DEVELOPMENT OF NOZZLE CLOGGING INDEX TO ASSESS THE CASTING BEHAVIOR DURING CONTINUOUS SLAB CASTER AT TATA STEEL

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Abstract

Formation and deposition of non-metallic inclusions inside submerged entry nozzle (SEN) as well as tundish is widely recognized as a crucial problem in continuous casting of Al-killed steel. The agglomeration of inclusion inside the wall of nozzle not only limits the production by restricting the passage of liquid steel into the mold, but also disturbs the flow pattern. In addition to that, periodic dislodgement of clogged alumina particles lead to undue melt level fluctuations in the mold and may become an important source of non-metallic macro-inclusions in the cast sections. Thus it is crucial to take in advance suitable corrective measures to avoid the severe clogging problem. In light of above, a model has been developed for a more precise quantification of nozzle clogging (clogging index). The model is capable of providing a real-time (on-line) measure of clogging during slab casting. This index is served as a more reliable tool for scheduling the tube change, SEN lancing, tundish change, manual flushing. In addition, extensive investigation was performed to correlate the rate of clogging with the available liquid steel cleanliness parameters viz., nitrogen pick-up, aluminium fading and LF addition practice to take suitable corrective measures in upstream for smooth casting operation.

Key words: Nozzle clogging, submerged entry nozzle, non-metallic inclusions, continuous casting

1. Introduction

The disorder of casting process due to submerged entry nozzle clogging is a long standing problem ever since the continuous casting process has been introduced. Deposition of solid nonmetallic inclusions inside the nozzle wall and port can be mainly attributed to deoxidation or reoxidation products of alloying elements such as aluminum or titanium, entrapment of ladle and tundish slag and refractory particles in the molten steel [1-2]. The incomplete removal of these inclusions during secondary metallurgy process causes severe clogging mostly in low carbon Al killed, low Si mild steel grades of steel [3].The gradual deposition of clogged materials not only decreases the productivity by causing the interruption of casting operation, but also affect the steel cleanliness by forming various surface defects (such as slivers and blisters) in the finish products [4-6].

A direct observation and visualization of the extent of clogging inside the SEN as well as in tundish well is not possible during the casting operation. Thus precise measure of nozzle clogging is necessary to know the extent of clogging during casting operation. Many researchers [7-8] have developed a clogging index factor by comparing the theoretical steel flow rate to the actual value. The major drawback of this approach is the calculation of

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theoretical flow rate, which needs initial calibration of stopper position. Monitoring the stopper opening and closing during casting is the common way to predict the amount clogging inside the SEN tube as well as in the tundish well. The estimation of clogging based on stopper position only may give false indication of clogging during low tundish weight and planned increase in casting speed. In light of above difficulties, a most suitable way to calculate the clogging percentage precisely during the casting operation has been developed and installed in the slab casting shop of Tata Steel. The details of the model can be found elsewhere [9]. The model calculates the clogging index value by using the dynamic process variables (stopper rod position, tundish weight, casting speed, mould cross section area) in a real time basis. The calculation of clogging index which is being displayed continuously in the control system of casting shop is shown in Figure. 1.

The frequency of SEN tube change is an indicator of poor cleanliness of the steel [10]. Thus nozzle clogging rate, which is nothing but the rate of deposition taking place during a particular heat, can be used to assess the steel castability during continuous casting of steel. It is reported that there are more than 30 factors influencing the formation and of Al_2O_3 and its entrapment in the liquid steel [11]. Thus the influence of individual parameters on the clogging needs to be investigated to minimize the severity of clogging during casting process.

In the present work, the calculated rate of clogging, an indicator of the severity of clogging during a heat has been correlated with the upstream process parameters (ladle furnace and caster) responsible for the formation and deposition of the inclusions. The goals of the present study were as follows:

1. To identify the steelmaking and casting variables for the enhancement or decrement of clogging in a particular heat.
2. To find out the optimum operating range for those parametersto minimize the clogging rate.
3. Change or recommendation of the practices for the removal of inclusions.

The present work has been carried out in slab caster shop of Tata steel. The detail of the slab caster machine is given in Table1.

2. Calculation of Clogging Rate

In the slab caster shop of Tata steel, SEN clogging has been quantified and clogging index has been monitored continuously, which is shown in Figure. 2. It has been observed that in some of the heats the variation of clogging index is minimal. However, sudden rise of clogging has been noticed in some heats which lead to undue melt level fluctuation and argon flushing. Thus, in the present study attempt has been made to correlate clogging rate with the upstream steelmaking process parameters (Ladle furnace and caster) to indentify the reason for increase in the rate of clogging in particular heats.

The slope of the clogging index graph is a direct measure of clogging rate in a particular heat. However the slope changes at time of flushing and thus a new methodology was adapted to calculate the average slope value in a heat. There are two possible cases:

Case I: (Clogging index either increasing or decreasing throughout the heat):

In this case the slope of the linearly fitted line of the clogging index graph gives the clogging rate value (as in region 1 in the Figure 3).

Case II (slope changes during the heat):

If in a particular heat (as shown in region 2 Figure 3) , the clogging index plot shows several slope changes, then the weighted average of all the slopes as given in Eq.(1) is consider as the effective clogging rate.

$$\text{Clogging rate}=\sum_{i=1}^{n} x_i m_i \qquad [1]$$

Where x_i= weighted time fraction

m_i= slope (e.g m_1= AB/AD as indicated in Figure 3)

n= number of slope change during a heat

3. Result and Discussion

3.1 Effect of steel reoxidation on clogging

3.1.1 Nitrogen pick up

Nitrogen pick-up during ladle to tundish transfer operation is an indication of areal oxidation and is a potential source for the formation of alumina inclusions. Thus N_2 pick up can be served as a crude measure of steel cleanliness and problems of SEN clogging [10].The calculation by Racker [12] showed that even 5ppm of $N_2$is sufficient to clog of 1m long and 20mm thick in a typical SEN.

Figure 4 shows the effect of nitrogen pick-up on the clogging rate. The figure shows that the N_2 pick up varies between 0 to 4 ppm in all the heats. A weak positive correlation has been found between the N_2 pick up and clogging rate indicating that the re-oxidation of aluminum due to contact with atmosphere is minimal.

3.1.2 Al Loss from LF to Tundish:

In low carbon Al killed steels (LCAK), the difference in soluble Al between the ladle and tundish is also an indicator of occurrence of reoxidation during the transfer operation [13]. However unlike N2 pickup which is primarily caused by aerial oxidation, reoxidation of Al can be taken place due to over oxidized slag e.g.FeO, MnO or other oxide components.

Figure 5 shows that there is a positive strong correlation found between clogging rate and Al fading , which indicates that aluminum reoxidation aggravates clogging during casting process. As the N_2 pick up shows a weak correlation with the clogging rate, the potential source of reoxidation of Al due to slag was further investigated by analyzing the oxide component (FeO+MnO) in the slag. These oxides FeO, MnO and SiO_2 in the slag react with the more powerful deoxidant Al present in the liquid steel to form inclusions near the slag or lining interface by the following reaction (Eq. 2):

$$SiO_2 / FeO / MnO + [Al] \rightarrow [Si]/[Fe]/[Mn] + Al_2O_3 \qquad [2]$$

These reoxidation products lead to more and larger alumina inclusions and may be act as a heterogeneous nucleation site for further grow of inclusions [16].

The Figure 6 shows that the effect of FeO+ MnO in the slag has been found to have strong correlation with the clogging rate. Higher oxide component of slag aggravates clogging, which indicates that the reoxidation of Al is primarily due to the high oxygen potential of slag.

3.2 Al addition practice in LF:

Particularly in LCAK steels, a step wise deoxidation practice is flowed to kill the oxygen to a lowest possible extend. In the first step during taping of steel from the vessel Al block is added and in the second step addition in the form of wire and blocks are added in the ladle furnace.

It has been observed that the more cube/block addition has beneficial effect of clogging which is shown in Figure. 7. It may be due to the fact that the Al cube is added at the beginning to reduce the oxide components (slag deoxidation) in the slag. The alumina inclusions, formed at the slag metal interface easily float out and thus reduce the clogging rate. However, the more wire addition leads to higher clogging due to formation of fine alumina inclusions inside the melt which is generally difficult to float out without adequate purging time or vacuum treatment. It is further seen that last stage Al addition at the ladle furnace processing lead to severe clogging (Figure. 8). It may be due to the addition of aluminum at the low saturation level of oxygen in the melt leading to angular, faceted type of inclusion morphology which having weak clustering tendency to float out. The morphology of inclusions deposited in the SEN clog sample is shown in Figure. 14.

Additions of Al in multiple batches were found to be more prone to clogging that the addition of Al in single batch (Figure.9). *Choudhary et al.* [16] found that multiple batch addition of Al leads to faceted alumina clusters, which is difficult to float out due to less clustering tendency. From the morphological examination of clog alumina particles (see Figure. 14) confirms the presence of faceted and plate like morphology which may be responsible for higher clogging tendency.

3.3 Total purging duration

A proper stirring practice in the ladle furnace is necessary to minimize the quantity of deoxidation inclusions [15]. Figure 10 shows the correlation between the clogging rates with the purging duration during the refining in Ladle furnace operation. It has been observed that the heats with higher purging duration is susceptible to less clogging comparing to the heats with less purging time. The studies by various researchers [15,16,17] shows that after alloying addition, vigorous stirring followed by gently argon bubbling is required for better floatation of alumina inclusions. Thus it is believed that the fine alumina inclusions which form under low super- saturation conditions must need sufficient stirring in the bath to coalescence and sinter together to form larger clusters for easy removal from the bath.

3.4 Superheat

Depending on the steel grade, the superheat value normally ranges from 20 to 40 ^{o}C with maximum casting speed to avoid breakouts. The network of clog grows rapidly when it is supported by solidified steel matrix [14] .These clogs generally contain a network of oxide particles which contains steel and forms an initial clog layer inside the inner wall of the tube. As the layer forms and the roughness of the inner wall increases the rate of clogging accelerates [15].

Figure 11 shows the correlation between the superheat and clogging rate. In spite of large scatter of data, it is evident that increase in superheat is beneficial to reduce clogging during casting. It is believed that increase in superheat improves the fluidity and hence lead to better alumina floatation.

3.5 Examination of clog morphology

The control of morphology of alumina during deoxidation to maximize the floatation has been studied by several investigators [16-17]. In the present study, the clog sample was collected from the exit hole of the SEN (Figure. 12). The clog sample was further investigated to examine by SEM at higher magnification for morphological characteristics. Angular, plate like and faceted morphology was observed in the collected clog sample, which is shown in Figure.13.The appearance of this type of inclusion morphology may be due the batch addition of Al in the ladle furnace or/and late addition of Al at low saturation of oxygen in the steel bath [16]. These faceted and plate like alumina inclusion generally have weak clustering tendency hence detrimental to castability of steel. Thus in order to improve the castability, attempt should be made to add aluminum in the ladle furnace in one batch as fast as possible [17].

4. Conclusion

Methodology to quantify the SEN clogging in a real-time basis, during casting operation has been developed. Further the influence of upstream process parameters on the clogging behavior was investigated. In addition to that, the morphology of clog material was studied to find the effect of addition pattern in LF and its influence on the inclusion morphology. The results of this work lead to the following conclusions:

1. A methodology for calculation of clogging index have been developed and its being installed in the casting shop to precise monitor of clogging during casting process. In addition to that the clogging rate per heat, an indicator of steel cleanliness was calculated to assess the casting behavior during casting.
2. Good correlation was found between the clogging rate and the LF process parameters. The increase of Al loss between ladle and tundish transfer operation, more oxidizing slag, addition more Al wire during the end of ladle furnace operation were found to increase the clogging rate. However addition of Al blocks, more purging time and addition of aluminums in single batch minimizes the clogging during continuous casting of steel.
3. Control of oxide component in slag, addition of Al at the beginning decrease the clogging rate.
4. The formation of faceted and plate like morphology of alumina in the clog is due to batch addition of aluminum and this practice should be avoided for better inclusion floatation.

Acknowledgements

The authors would like to acknowledge the support from the management of Tata Steel to carry out this work and publish the same. The authors would also like to thank Mr P. P. Sahoo, Principal Researcher, and Tata Steel for his support and help in editing the document.

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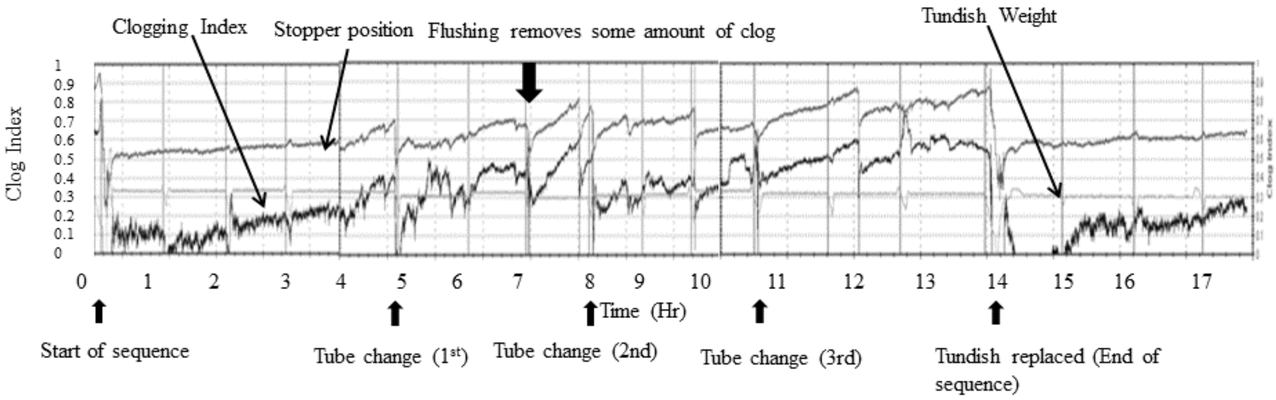

Fig 1: Nozzle clogging index model output from level 2 control system

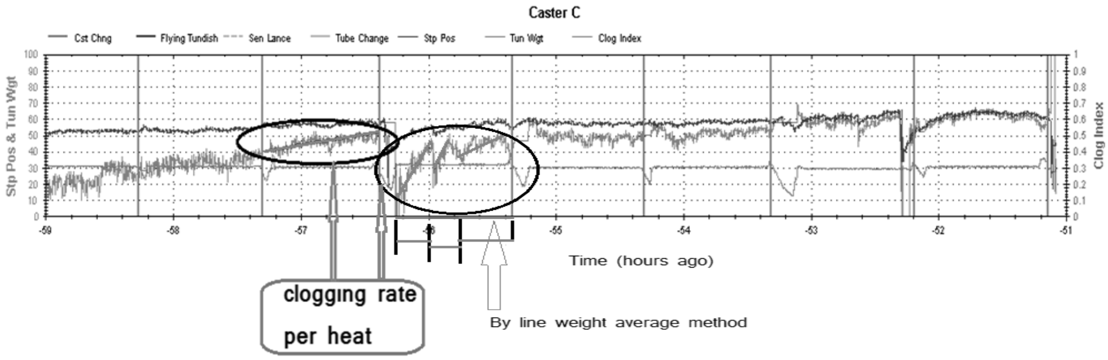

Figure. 2: Calculation of clogging rate from the clogging monitor graph

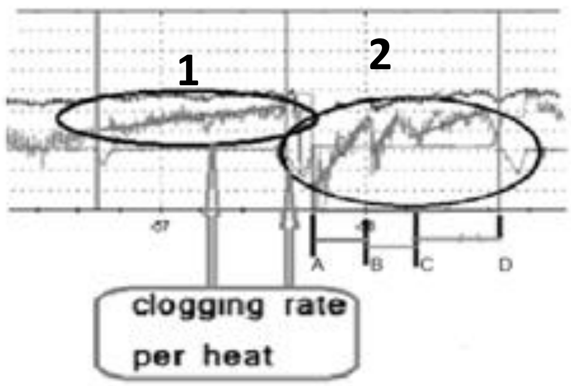

Figure. 3: Calculation of clogging rate in the heats where multiple flushing has occurred

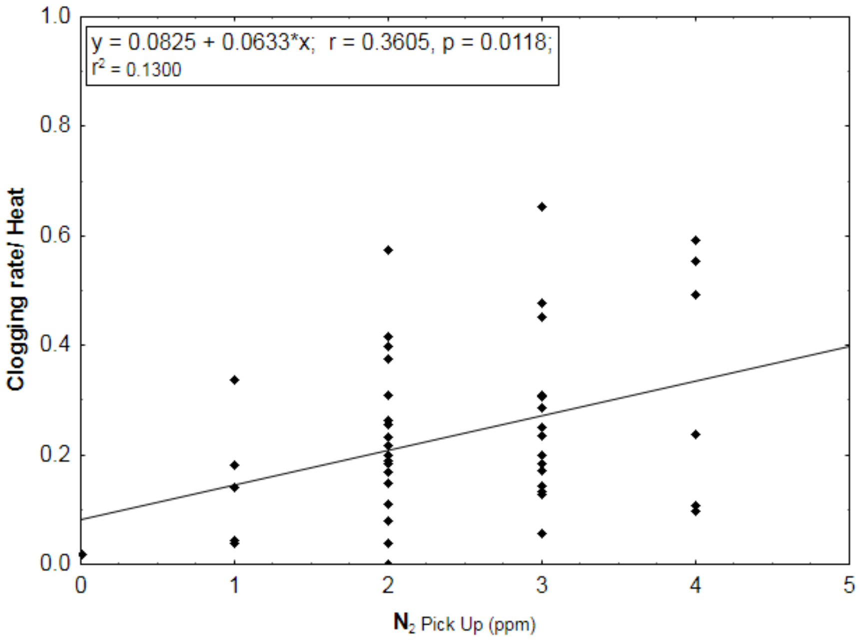

Figure. 4: Effect of N_2 pick up on clogging rate

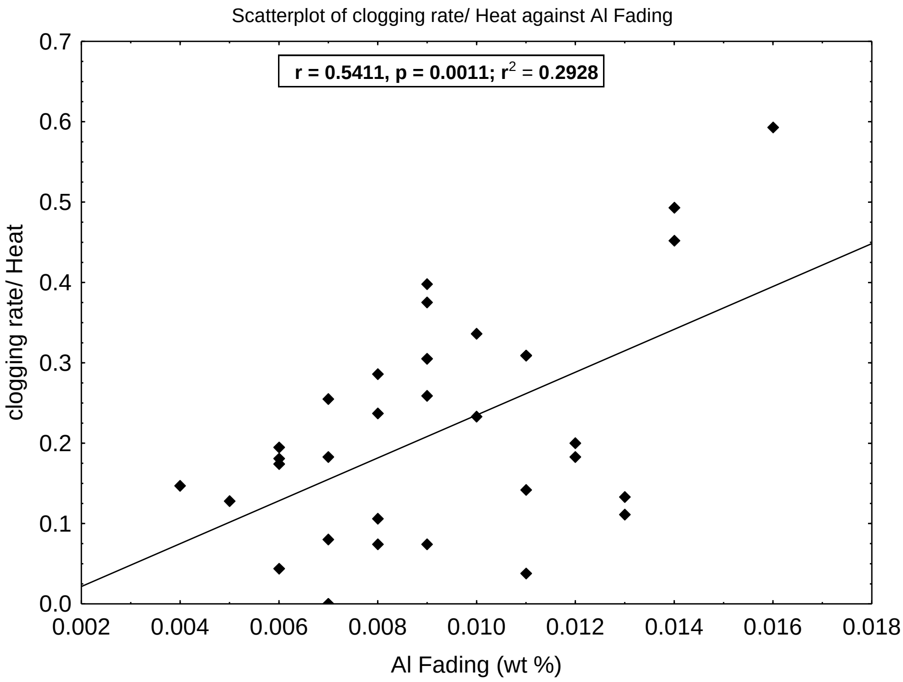

Figure. 5: Effect of Al fading on clogging rate

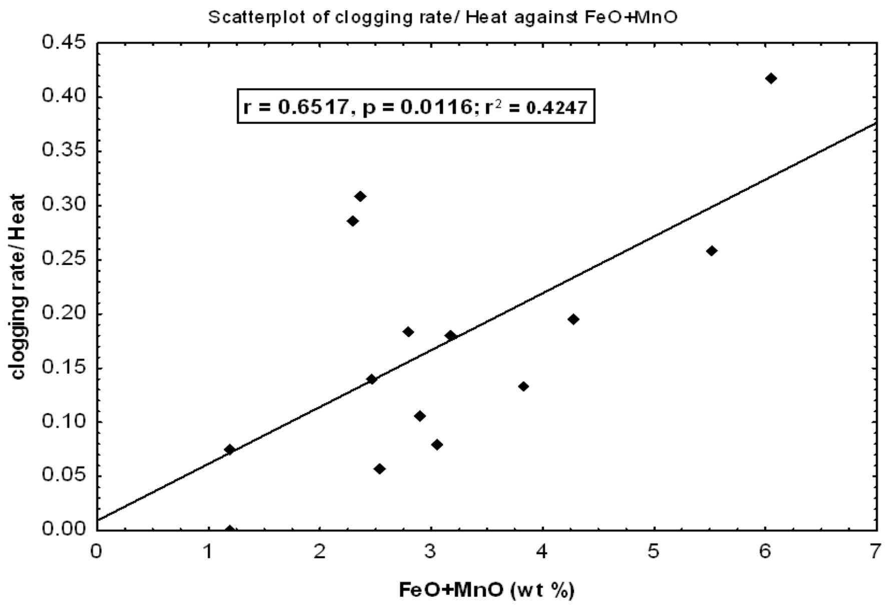

Figure. 6: Effect of oxide component of slag on clogging rate

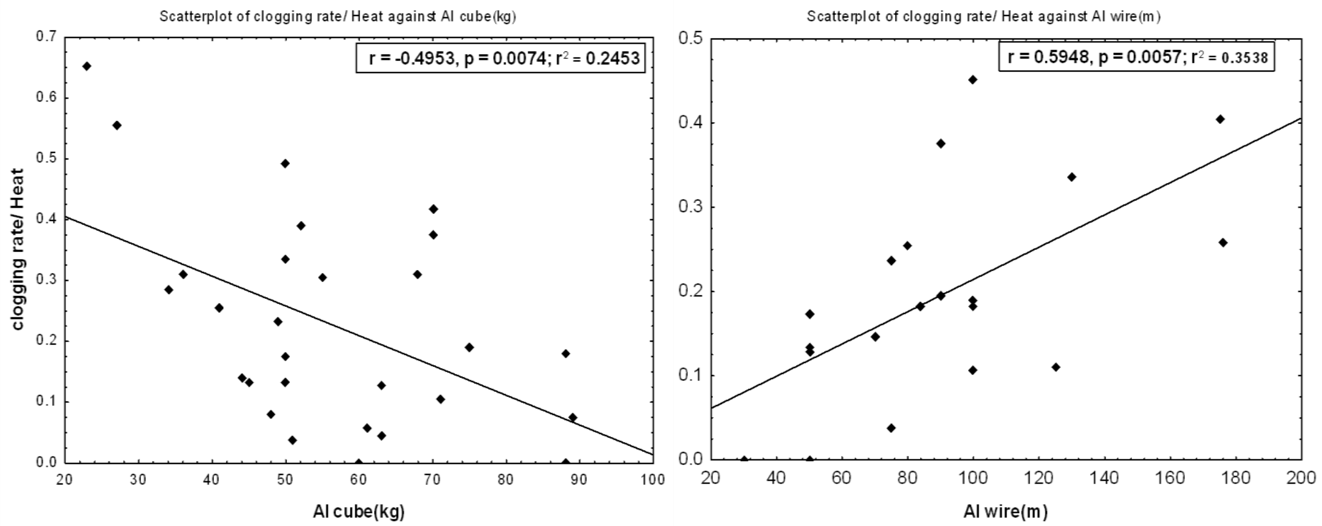

Figure. 7: Effect of type of Al addition on clogging rate a) Al block/cube addition b) Al wire addition

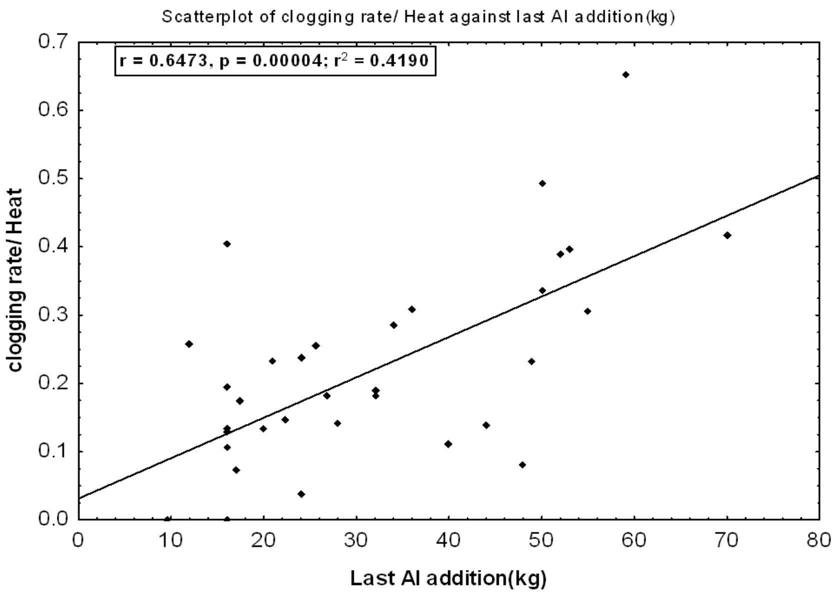

Figure. 8: Effect of the last Al addition on clogging rate

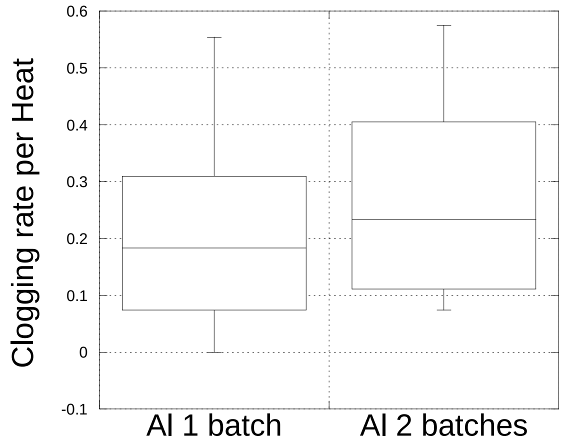

Figure. 9: Effect of batch addition of Al in Ladle furnace

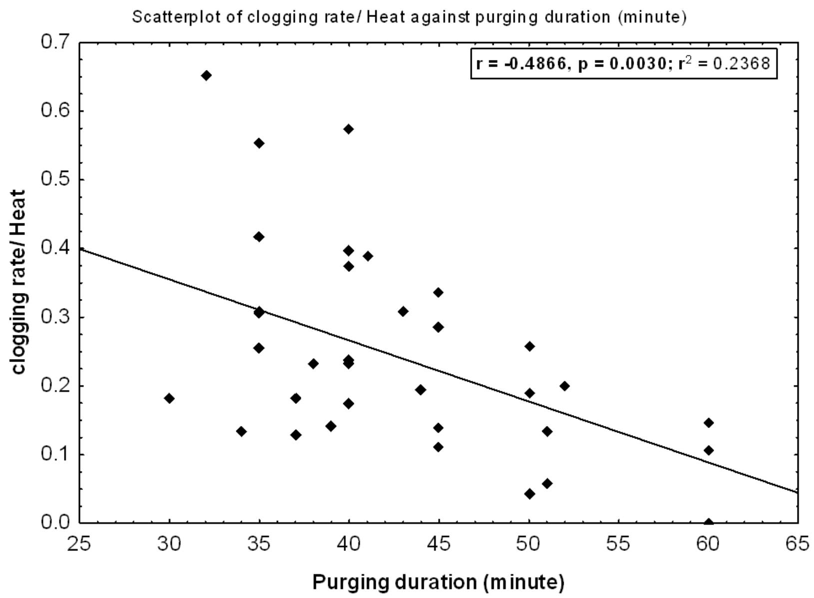

Figure.10: Effect of purging duration on clogging rate

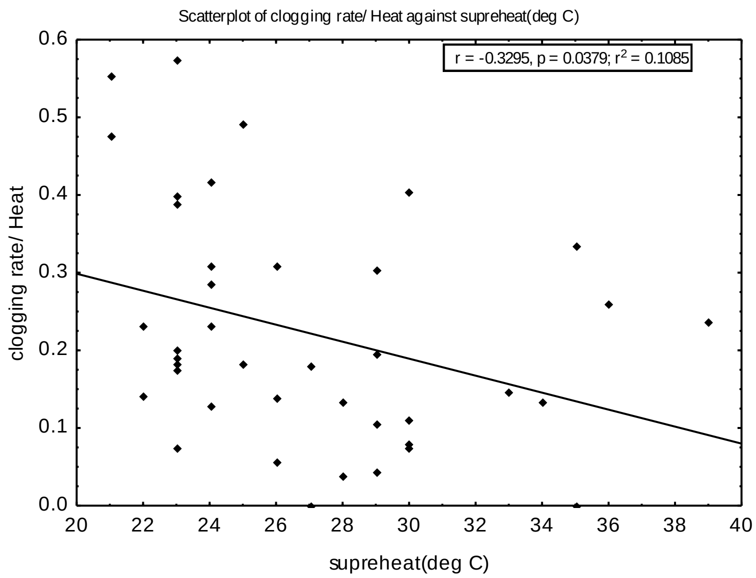

Figure. 11: Effect of superheat on clogging rate

Figure. 12: Cross section of clogged SEN, where samples were taken for analysis

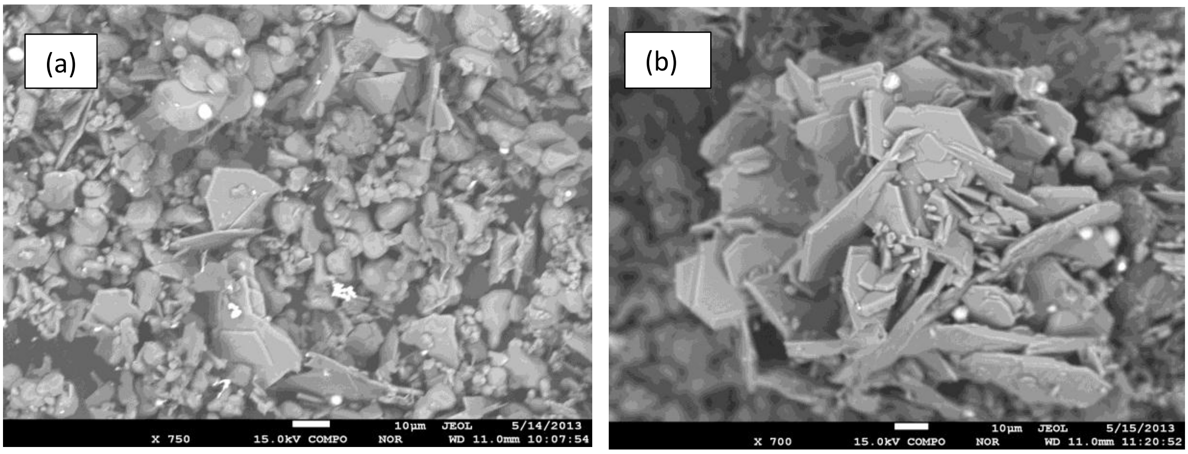

Figure. 13: Alumina inclusion morphologies (a) plate like and faceted inclusions (b) plate like clusters

Table 1: Details of slab casting machine

Specification of Slab caster	
Machine Type	Curved with continuous unbending
Machine Radius	9.6m
Number of strands	1
Heat size	160tonne
Slab width	950-1500mm
Slab thickness	215 mm
Casting speed	1.75 m/min (max)
Tundish capacity	36tonne