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Effect of reducing agent species on reduction and slag-metal separation from carbon composite pellets

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Abstract. The rotary hearth furnace iron nugget process has advantages of short reaction time and high quality product. Using semi-coke, bituminous coal, anthracite, charcoal and coke as raw material, effects of reducing agent species on reduction and melting separation of carbon composite pellets were studied. Results showed that reducing agent species had a great influence on reduction and melting separation behaviors of carbon composite pellets. Bituminous coal as the reducing agent could lead to the best reducing effect, but it played a negative role in slag-metal separation. For comprehensive consideration of economic benefits, melting separated quality and energy consumption, optimum reducing agent was semi-coke. Optimum reduction temperature and melting separated temperature was 1200℃ and 1375℃ respectively. Under this condition, the recovery rate of metallic iron could reach 92％.

Introduction

Compared with traditional blast furnace process, the rotary hearth furnace iron nugget process has advantages of short process, raw material flexibility, short reduction times and high quality iron nugget and has strong competitiveness in energy, cost, environmental protection, material adaptability and so on. So the rotary hearth furnace iron nugget process has vital significance to the ecofriendly development of iron and steel industry [1-3].

Reducing agent is an important part of iron ore carbon composite pellets and the properties of reducing agent have an important influence on reduction and melting separated behaviors. Therefore, the present work studied the effects of reducing agent species on reduction and melting separated behaviors of carbon composite pellets by pre-reduction and melting separation experiment. And optimum reference for selection and evaluation of carbonaceous reducing agent used in rotary hearth furnace iron nugget process was obtained.

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Experimental

Raw materials

The chemical composition of the iron concentrate used in this study is shown in Table 1. The iron grade was 60wt％ and 98wt％of the iron ore concentrate particles was smaller than 0.074mm. The proximate analysis and ash fusibility of different species of reducing agents used in this study are shown in Table 2. All reducing agent particles passed 0.048mm opening sieve.

Table1. Chemical composition of iron concentrate [wt％]

TFe	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	P	S
60	27.2	13.8	0.75	0.16	0.54	0.04	0.022	0.19

Table2. Proximate analysis and ash fusibility of reducing agents

Species	Proximate analysis[wt％]				Ash fusibility[℃]			
	FC_d	V_d	A_d	S	DT	ST	HT	FT
Semi-coke	70.77	8.81	20.42	0.15	1200	1210	1220	1230
Bituminous coal1	74.84	12.57	12.59	0.21	1180	1250	1280	1340
Bituminous coal2	71.86	16.52	11.62	0.61	1280	＞1500	-	-
Bituminous coal3	71.53	13.32	15.15	0.90	1350	＞1500	-	-
Anthracite	81.40	6.40	12.20	0.34	1300	1320	1350	1380
Charcoal	58.81	37.53	3.66	0.05	1395	1500	＞1500	-
Coke1	86.20	1.64	12.16	0.69	1460	＞1500	-	-
Coke2	85.73	1.87	12.40	0.67	1400	＞1500	-	-

Note: FCd represents the fixed carbon (dry basis), V_d the volatile matter (dry basis), A_d the ash (dry basis), S the total sulfur, DT the deformation temperature, ST the softening temperature, HT the hemispherical temperature, and FT the following temperature

Experimental procedure

The iron concentrate and reducing agent were fully mixed. The mole ratio between the fixed carbon in the reducing agent and the oxygen of iron oxides in the concentrate was 1.2. Slag basicity was 0.8 after the addition of $CaCO_3$ and Al_2O_3 content of iron concentrate was 6wt％ after the addition of Al_2O_3. The moisture content of the mixture was controlled at 7wt％, and the mixture was again fully mixed. The pelletizing process was performed through a manual ball press under a pressure of 20MPa. The size of the columnar pellet was φ20.0×11mm. The weight of each green pellet was 10g. Green pellets were dried at a temperature of 110℃ for 2h before the reduction experiment. Pellets were reduced using a vertical tube furnace from 1000℃ to 1200℃. High purity Ar was supplied to control the atmosphere in the furnace. Each sample was held at the target temperature in the furnace for over 30min to ensure completion of reactions. The melting separation was performed in closed MoSi2 box resistance furnace. The melting separated temperature was selected at 1350 and 1375℃ respectively. Metallization pellets and separated slag were ground into powder for chemical analysis. The mass fraction of iron and metallic iron of separated slag was obtained. Then the metallization rate and recovery rate of metallic iron of pellets were calculated.

Results and discussion

Fig.1 shows the effect of reducing agent species on metallization rate of reduced pellets. As evident in the figure, at 1000℃, the metallization rate of bituminous coal pellets was the highest and above 85%. The metallization rate of anthracite pellets, charcoal pellets and coke pellets was relatively close and about 83%, slightly lower than that of bituminous coal pellets. The metallization rate of semi-coke pellets was the lowest and only 76.17％. At 1100℃, the metallization rate of different species of reducing agent pellets increased significantly with the increase of temperature. The metallization rate of charcoal pellets and semi-coke pellets was relative low and 80.46％ and 85.05％ respectively. The metallization rate of other reducing agent pellets was about 90％. At 1200℃, the metallization rate of semi-coke pellets was still low and the metallization rate of other reducing agent pellets was about 92％. The ash fusion point of semi-coke was the lowest among eight species of carbonaceous reducing agent. Rapid melting of ash led to insufficiency of reduction of pellets and lower metallization rate of semi-coke pellets. The reactivity of charcoal was higher and the gasification rate of carbon was faster in the process of reduction, which caused lower utilization of CO and lower metallization rate of charcoal pellets at low temperature. At 1200℃， the utilization of CO and reduction efficiency of volatiles significantly improved, which caused the increase of metallization rate of charcoal pellets. In summary, when selected bituminous coal as reducing agent, high metallization rate could be achieved at relative low temperature and optimum reduction temperature was 1200℃.

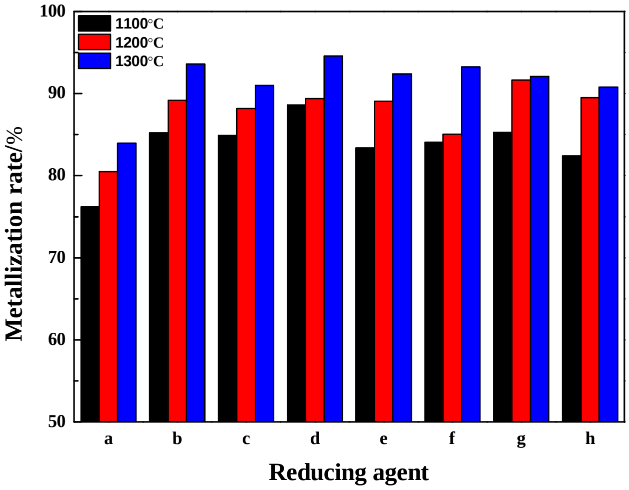

Fig1. Effect of reducing agent species on metallization rate (30min）

（a-Semi-coke，b-Bituminous coal1，c- Bituminous coal2，d- Bituminous coal3，e-Anthracite，f-Charcoal，g-Coke1，h- Coke2）

Effect of reducing agent species on morphology of melting separated product of pre-reduced pellets is shown in Fig. 2. As evident in the figure, at 1350℃, semi-coke pellets and anthracite pellets could realize complete slag-metal separation and other reducing agent pellets could not realize slag-metal separation. At 1375℃, the melting separated quality of bituminous coal3 pellets was poor and the rest of reducing agent pellets could realize complete slag-metal separation. The ash fusion point of semi-coke and anthracite was 1220℃ and 1350℃ respectively, which was lower than the melting separation temperature. Rapid melting of ash could promote slag formation and carburization of metallic iron, which was beneficial to melting separation of pellets. Although the ash fusion point of bituminous coal1 was also lower than 1350℃， bituminous coal1 pellets could not realize slag-metal separation. The volatiles of bituminous coal1 were higher than anthracite. The removal of volatiles was fast at early period of reduction process, which made the formation of void in pellet easier. The contact between carbon and the metallic iron particles was worse, which hindered the carburization of metallic iron and the melting separation of bituminous coal1 pellets. The recovery rate of metallic iron of semi-coke pellets and anthracite pellets was relatively close and about 92％. Compared with anthracite, semi-coke has advantages of lower cost. In summary, optimum reducing agent was semi-coke and optimum melting separated temperature was 1350℃.

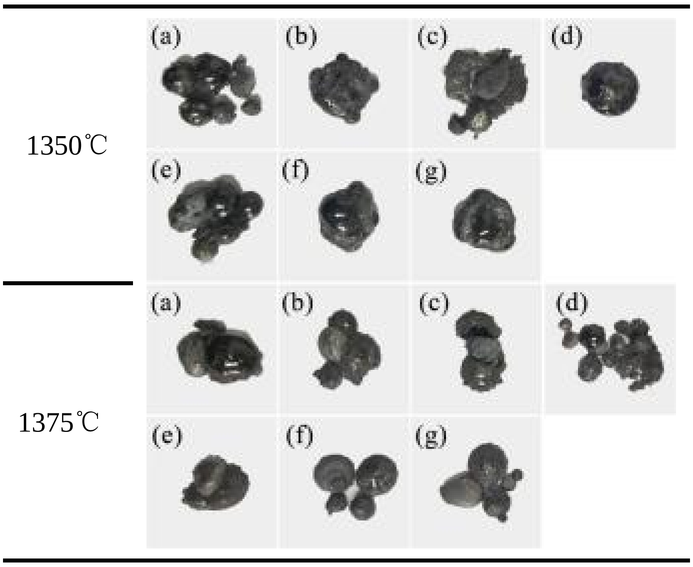

Fig2. Morphology of melting separated product of pre-reduced pellet

（a-Semi-coke，b-Bituminous coal1，c- Bituminous coal2，d- Bituminous coal3，e-Anthracite，f-Coke1，g- Coke2）

Conclusions

（1）Reducing agent species have an important influence on reduction and melting separation of pellets. Bituminous coal pellets could achieve high metallization rate at relative low temperature.

（2）For comprehensive consideration of economic benefits, melting separated quality and energy consumption, optimum reducing agent was semi-coke and optimum pre-reduced temperature and melting separated temperature was 1200℃ and 1350℃ respectively. Under this condition, the recovery rate of metallic iron could reach 92％.

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