EFFECTS OF TURBULENCE INHIBITORS ON SLAG EMULSIFICATION IN THE CONTINUOUS CASTING TUNDISH

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ABSTRACT

The steel slag emulsion takes place due to breaking of the interphase iron-slag caused by the draining of fluid. The beginning of the emulsion is a function of the operational practice and the slag properties: viscosity, density and interfacial tension. Thus, the beginning of the dragging tends to be related to the flux velocity, the breakage intensity and the physical properties of the slag. The emulsion of a less dense phase into a more dense one is one of the key problems which result in detriment to the product; that is to say: the emulsion of slag in the tundish may be responsible for the presence of inclusions in continuous casting steels. So, in order to produce clean steels via continuous casting the slag emulsification should be eliminated.

This paper present the results of a comparative analysis between a tundish with and without turbulence inhibitors. The experimental work was carried out on a physical model of the continuous casting tundish of Gerdau Aços Finos Piratani, built in scale 1:1, referring to residence time and characteristic volumes. In this model through image analysis, different inhibitors were evaluated as regards their efficiency in the elimination of slag emulsification during stationary casting and ladle change. The results of this work allow to reduce significantly the slag emulsification in the tundish; thus minimising the presence of macroinclusions in steels.

Key words: Turbulence inhibitor, slag emulsification, tundish, water model, inclusions

INTRODUCTION

During ladle changes in continuous casting the ladle which was in caster operation is swifted in such a way that a new ladle can be brought into the casting position. When the new ladle starts the casting process, the steel level in the tundish is lower than in normal operation but it increases quickly. This increase in the tundish level is carried out through the full opening of the ladle slide gate with a throughput three times the value taken during the normal casting process. This high throughput can cause slag emulsification in the pouring area around the shroud and so drag slag droplets from the tundish into the mold.

If the turbulence is not controlled properly, it can damage the capacity of removing the inclusions and can become a generator of inclusions. In general the floating of inclusions is due to the difference between its density and that of the liquid steel. Also, in a turbulent flux the inclusion course is strongly affected by the variations of the flow velocity. In this circumstances these inclusions will follow courses according to the turbulent velocity field of the flow instead of courses of natural floating [1].

The turbulent flow of liquid steel in the continuous casting tundish is originated by the high velocity of the steel coming from the ladle through the ladle shroud. This turbulent flow produces the shearing of the iron-slag interphase causing the dragging of slag, and serious refractory erosion to the side walls and tundish bottom as well as difficulties to the floating inclusions. Thus, the adjustment of the fluid velocity and the turbulence has been the aim of many steelmaking plants in order to carry out a clean practice [2].

The emulsification is also a function of the operating practice and the slag properties: viscosity, density and interphase tension. Thus, the beginning of the dragging tends to be related to the fluid velocity, the shearing tension intensity (frequently related to the slag layer thickness) and to the physical properties if the slag [3].

In stationary casting the condition can sometimes be controlled but during tundish filling, ladle change and other transient operations the situation can become out of control.

Morales [2] has identified the turbulence as one of the major causes of slag dragging in the tundish. In order to control the turbulent flow, various flow modifiers have been designed and their performances in the tundish have been reported in literature [1-3]. Recently, turbulence inhibitor used in continuous casting tundish have been reported as useful device to control the steel cleanness, mainly along the ladle change (or for reduction of steel mixing during the change of steel grades).

Knowing the residence time distribution (DTR curves) of liquid steel inside the tundish [4] it is possible to determine the maximum and medium time of residence. Those times allow the comparison of one in relation to another as regards the chances for the inclusion to reach the slag. The more the residence time of the steel in the tundish, the greater the possibility for inclusions to reach the slag. The aspect that are quoted in this paper on the topic “Distribution of residence times” have as source the works of Szekely and Themelis [5] and Szekely and Illegbusi [6].

This work was carried out in association by the Universidade Federal de Rio Grande do Sul (UFRGS), the Instituto Argentino de Siderurgia (IAS) and Gerdau Aços Finos Piratini (Gerdau AFP). The aim was to evaluate the reduction of the slag emulsification phenomena using different types of turbulence inhibitor in a full-scale water model of the continuous casting tundish of Gerdau AFP.

PHYSICAL MODEL

The Gerdau AFP billet and bloom caster has three strands and a T-shaped tundish, as shown in figure 1. Flow control is carried out with stopper rods. The water model, including ladle shroud and inhibitors, was made of acrylic in full scale in the Steelmaking Laboratory of UFRGS.

Tests were made without flow modifiers and with two turbulence inhibitors (cylindrical model with flange and without flange) shown in figure 2. This inhibitor was located in the pouring area, just under the shroud, as shown in figure 1.

In the model room temperature water is used to simulate liquid steel and kerosene to simulate slag. Flow visualisation is obtained using the $KMnO_4$ injection. The DTR curves are established through a test consisting of the addition of a tracer (HCl) to the liquid in the shroud and measuring its concentration in the tundish outlets.

EXPERIMENTAL PROCEDURE

The tests were made following the operating conditions (casting rate and liquid steel tonnage) of the Gerdau AFP's tundish. All the tests with tracers were made with the tundish operating under stationary conditions, that is to say with a constant volume of 12 t of liquid steel. The tests for slag emulsification and those for flow pattern visualisation were video recorded.

- *Slag emulsification test*

To evaluate the efficiency of two different types of turbulence inhibitors in slag emulsion control, two inhibitors were compared using the image analysis technique. To simulate ladle change, starting conditions were a liquid steel weight of 12 t in the tundish and a throughput corresponding to a casting speed of 2.3 m/min for three 150 mm square moulds. Tundish level was then diminished, and after that tundish refilling was carried out at a throughput increased 3.7 times. High values of casting speed as compared with the standard in the plant were used with the intention of better studying and identifying the emulsion phenomena.

- *DTR curves*

For each inhibitor tested three tests were made in order to determine the DTR curves. Then three DTR curves were obtained for the central strand and one of the two end strands, supposing symmetry for both ends (Figure 1).

A solution of 2% HCl was used as tracer; in all tests 300 ml were injected. Tracer injections were carried out through a pneumatic system connected next to the end of the shroud. The injection of the tracer was carried out in a short period of time (1.5 to 2.5 s).

DTR curves were obtained with a sensor for continuous measurement of conductivity and a data acquisition system. The results in terms of conductivity were converted for the tracer concentration and the DTR curves were drawn. A liquid steel volume of 12 t and a throughput corresponding to a casting speed of 1.5 m/min in each 150 mm square strand.

RESULTS AND DISCUSSION

- *Slag emulsion*

Figure 3 (left) presents slag emulsification during ladle change using inhibitor without flange, when the slide gate is open with the shroud not yet submerged. Figure 3 (right) presents the situation when the ladle valve is opened with the shroud already submerged.

Comparing these two situations it can be observed that when the ladle valve is opened with the shroud above the slag layer, a strong air entrainment occurs. This means reoxidation of the liquid steel. Up to shroud submersion, the steel surface around the shroud is free of slag due to the high turbulence energy at the moment of the opening of ladle (figure 4). Both cases present slag emulsification. Figure 4 shows slag emulsification around the shroud (front and top views of the tundish).

During the tests the emulsification was evident only under the condition of a quick tundish refilling. No emulsification was observed during stationary conditions. It was also observed a decrease in the slag emulsification when the shroud submersion was diminished.

It was evident from the comparison with the situation with no modifiers, that with both turbulence inhibitors type 1 and 2, slag emulsification was diminished. The best results were obtained with type 1, as the design with flanges facilitate flow recirculation inside the inhibitor, reducing in this way the turbulent energy.

- *DTR Curves*

All the characteristic time values are presented as normalised values. Observing the average behaviour of the tundish, that is considering the contribution of each strand, it can be verified that the longest medium residence medium time is obtained with the use of the inhibitor with flange. So by using this turbulence inhibitor the inclusions can reach the slag layer more easily.

It is observed that with the use of turbulence inhibitor the minimum residence time is increased. That means a better condition for the floating of inclusions. Besides, when the inhibitor with flange is used the minimum residence time is increased by 50%.

Figure 7 present the data of characteristic volumes for the three situations studied (tundish without modifiers, tundish with turbulence inhibitor with and without flange). The results show that:

- The turbulence inhibitor eliminates the short cut existing in the tundish.
- The largest perfect mix volume is found when the inhibitor with flange is used; this also represents the least dead volume.
- It was observed that the tundish without flow modifier has a plug flow volume of 16%; 11% for the inhibitor with flange and 7% for inhibitor without flange. Again the flange has a positive result.

CONCLUSIONS

The use of turbulence inhibitors improves the situation in the tundish with regards to control of slag emulsification during ladle changes. The inhibitor with flange behaves better than the one without flange.

The high throughput used for tundish refilling just after ladle change is responsible for the highly turbulent condition around the ladle shroud that creates slag emulsification. The situation improves with normal stationary throughput.

For stationary conditions, minimum and medium residence times are longer for the tundish with inhibitor. The inhibitor with flange gives longer times than the one without flange.
Dead volume is the least when using the turbulence inhibitor with flange, and perfect mix volume is the maximum. Plug flow volume is maximum for the tundish without flow modifiers.

Open casting (shroud end positioned above slag level) brings about reoxidation rather than slag emulsification, as the turbulence generated by the steel stream opens the eye and keep the slag far from the impact point.

Improvements in design are required to equalise residence time for central and end strands.

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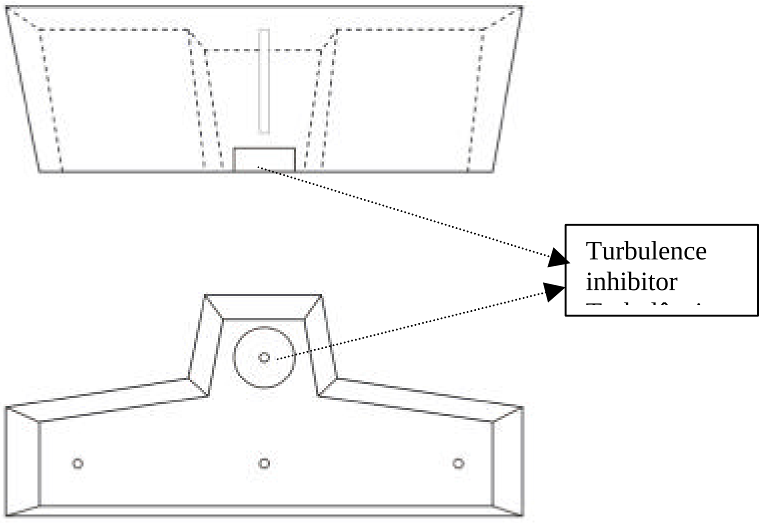

Figure 1. Continuous casting tundish of Gerdau AFP, with the location for the turbulence inhibitor 2.

Inhibitor with flange   Inhibitor without flange

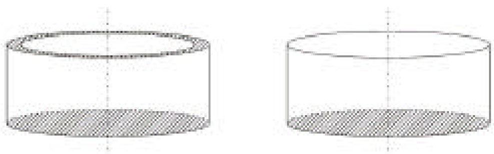

Figure 2. Turbulence inhibitors tested.

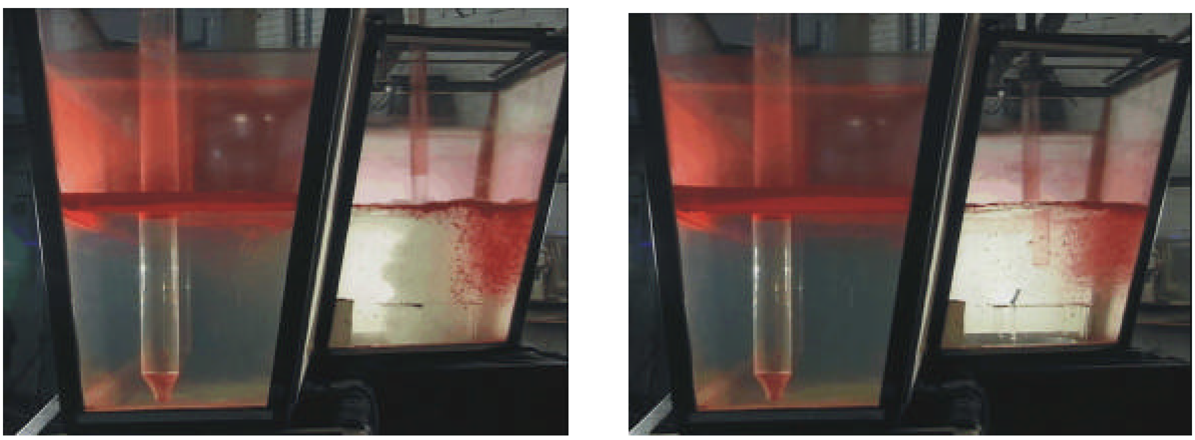

Figure 3. Characteristics of slag emulsification with inhibitor type 1. Left: Ladle opened above slag level. Right: Ladle with opened with the shroud previously submerged.

Figure 4. View of slag emulsification in the area around the ladle shroud. Left: Top view. Right: Front view.

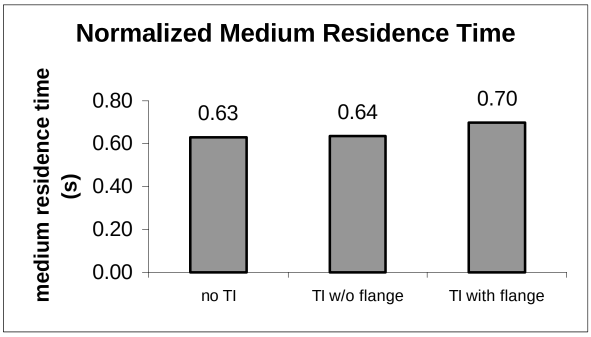

Figure 5. Medium Residence Time for the three situations tested.

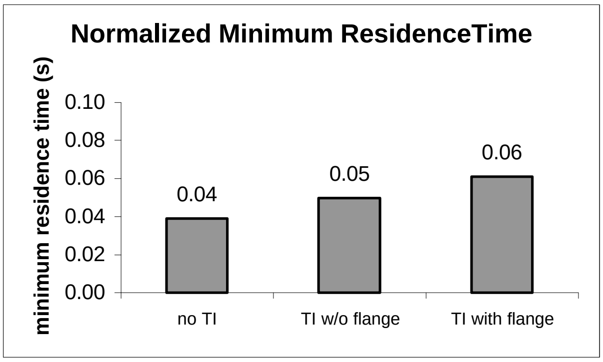

Figure 6. Minimum Residence Time of all tundish for the different type of inhibitor.

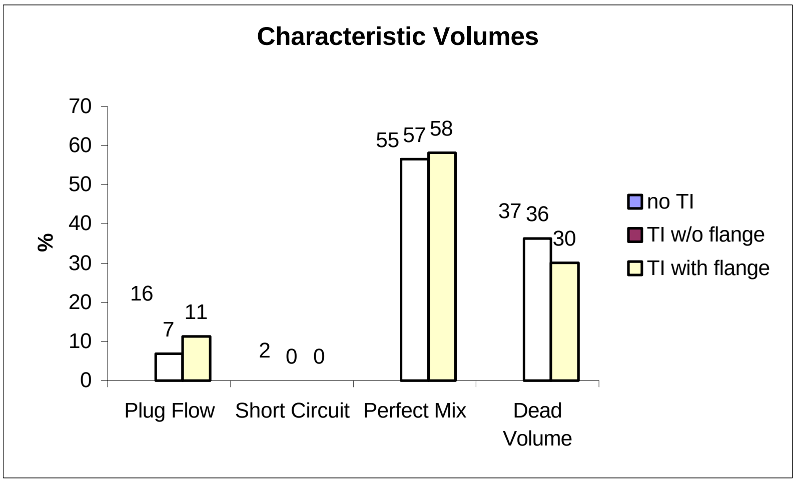

Figure 7. Characteristic volumes for all tundish to each inhibitor.