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Vacuum Degassing of Steel used for Forged Ingots

As part of the economy, metallurgy must address the problem of product quality in all aspects, especially in view of the the usage properties and physico-mechanical characteristics. The paper deals with vacuum melting processes used to eliminate gases and inclusions from both small amounts of molten steel and from large ingots.

Keywords: *absorbed gases, flaking, brittleness, inclusions, vacuum degassing*

1. Introduction

The gases absorbed by the liquid steel from the atmosphere and the raw materials used for steelmaking may give rise to flaking, brittleness, voids, inclusions and other defects unwanted or even harmful for the steel after solidification. In particular, hydrogen has been recognized to cause flaking and brittleness for a long time. Until recently, the introduced materials were roasted and dried. Even if measures were taken, after solidifying the steel was subject to long cycles of heating and cooling in order to disseminate the hydrogen absorbed by steel.

Oxygen and nitrogen are combined with various alloying elements added to form oxides, hydrogen cyanide and nitrogen compounds that remain in the steel as inclusions which may be removed only through certain remelting operations.

Through the vacuum melting process, it is possible to eliminate the gas and inclusions both for small quantities of molten steel for a reasonable cost price and for larger quantities, however, entailing considerable costs.

2. Method

Recently, various methods were developed to degas large quantities (up to 300 tons) of liquid steel produced in Martin or electric arc furnaces.

The most common are such as [2]: ladle degassing, liquid steel jet degassing, the D-H (Dortmund-Horder) process and the R-H (Ruhrstahl-Heraeus) process. The principles underlying these methods are shown in figures 1, 2 and 3.

Hydrogen can be effectively discharged by any of these processes, some of them removing also the oxygen which has not previously been deoxidised with silicon or aluminum.

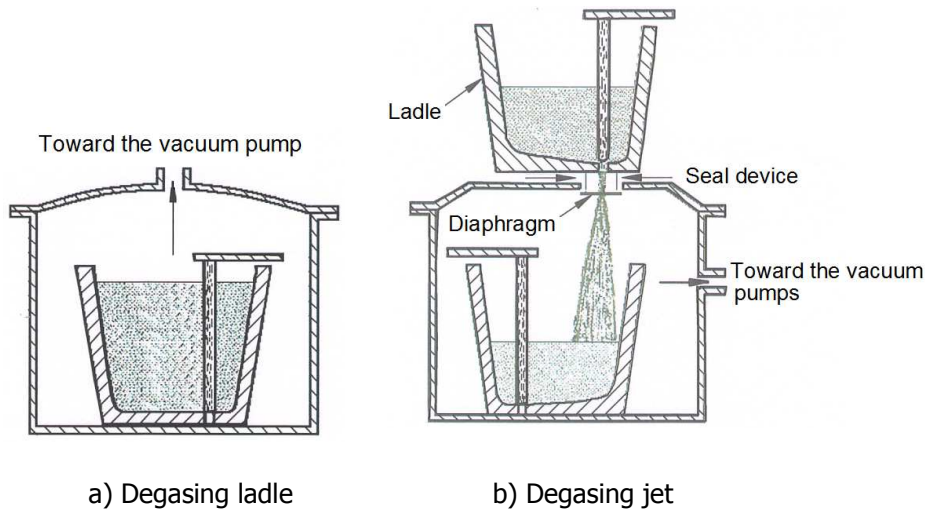


Figure 1. Layout scheme of used equipment: (a) degassing ladle, (b) degassing jet

Through the process of degassing ladle (figure 1,a) the ladle which is to be degassed is placed in a sealed container having an opening through which it is connected to the vacuum pump.

In both methods, the degassed steel is then usually poured into ingot molds. The variants (a) and (b) are analyzed in the text.

The air exhaust from the container let the gas in the steel to come out; this operation is simultaneous with a bubbling operation imposed to the liquid steel. The funnels at the top of the container are provided for the materials that will be added in the ladle. In the steel in the ladle an inert gas is injected such as argon or helium to stir the bath and to produce bubbling. For some purposes it is possible to use induction stirring (stirring by induction requires ladle made of non-magnetic stainless steel). When degassing is complete, the container is washed with an inert gas to eliminate the possibility of ignition of flammable gases and metal dust accumulated in the container. After that, the pressure is risen in the container to the atmospheric pressure to permit the ladle removal. The degassed steel is then cast as usual.

2.1. The the steel jet degassing

The jet degassing is carried out by placing a steel ladle into a container (figure 1.b).

On the top of this container a ladle provided with an outlet at the bottom is placed. The bottom of the ladle and the upper part of the container are provided with tight seals to prevent the ingress of air. When the rod of the loaded ladle is risen, the molten metal flows through the brick funnel, melts away a diaphragm which closes the container and goes into the ladle placed in the vacuum container. When the jet of molten steel enters the vacuum space, turns into very small droplets thus exposing a large area to the influence of vacuum degassing, falling in the ladle afterwards. After washing the container to eliminate flammable gases and their replacement with an inert gas, the container opens and the ladle with degassed steel is taken by a crane, the steel being poured in the usual manner.

A variant of the described methods is to place the vacuum machine at the outlet of the electric arc furnace. The ladle receiving the degassed steel is provided with a tight lid with holes for intaking the filler material from a funnel (hopper), to exhaust the air out of the ladle and to introduce the molten steel. After the ladle is vacuum, the steel in the electric arc furnace is poured in a funnel and from there, by raising the stopper, in the vacuum space of the ladle through the aperture provided in the lid of the ladle. A process for degassing the steel jet for casting large ingots is discussed below.

The process D-H (Dortmund-Horder) for degassing the liquid steel (fig. 2) carries out both the refining and mixture intensively, allowing the addition of alloying elements.

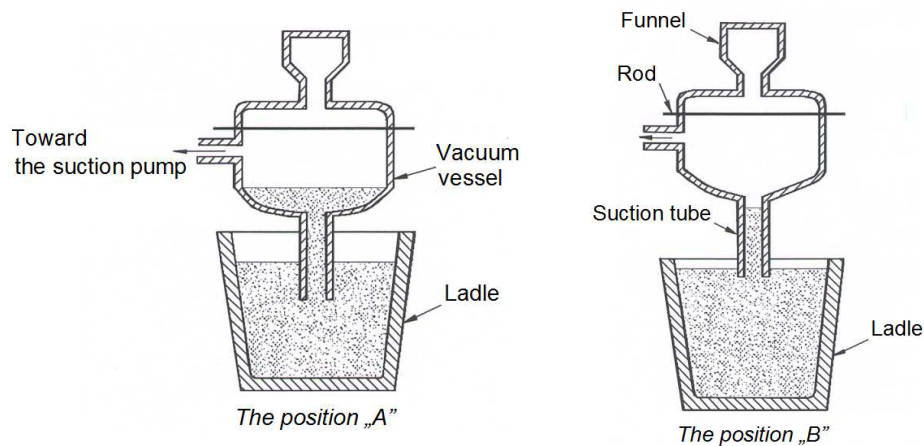


Figure 2. Schematic diagram representing the principle of the D-H (Dortmund-Horder) process

The vacuum vessel is lowered until the funnel head enters through the slag in the molten steel in the ladle. At this point, the vacuum pumps drop rapidly the pressure in the chamber to about 1 mm Hg and the atmospheric pressure causes the liquid steel to rise in the chamber [1].

When the steel enters the vacuum space, a violent release of gases takes place that exposes a large area of steel to the vacuum (dropwise). By lifting the container, without removing the funnel from the liquid metal out of the ladle, the degassed steel is allowed to partially leak back into the ladle. Repeating this operation, the entire content of the ladle can be degassed. The heat losses are compensated by a heating element through an electrical resistance of graphite placed at the top of the vacuum chamber. During the operation the following chemical changes occur: (1) the hydrogen is eliminated, (2) the carbon content is reduced due to the reaction with the oxygen in the steel to form carbon monoxide, and (3) some losses of manganese occur. The steel of desired composition is produced by the initial offset of the carbon and manganese losses or by adding some elements of replacement through bunkers that allow this operation without spoiling the vacuum. After the degassing has been complete, the chamber is flushed with nitrogen; then the funnel is risen above the liquid steel to prevent the ignition of flammable gases accumulated in the vessel.

When the vacuum vessel is lowered and then raised, the atmospheric pressure causes the molten steel to rise in the vacuum space and then fall back into the ladle.

The principle of the R-H (Ruhrstahl - Heraeus) procedure is shown in figure 3.

The argon is injected into one of the vessel tubes causing the steel to rise in the emptied chamber through a bubbling action which releases the gases out of steel to the top and then descends into the ladle through the second leg. Continuous steel circulation is maintained until the desired degree of degassing is obtained.

The equipment consists of a vessel having two long tubes. One of these tubes is provided with an inlet hole for injecting an inert gas. The vessel is lowered until the ends of the two tubes are at a short distance from the surface of the liquid steel in the ladle after emptying the vessel. Due to the atmospheric pressure, the liquid steel rises in tubes. Argon is injected through the orifice provided tube and it decreases the density of the liquid metal column in this tube creating an action of "pumping" resulted from the disequilibrium between this column and the column of liquid metal in the other tube. When the liquid metal rises in the emptied chamber through the tube where argon is injected, the absorbed gas leaves the metal due to a boiling action and the degassed metal returns in the ladle through the other tube. The circulation of the metal from the ladle in this emptied chamber continues until the desired gas content is obtained in the steel.

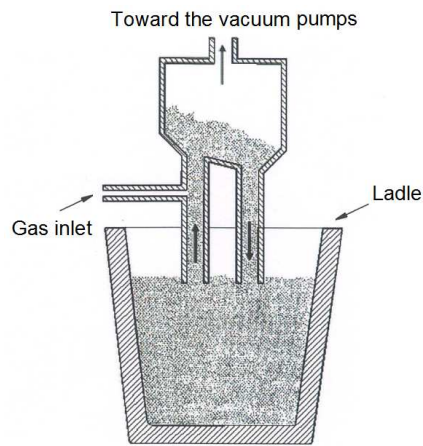


Figure 3. The principle of the R-H (Ruhrstahl-Heraeus) process

2.2. Vacuum casting of the large forging ingots

Figure 4 shows a vacuum casting equipment for the production of large ingots for forging, where the hydrogen content was reduced to a level to which the steel is insensitive to flake formation [3]. This system uses the principle of the steel jet degassing, ladle – ingot mold.

The layout scheme of the vacuum container and the pumping system are shown in figure 4.

With the pump running, the pressure in the vacuum container having the required minimum value, the ladle with the steel that is to be degassed, is placed on an intermediate ladle and the steel cast begins. When the intermediate pot is three-quarters full, its funnel is opened, the liquid steel melts the diaphragm between the intermediate ladle and the container, and metal enters in the low pressure atmosphere in the container.

The refractory collar around the intermediate ladle funnel limits the steel jet in order to prevent the excessive spraying due to the gas release when the jet breaks up into small drops.

The molten steel then drips into the ladle. On completion of the casting, the container is washed with an inert gas before the vacuum is spoiled, by introducing air at atmospheric pressure.

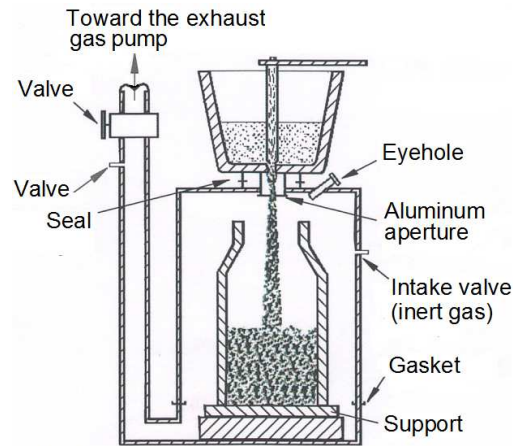


Figure 4. The schematic arrangement of the vacuum casting system, used for the degassing technique of the steel jet stream.

3. Conclusion

Some of the variables that affect the amount of hydrogen removed from the steel during vacuum molding are such as: the amount of gas dissolved in the steel, the steel composition, the absolute pressure during degassing, the casting speed, the humidity in the container and the atmospheric air ingress.

Steels developed without additions of aluminum, silicon or other strong deoxidants are deoxidized by reacting carbon with oxygen when these steels are exposed to low pressure. Steels deoxidized with aluminum or other strong deoxidants are not suitable for vacuum deoxidation as such deoxidant substances form with the oxygen stable compounds that can be eliminated only if the vacuum casting pressure is lower than the dissociation pressure of these compounds.

Acknowledgements

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