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Effect of temperature on the present forms of MgO in the reconstruction of steel slags

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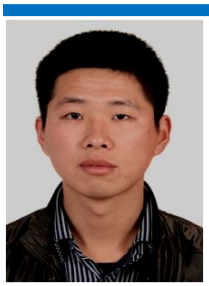
ABSTRACT

By varying reconstructed temperature of steel slag, present form, crystallizing conditions and lithofacies characteristics of MgO and RO were tested by XRD, SEM and lithofacies analyses. Contents of MgO and RO phase in other phases of steel slag were analyzed by phase separation. The results show that when the reconstructed temperature of steel slag increases, the content of gel minerals also increases, and the degree of crystallization comes nearer to completion. The existing state of MgO changed to solid solution state from the free state. When the reconstructed temperature of steel slag was at 1300 ºC, the contents of MgO solid dissolved in gel minerals (e.g., silicate and mesophase). However, at very high temperature, recrystallization occurred in the steel slag, and larger amounts of free MgO were generated, which could affect the strength of steel slag.

Keywords: Steel slag; temperature of reconstruction; RO phase; crystallization.



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Introduction

Steel slag, a byproduct of the steel industry, is produced during the separation of molten steel from impurities in the steel-making furnaces. The amount of steel slag is approximately 15–20% of the produced steel. Nearly 100 million tons of steel slags are deposited annually, and the amount is continually increasing. The utilization of steel slag is limited because the MgO and RO phase could affect its strength. The state of MgO depends on the alkalinity of the steel slag. In low-alkaline slag (such as electric furnace slag), MgO mainly exists as forms of calcium magnesium olivine and magnesium rhodonite. The RO phase is mainly wustite [**1, 2**]. In contrast, the FeO and MnO become a solid solution, which is the RO phase. Because there is almost no FeO in electric furnace slag, MgO exists purely as periclase [**3**].The hydration of pure periclase produces $Mg(OH)_2$, which affects the structure of steel slag. However, the effect of RO phase on the structure of steel slag remains uncertain [**4–7**].

Many scholars have adjusted the ratio of the various chemical components by adding different calibration materials, and have reconstructed and improved steel slags by adjusting the processing conditions and generating gelation of minerals [**8, 9**]. In this paper, the effects of reconstructed temperature on the presence and distribution of RO phase and MgO are studied in order to determine effective way to maintain the structure of steel slag.

Experimental

Raw materials

Steel slag was provided by Jinan Iron and Steel Company (Shandong, China). Alumina, calcium carbonate, silica, cyclohexane, sugar, potassium hydroxide, salicylic acid, and methanol, were produced by Chemical Reagent Co. Ltd. Guangcheng (Tianjin, China). The chemical composition of steel slag is shown in **Table 1**.

Table 1. Chemical compositions of steel slag %.

Material	Loss	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	P_2O_3
Steel slag	1.2	39.52	18.07	4.75	18.67	8.77	2.19	0.47

Preparation of reconstructive steel slag

During the experiment process, with rate value: KH = 0.92, n = 2.5, p = 1.5 to adjust the composition of steel slag at different temperatures, using water-cooling method [**8, 9**].

Determination of RO phase and MgO

The middle phases of steel slag and reconstructed slag were extracted by sucrose potassium hydroxide (KOSH). The silicate phase was extracted by salicylic acid-methanol (SAM) solution [**10, 11**]. The content and distribution of RO phase and MgO were determined by chemical analysis.

Results and discussion

Influences of reconstruction temperature on lithofacies features of MgO and RO phase

Photos of steel slag under polarizing microscope are shown in **Fig. 1**.

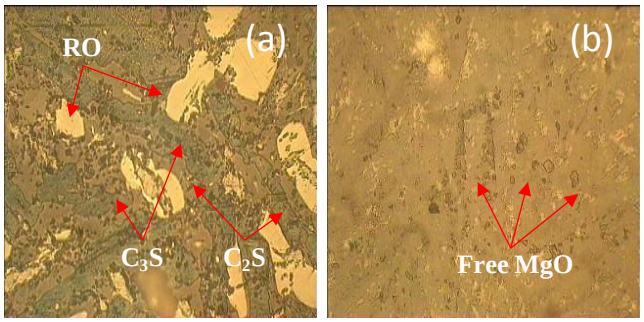

Fig. 1. Lithofacies photograph of original steel slag of (a) 1% NH_4CI solution erosion (×400), and (b) uncorroded (×400).

Fig. 1(a) shows that C_3S became blue and C_2S became brown after erosion using 1% NH_4CI solution. The color of free MgO (f-MgO) did not change; however, there were obvious black-edged protrusions with very clear borders, and the shell lines showed obvious stretching under the microscope. Another main mineral that was present was a yellow or light-yellow solid solution formed from CaO, FeO, MnO, and MgO, among others. Using the attribute calculation parameters formula of RO phase [i.e., KM=MgO/(FeO+MnO)], KM < 1. The RO phase was mainly wustite phase, which had a large amount of MgO. **Fig. 1(b)** shows the f-MgO piled together. Once hydrated, this produced Mg $(OH)_2$. From f-MgO to Mg $(OH)_2$, the volume increased by 148%, thereby affecting the soundness of steel slag. Hou Huagui et al. proved that a certain amount of solid MgO can be dissolved in silicate phase [**3**]. Therefore, for steel slag, the existent forms of MgO are mainly dissolved solids in the RO phase and silicate phase, and piled together with f-MgO.

Fig. 2 shows the characteristic lithofacies of the RO phase and MgO when the steel slag is treated using different reconstructed temperatures.

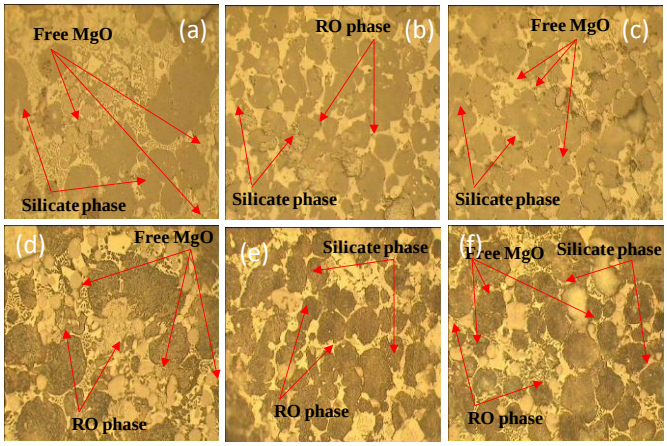

Fig. 2. Lithofacies photograph of steel slag at (a) 1250℃ uncorroded (×400), (b) 1300℃uncorroded (×400), (c) 1350℃uncorroded (×400), (d) 1250℃ 1% NH_4CI solution eroded (×400) (e) 1300℃ 1% NH_4CI solution eroded (×400) and (f) 1350℃ 1% NH_4CI solution eroded (×400).

Fig. 2(a)–(c) show that the reconstructed temperature of steel slag increased, the content of gel minerals increased, and the degree of crystallization neared completion. The grain boundary is clear, and the forms of MgO and RO phase significantly changed. Increasing the reconstructed temperature, the distribution range of RO expanded, which shows that improving reconstructed temperature was conducive to the formation of RO phase. However, the distribution range of MgO was first reduced, then increased. **Fig. 2(c)** shows that f-MgO emerged in the reconstructed steel slag at 1350 ºC because of the liquid phase caused recrystallization of the MgO. **Fig. 2(d)–(f)** show that, after the 1% NH_4CI solution eroded the reconstructed steel slag after the high-temperature treatment, a large number of silicates were generated. The f-MgO amount in reconstructed steel slag at 1300 ºC decreased. Although the content of silicate phase and RO phase increased at 1350 ºC, the f-MgO again appeared, indicating that, at higher temperature, the Mg is not easily dissolved in the silicate and RO phases.

Phase analysis of steel slag at different reconstruction temperature

X-ray diffraction patterns of the reconstructed steel slag are shown in **Fig. 3**.

The XRD patterns show that, when steel slag was reconstructed, the intensity of diffraction peaks of the gel minerals (C_3S, C_2S, and others) was significantly stronger than that of original slag. The intensity of diffraction peaks of gel minerals at different reconstructed temperature was

significantly different; the higher the reconstructed temperature, the stronger the intensity of diffraction peaks of gel minerals. Past studies have suggested that crystals of gel minerals grow better, and that the degree of crystallization is higher at higher reconstructed temperature [**9**]. However, the intensity of diffraction peak of f-MgO shifted from strong to weak, and then became strong again with rising temperature. This is perhaps caused by the changing reconstructed temperatures, which lead to MgO recrystallization. This result is consistent with the petrographic characteristics. When the reconstructed temperature was 1300 ºC, the diffraction peak of RO-phase was higher, and the peak of f-MgO was at its lowest. At this temperature, there was more production of liquid, which is conducive to MgO dissolved solids in the silicate and RO phases. The characteristic peak of f-MgO was not obvious, revealing that the content of f-MgO was not high. This result is good for the soundness of steel slag.

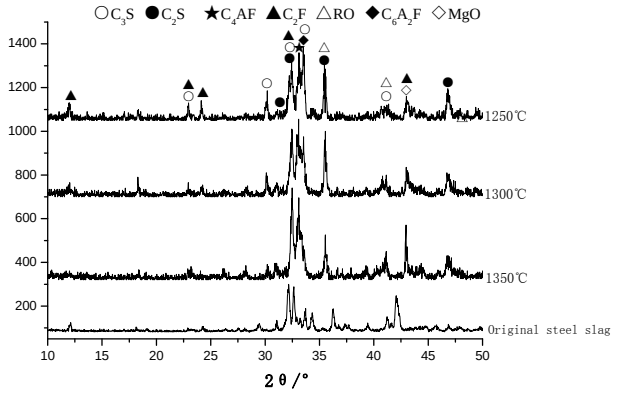

Fig. 3. X-ray diffraction patterns of steel slag which by different temperature treatment.

The SEM images of the steel slag at different reconstructed temperatures are depicted in **Fig. 4**.

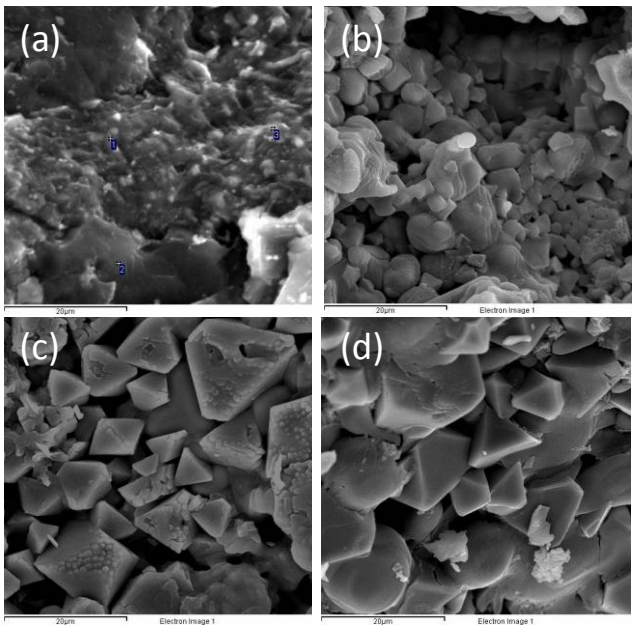

Fig. 4. SEM photograph of steel slag which by different reconstruction temperature treatment.

After heat treatment, the mineral composition of steel slag changed. The different heat-treatment temperatures had a significant impact on the morphology, crystal size, and other characteristics of the MgO. **Fig. 4** shows the reconstructed steel slag at high-temperature heat treatment. Compared with the original steel slag, the reconstructed steel slag has a higher number of gel minerals and wustite in the form of the RO-phase. As the temperature increased, the grain boundary of the mineral crystal became clearer, and crystal neared perfection. This result is consistent with the XRD pattern. Relative to 1250 ºC, the solid solution was generated more completely at higher temperatures, and more MgO dissolved solid was present in the RO phase. When the reconstructed temperature was 1350 ºC, a greater amount of f-MgO was generated. Taking into account the influence of f-MgO on the soundness, 1300 ºC was chosen as the optimal reconstructed temperature.

Influence of reconstructed temperature on the distribution of MgO in steel slag

The chemical phases of reconstructed steel slag at different heat treatment temperatures were separated by chemical phase separation methods. The content and distribution of MgO in reconstructed steel slag are depicted in **Table 2** and **Fig. 5**.

Table 2. Content and distribution of MgO in reconstructed steel slag which by different temperature treatment.

Name	The content and distribution of MgO								
		Silicate phase		*Mesophase*		*RO phase*		*Free state*	
	Total mass /g	Mass /g	Mass /w%	Mass /g	Mass /w%	Mass /g	Mass /w%	Mass /g	Mass /w%
Original steel slag	8.77	0.80	9.18	0.20	2.24	3.04	34.61	4.73	53.97
1250℃	8.15	0.89	10.94	0.40	4.88	3.31	40.67	3.55	43.51
1300℃	8.14	2.60	31.87	1.04	12.80	4.06	49.91	0.44	5.42
1350℃	8.20	2.44	29.77	0.93	11.32	3.91	47.72	0.92	11.19

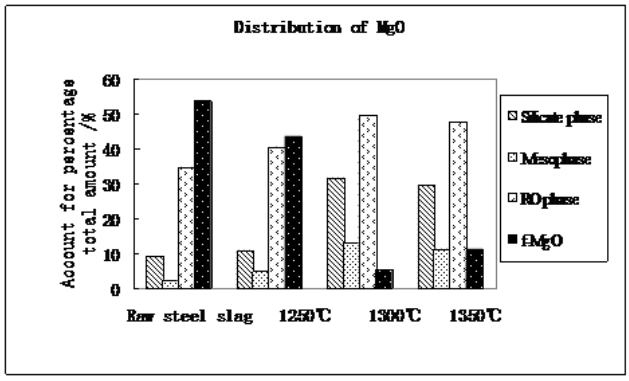

Fig. 5. Distribution of MgO in reconstructird steel slag which by different temperature treatment.

Table 2 and **Fig. 5** show that the content and distribution of MgO are significantly different at different reconstructed temperatures. After high-temperature calcination, large amounts of gel minerals (silicate phase and mesophase) were produced. At 1300 ºC, approximately 44.67% of MgO solid dissolved in the silicate phase and mesophase. The content of MgO in RO phase increased with increasing temperature; nearly 49.91% of the MgO solid dissolved in the RO phase, with FeO and MnO forming a solid solution. Therefore, improving the

reconstructed temperature is beneficial to produce MgO solid solution. However, when the temperature is too high, the content of f-MgO increases because of crystal growth under high temperature, and devitrification occurs, producing the f-MgO.

Conclusion

Steel slag under high-temperature heat treatment was compared with the existing state of MgO. Free state changed to solid solution state, changing the silicate phase, mesophase, and RO phase into solid. Only small amount of MgO exists at free state. At 1300 ºC reconstructed temperature, the steel slag has optimal performance. At this temperature, approximately 44.67% and 49.91% of the MgO solid dissolve in gel minerals and RO phase, respectively. The MgO recrystallizes into free state at 1350 ºC. The steel slag has optimal performance because the liquid phase content increases when the temperature is high, leading to the appearance of free MgO.

Acknowledgement
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