Study on change in mould slag characteristics during casting Ti *containing steel grades.*

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ABSTRACT

The change in mould slag composition during casting of high alloy steel is caused by the redox reaction between molten steel and mould flux. Mould flux generally contains a certain amount of SiO_2, but elements such as Al, Mn and Ti in high alloy steels reduce the SiO_2 in the mould flux, causing remarkable changes in the composition of the mould flux. As a result, the properties of the mould flux change greatly as continuous casting proceeds, and casting becomes unstable, causing various types of process abnormality and defects. Effect of Ti in steel grade on mould slag is studied extensively through high temperature laboratory measurements to find out the reason for high heat flux in the mould. TiO_2 gets picked up by the mould slag up to an extent of 3%. This results in decreasing the slag viscosity by up to 10% and decreases slag break temperature by 30-40^{o}C.

INTRODUCTION

Mould flux plays many important roles in the continuous casting of steel, including (1) providing insulation to molten steel, (2) prevents reoxidation of the molten steel, (3) helps in adsorption of inclusions, (4) controls mould heat transfer, and (5) ensures lubrication between the mould and solidified shell as described by (Mills, 2003, 2016). In order to produce high-quality slabs and realize stable production, it is extremely important to design and use the optimum mould flux that can fulfill these roles based on the molten steel composition and casting conditions. Even if mould fluxes are designed and used their properties change during casting. For example, as described by (Mills, 2016, Rudnizki, 2014, Wang 2017) the composition change that occurs in the mould flux during casting of high alloy steels such as high Al, high Mn, and Ti steel.

Cho, 2017, Kim, 2018 and He, 2019 showed that, composition change of mould flux during casting of high alloy steel is reportedly caused by the reduction reaction between molten steel and mould flux. Mould flux generally contains a certain amount of SiO_2, but elements such as Al and Ti in high alloy steels reduce SiO_2 in the mould flux, causing remarkable changes in the composition of the mould flux. As a result, the properties of the mould flux change greatly as continuous casting proceeds, and casting becomes unstable, causing various types of problems and defects. This can be attributed to the mould flux and liquid steel interaction and the reactions are mentioned below:

$$3SiO_2 + 4Al \rightarrow 2Al_2O_3 + 3Si \ldots (1)$$

$$3MnO + 2Al \rightarrow Al_2O_3 + 3Mn \ldots (2)$$

$$SiO_2 + Ti \rightarrow Si + TiO_2 \ldots (3)$$

SiO_2 in the mould flux is continuously reduced by Al and Ti and form Al_2O_3 and TiO_2. In the following study, effect of Ti on mould flux behavior is reported.

EXPERIMENTATION

Steel grade containing Ti and another steel grade without Ti are chosen for experimentation during continuous casting of steel. The compositions of both steel grades are presented in Table 1.

Table 1: Composition of steel used for plant trials

Steel Grade	C	Mn	Al	Si	Ti
Grade 1	0.04	1.2	0.02	0.09	0.1
Grade 2	0.05	0.45	0.02	0.07	0.01

It is ensured that the same mould flux is used during casting of both steel grades to study the effect of Ti on mould slag properties. Slag samples are collected at a particular interval from each heat from a casting sequence for both steel grades. The timing chosen for sample collection is in the middle of the casting for the particular heat. Sampling is done carefully by removing the top dry powder layer and sinter layer, so that only liquid slag is collected using a stainless-steel spatula. The collected slag samples are sent for the following analysis after grinding them in a ring mill.

1. Chemical analysis using XRF
2. Hemisphere and flow temperature measurement using a heating microscopy
3. Viscosity and crystallization temperature measurement using high temperature viscometer
4. Measurement of fluidity using inclined plane test
5. SEM-EDS analysis of mould slag

RESULTS AND DISCUSSIONS

Change in Chemical Composition:

After collecting mould powder and mould slag, the slag is sent for chemical analysis using XRF. The results for the interacting components of mould powder and mould slag are reported in Table 2 below. We can observe that in case of casting of steel grade containing Ti, an increase of about 3% of TiO_2 is observed in the mould slag. This increase in TiO_2 can be attributed to equation (3). Similarly the MnO pick up in the Ti containing steel grade is higher due to higher Mn in steel.

Table 2: Chemical composition of mould slag with only the affected components (A) Mould Powder, (B) Steel grade without Ti (C) Steel grade with Ti

(A)

Mould Powder	Fe(T)	CaO	SiO2	MgO	MnO	Al2O3	TiO2
Mould Powder	1.3	32.3	36.4	0.93	0.83	5.1	0.08

(B)

Heat no	Fe(T)	CaO	SiO2	MgO	MnO	Al2O3	TiO2
Heat 1	1.27	34.6	38.53	0.89	1.65	9.9	0.26
Heat 2	0.92	34.97	38.73	0.97	1.29	9.74	0.27
Heat 3	0.9	37.65	37.78	0.84	1.62	9.43	0.24

(C)

Heat no	Fe(T)	CaO	SiO2	MgO	MnO	Al2O3	TiO2
Heat 1	1.29	43.68	32.72	1.31	4.03	8.47	**2.74**
Heat 2	1.07	45.22	31.49	1.37	5.17	8.65	**2.34**
Heat 3	1.25	43.08	33.9	1.23	4	7.9	**2.89**

Change in Melting Characteristics of Slag:

The melting characteristics of slag are determined using a heating microscope (Model: EM201 – 15, Hesse instruments). A cylindrical pellet of size 3 mm height and 3 mm diameter is made with pellet making hand press using the fine slag powders. This pellet is then put inside the furnace to see the continuous change in its shape and other characteristics while heating the furnace. The images are captured continuously using a CCD camera. A sample image showing the hemisphere temperature and flow temperature of slag is shown in Figure 1.

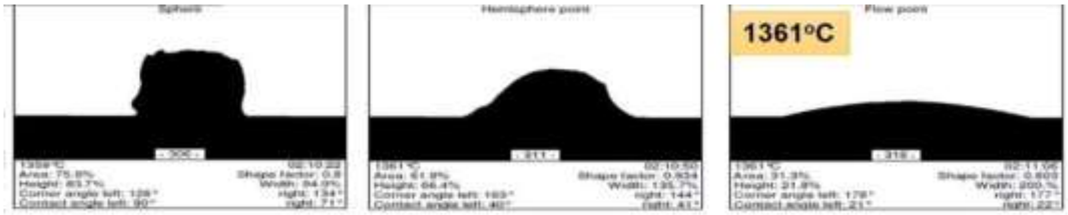

Figure 1: Determination of hemisphere and flow temperature using heating microscope

The results of measurement of all slag samples are reported in Table 3. We can observe that the melting/flow temperature of the slag increased by 50 - 60ºC with increase in TiO_2 content in the slag.

Table 3: Change in melting characteristics:

		Hemisphere Temp.	**Flow Temp (ºC).**
Grades without Ti			
	Heat 1	1108.7	1115
	Heat 2	1101.6	1112
	Heat 3	1109.2	1120
Grades with Ti			
	Heat 1	1140	1161
	Heat 2	1146	1169
	Heat 3	1133	1160

Change in Viscosity and crystallization of the slag:

Two the slag samples, one with TiO_2 and one without TiO_2, are subjected to measurement of high temperature viscosity using a high temperature viscometer. The results of viscosity measurement are reported in Figure 2. As we can see, the viscosity of the mould slag decreased by 10% at 1300ºC when there is a TiO_2 pick up of about 3%. At the same time the break temperature falls drastically by 50°C making the slag more glassy. This will increase the heat flux through the mould wall.

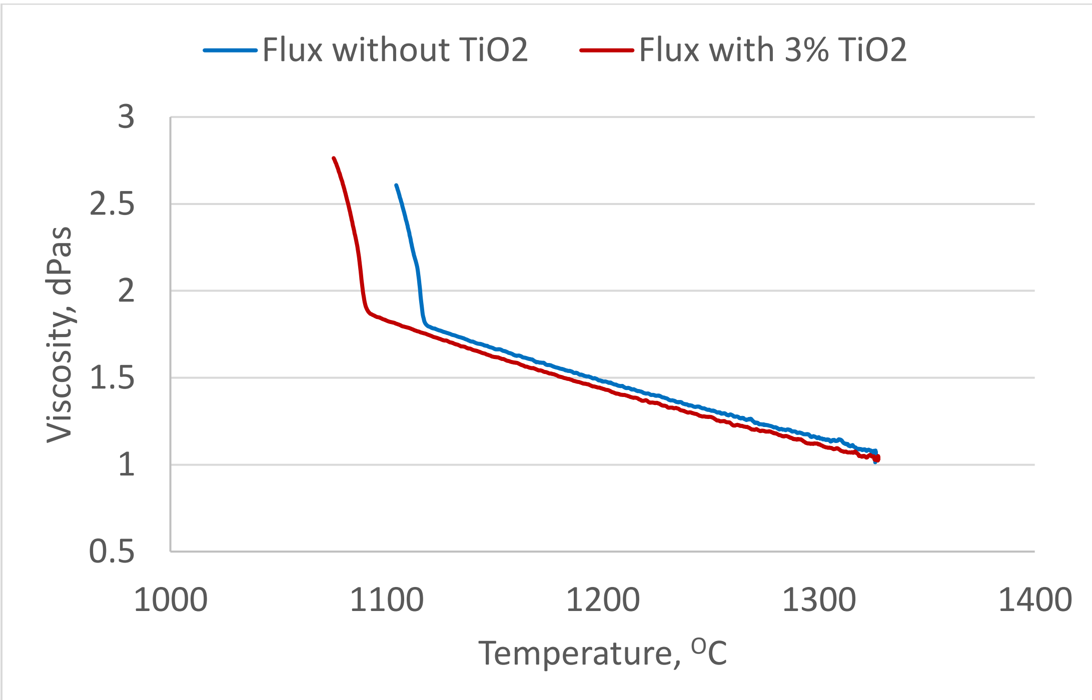

Figure 2: Viscosity and Break Temperature of mould slag with and without TiO_2

Slag Microstructure using SEM and EDS

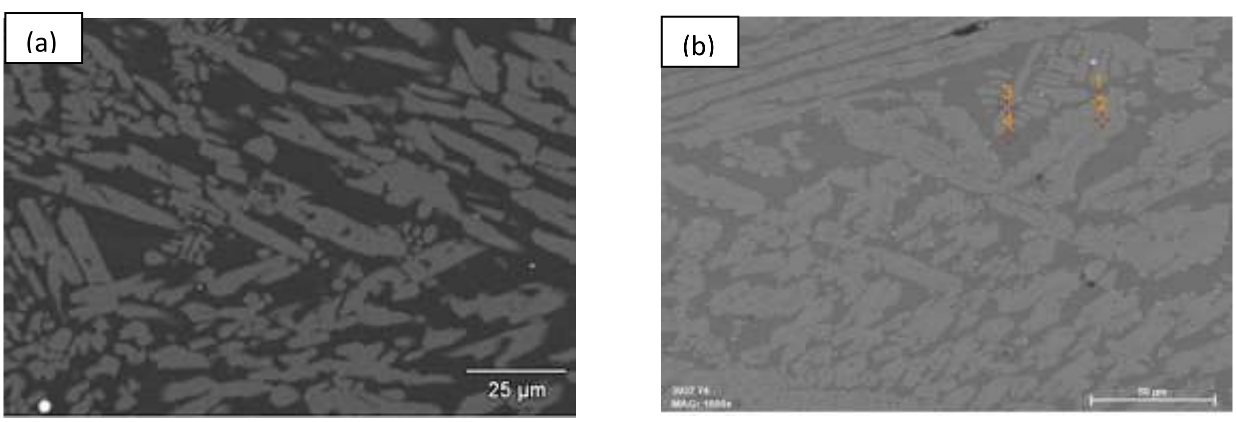

Figure 3: SEM-EDS analysis of Mould slag (a) showing only cuspidine in non TiO_2 containing slag, (b) showing Perovskite formation (Point 1), Cuspidine (Point 3 and 4) for Mould slag containing 3% TiO_2

Further analysis of mould slag from the Ti containing steel grade under scanning electron microscope proved the formation of secondary phase of Perovskite ($CaTiO_3$) along with Cuspidine ($3CaO.2SiO_2.CaF_2$) as shown in Figure 3.

Change in Fluidity of slag

The fluidity of slag is measured using an inclined plane test, where a measured quantity of slag is melted at 1350ºC in a furnace and poured over inclined plane to solidify. The ribbon length is measured which is a measure of its comparative fluidity. The results are reported in Figure 4. As can be seen clearly, the slag with TiO_2 had more ribbon length compared to the slag without TiO_2. This also corroborate the lower viscosity value as shown above for the TiO_2 containing slag.

Mould Slag from steel grade without Ti					**Mould Slag from steel grade with Ti**			
Heat 3	Heat 2	Heat 1	Mould Powder		Heat 3	Heat 2	Heat 1	Mould Powder

Figure 4: Fluidity of slag measured using inclined plane test method.

CONCLUSIONS

The following points can be concluded from the above study:

- TiO_2 gets picked up by the mould slag while casting of Ti containing steel grade up to an extent of about 3% when the steel contained 0.1% Ti.
- The melting temperature of mould slag with TiO2 increases by ~50ºC when there is TiO_2 pick up in the slag by 3%.
- TiO_2 in mould slag decreased the slag viscosity by up to 10% and decreased slag break temperature by ~40ºC.
- Perovskite phase formation is observed in case of TiO_2 pick up in mould slag.
- This reduces the slag pool depth, hence due to thin glassy slag layer between the mould and the solidifying strand, the heat transfer is high and reflected in the Breakout Detection System.

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