Available online at www.sciencedirect.com
ScienceDirect

JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2016, 23(4): 314-321

Self-reduction Mechanism of Coal Composite Stainless Steel Dust Hot Briquette

Sok-chol RI[1,2], Man-sheng CHU[1], Shuang-yin CHEN[1], Zheng-gen LIU[1], Hun HONG[2]

(1. School of Metallurgy, Northeastern University, Shenyang 110819, Liaoning, China; 2. School of Metallurgical Engineering, Kim Chaek University of Technology, Pyongyang 999093, DPR of Korea)

Abstract: To efficiently recycle valuable metals such as chromium and nickel in stainless steel dust, self-reduction experiments were carried out to study the reduction mechanism of metal oxides in coal composite stainless steel dust hot briquette, which is defined as a CCSB here. Self-reduction of CCSB is proceeded by volatile matter and fixed carbon contained within CCSB. Experiments were performed to study the effects of temperature and carbon to oxygen (C/O_{Coal}) ratio on self-reduction of CCSB. At 1400 and 1450 ℃, volatile matter in coal used for experiment could take the place of about 40% of fixed carbon in coal. Under the present experimental conditions, reduction product of chromium appears as $FeCr_2O_4$, Cr_2O_3, Cr_7C_3, and [Cr] in turn during reduction. To evaluate the formation of metal nuggets in self-reduction process of CCSB, metal nuggets containing chromium and nickel were observed in outside of reduction products under various conditions, and thermodynamic equilibrium calculation was carried out for possible products and formation of molten metal by fixed carbon. SEM and EDS analyses were made for metal nugget and slag in reduced product. The results reveal that it is reasonable to achieve the metal nuggets at 1450 ℃, 0.8 of C/O_{Coal} ratio and 20 min of reduction time. The nugget formation can indicate one innovative process for comprehensive utilization of stainless steel dust.

Key words: stainless steel dust; coal composite; hot briquette; self-reduction; metal nugget

Stainless steel dust is generated in stainless steel production using electric furnace and AOD/VOD furnace, which contains a large amount of valuable metals such as iron, chromium and nickel. Generally, about 13−38 kg of stainless steel dust is generated when producing 1 t stainless steel[1,2]. In recent years, stainless steel production has been sharply increasing in the world, and stainless steel production was increased to 3.9 Mt in 2014. Accordingly, stainless steel dust is generated more and more. Moreover, stainless steel dust is classified as a hazardous industrial waste because of large amounts of chromium. Therefore, it is of great significance to recycle valuable metals in stainless steel dust.

Up to now, several processes have been developed for recycling chromium and nickel in stainless steel dust, for example, INMETCO, Fastmet/Fastmelt, OXYCUP, etc. INMETCO process produces a hot iron alloy containing chromium and nickel by melting separation in an arc furnace after direct reduction in a rotary hearth furnace, which consists of preparation of raw materials, pretreatment, mixing, pelletizing, direct reduction, smelting and final reduction[3,4]. Fastmet/Fastmelt process is very similar to INMETCO, which has the advantages of shorter process flow and smaller layout area, but chromium recovery rate is low[5]. OXYCUP process produces hot metal containing chromium using coke in an OXYCUP shaft furnace, with disadvantages of large amount of slag and high Si content in hot metal[6]. The aforementioned processes have been used to recycle chromium and nickel with carbon composite stainless steel dust agglomerates containing binder.

Recently, more attention has been paid to the carbon composite agglomerates in ironmaking indus-

Foundation Item: Item Sponsored by Fundamental Research Funds for the Central Universities of China (N110202001)
Biography: Sok-chol RI, Doctor Candidate; **E-mail**: lscl07@126.com; **Received Date**: March 2, 2015
Corresponding Author: Man-sheng CHU, Doctor, Professor; **E-mail**: chums@smm.neu.edu.cn

try because of its shorter reduction time. As a result, studies were extensively carried out about mechanism and kinetics of carbothermic reduction of iron oxide in the carbon composite iron oxide agglomerates[7-9]. Direct reduction of carbon composite Sukinda chromite ore agglomerates was studied at high temperature to recover Fe, Cr and Ni by Kapure et al.[10]. A novel process was proposed to produce ferronickel alloy nugget at a relatively low temperature from carbon composite nickel laterite agglomerates by semi-molten reduction in the reactor like RHF[11]. Besides, as a new type of ironmaking raw materials, carbon composite iron ore briquette (CCB) is made through hot briquetting, and the reduction of CCB takes place only by heating; the CCB has an excellent reduction performance. CCB does not need any binder such as cement or bentonite because it is formed at temperatures where thermal plasticity of coal appears, with the help of hot briquetting. It does not take long time to cure agglomerates, especially has a high heat conductivity and high reducibility due to an intimate contact between ore and fixed carbon, self-reduction action of volatile matter and its lower porosity[12-15]. However, no report has been made yet on manufacture of coal composite stainless steel dust briquettes (CCSB) and its reduction mechanism.

In the present study, CCSB are manufactured through hot briquetting; the effect of volatile matter was evaluated in self-reduction process. In self-reduction process of CCSB, reduction mechanism of chromium oxide was experimentally and theoretically interpreted. The reduction conditions favorable to form liquid phase (metal nugget) were determined, and thermodynamic equilibrium calculation results and experimental results were discussed.

1 Experimental

1.1 Raw materials

Chemical compositions of stainless steel dust used in the present study are given in Table 1. Fe, Cr and Ni contents of stainless steel dust were 33.18%, 11.81% and 2.10%, respectively.

X-ray diffraction pattern of the stainless steel dust is shown in Fig. 1. Fe in the stainless steel dust exists in the form of Fe_2O_3, Fe_3O_4, $FeCr_2O_4$ and $NiFe_2O_4$, most of which is Fe_3O_4 and $FeCr_2O_4$. Cr exists in the form of $FeCr_2O_4$, and Ni exists in the form of $NiFe_2O_4$ and NiO, most of which is NiO. A large amount of CaO is included in gangue, some of which exists as calcium carbonate.

Table 1 Chemical compositions of stainless steel dust mass%

TFe	FeO	Ni	Cr	Zn	SiO_2	CaO	Al_2O_3	MgO	LOI
33.18	18.67	2.10	11.81	0.28	4.15	15.01	1.13	1.01	6.42

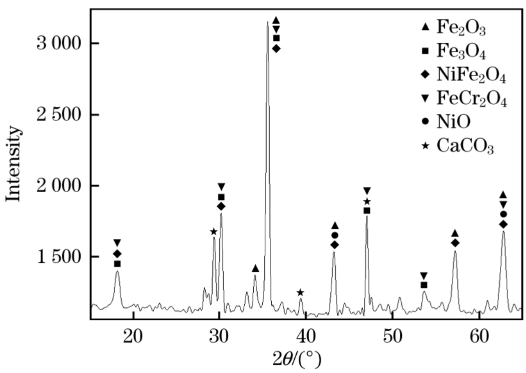

Fig. 1 X-ray diffraction pattern of the stainless steel dust

Proximate analysis of coal and chemical analysis of ash are given in Table 2. The coal, especially high in volatile matters (34.86%), is favorable for self-reduction of CCSB.

Table 2 Proximate analysis of coal and chemical analysis of ash mass%

Proximate analysis of coal			Chemical analysis of ash			
FC	V_{daf}	A_{ad}	CaO	SiO_2	Al_2O_3	MgO
57.87	34.86	7.24	5.19	70.09	22.79	1.01

Stainless steel dust and coal powders, having an average particle size of about 74 μm, were used. The powders were weighed accurately and then mixed thoroughly. CCSB were manufactured through hot briquetting under a pressure of 35 MPa at 200 ℃. In this case, CCSB possessed enough strength for rotary hearth furnace, and the average compressive strength was 900 N/pellet.

1.2 Experimental apparatus

Fig. 2 shows the schematic illustration of the experimental apparatus. The maximum operating temperature of 1863 K could be achieved with $MoSi_2$ heating elements.

Temperature was adjusted by two thermocouples