Characterization of Fibrous Particles in Blast Furnace Slag Quenched by Water-spray

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(Received on June 19, 2003; accepted in final form on August 19, 2003)

1. Introduction

A great deal of iron and steel making slags have been reused for many purposes such as road construction.1–6) There is also a new demand to use them in the field of protecting or improving the environment. One example is the usage of the blast furnace (BF) slag to reclaim the seabed having lost the Pisces by picking. The composition of the BF slag is very similar to that of the natural sand in the seabed, so the BF slag can hopefully be utilized in the recovery of the seabed.6) But CaS in the BF slag may dissolve into water during oxidation, if the slag is cooled slowly to crystallize. Therefore, it should be quenched by water-spray to make slag amorphous for fixing sulfur. At present, about 70% of the BF slag in Japan is quenched by water-spray.7) The water-spray quenched slag has the higher water permeability than the natural sand, which is accepted as a good property to the seabed construction.6) The water-spray quenching, however, forms fibrous particles possibly causing a bad effect on the sea life for the needle-like shape of the particles with sharp ends. Thus, it is important to understand the formation mechanism of the fibrous particles in the slag formed during water-spray quenching. This article presents the investigation results on the fibrous particles and discusses on the formation mechanism.

2. Experimental

Field emission scanning electron microscopic (FE-SEM) images of typical BF slag samples used in the present investigation are demonstrated in Fig. 1. The considerable feature is that the BF slag contains a lot of fibrous particles (Diameter=300 μm) with porous slags. Chemical composition of the BF slag is shown in Table 1. In Fig. 2, the X-ray powder diffraction analysis (XRD) pattern of the BF slag is shown. The present sample shows a typical amorphous pattern. In order to understand the formation mechanism of the fibrous particles, the surface and the cross-section of the fibrous particles were investigated using a field emission scanning electron microscopy (Hitachi, FE-SEM S4200, 8–15 kV) and the composition of the particles was analyzed with an energy dispersive X-ray analysis (EDX, working distance=20 mm).

![Image 1](https://example.com/image1.png)

**Fig. 1.** FE-SEM images of the BF slag: (a) morphology and (b) perpendicular cross-section of the fibrous particle. The places for EDX analysis are shown with arrows.

| Table 1. Chemical composition of the blast furnace slag (mass%). |
|----------------------|------------------|------------------|------------------|------------------|
| CaO | SiO₂ | Al₂O₃ | Fe | MgO | MnO | TiO₂ |
| 43.21 | 34.00 | 15.00 | 0.37 | 4.91 | 0.22 | 0.97 |

![Image 2](https://example.com/image2.png)

**Fig. 2.** X-ray intensity profile for the BF slag.
3. Results and Discussion

3.1. Surface Investigation

EDX analysis on the side face (Fig. 1(a)) and the perpendicular cross-section (Fig. 1(b)) of the fibrous particles are shown in Figs. 3(a) and 3(b), respectively. EDX analysis on the side face of the fibrous particle shows strong Ca, Si, Al, Mg and O Kα peaks, and the composition of the fibrous particle (Table 2) is in agreement with the bulk composition of the BF slag, whereas the analysis result on the cross-section shows a remarkable Ca peak. This result indicates that the composition of the phase inside the fibrous particles is different from that of the BF slag.

3.2. Cross-section Investigation

In order to clarify the phase inside the fibrous particles, the horizontal cross-section was investigated. Figure 4 shows a cross-section of a fibrous particle with 4.8 mm length and 200 μm diameter. It is found that globules (the phase A) is encircled by the amorphous phase B. An EDX analysis on these phases shows no difference in chemical composition with each other. Even though the phase A might have been formed before the formation of the phase B, the phase A should have been enlarged before the fibrous particle formation. Accordingly, the whole phase of A might not be the original seed of this particle. In Fig. 5, a cross-section containing relatively small globules of the phase A (A-1: 50 μm and A-2: 10 μm) is shown. It is considerable that EDX analysis on A-2 shows a remarkable Ca peak as shown in Fig. 6. An EDX analysis on A-1 shows almost the same result as B, but a line analysis at the tip of A-1 shows a strong Ca peak. (Fig. 7) Thus, the A-2 phase and the tip of A-1 phase are considered calcium-rich phase. Additional investigations showed that small “globules” of 1–20 μm in diameter were calcium-rich phase. The cross-section of the fibrous particle sample was observed after rough polishing (with sand papers #200 and #600), so that the oxygen peak with the low energy level was hard to detect. In the present study, assuming stoichiometric compounds, the composition of A-2 and B were calculated and listed in Table 3.

3.3. Formation Mechanism of Fibrous Particles

The calcium-rich phase could not be precipitated after fibrous particles formed, because the slag system is a eutectic. Thus, the calcium-rich region could exist in the liquid slag before the formation of fibrous particles, and might work as seeds of the formation of fibrous particles. When the same slag was remelted and quenched into pure water in the laboratory experiment, no fibrous particle was found. Thus, the calcium-rich phase might be formed (or existed) by another path. Two possibilities can be considered as a source of the calcium-rich phase formation: (i) CaO-rich particles...
particles contaminated physically in or after the tapping process and (ii) precipitation of calcium oxide or hydroxide from Ca dissolved in the spraying water. Once the calcium-rich phase is formed in the slag, the following mechanism of the formation of fibrous particles may be considered. Owing to a slight temperature drop during the tapping, a tiny globule such as the phase A in Figs. 4 and 5 could be formed around the calcium-rich particle in a slag flow, then the fibrous glassy particles might grow holding the globules by some rheological reasons with rapid expansion of vaporized water.

4. Conclusions

The blast furnace slag having fibrous particles were characterized using a FE-SEM analyzer with EDX. Observation result shows that calcium-rich small globules exist inside the fibrous particles, and these globules are considered as the seeds of the formation of fibrous particles.

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