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Corrosion Behaviour of Submerged Entry Nozzle (SEN) During Continuous Casting of Steel

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Abstract: Submerged Entry Nozzle (SEN) is a type of ceramic or composite tube. This tube used in continuous casting machines is installed between the reservoir (tundish) and the copper mold. The main function of this tube is not only deliver and control the flow direction of liquid steel into the mold but also to protect reoxidation of liquid steel during transfer from the tundish into the copper mold. In general, SEN should be durable and stable at high temperatures during long sequence continuous casting. One important factor on life time of SEN during operation is by preheating of the SEN itself. In this research, effects of preheating temperature and preheating time of different commercial SEN grades are taken into consideration. To observe the corrosion behavior and life time of the SEN during continuous casting, each preheated SEN is installed in a real plant during casting of various liquid steel grades. Results of this study can be used to select a suitable preheating condition of the SEN to minimize any trouble for long sequence of continuous casting process of steel.

Key words: Continuous casting of steel, Submerged Entry Nozzle (SEN)

INTRODUCTION

The occurrence of Submerged Entry Nozzle (SEN) corrosion is often a phenomenon determining the duration of the continuous casting sequence. Flow of liquid steel through inner wall causes erosion and finally, leads to corrosion of the SEN. This problem leads to lower productivity and higher production costs. To avoid corrosion problem or extend the life time of SEN during casting, the SEN must be properly prepared before it is installed into casting machine. Suitably, preheating temperature and preheating time are consideration for preparation of SEN. Too low preheating temperature leads to clogging problem and fracture of the SEN may occur. Too high preheating temperature leads to oxidation of the SEN itself. Termination of sequence continuous casting due to clogging and shape design of SEN to prevent any clogging problems are widely reported (Dekkers, 2002; Zhang *et al.*, 2008; Wanschoor, 2001). However, only few has mentioned to the relation of preheating process and degradation of SEN during casting of steel. In this study, therefore, the effect of preheating method on corrosion of SEN during casting of steel is taken into consideration. Test series are made in a real Continuous Casting Machine (CCM) to produce a billet of steel.

MATERIALS AND METHODS

Size and shape of SEN: Two types of commercial SEN grades, type A and B are used in this study. Figure 1 shows a scheme of shape and size of SEN samples which were used in this study. Main properties are given in Table 1.

Preheating process

To compare the physical change: The samples of SEN are preheated at 750-900°C then these samples are installed in CCM. To compare the change of physical property during casting, 3 pieces of SEN type A and 2 pieces of SEN type B are installed to produce the same chemical composition of steel simultaneously. Corrosion behavior and leakage of SEN during casting will be monitored and documented.

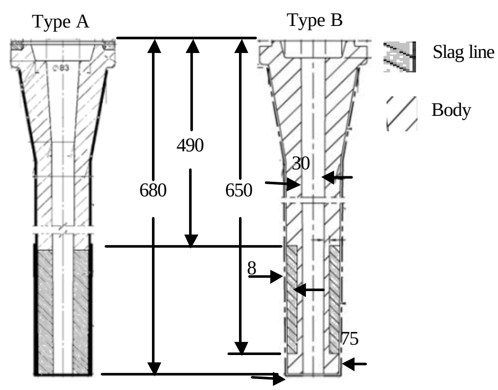

Fig. 1: The shape and size of SEN type A and B

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Table 1: Chemical composition and properties of SEN type A and B

Type, part	Material and component: Materials	Material and component: Main component	Bonding	Composition (wt%): Al_2O_3	Composition (wt%): SiO_2	Composition (wt%): ZrO_2	Composition (wt%): LOI	Physical property: Condense (g cm^{-3})	Physical property: Porosity (vol.%)
Type A, body	Alumina-carbon	Graphite, brown fused alumina	Carbon bond	71.4	19.7	-	32.3	2.36	17.20
Type A, body	Zirconia -carbon	Zirconia, graphite	Carbon bond	0.7	0.5	92.7	12.0	4.00	15.70
Type A, body	Alumina-carbon	Graphite, brown fused alumina	Carbon bond	59.0	11.0	-	29.0	2.51	16.00
Type A, body	Zirconia -carbon	Zirconia, graphite	Carbon bond	-	0.5	82.0	12.5	4.00	14.00

To adjust the proper preheating temperature: The SENs are preheated with different temperature in between 500 and 1000°C before they are installed in CCM. The physical change of each SEN during casing are monitored and documented.

To adjust the proper preheating time: In order to determine, the preheating time to homogenize the temperature of SEN, the temperature during heating up is measured every 5 min.

RESULTS AND DISCUSSION

Corrosion behavior and life time of SEN: Data of physical change of SEN was collected from two sequences casting, set 1 are given in Table 2 and set 2 are given in Table 3. These SENs were installed in the same CCM to produce steel billet with the same chemical composition and the same casting conditions.

With preheating at 750-900°C, SEN type A showed that corrosion occurred at the outer surface of SEN around slag zone. Inner surface of SEN type, A showed only shallow local corrosion. By the same preheating temperature, SEN type B showed the intensive corrosion at inner surface. Finally, leakage of SEN is appeared and lead to stop the casting sequence. It can be observed that the whole slag zone of SEN type A is made of zirconia while type B is made of zirconia only at outer surface.

We can indicate that zirconia is a necessary component of SEN slag zone. This is due to its high resistance against corrosion. Moreover, the leakage data of SEN of 13 casting sequences (65 pieces used) were documented. It was found that 7 of 48 pieces or 14.6% of SEN type A is leaked but 7 of 17 of 41.2% of SEN type B is leaked. This is indicated that life service time of SEN type A is longer than that of SEN type B.

Proper preheating temperature: To study the effect of preheating temperature on corrosion behavior the different types of SEN were preheated at different temperature.

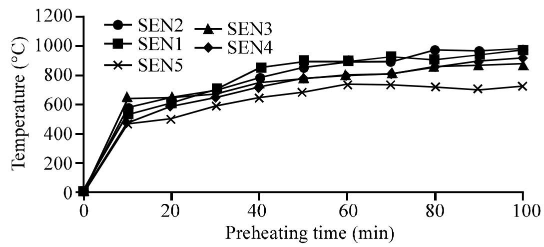


Fig. 2: Heating curve of SEN

SEN type A were preheated in the range of temperature between 900 and 1100°C. Test conditions are given in Table 4. It is found that SEN at strand 2 (preheated at 1100°C) has a higher corrosion level in compare with strand 3 and 4 (preheated at 1000°C). SEN at Strand 5 with preheated at lower temperature (900°C) shows a lower corrosion level.

SEN type B were preheated in the temperature range of 500 and 1000°C. Test conditions are given in Table 5. It is found that SEN at strand 1 preheated at lower temperature (560°C) showed the higher corrosion level in compare with other 4 SENs. SEN at strand 2 with preheated at 990°C revealed the high corrosion level at inner surface and moderate corrosion level at outer surface. SEN at strand 3-5 with preheated in between 700-900°C showed a little corrosion level at inner and outer surface.

Re-test series to study the effect of preheating temperature on corrosion behavior of SEN type A were done. Results in Table 6 indicated that low corrosion level is appeared when the SEN are preheated in the temperature range of 750 and 900°C.

Proper preheating time: Relation of preheating temperature with time is shown in Fig. 2. It indicated that the temperature of SEN is quickly raised within 10 min and then slowly increased. After 40 min, the temperature of SEN was increased very slowly and is then relatively constant. Therefore, to ensure the homogenization of the SEN temperature, the duration of preheating process should be at least 40 min but should not exceed 90 min. This is due to too long preheating period may cause oxidation of the SEN itself (Hanse, 2000; Vesuvius, 2000).

Table 2: Comparative data of SEN of casting set 1

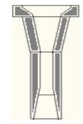
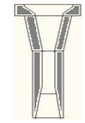
Data of casting	Strand number-SEN type 1-Type A	2-Type A	3-Type A	4-Type B	5-Type B
SEN preheating temperature (°C)	760	820	790	850	780
Casting time (h)	17.59	17.57	18.04	15.18	14.22
No. of heat in sequence	24	24	24	21*	20*
Appearance of corrosion				 SEN tip is lost	 SEN tip is lost
Height of SEN after stop sequence (mm)	680	680	680	470	460
Inner diameter after stop sequence (mm)	36	37	35	72	70

Table 3: Comparative data of SEN of casting set 2

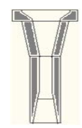
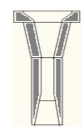
Data of casting	Strand number-SEN type 1-Type A	2-Type A	3-Type A	4-Type B	5-Type B
SEN Preheating Temperature (°C)	719	609	890	566	622
Casting time (h)	15.6	16.0	15.6	16.0	11.5
No. of heat in sequence	21	21	21	21	13*
Appearance of corrosion				 SEN tip is lost	 SEN tip is lost
Height of SEN after stop sequence (mm)	680	680	680	550	475
Inner diameter after stop sequence (mm)	33	34	32	67	70

Table 4: Effect of preheating temperature on corrosion behavior of SEN, trial 1 SEN type A

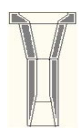
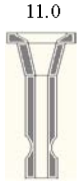
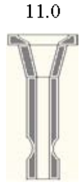
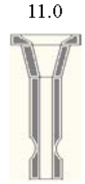
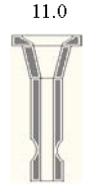
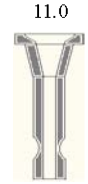
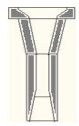
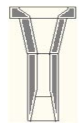
Casting details	Strand number-SEN type 1-Type A	2-Type A	3-Type A	4-Type A	5-Type A
Preheating temperature (°C)	1,100	1,100	1,000.00	1,000.00	900.00
Preheating period (h)	0	12.49	12.48	12.43	12.43
No. of heat in sequence (heat)	0*	16	16.00	16.00	16.00
Appearance of corrosion	-	 SEN tip is lost			
Height of SEN (mm)	-	600	680.00	680.00	680.00
Inner diameter (mm)	-	48.0	34.00	34.00	33.50
Outer diameter (mm)	-	-	59.50	60.00	62.00

Table 5: Effect of preheating temperature on corrosion behavior of SEN, trial 2 SEN type B

Casting details	Strand number-SEN type 1-Type B	2-Type B	3-Type B	4-Type B	5-Type B
Preheating temperature (°C)	560.0	990.0	900.0	800.0	770.0
Preheating period (h)	8.2	8.2	8.2	8.2	8.2
No. of heat in sequence (heat)	11.0	11.0	11.0	11.0	11.0
Appearance of corrosion					
Height of SEN (mm)	680.0	680.0	680.0	680.0	680.0
Inner diameter (mm)	39.0	39.0	35.0	34.0	34.5
Outer diameter (mm)	57.5	65.0	74.5	78.0	77.5

*Leak before the casting is finished

Table 6: Effect of preheating temperature on corrosion behavior of SEN, trial 3 SEN type A (retrial)

	Strand number-SEN type				
Casting details	1-Type A	2-Type A	3-Type A	4-Type A	5-Type A
Preheating temperature (°C)	640	1,000	900.0	810.0	730
Preheating period (h)	11.1	5.1	11.1	11.1	8.6
No. of heat in sequence (heat)	13	7*	13.0	13.0	11*
Appearance of corrosion	 SEN tip is lost	 SEN tip is lost			
Height of SEN (mm)	570	665	680.0	680.0	680
Inner diameter (mm)	60.0	51.0	32.8	32.6	34.0
Outer diameter (mm)	-	-	63.0	66.0	62.0

*Leak before the casting is finished

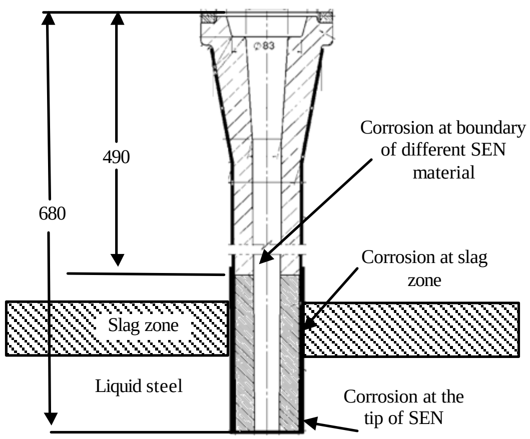


Fig. 3: A schematic representation of the installation of SEN in CCM during sequence casting

Simulation of corrosion behavior of SEN: A schematic diagram of the installation set up of SEN in the CCM is shown in Fig. 3. During casting the outer surface of the SEN contacts directly with liquid steel and slag. The interaction between slag and SEN's body at high temperature for long sequence casting will lead to corrosion of the SEN materials. At the tip of SEN, the boundary of SEN's materials and slag zone are often found the higher corrosion level. It was found that the critical area always comes from the boundary of different SEN material. This area composed of different chemical composition and easily reacts with liquid steel or with slag at high temperature. The corrosion of SEN is originated in this area. Other critical corrosion area of SEN is around the slag zone. According to investigation, the corrosion mechanism of this area is based on dissolution of the refractory oxide phase dissolve in the slag. This leads to breakage of the SEN and finally stop sequence casting.

CONCLUSION

This investigation has been carried on the corrosion behavior of commercial SEN in a real continuous casting machine. Key findings of this study can be concluded as follows:

- Resistance against corrosion and lifetime of SEN type A are higher than that of SEN type B. This is due to the body of slag zone of SEN type A is made of zirconia while slag zone of SEN type B composed of zirconia only on outer surface
- Proper preheating temperature for both SEN type is in between 750 and 900°C. This temperature range gives lower corrosion level of SEN
- Proper preheating period time for both SEN type is 40-90 min
- Corrosion originated at the boundary of SEN materials is the primary degradation of SEN. This corrosion type often appears. Corrosion at slag zone of SEN is also observed

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