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GRAVITATIONAL SEGREGATION OF LIQUID SLAG IN LARGE LADLE

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The process of gravitational segregation makes liquid steel slag components occur differentiation. And it shows that the upper part slag in the slag ladle contains higher CaO; and the lower part slag contains higher SiO_2. The content of MgO (5,48 %) in the upper part slag is higher than that of the lower part (2,50 %), and only Al_2O_3 content of the upper and the lower part slag is close to each other. The difference of chemical compositions in the slag ladle shows that there is gravitational segregation during slow solidification of liquid steel slag, which will has some impact of the steel slag processing on the large slag ladle.

Key words: steel, liquid slag, gravitational segregation, slag ladle, metallurgical solid waste

Gravitacijska segregacija tekuće troske u velikom loncu. Proces gravitacije segregacije omogućuje pojavu diferenciranja komponenata tekuće čelične troske. Također pokazuje da u gornjem dijelu tekuća troske u loncu za trosku sadrži više CaO, a u donjem dijelu troske sadrži više SiO_2. Sadržaj MgO (5,48 %) u gornjem dijelu troske veći je nego u donjem dijelu (2,50 %), a samo sadržaj Al_2O_3 u gornjem i donjem dijelu troske približno je jednak. Razlika kemijskog sastava u loncu za trosku pokazuje gravitacijsku segregaciju tokom polaganog skrućivanja tekuće čelične troske, koja ima određeni utjecaj na obradu čelične troske u velikom loncu za trosku.

Ključne riječi: čelik, tekuća troska, gravitacijska segregacija, lonac za trosku, čvrsti metalurški otpadak

INTRODUCTION

Because the large difference between the primary crystals and melt in the specific gravity, makes the primary crystals sink or float in the melt due to the specific gravitational difference in the process of alloy solidification, which resulting a non-uniform phenomenon of chemical compositions is known as gravitational segregation, also known as specific gravitational segregation. Gravitational segregation is common in the liquid metal, such as Zn-Al alloy [1], Au-Ge alloy [2], Ti, Al, Mn in ferrotitanium alloy [3]. Since the early use of the steel slag ladle is relatively small and it is smaller density difference between compositions in liquid steel slag, the gravitational segregation in the liquid steel slag is generally difficult to observe. With the development of large-scale metallurgical equipment and the use of large slag ladle increasing, the gravitational segregation of liquid steel slag has become a common phenomenon.

EXPERIMENTAL WORK

The liquid slag weight in large steel slag ladle is more than 20 tons. After slow cooling solidification of the liquid slag, it was sampled in the upper and lower part of the slag, respectively. Electron microprobe and XRD were used to analyze the compositions and phases.

RESULTS AND DISCUSSION

Phase and composition of upper part slag

The composition of microstructure of upper part slag in the slag ladle is shown in Figure 1, Figure 2 and Table 1. The average calcium silicon mole ratio (CaO: SiO_2) of the upper part slag is 2,38:1 and the slag basicity (CaO/SiO_2) is 2,22, with MgO 5,48 %, Al_2O_3 0,82 %. The main slag phase is tricalcium silicate and a small amount of free magnesium oxide phase appears.

Dicalcium silicate also appears at the upper part slag (shown in Figure 2 and Table 2), and a small amount of free calcium oxide appears. The average slag basicity (CaO/SiO_2) is 2,25.

According to XRD phase analysis of the upper slag (shown in Figure 3), the main phase of the slag is dicalcium silicate, and there are a small amount of free MgO phase, calcium hydroxide phase, aluminum calcium silicate phase, aluminum silicate magnesium phase, calcium borate phase and iron chrome oxide phase.

Phase and composition of lower part slag

The composition of microstructure of the lower part slag in the slag ladle is shown in Figure 5, Figure 6 and

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Table 1 **Electron microprobe composition analysis of the upper part slag**

Analysis Position	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	CrO	MnO	FeO	NiO	Total	Slag phase
Average composition	0,21	5,48	0,82	19,97	0,05	0,02	0,18	44,27	0,11	0,27	0,00	0,02	0,00	71,41	$CaO:SiO_2$= 2,38:1
Point No.1 in Figure 1	0,00	0,99	3.57	21,60	0,15	0,12	0,27	72,40	0,40	0,00	0,00	0,00	0,00	99.50	$3CaO·SiO_2$
Point No.2 in Figure 1	0,16	1.22	0,71	23,70	0,35	0,08	0,22	67,99	0,07	0,00	0,02	0,00	0,00	94.52	$3CaO·SiO_2$
Point No.3 in Figure 1	0,03	1.35	2.14	16,37	0,12	0,66	0,16	54,76	0,43	0,33	0,13	0,10	0,00	76.60	$3CaO·SiO_2$
Point No.4 in Figure 1	0,00	0,52	0,08	0,51	0,15	0,20	0,16	72,77	0,00	0,00	0,00	0,05	0,00	74.44	Free CaO
Point No.5 in Figure 1	0,00	98,62	0,46	0,17	0,00	0,00	0,00	0,92	0,00	0,00	0,20	0,05	0,00	100,42	Free MgO

Table 2 **Electron microprobe composition analysis of the upper part slag**

Analysis Position	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	CrO	MnO	FeO	NiO	Total	Slag phase
Average composition	0,16	6,55	0,82	19,35	0,04	0,13	0,16	43,62	0,12	0,31	0,03	0,14	0,00	71,43	$CaO:SiO_2$ =2,412:1
Point No.1 in Figure 2	0,12	0,91	2,67	19,96	0,07	0,24	0,90	67,54	0,39	0,28	0,00	0,00	0,00	93,10	$3CaO·SiO_2$
Point No.2 in Figure 2	0,01	1.22	0,71	20,76	0,17	0,02	1,09	69,11	0,23	0,32	0,00	0,00	0,16	93,80	$3CaO·SiO_2$
Point No.3 in Figure 2	0,08	0,08	0,04	0,70	0,28	0,13	0,94	67,29	0,35	0,00	0,15	0,17	0,00	70,21	Free CaO
Point No.4 in Figure 2	0,00	98,35	0,39	0,08	0,00	0,12	0,12	0,53	0,00	0,28	0,03	0,00	0,08	99,98	Free MgO
Point No.5 in Figure 2	0,00	0,85	1,06	13,61	0,09	0,08	0,14	26,98	0,57	0,10	0,02	0,02	0,00	43,52	$2CaO·SiO_2$

Table 3 **Electron microprobe composition analysis of the lower part slag**

Analysis Position	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	CrO	MnO	FeO	NiO	Total	Slag phase
Average composition	0,00	2,50	0,98	24,93	0,07	0,02	0,09	39,16	0,13	0,39	0,05	0,54	0,00	68,85	$CaO:SiO_2$=1.680:1
	0,21	3,25	0,34	25,28	0,00	0,13	0,10	41,11	0,12	0,54	0,00	0,33	0,00	71,41	$CaO:SiO_2$=1.743:1
Point No.1 in Figure 6	0,00	0,02	0,00	34,21	0,57	0,12	0,90	63,26	0,30	0,68	0,00	0,21	0,07	100,34	$2CaO·SiO_2$
Point No.2 in Figure 6	0,10	0,21	0,00	34,18	0,19	0,08	0,11	62,90	0,07	0,54	0,00	0,16	0,00	98,54	$2CaO·SiO_2$
Point No.3 in Figure 6	0,00	77,85	0,42	0,38	0,00	0,03	0,00	0,60	0,06	1.02	0,54	0,00	0,00	80,90	Free of MgO
Point No.4 in Figure 6	0,00	103,05	1,21	0,88	0,02	0,12	0,00	0,25	0,11	0,62	0,19	0,69	0,00	107,14	Free of MgO
Point No.5 in Figure 6	0,10	0,23	2,71	4,17	0,22	0,39	0,29	58,73	0,03	0,10	0,15	0,30	0,15	67,57	Free of CaO

Table 3. The average calcium silicon mole ratio (CaO: SiO_2) of the lower slag is 1,680 ~ 1,743:1, and the slag basicity (CaO/SiO_2) is 1,57 ~ 1,63, with MgO 2,50 %, $Al_2O_3$0,98 %. The main slag phase is dicalcium silicate containing boron and a small amount of free calcium oxide and free magnesium oxide appear.

According to XRD phase analysis (shown in Figure 4), the main phase of slag is dicalcium silicate and calcium silicate, and there are a small amount of free magnesium oxide phase, calcium oxide phase, calcium hydroxide, Ca-Si-Al and Al-Si-Mg phase, iron-chrome oxide phase. In the lower part of the slag ladle, the proportion of dicalcium silicate is increased obviously.

Comparison of the components of electron microprobe between the lower part slag and the upper slag, the average basicity of upper part slag is 2,22 ~ 2,25 and

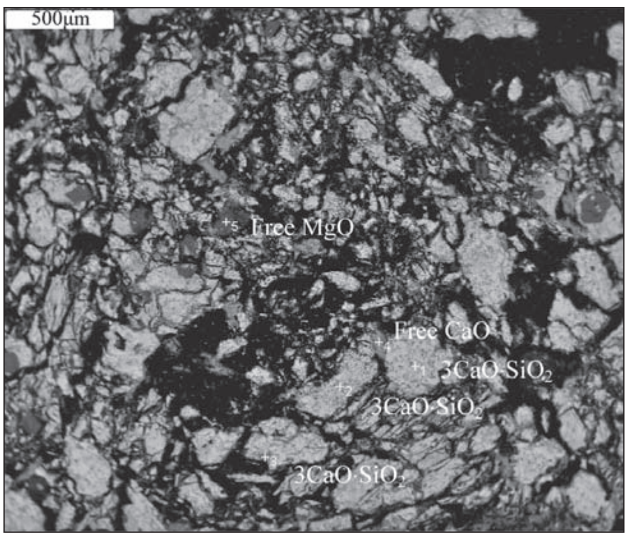

Figure 1 Slag phase of the upper part slag

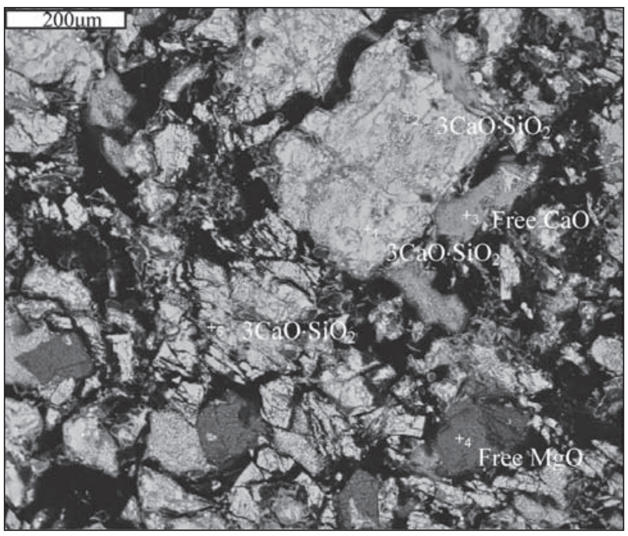

Figure 2 Slag phase of the upper part slag

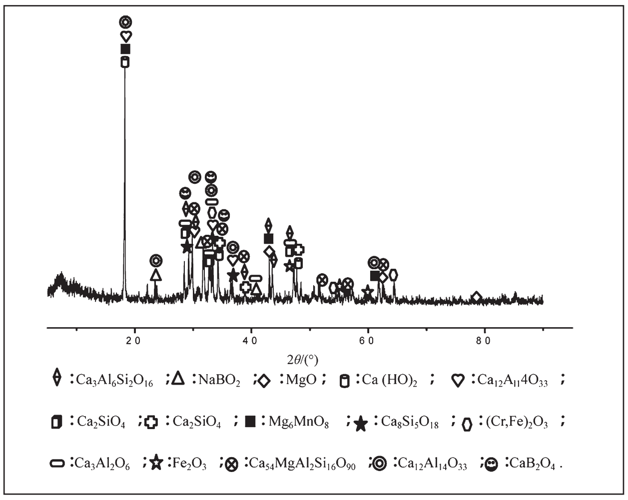

Figure 3 XRD slag phase analysis of the upper part slag

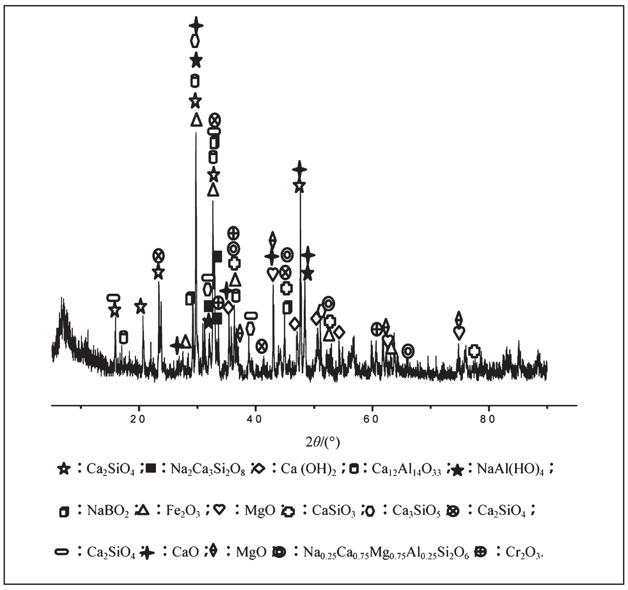

Figure 4 Slag phase analysis of the lower part slag

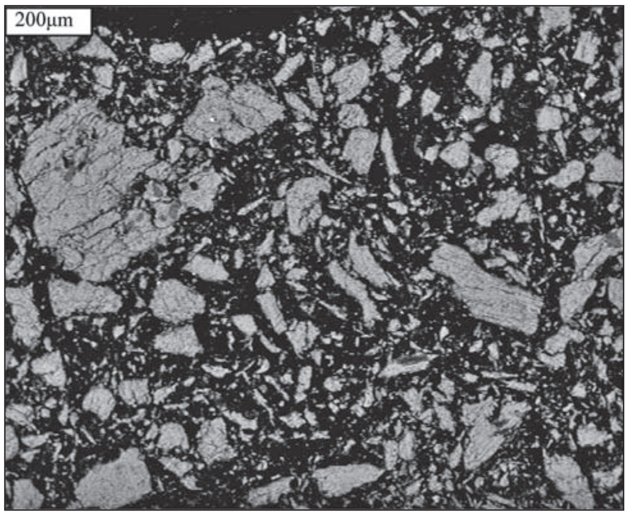

Figure 5 Slag phase of the lower part slag

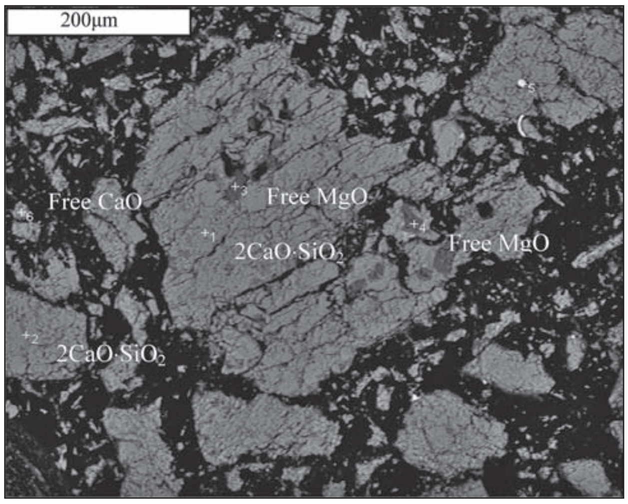

Figure 6 Slag phase of the lower part slag

higher than that of lower part slag (1,57 ~ 1,63). The content of MgO in the upper slag is 5,48 % and higher than that of the lower part slag (2,50%), only the content of Al_2O_3 is closed to each other between the upper part slag (Al_2O_3 0,82%) and lower part slag (Al_2O_3 0,98%). The difference of chemical compositions between them shows that the segregation of chemical compositions occurs during solidification of the liquid slag. When the liquid slag was poured into the slag ladle, the initial chemical composition was homogeneous. But in a longer time of transportation process and static cool down process, the gravitational differentiation occurs under the effect of the earth gravity field. The molecular weight of SiO_2 is 60 and that of CaO is 56, which the heavyweight material sinks and the lightweight material floats, which cause the basicity of the upper part slag increases, and the basicity of lower part slag decreases. The molecular weight of MgO is 40 and it is much smaller than that of SiO_2 and CaO. It is also happened the gravitational segregation with CaO, this is, the content of CaO and MgO of upper part slag is relatively higher and SiO_2 is relatively lower; while the content of CaO and MgO in the lower part slag is relatively lower and SiO_2 is relatively higher. The molecular weight of Al_2O_3 is 102 and it also be affected by the gravitational segregation. The content of Al_2O_3 of the upper part slag is 0,82 %, while the lower part slag is 0,98 %. Only because of the content of Al_2O_3 being too little, the gravitational segregation of Al_2O_3 is not performed significantly as that of CaO and MgO.

The gravitational segregation makes the components of slag, such as CaO, MgO, SiO_2, Al_2O_3, occurring macro-segregation. The content of the upper part slag is CaO higher and the main phase is tricalcium silicate; while the content of the lower part slag is SiO_2 higher and the main phase is dicalcium silicate.

CONCLUSION

The gravitational segregation makes the components of slag, such as CaO, MgO, SiO_2, Al_2O_3, occur (occurring) the macro-segregation.

The content of CaO is higher and the main phase is tricalcium silicate in the upper part slag; while the content of SiO_2 is higher and the main phase is dicalcium silicate in the lower part slag.

Using the gravitational segregation during solidification of liquid slag, it can be achieved control of slag phase structure, and so as to provide a new way of steel slag recycling.

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Note: The responsible for English language is the lecturer from College of Materials Sciences and Engineering, Taiyuan, China.