IMPROVEMENT OF NOZZLE CLOGGING FOR CONTINUOUS CASTING OF ULTRA LOW CARBON STEEL

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ABSTRACT

In the continuous casting of steel, the submerged entry nozzle is used to prevent reoxidation by air during the pouring of the molten steel supplied from the tundish to the mold. The submerged entry nozzle, therefore, plays a very important role in assuring high product quality.
However, clogging of the submerged entry nozzle often occurs in the continuous casting of ultra low carbon steel, which causes degrading product quality, and also can lead to stoppage of the casting process. So, many researchers have been trying to develop the nozzle to suppress clogging. But, evaluation of the nozzle performance is difficult, because nozzle clogging is complexly affected by operation condition of steelmaking and continuous casting process.
In this paper, a new test method with the nozzle that has two different materials of inner section was used to consider performance of the nozzle only.
The test nozzle with conventional material(more than 20wt% carbon) and with low carbon material(less than 5wt% carbon) of Al_2O_3, SiO_2, C was manufactured by Vesuvius and was used in field test. After casting, in order to evaluate performance of the nozzle material, measurements of the clogging thickness of two different materials were carried out. According to test results, Hyundai Steel Company was able to improve clogging by optimizing the nozzle material.
Keywords : continuous casting, SEN, clogging

INTRODUCTION

The morphology of clogging on the inner wall of the submerged entry nozzle(SEN) is classified into the following four cases as shown in Fig. 1. Type 1 is powdery alumina layer, type 2 is mixture of metal and inclusions, type 3 is mixture of type 1 and type 2, type 4 is only metal without inclusions. In case of SEN clogging of ultra low carbon steel, the network alumina layer exists on the nozzle side and metal containing many alumina clusters exists on the molten steel side like type 3.[1]
SEN clogging of ultra low carbon steel is mainly influenced by cleanliness of molten steel and is accelerated by CO, SiO gases emitted from SEN material at refractory and molten steel boundary due to Al_2O_3 that is generated by reaction dissolved Al in molten and CO, SiO gases at high temperature.[1, 2] For reduction of this clogging, low carbon liner SEN has been used at some companies. The low carbon liner contains a small amount of carbon component so that it does not emit these gases and make liquid layer by penetration of MnO. MnO is generated by reaction between SiO_2 in liner and Mn in molten steel.[3, 4]

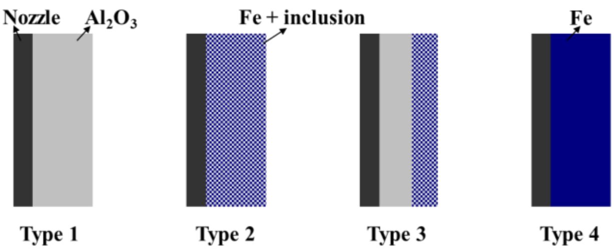


Fig. 1 Morphology of nozzle clogging

So, low carbon liner SEN was manufactured by Vesuvius and was tested at Hyundai-steel company to decrease a clogging of ultra low carbon steel.
Up to the present, SEN tests have been carried out by the way which is conventional SEN in one strand and new SEN in the other strand.
However these tests are hard to evaluate by difference between both strands such as deviation of molten steel flow, installation deviation of tundish refractories, air entrainment by Ar line leak of stopper and inner nozzle.
So, many test methods were considered and new test method was finally designed to evaluate two materials at one strand without disturbance factors.
This study reports method and the results of the new test.

EXPERIMENTAL PROCEDURE

All SENs were tested at ultra low carbon steel, and performance test was carried out, after new test.
After the tests, all SENs were longitudinally cut for comparison evaluation of clogging thickness.
In case of new tests, two liner materials were evaluated at one SEN, and in case of performance tests, two materials were used in each strand and were evaluated.

1. Testing Nozzle

Testing nozzle is the new SEN that has two different material liners, and is designed to evaluate two materials at one strand. Two liners are located from upper part of port to upper part of slagline, and conventional liner is placed in half of SEN while low carbon liner in the other half of SEN as shown in Fig. 2.

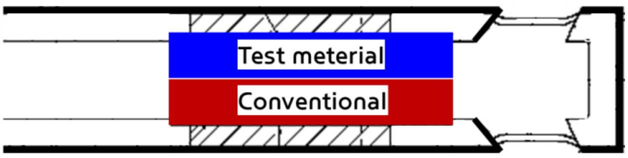


Fig. 2 Sketch of testing nozzle

2. Chemical composition

Main compositions of liners are as below.

Tab.1 Main compositions of liners

Composition	SiO_2	Al_2O_3	C
Conventional	31.1	40.9	25.0
Low Carbon	42.0	50.1	5.0

RESULTS AND DISCUSSION

1. New test

1.1 Preheat test

Refractory is vulnerable to thermal shock as carbon content decreases.
Testing nozzle has low carbon liner, and in addition, is especially possible to crack at interface of two liners. So, before

new test, preheat test was carried out for confirmation of crack occurrence.

SEN was preheated for 150 minutes by the burner that is used at continuous casting plants. Final preheat temperature was 1250℃. Fig. 3 shows result of preheat test. Crack are not observed at anywhere of SEN.

Fig. 3 Cross section of testing nozzle, after preheat test

1.2 Test result

Fig. 4 shows a 4th test result of new tests. Upper part of picture is conventional liner, and lower part is low carbon liner. Clogging thickness of low carbon liner is less than conventional liner.

So, when SEN is longitudinally cut after test, it is possible to check difference of clogging thickness of two liners for comparison evaluation. With this method, tests were carried out.

Fig. 5 shows clogging index of new tests. Clogging thickness was different by each test, but difference of clogging thickness by liners in testing nozzle was checked without disturbance factors.

Low carbon liner is clogged more than conventional liner in the 4th test that clogging thickness of both liners was the thinnest in the tests. But, in all tests except for 4th test, low carbon liner is clogged less than conventional SEN.

Fig. 4 Cross section of testing nozzle of 4th test

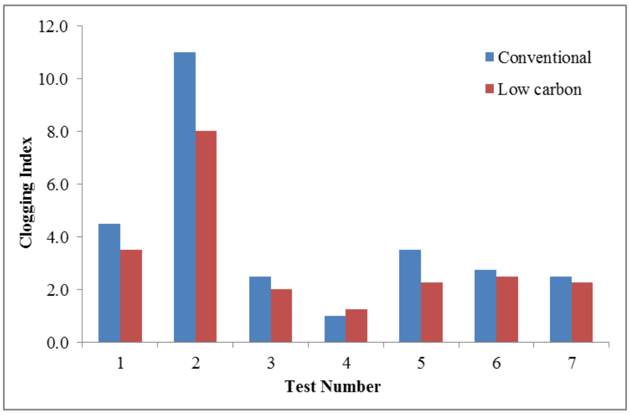
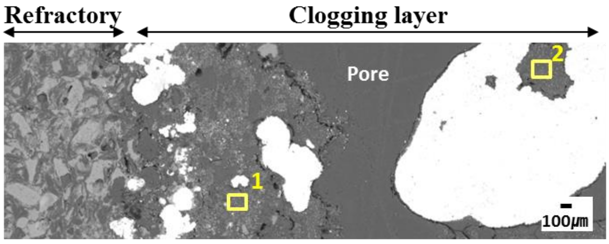


Fig. 5 Comparison of the clogging thickness in conventional and low carbon liner

1.3 SEM-EDS analysis of liner

Fig. 6 shows the microstructure of conventional liner. Liner is divided into refractory layer and clogging layer that is composed of inclusions and metal.

Fig. 7 shows SEM-EDS analysis result of low carbon liner. In case of low carbon liner, reaction layer is found between refractory layer and clogging layer. So, low carbon liner has three layers. Refractory layer is seemed to be sintered. And main compositions of reaction layer are SiO_2-Al_2O_3-Na_2O. The calculated reaction layer is plotted in Fig. 8. Fig. 8 represents that the approximate compositions of reaction layer generate liquid phase at casting temperature.



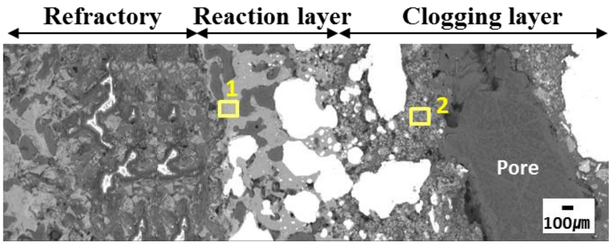
<1>

Element	wt%
O	55.63
Al	37.48
Fe	6.89

<2>

Element	wt%
O	59.02
Al	38.22
Fe	2.75

Fig. 6 SEM-EDS analysis of conventional liner



<1>

Element	wt%
O	56.51
Na	3.76
Mg	0.61
Al	9.53
Si	26.20
K	1.22
Ca	0.41
Ti	0.61
Mn	0.66
Fe	0.49

<2>

Element	wt%
O	44.63
Al	42.16
Si	2.57
Ti	1.36
Mn	0.36
Fe	8.92

Fig. 7 SEM-EDS analysis of low carbon liner

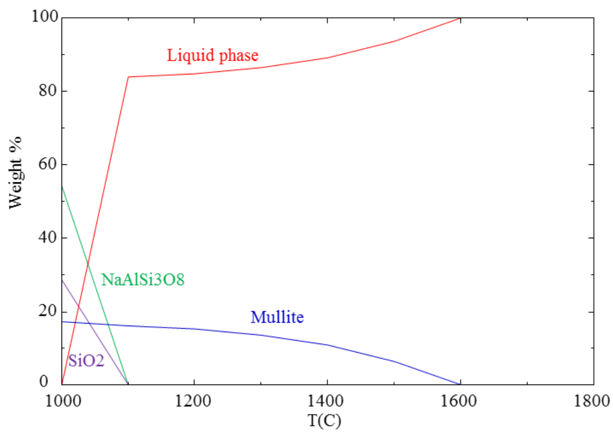


Fig. 8 Amount and composition of reaction layer calculated from FactSage thermochemical computing system

Unlike other studies, MnO is not found at reaction layer. The reason for this analysis result is low Mn content in ultra low carbon steel.(about 0.1wt%)
Inclusion of clogging layer on the molten steel side contains SiO_2, and this inclusion is estimated to be reaction with between Al in the molten steel and SiO_2 from refractory.
By these analysis results, low melting point phase is formed on the molten steel side of high temperature. So, this liquid layer is estimated to reduce clogging thickness of SEN.

2. Performance Test

SENs that have one liner material were tested. Two types of SENs of conventional liner and low carbon liner were tested.
Fig. 9 shows results of comparison with conventional liner SEN and low carbon liner SEN.
Clogging index of all conventional SENs is 1 or more, and average is 2.2. On the other hand, clogging index of all low carbon liner SENs is less than 1, and average is 0.7.
So, we confirmed that clogging of low carbon liner SEN is highly reduced compared to conventional SEN.

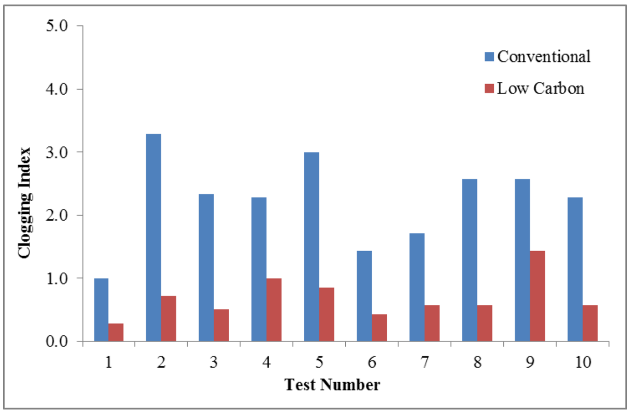


Fig. 9 Comparison of the clogging thickness in conventional SEN and low carbon liner SEN

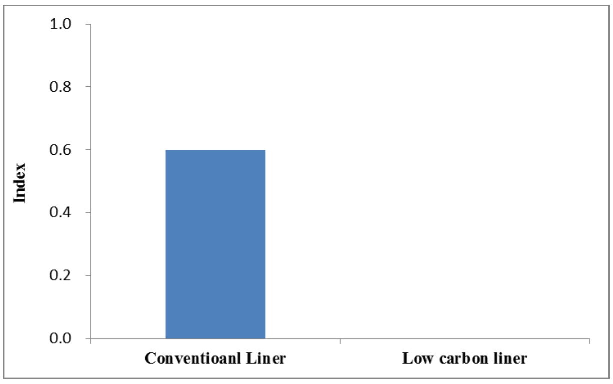


Fig. 10 Coil defect of inclusion type in performance test

We confirmed also that low carbon liner SEN reduces coil defect as well as nozzle clogging. Fig. 10 shows coil defect index of inclusion type by SEN type in performance test.
Conventional liner has a little defect. On the other hand index of low carbon liner SEN is zero.
Coil defect of inclusion type is mainly caused by clogging material.
Inclusion is attached and grows on the wall of the SEN, and when this inclusion is dropped out, coil defect is caused.
So, the reason for this analysis results is estimated that low carbon liner has a little clogging compared to conventional SEN.

CONCLUSIONS

1) We tested liner materials of SEN by new test method. It was possible to evaluate different liners without disturbance factor.

2) Low melting point phase could be formed on the molten steel side at low carbon liner of the low carbon steel. It reduced clogging thickness.

3) Main compositions of low melting point phase were SiO_2-Al_2O_3-Na_2O.

4) Low carbon liner also reduced coil defect due to reduction of clogging thickness.

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