR crucible as shown in Figure 2. During the first test the consumable tube was continuously welded to the side of the electrode to prevent the tube from bowing and arcing to the crucible. Installation was simplified for the latter tests by tacking the tube approximately every 20 cm (8 in).

The covers were made from 1.3 cm (0.5 in) thick refractory fiberboard material. They were cut in two semi-circular sections to permit easy installation and removal. With the cover in place a gap of 0.64 cm (0.25 in) remained around the electrode or stinger.

The oxygen readings were taken at the top and bottom of the crucible. The top sample point was about 30 cm (12 in) below the edge of the crucible. The bottom readings were taken at the slag level using a consumable sampling tube similar to the tube used for inerting. The same technique for attaching this tube to the electrode was employed.

Chemical analysis on the 718 alloy ingots was done by first removing 7.6 cm (3 in) from either end and then sectioning the ingot in half. A 2.54 cm (1 in) thick disk was then cut from the top, middle and bottom locations from which a center sample was taken for chemical analysis.

When using an inerting system, especially one that uses an argon purge gas, the risk of asphyxiation must be addressed. To this end, an oxygen analyzer was placed in the pit area beneath the ESR. This analyzer operated continuously and was set to alarm if the pit O_2 levels dropped below 19.5%.

RESULTS

Stage I (iron electrode) - The O_2 levels for both inerting methods, with and without a cover are shown in Figures 3 and 4. These graphs are based on readings taken at the molten slag level with the consumable sampling tube.

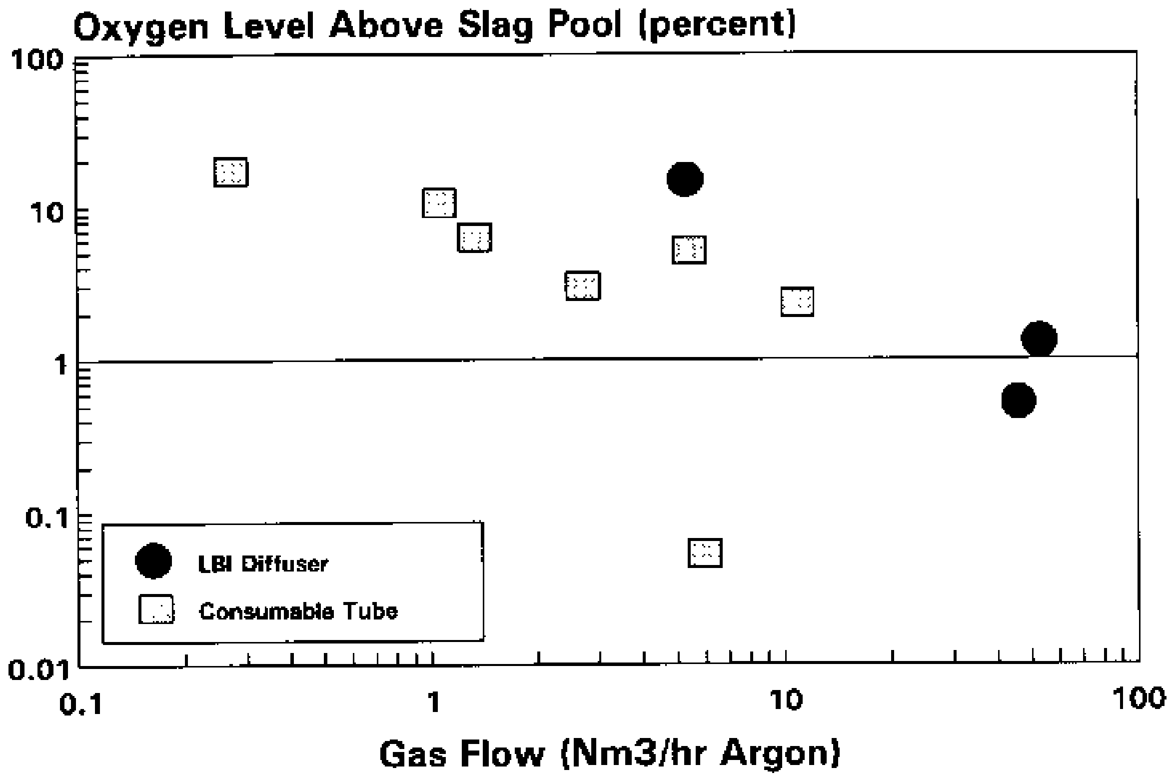

Figure 3 LBI Diffuser and Consumable Tube Tests without Cover

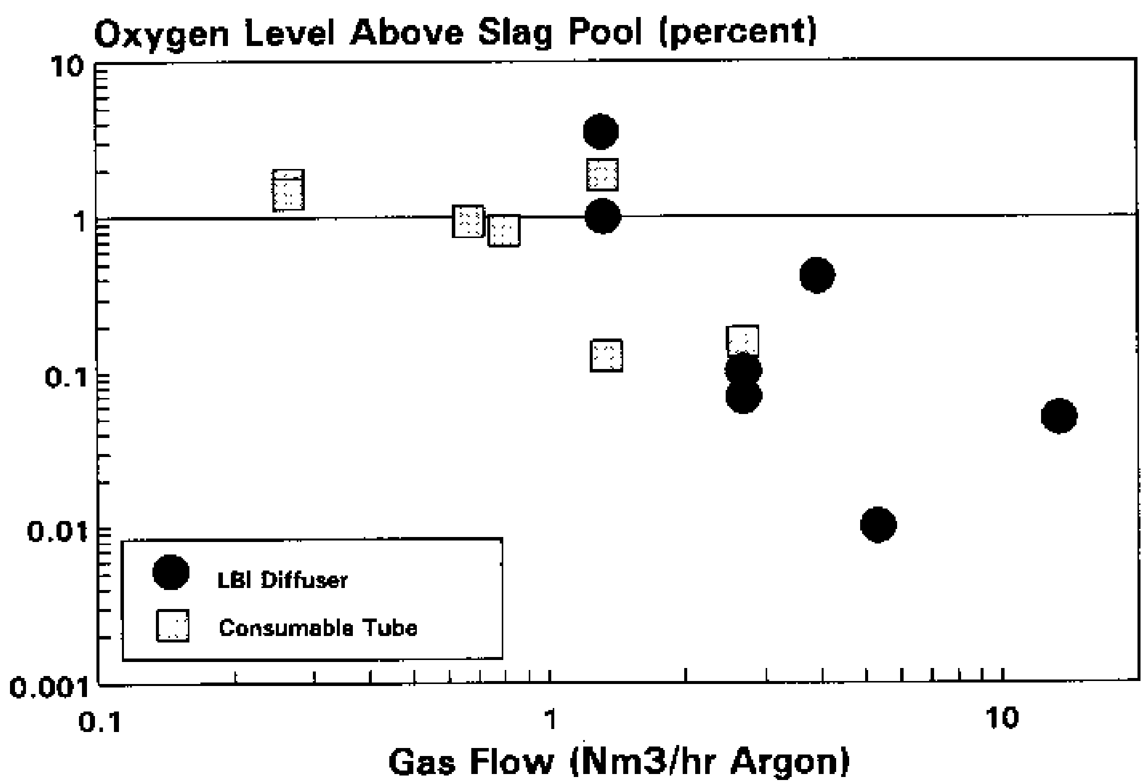

Figure 4 LBI Diffuser and Consumable Tube Tests with Cover

Without a cover the argon flows for LBI were 47 Nm3/hr (1800 SCFH) to maintain O_2 levels of 1 percent or less. With a cover installed the flow requirement dropped to 2.6 Nm3/hr (100 SCFH). When using the consumable tube without a cover, flow of up to 10.5 Nm3/hr (400 SCFH) could not consistently lower the levels to 1 percent. Flow above this level caused excessive splashing of the slag along with localized melting of the electrode near the tube outlet. With a consumable tube and cover arrangement flows of 1.3 - 2.0 Nm3/hr (50 - 75 SCFH) yielded acceptable O_2 levels.

With covers, flow for both inerting methods remained constant throughout the melt. Without covers, flow requirements increased near the end of the melt because of the hot, buoyant gas in the relatively shallow crucible headspace. It is important to note that the fume collection system did not degrade the performance of either inerting arrangement.

Stage 2 (718 alloy tests) - Inerting Performance - Because of the results from stage one both heats were processed with covers in place whenever possible. For the LBI test, diffuser flow was set at 2.6 Nm3/hr (100 SCFH) and the crucible was purged until the oxygen level dropped below 1 percent. In 15 minutes an acceptable O_2 level was reached and power was turned on. The standard operating procedure was followed for the remainder of the melt.

The oxygen reading at the slag layer with LBI was less than 1% throughout the melt. The non-consumable sampling tube in the top of the crucible gave readings of 1-2%. Flow was increased at the point where the electrode passed beneath the diffuser. Installing another cover to close the gap between the diffuser and stinger (see Figure 2) allowed the flows to be reduced to the original setting.

The argon flow was set at 1.3 Nm3/hr (50 SCFH) for the consumable tube test. Introducing the argon at the bottom of the crucible lowered the time required for purging to 5 minutes. The melt parameters for this heat were identical to the first. Oxygen was sampled at the same two locations. During the melt, readings of <1% were recorded on the bottom consumable sampling tube while the upper non consumable tube gave readings of 1-5% depending on cover integrity.

The headspace oxygen concentration was continuously sampled during these tests. Some difficulties were encountered with blockage at the end of the consumable sampling tube and accumulation of particulate in the filter upstream of the oxygen analyzer. The former problem was overcome by immersing the electrode into the slag prior to taking an oxygen reading. This presumably caused the tube end to melt back and open up at the slag surface. The latter problem was simply addressed by back-purging the line and periodic filter cleaning/replacement.

Stage 2 (718 alloy tests) - Metallurgical Results - Using an argon atmosphere for ESR processing of 718 alloy resulted in improved ingot chemistry control. The main improvement was elimination of the typical aluminum fade from electrode to ingot. Aluminum content of the ingot was also extremely consistent from top to bottom. Titanium recoveries were high, but no greater than for conventional processing of this alloy at Teledyne.

The dissolved gasses (N and O) and sulphur content in the ingot appeared unchanged from conventional practice. This may be misleading since air (not vacuum) melted electrode with low sulphur levels was used for the tests.

DISCUSSION

Inerting method - There are pros and cons to both inerting techniques. The inerting system of choice will be largely determined by operating conditions. Currently, the consumable tube can be easily applied to crucibles of varying sizes while the diffuser is typically sized for a specific crucible size. Either technique can be integrated into a cold or hot start practice.

The flow requirements for either inerting method are drastically reduced by using covers. With the cover in place the LBI diffuser uses slightly more gas, but by increasing gas flow it can maintain an inert (O_2<or =1%) atmosphere when the covers must

be removed. Without the covers multiple consumable tubes might work better than the single tube used for the tests. With this arrangement larger volumes of gas could be introduced without disturbing the slag pool. If the covers need not be removed for extended periods, as was true for our tests, a single consumable tube should work well.

The gas costs for either technique with a cover are relatively low, ranging from about $3.3 - $6.6/ton. Capital cost for the diffuser is greater than a consumable tube, but the consumable tube has appreciable operating and labor costs. Consumable tube costs alone would pay for a typical diffuser in about 25 heats. These costs do not include the labor for welding the tube to the electrode. A diffuser can be installed or removed in a matter of seconds due to its sectional design.

The refractory fiber covers work well, but cutting them can be time consuming. Adopting a practice that uses a consistent diameter stinger can simplify cover fabrication. It is more economical to have the covers molded when large quantities are needed.

Metallurgical Benefits - An argon atmosphere above the slag appears to lower the oxygen potential of the slag resulting in less aluminum oxidation of the electrode. However, titanium recoveries changed little compared to ingot melted under conventional practice for several reasons. First the Ti level of 718 alloy is relatively low (1.0%). Most of the Ti fade occurred at the ingot bottom, as is common for electroslag remelted product. Fade of this type may be caused by hydrates in the slag that oxidize the titanium independent of the atmosphere in the crucible as noted by Tommaney, et al.[4] Last and most important, Teledyne Allvac uses a proprietary technique to control Ti fade.

How inerting affects the level of dissolved nitrogen and oxygen in the ingot is difficult to quantify from this limited test data. Air-melted electrode was used for these tests making it difficult to determine what fraction of gas pick up occurs during casting of the electrode or subsequent ESR processing. Degassing, similar to that in VAR processing, was not noted. This is not surprising since an inert atmosphere only serves prevent gas absorption, not to remove dissolved gases from the molten pool.

Inerting did not seem to influence desulphurization, but starting sulfur levels in the test electrodes were in the low ppm range. At these levels, very little further reduction occurs during electroslag remelting. Therefore, more tests using electrodes with higher sulphur content are warranted before a strong conclusion can be drawn.

Overall, there was no discernible difference in metal quality improvements when using either inerting method.

While argon was the gas used for these experiments, nitrogen can be employed for alloys that are not nitrogen sensitive. Nitrogen purging to reduce H pick up in tool steel alloys is currently being tested. Further benefits may be realized by eliminating the costs associated with a dry air supply system.

Inerting Safety - Due to the relatively low flows and the fume collection system there were no instances of low oxygen content in the pit area during the tests. Operating at the higher flow rates >40 Nm3/hr (>1500 scfh), with the fume collection system off, did cause an oxygen deficient condition (<19.5%) in about 15-20 minutes. With fume collection this condition did not reoccur.

Process Control - No negative effects on start up and processing in the electroslag remelt furnace was noted with inerting. Except for the crucible prepurge at the start all melts were conducted in a normal fashion.

CONCLUSIONS

Laminar Barrier Inerting and the consumable tube method of inerting were effective at relatively low argon flow rates when a cover at the top of the crucible was used. Without a cover only LBI could maintain the inert atmosphere, but this is done at the expense of increased gas flow. This larger flow requirement makes continuous inerting without a cover uneconomical for most ESR processing.

ESR ingot chemistry control was improved by applying an argon atmosphere with ~1% oxygen above the slag during processing. Aluminum content of the ingot was very uniform from top to bottom and there was no loss of aluminum from electrode to ingot.

ACKNOWLEDGMENT

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REFERENCES

1. M.S. Nowotarski, "Wide Laminar Fluid Doors", U.S. Patent 4,823,680

2. S.K. Sharma and M.S. Nowotarski: "Laminar Barrier Inerting for Induction Melting", Proceedings of the 37th Annual Technical Meeting of the Investment Casting Institute, Oct. 15-18 1989, Los Angeles, also excerpted in Modern Casting, Nov. 1990.

3. M.F. Riley, S.K. Sharma and C.J. Messina: "Oxygen Control During Atomization Using Laminar Barriers", Advances in Powder Metallurgy, Vol. I, 1990 pp. 25-36.

4. J.W. Tommaney, et al.: "Method and Means of Reducing the Oxidation of Reactive Elements in an Electroslag Remelting Operation", U.S. Patent 4,953,177, August 28, 1990

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