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STUDY ON CLOGGING MECHANISM OF SUBMERGED ENTRY NOZZLE OF STEEL 38CrMoAl

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By phase analysis of the clog of nozzle and type analysis of inclusion in 38CrMoAl steel, the effects of calcium treatment on nozzle scabbiness were analyzed and the mechanisms of clogging were discussed. The results indicated that the clogs of nozzle consist of Al_2O_3, $MgO·Al_2O_3$, CaS and calcium aluminate mixture, Because the inclusion in molten steel with high melting point aggregating in nozzle inner wall. Clogging has been caused by high sulfur content of steel liquid, irrelevant refining slag system and excessive calcium treatment. The nozzle clogging was analyzed and some measures were put forward.

Key words: 38CrMoAl; calcium treatment; inclusion; nozzle clogging; X-Ray Diffraction (XRD)

INTRODUCTION

Because of continuous casting technology has advantages on low cost, high production efficiency and resource saving, some steel mills have begun to use continuous casting in recent years, such as A1-TRIP steel, 38CrMoAl steel, etc [1,2]. However, this type of steel can be poorly watered in continuous casting process, with serious water nodules and there are even the occurred of casting interruption. The nozzle clogging will cause many adverse effects on the quality and production of the steel: Changing the flow field of molten steel in continuous casting billet mold; Receding the floating of nonmetallic inclusions; Reducing the life of the nozzle. Therefore, how to reduce the clogging of submerged entry nozzle became the most important problem of the steel enterprises.

This paper analyzes the clogs on the submerged entry nozzle of 38CrMoAl steel whether calcium treatment in order to draw the relevant improvement measures.

EXPERIMENT

The typical blocked nozzles whether calcium treatment were collected. In this study, the clogging nozzle was divided into three different layers. The first layer of the clogging nozzle consist functional refractories from external to internal parts. The second is transition layer which has structure loosing and low hardness. A portion of this layer was used cold mosaicking in order to keep the original features and investigated by scanning electron microscope (SEM). Another part was pulverized 0,075mm to improve homogeneity and studied by X-Ray Diffraction (XRD). The third layer is central layer which is too hard to grind. This layer was used hot mosaicking and investigated the powder in surface by XRD.

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RESULTS AND ANALYSIS

The blocked nozzles with calcium treatment

According to the steel plant which adopts basic oxygen furnace / the bottom of the bottom of the steel arc furnace →ladle furnace →vacuum degassing furnace →continuous casting process to product 38CrMoAl steel. The composition of the 38CrMoAl steel is exhibited in Table 1. It is easy to cause Al_2O_3 inclusion in 38CrMoAl steel because of high Al content of steel. In order to turn Al_2O_3 into low melting point plastic calcium-aluminates, the steel mill adopted calcium treatment according to the experience of producing Al-killed steel. The nozzle clogging became heavy after between two to three times furnaces.

Table 1 **Composition of 38CrMoAl steel / %**

C	Si	Mn	Cr
0,35~ 0,40	0,25~ 0,40	0,40~ 0,60	1,40~ 1,55
Mo	Al	P	S
0,15~ 0,20	0,70~ 1,10	≤ 0,20	≤ 0,015

The central layer with calcium treatment was analyzed with SEM and XRD are shown in Figure 1 and Figure 2 as well as Table 2. The results indicate that main composition of the central layer with calcium treatment are $MgO·Al_2O_3$, Al_2O_3 and CaS. This phenomenon may be caused by high [Ca] content of steel easily reacting with [S] to form CaS which adhesion with Al_2O_3 on transition layer.

Table 2 **Composition of the central layer with calcium treatment / %**

Point	O	Mg	Al	Ca	Fe
A	25,91	3,50	26,31	9,10	35,18

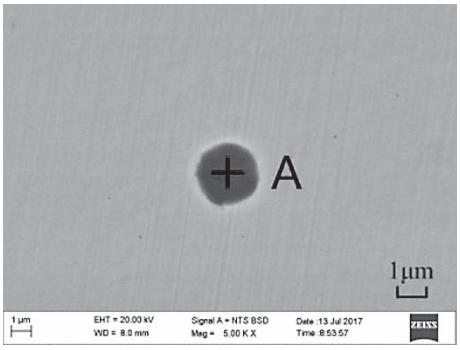

Figure 1 The central layer with calcium treatment by SEM

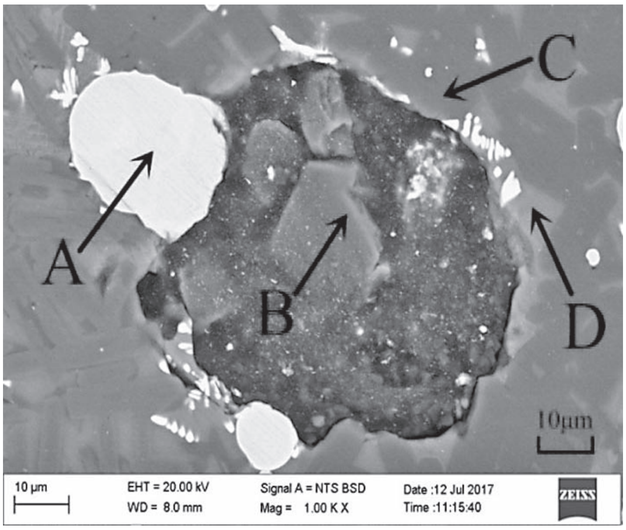

Figure 3 The transition layer with calcium treatment by SEM

Table 3 **Composition of the transition layer with calcium treatment / %**

Element	A	B	C	D
O	—	50,29	49,63	40,68
Al	—	48,81	43,68	19,99
Ca	—	—	—	23,00
Fe	85,51	—	—	—
Mg	—	—	2,63	0,60
Si	13,24	—	—	5,39
F	—	—	—	8,06
Na	—	—	4,05	2,32

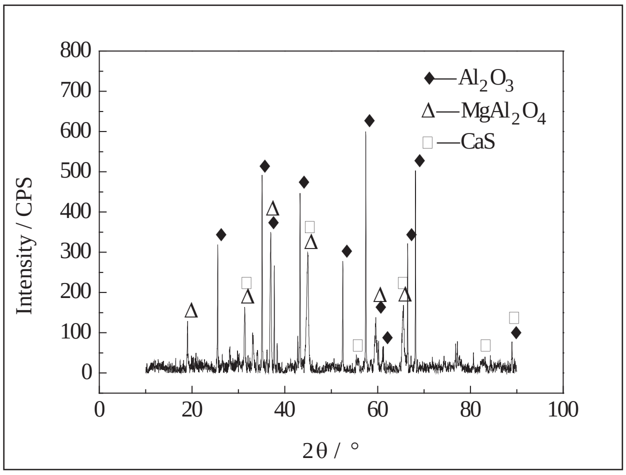

Figure 2 XRD of deposits for the central layer with calcium treatment

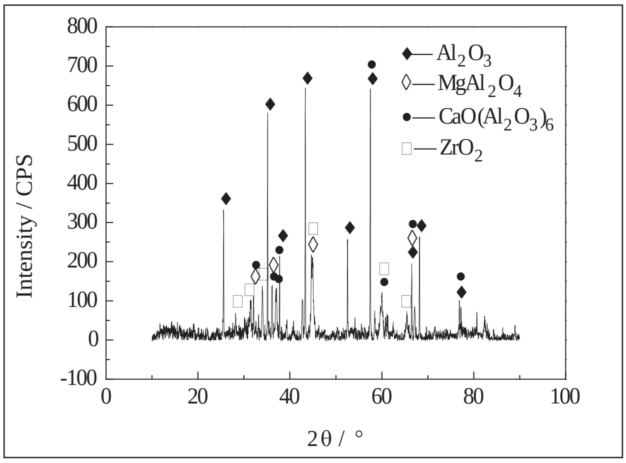

Figure 4 XRD of nozzle transition layer with the calcium treatment

As can be seen from Figure 3, Table 3 and Figure 4, the center layer with calcium treatment is composed of Al_2O_3, $MgO·Al_2O_3$ and $CaO·6Al_2O_3$. XRD is used to measure CaF_2 in point D, Na_2O in point C and D. Both CaF_2 and Na_2O belong to casting powder. The results demonstrate that dynamic condition get worse with calcium treatment, and easily appear the slag entrapment. This conclusion is in agreement with practical situation. And slag entrapment behaviors have an effect on inclusion flotation, liquid mold flux fluid capability and spreadability, shell growth, etc.

This can be seen that the transition layer with the calcium treatment consist $CaO·6Al_2O_3$ by Figure 4. Through analysis $CaO-Al_2O_3$ phase diagram, calcium-aluminates build sequence with the increase of calcium content in steel: $Al_2O_3 \rightarrow CaO·6Al_2O_3 \rightarrow CaO·2Al_2O_3 \rightarrow CaO·Al_2O_3 \rightarrow 12CaO·7Al_2O_3 \rightarrow 3CaO·Al_2O_3 \rightarrow CaO$ [3-5].

According to thermodynamic calculation, The ratio between [Ca] and [Al] in liquid steel should be greater 1,27 in order to turn Al_2O_3 into $12CaO·7Al_2O_3$ with low melting point. But it will be high [Ca] content because of [Al] = 0,7 %-1.,1 % in 38CrMoAl liquid steel. At 1 600 °C , activity of CaO is 0,50 and Al_2O_3 is 0,39, which calculated by Factsage software. To turn Al_2O_3 into $12CaO·7Al_2O_3$, [Ca] in liquid steel must be up to 0,049 % if [Al] = 1,0 % in liquid steel. But [Ca] is only 0,032 % through binary Fe-Ca phase diagram, as shown in Figure 5. This is obviously that the calcium treatment cannot turn Al_2O_3 into $12CaO·7Al_2O_3$.

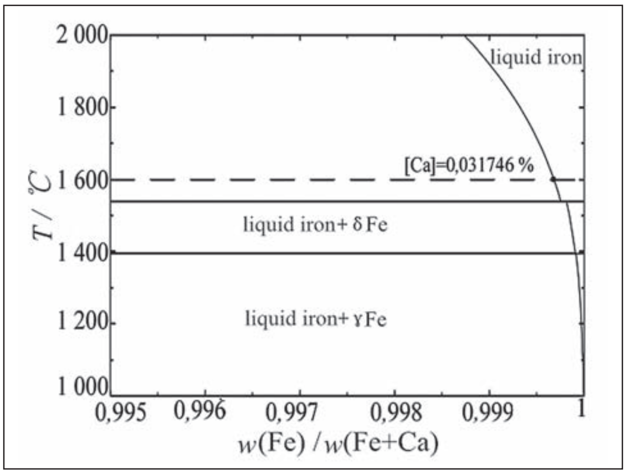

Figure 5 Phase diagram of Ca-Fe binary system

The blocked nozzles without calcium treatment

According to the discussion above, the steel mill stopped calcium treatment with 38CrMoAl steel. The nozzle could work for four to five times furnaces.

The microstructure of the central layer without calcium treatment was studied and analyzed by SEM-EDS and XRD, the results are shown in Figure 6, Table 4 and Figure 7.

From the above it can be seen that the central layer which without calcium treatment contains Al_2O_3, $MgO·Al_2O_3$ and CaS. The results show clearly that 38CrMoAl of the steel mill contains a higher amount of sulfur by comparing Figure 2 with the Figure 7. The central layer with calcium treatment was analyzed by SEM and XRD are shown in Figure 8 and Figure 9 as well as Table 5.

According to analyze the point A in Figure 3 and point C in Figure 8 have high contain of Si. It is because SiO_2 in slag have strong deoxidizing ability when content of Al in liquid steel is too high. The chemical equations are as follows:

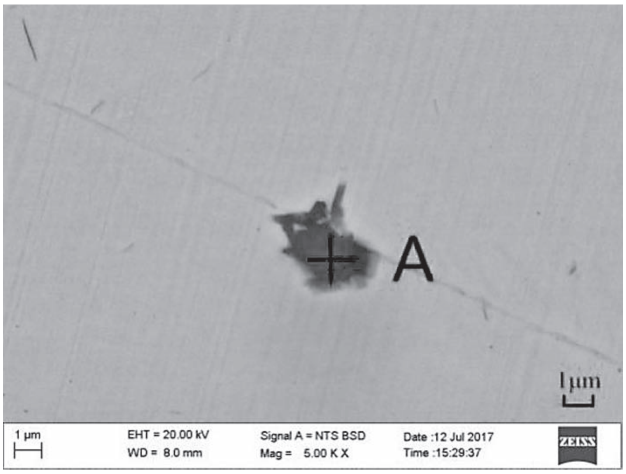

Figure 6 The central layer without calcium treatment by SEM

Table 4 **Composition of the central layer without calcium treatment / %**

Point	O	Mg	Al	S	Ca
A	38,66	24,89	13,21	5,19	3,83

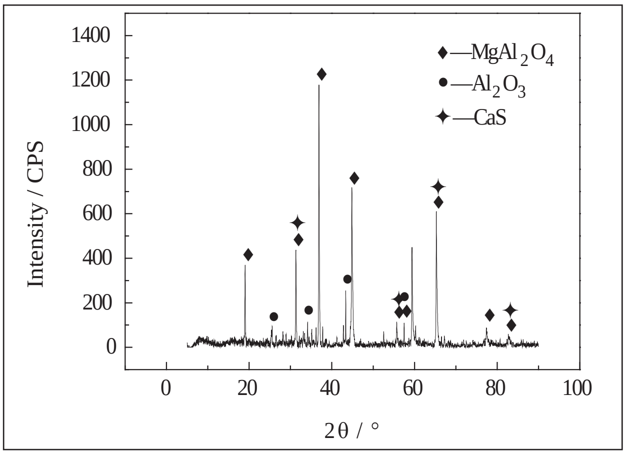

Figure 7 XRD of deposits for the central layer without calcium treatment

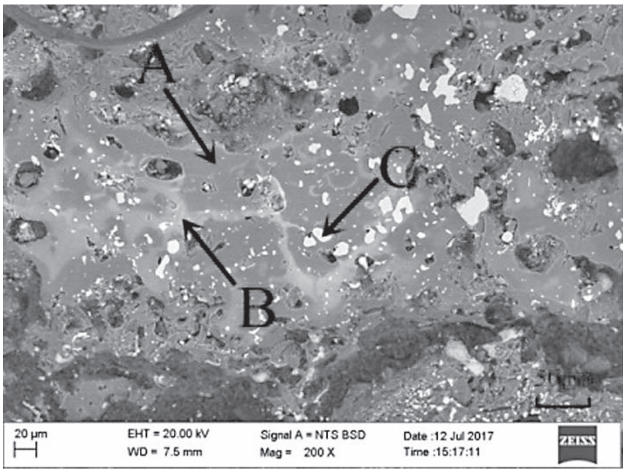

Figure 8 The transition layer without calcium treatment by SEM

$$(Al)+3/4(SiO_2) = 1/2(Al_2O_3)+3/4(Si)$$
$$\Delta G^{\Theta} = -164\ 550+26{,}775T$$

Three samples of slag without calcium treatment were collected for testing without calcium treatment. The result is shown in Figure 10.

According to the result of slag sample, the vast majority of slag is reduced into steel, which is consistent with thermodynamic analysis results. The content of SiO_2 is normally high in conventional slag, which will result in the re-oxidation reaction between steel and slag[6]. Therefore, the covering slag should include low or none of SiO_2. Meanwhile, the control of slag under converter and argon blowing management in refining process should be strengthened, specific deoxidizer should be used in steel tapping and refining process, making use of refining slag and aluminum pellet for controlling the composition of ladle slag. So the aim of quick slag formation for sulfur removal and absorbing inclusion in steel can be achieved.

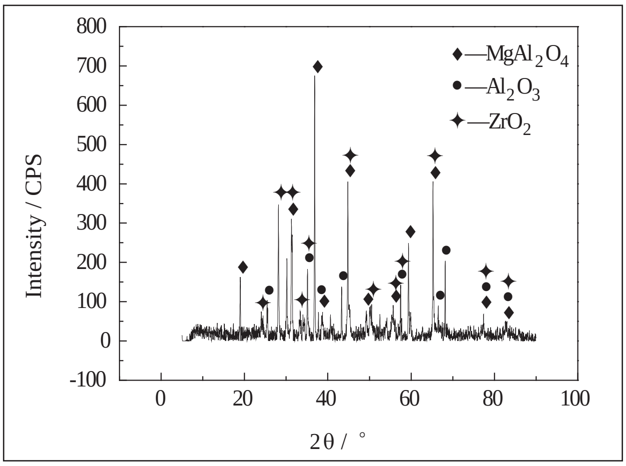

Figure 9 XRD of nozzle transition layer without the calcium treatment

Table 5 **Composition of the transition layer without calcium treatment / %**

Element	A	B	C
O	54,06	57,25	—
Al	31,82	29,30	—
Fe	—	—	72,79
Mg	14,12	13,45	—
Si	—	—	25,45
Cr	—	—	1,76

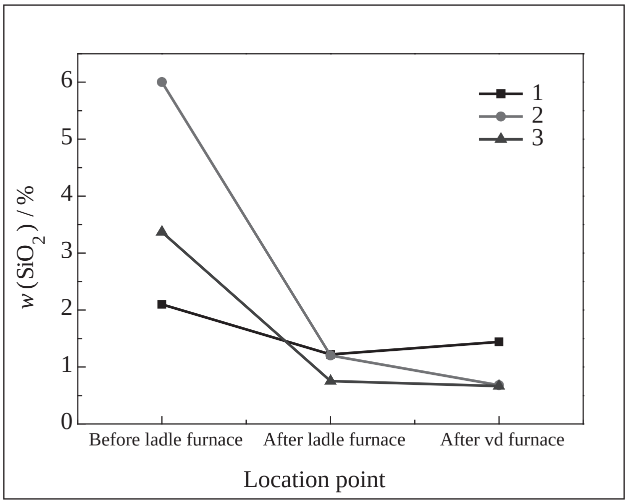

Figure 10 Variation of SiO_2 content at different work stations

CONCLUSION

In 38CrMoAl steel, both theory analysis and industrial experiment show that the calcium treatment cannot turn Al_2O_3 into calcium-aluminates which has low melting point. The inclusion has high melting point after calcium treatment and cause even more serious nozzle blockage.

The results indicate that the main composition of nozzle blockage without calcium treatment is Al_2O_3, $MgO·Al_2O_3$ and CaS. The nozzle blockage is as same as deoxidization products through comparing their components. So, it is necessary to reduce (S) and the secondary oxidation of liquid steel.

The production test reveals that 38CrMoAl steel with high Al content can be easily reactive with SiO_2 of slag. The generated Al_2O_3 is the major cause of nozzle blockage. Therefore, there must have less or without SiO_2 in slag.

Acknowledgements

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Note: The responsible for English language is the lecturer from University