

Recovering titanium and iron by co-reduction roasting of seaside titanomagnetite and blast furnace dust



Tianyang Hu, Tichang Sun^{*}, Jue Kou, Chao Geng, Xiaoping Wang, Chao Chen

School of Civil and Environmental Engineering, Beijing University of Science and Technology, China
Key Laboratory of Ministry of Education of China for Efficient Mining and Safety of Metal Mines, China

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ABSTRACT

Co-reduction roasting of seaside titanomagnetite and blast furnace dust was investigated to maximize the use of these ores in Indonesia. This direct reduction process utilizes fixed carbon in BFD to reduce iron from BFD and titanomagnetite. X-ray diffraction and X-ray fluorescence analyses were performed to characterize the reduced iron powder. The influences of reduction conditions, such as reduction temperature and duration, C/Fe molar ratio, grinding fineness and fluorite dose, on the indicators of reduced iron powder were evaluated. Fixed carbon and volatile matter contents were lower in BFD than those in coal. However, reduction and separation of titanium and iron exhibited similar effects on reduction roasting. Results showed that the optimum conditions of roasting reduction included C/Fe molar ratio of 0.65, fluorite dose of 4 mass%, and roasting temperature of 1300 °C for 60 min. The reduced iron powder was obtained through two-stage grinding and two-stage magnetic separation of the roasted product. The former contained 94.23 mass% Fe and 0.58 mass% TiO₂ and showed total iron recovery of 87.62%. The latter contained 19.72 mass% Fe and 25.47 mass% TiO₂, thereby providing prerequisites for titanium recycling.

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1. Introduction

Titanium is mainly recovered from rutile and ilmenite concentrates. However, high-grade rutile and ilmenite deposits are depleted, and processing of these ores results in environmental pollution; as such, titanomagnetite deposits have gained increased attention as a source of titanium and iron. The Indonesian coastline contains numerous seaside titanomagnetite (STTM) resources (Hu et al. 2009). STTM features high potential value, easy mining and low treatment cost, and thus can be used as raw materials for iron and steel making as well as titanium production (Sun and Chen 2010).

Numerous studies were conducted to improve the utilization of titanomagnetites. Several new techniques, such as pyrometallurgical and hydrometallurgical processes (Jena et al. 1995; Liang and Liang 2008; Wei and Zhang 2008), acid leaching, and solvent extraction (Sole 1999a, 1999b; Sole et al. 1999), have been studied. However, these processes not only cause environmental pollution but also result in considerable wastage of iron and titanium resources. Iron, with

high grade and recovery, can be processed using coal-based direct reduction followed by magnetic separation (Gao et al. 2013; Gao et al. 2012; Yu et al. 2014). Direct reduction is a practical and effective technique but depends on fixed carbon in coal (Jiang et al. 2015; Hu et al. 2013). The use of coal as reductant increases processing costs.

Blast furnace dust (BFD) is a solid waste that is not utilized completely. BFD mainly contains iron and carbon as well as low amounts of silicon, aluminum, calcium, and magnesium. Approximately 10 million tons of BFD are produced annually by the blast furnace ironmaking industry in China (Shi 2004). But only portions of BFD are used by returning sintering plants, and most domestic plants do not effectively use this material (Wang et al. 1998; Smith et al. 2000). Fixed carbon in BFD can replace coal to reduce iron from BFD and STTM during direct reduction because BFD contains a certain amount of fixed carbon, magnetite, and hematite. In this paper, the direct reduction process with BFD and STTM is called co-reduction roasting process. This process is a new approach for highly effective utilization of BFD if its carbon and iron contents can be used fully in co-reduction roasting.

This study aims to investigate the co-reduction roasting behavior of STTM and BFD. The influence of co-reduction conditions, such as reduction temperature and duration, C/Fe molar ratio, grinding fineness and fluorite dose, on Fe grade, iron recovery, and TiO₂ content of the reduced iron powder (RIP) were studied.

^{*} Corresponding author at: School of Civil and Environmental Engineering, Beijing University of Science and Technology, China.
E-mail address: suntc@ces.ustb.edu.cn (T. Sun).

Table 1
Seaside titanomagnetite ore analyzed using X-ray fluorescence (mass%).

Component	Fe	TiO ₂	SiO ₂	Al ₂ O ₃	MgO	CaO
Content	53.51	11.26	10.37	5.73	2.89	0.98
Component	MnO	ZnO	Na ₂ O	K ₂ O	P	S
Content	0.52	0.07	0.40	0.09	0.05	0.02

2. Experimental

2.1. Seaside titanomagnetite ore

The STTM ore (particle size of <1 mm) was obtained from the Indonesian coast. Mineral composition of the titanomagnetite ore was determined through X-ray diffraction (XRD) analysis, and chemical contents were evaluated using X-ray fluorescence (XRF) analysis. The results are shown in Table 1 and Fig. 1.

Table 1 shows that the STTM ore contains 53.51 mass% Fe and 11.26 mass% TiO₂ as well as low S and P contents. Fig. 1 indicates that the major valuable mineral is titanomagnetite. The main gangue minerals are pyroxene and spinel.

2.2. Blast furnace dust and fluorite

BFD was obtained from an iron and steel making company in Hebei Province. The mineral and chemical compositions of the BFD ore were determined through XRD and XRF analyses, respectively. The results are shown in Table 2 and Fig. 2.

Industrial analysis results (air dry) of the BFD included the following: 33.73 mass% fixed carbon, 8.88 mass% volatile, 57.40 mass% ash, and 2.10 mass% moisture. Fixed carbon and volatile matter contents are lower, but ash content is higher in the BFD than that in coal.

Table 2 indicates that iron, silicon, aluminum, and calcium contents are higher in BFD than those in coal; the main composition of BFD is iron, which reaches 22.31 mass%. Fig. 2 shows that the major valuable minerals in BFD are magnetite and hematite. The main gangue minerals are quartz and gypsum. The additive used was fluorite, with 60 mass% CaF₂ and 40 mass% SiO₂.

2.3. Experimental methods

Co-reduction experiments were performed in a furnace under a controlled temperature within ± 5 °C. The STTM ore, BFD, and fluorite were mixed in each experiment. The mixture was placed in a sealed graphite crucible and heated in a furnace (CD-1400X) at the target temperature for specific durations. The graphite crucible was removed from the

Table 2
BFD analyzed using X-ray fluorescence (mass%).

Component	Fe	TiO ₂	SiO ₂	Al ₂ O ₃	ZnO
Content	22.31	0.35	13.41	5.93	7.39
Component	MgO	CaO	K ₂ O	P	S
Content	3.32	6.82	0.44	0.06	3.48

furnace and cooled to ambient temperature. The roasted ore was processed by two-stage grinding and two-stage magnetic separation. The magnetic products include RIP, and the non-magnetic products are titania-rich slag. The process flow diagram is shown in Fig. 3.

Fe grade, TiO₂ content, and total iron recovery of RIP were used as evaluation indices of co-reduction followed by magnetic separation. Fe grade and total iron recovery characterize the amount of iron in RIP, and TiO₂ content indicates the effectiveness of separation of iron and titanium.

The total iron recovery of RIP was calculated using the following formula:

$$\text{Total iron recovery of RIP} = \frac{\text{RIP mass} \times \text{Fe grade of RIP}}{\text{STTM mass} \times \text{Fe grade of STTM} + \text{BFD mass} \times \text{Fe grade of BFD}} \times 100\%$$

Material properties of the STTM ore and BFD were performed by XRD. The samples were ground to 100 mass% with particle size of <74 μm to analyze the mineralogical compositions through power XRD with a diffractometer (RigakuDmax-RD12 kW, Japan).

3. Results and discussion

3.1. Effect of roasting temperature on co-reduction

Roasting temperature affects reduction rate and degree. Gao et al. (2013) reported that the initial reduction conditions include C/Fe molar ratio of 0.65 and reduction roasting duration of 60 min. The low-intensity magnetic field strength is 151 kA·m⁻¹.

At 1000 °C–1300 °C, iron oxide is rapidly restored but titanium oxide is difficult to reduce. Thus, the total iron recovery, Fe grade, and TiO₂ content of RIP were studied at 1150 °C–1300 °C. The reduction curve is presented in Fig. 4.

The total iron recovery and Fe grade are higher than 85% and 90 mass%, respectively. The TiO₂ content reached <3% at 1150 °C–1300 °C. The result indicated that the reduction effect was achieved, but the effect of titanium and iron separation was not optimal. Thus,

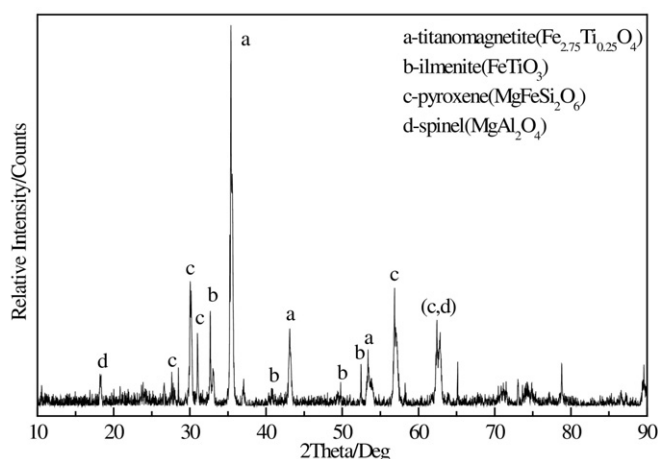


Fig. 1. X-ray diffraction patterns of STTM ore.

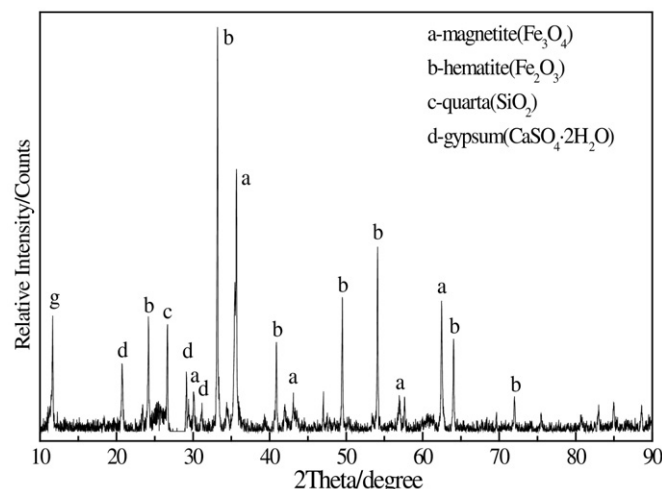


Fig. 2. X-ray diffraction patterns comparison of BFD.

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