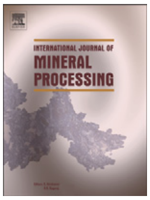
International Journal of Mineral Processing 142 (2015) 125–133

Contents lists available at ScienceDirect

International Journal of Mineral Processing

journal homepage: www.elsevier.com/locate/ijminpro



Vanadium–titanium magnetite ore blend optimization for sinter strength based on iron ore basic sintering characteristics

Mi Zhou *, Tao Jiang, Songtao Yang, Xiangxin Xue *

School of Materials and Metallurgy, Northeastern University, Shenyang 110819, China

ARTICLE INFO

Article history:
Received 28 September 2014
Received in revised form 25 April 2015
Accepted 28 April 2015
Available online 30 April 2015

Keywords:
Vanadium and titanium magnetite ore
Optimization of matching ores
Sinter
Basic sintering characteristics
Sinter strength

ABSTRACT

Vanadium titanium magnetite (V–Ti) ore is one kind of important polymetallic minerals in China and the mainstream route of comprehensive utilization process is blast furnace (BF) → basic oxygen furnace (BOF). V–Ti sinter is one of the main burdens employed for BF and poor tumbler strength (TI) limits its efficiency. In order to optimize the V–Ti blends for sinter TI, the basic sintering characteristics (BSCs) of 5 kinds of V–Ti ores, 2 ordinary ores and 3 groups of optimization V–Ti blends were studied. In addition, the sinter pot tests were conducted to obtain the TI of the produced sinter. The influencing factors on assimilation temperature (AT), the relations between the 4 characteristics of BSCs, and the factors influencing the V–Ti sinter TI were analyzed. The results showed that the BSCs of 5 kinds of V–Ti ores DB, HW, YT, JL and FH were good except liquid phase fluidity characteristic index (LF). The key reason why V–Ti sinter had a poor TI was the low LF, which caused the sinter with a large-pore structure. Therefore, the matching ores for optimization V–Ti blends should have a high LF. In addition, self-strength of the bonding phase (BS) and crystal intensity (CI) had an important impact on TI when the melt formed was sufficient and meanwhile the melt had a high LF. Moreover, the proper AT was the prior factor for the melt generation. In addition, the optimization V–Ti blends had good BSCs. The sinter TI with 7% NF ore addition could meet the production requirements for its TI was higher than 65%. Totally, the method of V–Ti magnetite ore blend optimization for sinter strength based on iron ore basic sintering characteristics was useful.

1. Introduction

Vanadium and titanium magnetite (V–Ti) ore has a very high comprehensive utilization value due to its high-content vanadium, titanium, iron, etc. In addition, V–Ti ore as a major source of vanadium is found in various countries, such as Australia, China, Russia, and South Africa (Moskalyk and Alfantazi, 2003; Deng et al., 2012; Yu, 2004). But because of its complicated phase structure, and numerous mineral components (Hu et al., 2013), V–Ti ore is classified as a typical polymetallic paragenic resource that is difficult to treat and utilize (Si et al., 2012). Currently, the mainstream route of the comprehensive utilization of V–Ti ore is blast furnace (BF) → basic oxygen furnace (BOF). However, it is found that the smelting operation and the comprehensive utilization of V–Ti burden in BF affected seriously for its poor tumbler strength (TI) compared with that of ordinary sinter.

Thus, the researches on the improvement of V–Ti sinter quality especially TI are valuable. The research on the properties of raw materials, especially the characteristics of iron ores is fundamental and important. In addition to the traditional room temperature characteristics of iron ores, generally including physical structure (Ono et al., 2009; Formoso et al., 2003; Ellis et al., 2007), chemical composition (Hsieh, 2005; Wu et al., 2011; Zhang et al., 2014), and basic sintering characteristics (BSCs) of iron ores proposed by Wu et al. (2002a) get more and more attention of the researchers. BSCs including 4 kinds of high temperature characteristics of iron ores, such as assimilation characteristic, liquid phase fluidity characteristic, self-strength of bonding phase, and crystal intensity characteristic, could reflect the behavior and exhibit some physical and chemical characteristic of iron ores in the sintering process. Extensive work (Zhang et al., 2012, 2013, 2014; Wu et al., 2010) on BSCs has been conducted to optimize the iron ore blends and the results confirm that there is great significance in mastering the BSCs of iron ores, which will be beneficial to improving sinter properties and productivity. Though, the previous work almost focuses on the ordinary iron ores and the ordinary ore blends, there are limited studies on the BSCs of V–Ti ores and their blends. In addition, the previous work on the optimization of iron ore blends usually is based on one of the BSCs such as assimilation characteristic. Furthermore, the relations between the BSCs and the produced sinter's properties such as TI were not revealed.

Therefore, in the present research, firstly, the BSCs of 5 kinds of V–Ti ores FH, DB, HW, YT, JL, and 2 kinds of ordinary ores YD and NF were studied. Secondly, 3 groups of optimization V–Ti blends YH, NH-1, and NH-2, mixed with ordinary iron ores, were designed and determined based on the results of the first research. Thirdly, sinter pot tests were carried out to verify the method's usefulness and to aiming to achieve

---

* Corresponding authors.
E-mail addresses: zhoumineu@163.com (M. Zhou), xuexx@mail.neu.edu.cn (X. Xue).

http://dx.doi.org/10.1016/j.minpro.2015.04.019
0301-7516/

the sinter TI. Fourthly, the relations between the 4 characteristics of BSCs and the produced sinter's TI were obtained. Finally, the rules of V–Ti ore blend optimization for the sinter TI were proposed and it would be useful to the V–Ti iron ore optimization for achieving a high value of sinter TI.

2. Experimental

2.1. Experimental materials

The 5 kinds of vanadium–titanium magnetite ores DB, HW, YT, JL, and FH (mixed by DB, HW, YT and JL) and 2 ordinary ores (hematite) YD, and NF used in this study are supplied by Chengde Jianlong Iron and Steel Group Company, China. The chemical composition of iron ores and coke breeze for experimental work are listed in Tables 1 and 2.

It can be seen from Table 1 that the total iron content of 5 kinds of V–Ti ores is higher than that of ores NF and YD especially YD, and the TiO_2 content of V–Ti ores varies from 1.45% to 3.15% along with the V_2O_5 content of V–Ti ores that varies from 0.37% to 0.59%. Therefore, it will have a significant effect on the iron grade of the sinter and the content of TiO_2 has a negative influence on the sinter quality especially TI to a certain extent. In addition, the content silica of 5 kinds of V–Ti ores is smaller than 5.00% while the total iron content is larger than 63.00%, which are high iron and low silica ores.

2.2. Experimental methods

2.2.1. BSCs of iron ores

The entire experiments determining BSCs were carried out using an infrared heating furnace with a working tube of 50 mm in diameter, the schematic representation of the furnace and the image of equipment set-up were shown in Fig. 1(a) and (b), respectively. The main feature of the equipment set-up was its quick and precisely controlled heating and cooling rates due to the principle of infrared heating, enabling a close simulation of the real sintering process that arose in a sintering machine. The experimental atmosphere in the equipment set-up was also controlled by introducing a desired gas. The standard temperature profile used was shown in Table 3. Due to the influence of particle size of the iron ores (Kasai and Saito, 1996; Venkataramana et al., 1999), and to avoid its influence on BSCs, in this work, the particle size of the iron ores is kept in the same region (−0.074 mm).

2.2.1.1. Assimilation characteristic. Sinter mixes are granulated prior to charging into a sinter machine. During granulation fine particles adhere onto the surface of large particles with the assistance of water lenses to form granules. It is well established that the initial melt is generated from these adhering fines during sintering via reactions between iron ore and fluxes. This melt then assimilates the nuclei particles to produce more melt. Before complete melting is reached, the sintering temperature drops. The melt solidifies and mineral phases precipitate out of the melt forming bonding phases such as calcium ferrite, and silicate, which cement the un-melted materials and form lumpy sinter. Obviously, the chemical reactions for melt formation mainly take place in the high temperature zone of the sinter bed in a very short period of time and this is an extremely complex process.

Table 1
Chemical compositions of raw material (mass, %).

Items	TFe	SiO_2	CaO	MgO	Al_2O_3	TiO_2	V_2O_5
V–Ti DB	63.08	4.41	1.73	1.52	1.44	1.98	0.42
V–Ti HW	63.62	3.20	1.28	1.12	1.82	2.61	0.53
V–Ti YT	63.81	3.84	0.77	0.74	1.95	3.15	0.59
V–Ti JL	63.52	4.20	1.69	1.76	1.23	1.45	0.37
V–Ti FH	63.50	3.96	1.46	1.25	1.57	2.18	0.50
YD	56.06	5.57	0.06	0.15	5.63	–	–
NF	63.00	6.50	0.16	0.16	1.90	–	–
Return 1	54.06	5.37	10.39	2.72	2.45	1.78	0.33
Return 2	54.96	5.35	9.37	2.69	2.31	1.78	0.34
BF dust	33.28	7.26	5.65	1.98	4.55	1.32	0.25
Slags	30.68	16.97	2.44	2.82	1.53	9.81	1.22
Magnetic separation powder	21.20	10.58	37.89	9.49	4.34	1.25	1.60
Dolomite		2.47	44.26	31.67			
Limestone		2.91	45.35	6.81			
Quicklime		2.52	83.07	3.50			

Table 2
Industrial analysis of coke breeze and chemical compositions of the ash (mass, %).

Fixed carbon	Volatile	Organic compounds	Ash (14.00)						Σ
			FeO	CaO	SiO_2	MgO	Al_2O_3	others	
84.00	0.50	1.50	0.14	0.48	7.50	0.15	2.72	2.89	100.00

To simulate the assimilation reaction of iron ores plainly, the reaction ability between CaO and iron ores is named for assimilation characteristic, and the evaluation index of assimilation characteristic of iron ores in the present work was assimilation temperature (AT). AT is entrenched by the beginning bonding of the CaO and iron ores, reflecting the beginning reaction temperature of CaO and iron ores, the schematic diagram of the assimilation reaction was shown in Fig. 2.

In this section, 5 kinds of V–Ti ores and 2 ordinary ores were grinded to −0.074 mm by using a sealed crusher. CaO pure and iron ores were shaped into tablets by using two steel molds under a pressure of 15 MPa for 2 min and the weights of CaO tablet and iron ore tablets were 2.0 g and 0.8 g, respectively. Then put the iron ore tablet on the CaO tablet, and the two tablets were sintered in the equipment set-up later.

Due to the fact that the iron ore sintering is a non-uniform process, in order to avoid the decrease of the nuclei ores in the consolidation framework and the deterioration of the permeability of the sintering bed, the assimilation ability of iron ores is not desired to be too high, which may cause over-melting and has a negative effect on the yield and quality of the sinter (Wu et al., 2010) (Fig. 2). Therefore, the iron ores with proper assimilation ability are required.

As mentioned above, neither high AT nor low AT is good for sintering. The optimal AT region is 1250 °C–1280 °C (Wu et al., 2002b).

2.2.1.2. Liquid phase fluidity characteristic. Liquid phase fluidity characteristic is the flowing capacity of the melt generated in the high temperature zone of the sinter bed through a series of extremely complex chemical reactions.

In this work, the liquid phase fluidity index (LF) was used to evaluate liquid phase fluidity characteristic. The sample preparation process was almost the same to that in assimilation tests, except the sample was a mixture composed of iron ores and CaO pure. And the binary basicity was 4.0, adjusted by the addition of CaO pure. The equipment, temperature, and atmosphere in these tests were also almost the same to the tests in assimilation characteristic except the experiment temperature was 1280 °C and the desired atmosphere should be switched to nitrogen after 600 °C. The vertical projected area of the cake after the test was measured to calculate the LF, and to evaluate the liquid phase fluidity characteristic. The sketch map of the experiment for the liquid phase fluidity was shown in Fig. 3. Liquid phase fluidity characteristic was calculated as shown in Eq. (1),

$$LF = (AA - BA)/BA. \tag{1}$$

Which, LF is index of fluidity of liquid phase; AA is flowing area after sinter test, mm^2; and BA is original area before sinter test, mm^2. The optimal LF range is 0.6–1.6.

2.2.1.3. Self-strength of bonding phase. The un-melted materials were bonded by the bonding phases precipitating out of the melt generated