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An Innovative Process for Direct Reduction of Cold-bound Pellets from Iron Concentrate with a Coal-based Rotary Kiln

ZHU De-qing, QIU Guan-zhou, JIANG Tao, XU Jin-chang

(Institute of Sintering & Pelletizing, Central South University of Technology, Changsha 410083, China)

Abstract: Successfully developed an innovative process of direct reduction of cold-bound pellets from iron ore concentrate with a coal-based rotary kiln, in comparison with the traditional direct reduction of fired oxide pellets in coal-based rotary kilns, possesses such advantages as: shorter flowsheet, lower capital investment, greater economic profit, good quality of direct reduced iron. The key technologies, such as the composite binder and corresponding feasible techniques were employed in practice. A mill utilizing this process and with an annual capacity of 50 thousand ton DRI has been put into operation.

Key words: direct reduction; rotary kiln; cold-bound pellets; iron concentrate
Document code: A

Direct reduction-electric arc furnace (DR-EAF) for steel-making is regarded as the third revolution in the iron and steel industry, which is competitive in production cost and environment protection with scrap as raw materials, but direct reduced iron (DRI) is one kind of the best substitutes for scrap to make special quality steel[1~3]. Using iron concentrates as raw materials for production of DRI, fired oxide pellets are usually utilized as charges for direct reduction furnaces, the process of direct reduction of fired pellets (two-step process) has some disadvantages as follows:

1) Greater capital investment owing to more high temperature resistant apparatus and longer flowsheet;

2) Low temperature disintegration due to oxide phase transfer during direct reduction, which is a risk leading to kiln accretion[3];

3) Lower iron grade of DRI because of adding bentonite as a binder for making pellets;

4) More energy consumption because of two high temperature steps, i.e. firing of green pellets and direct reduction of fired pellets.

In order to reduce cost and energy consumption, and improve environment, an innovative process of direct reduction of cold-bound pellets, called one-step process was developed[4,5]. A commercial plant utilizing the one-step process and with an annual capacity of 50 thousand ton DRI was started up in Louzhong Company of Mines and Metallurgy, in 1997. In this paper, the main characteristics of this process will be present.

1 Raw Materials

The chemical analysis of iron concentrate used is shown in Table 1. The concentrate is magnetite ore from Louzhong Company of Mines and Metallurgy, Shandong Province, China. The particle sizes less than 0.075 mm account for 76.51% by wet screening.

The composite binder used for cold-bound pellet manufacture was produced by Central South University of Technology, whose main ingredients were demonstrated in Ref. [4]. The fineness of the binders less than 0.50 mm amounts to 78.33% by dry screening.

The chemical analyses of reductant coal mined in Huapin, Yunan Province, are presented in Table 2. The sizes of coal are 5 ~ 20 mm, which amount to 74.82%.

Table 1 Results of chemical analyses of iron concentrate *w*/%

TFe	FeO	SiO_2	Al_2O_3	CaO	MgO	P	S	K_2O	Na_2O	Cu
67.12	19.89	1.08	1.12	0.53	3.16	0.008	0.007	0.044	0.038	0.021

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Biography of the first author: ZHU De-qing, associate professor, received Ph. D. in Mineral Engineering in 1994, majoring in mineral processing and ferrous metallurgy.

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Table 2 Chemical analyses of reductant coal and its ash

Industrial analyses					Ash composition/%						
Ash/%	Volatile matter/%	Fixed carbon/%	Sulfur/%	Heat value/($MJ \cdot kg^{-1}$)	CaO	SiO_2	Al_2O_3	MgO	MnO	Fe_2O_3	S
23.02	23.03	53.95	0.43	26.53	7.84	44.92	26.36	2.10	0.80	8.30	0.49

2 Technique and Financial Considerations

The flowsheet of one-step process is demonstrated in Fig.1. The process includes six sections: proportioning, damp milling, balling, hardening, reducing, cooling and dry magnetic separation.

From the flowsheet, it can be seen that this innovative process only contains one-step high temperature process, i.e. reducing cold-bound pellets at about 1 050 ℃ in a rotary kiln, and the hardening step of high temperature firing at 1 200 ~ 1 300 ℃ in the two-step process is replaced by low temperature baking at 150 ~ 250 ℃. The main technological-economic data achieved in the industrial test are as follows, which was performed in a coal-based rotary kiln of Φ2.4 m × 30 m.

Cold-bound pellets: compressive strength 228.30 N per individual pellet,

drop number 4.2 times from 1m height,

tumbling index 2.85% of − 3 mm fraction(AC tumbler);

Direct reduction: productivity per unit kiln volume 0.41t/($m^3 \cdot d$),

total iron of DRI 88.12%,

recovery of iron 91.04%,

sulfur content of DRI 0.022%,

yield rate of magnetic powder 10.56%,

consumption of coal 776 kg/(t·DRI) (702 kg standard coal/t·DRI),

work rate 96.01%

Based on the above data and compared with a plant of the same capacity, which uses the traditional two-step process, a plant employing the one-step process and with a capacity of 50 thousand ton DRI/year can reduce capital investment cost by 44.2%, save energy consumption 33.3%, lower production cost 21.4%, raise throughput 37.5% and the iron grade of DRI is 1.5% ~ 2% higher than when bentonite was added as binder.

3 Characteristics of the Process

3.1 The functions of composite binder

The composite binder possesses multiple functions such as binding, reducing and catalyzing, which not only improve the pelletizability and hardened pellet strength, but also enhance pellet reducibility and do not lower the iron grade of DRI.

3.1.1 Binding properties

The infrared spectrum of particle surface treated with the composite binder is shown in Fig.2. The active binding ingredients of the binder are chemically absorbed on the particle surface of iron concentrate, resulting in the decrease of contact angle from 46° to 0°, and the increase in wetting heat from 0.08 J/g to 0.38 J/g[5], which causes a greater hydrophilicity and better ballability for iron concentrate.

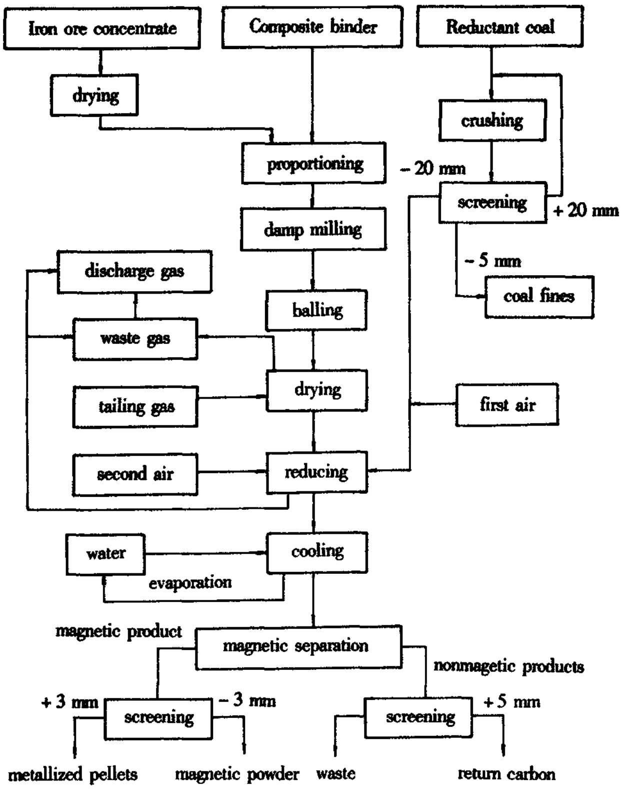


Fig. 1 Industrial test flowsheet

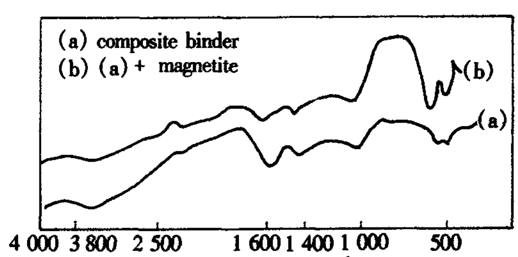


Fig. 2 Infrared spectrum of iron concentrate

On the basis of the comprehensive interfacial energy model derived by author for expression of green pellet strength, the controlling factors for pelletizing depend on three interactions, including capillary attractions, viscous impeding response and chemical adhesion. The green pellets containing the composite binder attribute their substantial strength increase to the above mentioned interactions among particles inside pellets by zero contact angle, higher viscosity of bridging liquid and greater chemical adhesion.

According to Mohr Strength Theory, the strength of bonded body depends on the binding force and friction force[6], the strength of hardened pellets with the embracement of binder greatly depends on binding force of binder molecular, frictional force and Van der Walls attractions.

For any given materials, frictional force and Van der Walls attractions are constant, and the strength of hardened pellets result from the binding force. During solidification of green pellets, condensation polymerization occurs among the chemically absorbed moleculars of composite binder, forming fibre network in pellets, which further leads to pellet shrinkage and increases the binding force and Van der Walls attractions in turn.

Since interactions among bentonite and iron ore particles are far less than that among the molecular of composite binder and iron ore particles because no chemical absorption of bentonite occurs on particle surface, the strength of incurated pellets is worse when bentonite is added as binder. Bentonite is not suitable for preparation of cold bound pellets. Bentonite will show strong binding force only when the large bentonite particle are further decomposed into microfines above 900 ~ 950 ℃, and a target strength of hardened pellets is achieved by enhancing bentonite solid phase diffuse or liquid phase binding effect at higher temperatures[6,7].

3.1.2 Reducing and catalyzing effects

The inherent fixed carbon and hydrocarbon of the composite binder take part in the reduction of iron oxide while direct reduction of cold-bound pellets occurs in coal-fired rotary kiln, which will increase the internal voidage of pellets and ameliorate heat and mass transfer inside and outside pellets.

The reducibility and catalyzing effects were proved by the developed "Volumetric reaction model" for reducing cold-bound pellets containing complex binder and using coal as reductant[8,9], and the comparison of reducibility was made between cold bound pellets containing composite binder and fired oxide pellets utilizing bentonite as binder, as is shown in Fig.3. The time taken to achieve 90% of metallization is 40 minutes less for the former than that for the latter. It can be concluded that the reducibility of cold-bound pellets is much better than that of fired ones.

3.2 Replacement of high temperature firing by baking hardening

Although high temperature firing at 1 200 ~ 1 300 ℃ was replaced by baking hardening at 150 ~ 250 ℃, the strength of cold-bound pellets can meet the requirement values of direct reduction in an industrial rotary kiln, which will decrease capital investment cost, increase work rate and lessen energy consumption.

The strength variations of commercial cold-bound pellets, pre-heated pellets[9] and fired pellets[3] by using bentonite as binder are given in Figs.4 and 5, respectively. It can be revealed that compressive strength of cold-bound pellets only drops 15.0% and the trough is more narrow. However, compressive strength of pre-heated pellets decreases from 476 N/pellet to 132 N/pellet and the minus gain is 73.10% and the trough is wider.

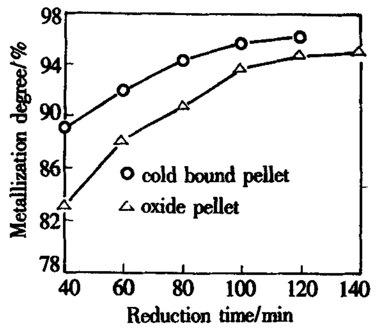
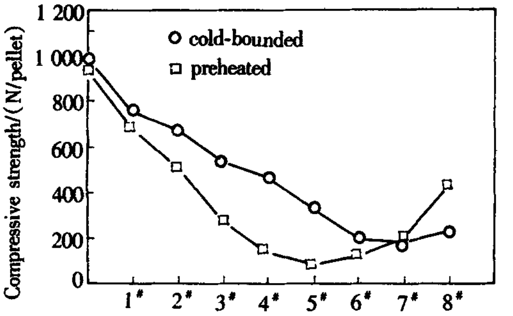


Fig. 3 Comparison of reducibility between cold-bound pellets and fired oxide pellets



1#—2.1 m(distance from the kiln head, the same below); 2#—4.9 m; 3#—8.2 m; 4#—12 m; 5#—17.2 m; 6#—21 m; 7#—24.8 m; 8#—30 m

Fig. 4 Strength variations for cold-bounded and pre-heated pellets

It can be seen from Fig. 5 that the compressive strength of fired oxide pellets decreases by about 90%, which is the steepest among the above three kinds of pellets. Even though compressive strength before reduction is as high as 2 000 N/pellet, the lowest only 150 ~ 200 N/pellet during reduction, which will result in reduction disintegration because of the volume expansion, and lead to the risk of accretion.

It can be concluded that even if the compressive strength of cold-bound pellets before reduction is lower than that of pre-heated and fired oxide pellets cherishing bentonite, they can meet the requirement value of commercial rotary kiln and eliminate the hidden danger of kiln accretion. Since the reducibility of cold bound pellets is higher, there is less decrease and more narrow valley of strength during reduction and there is no occurrence of low temperature reduction degradation.

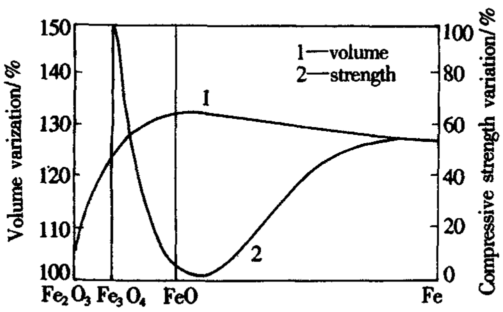


Fig. 5 Strength variation of fired oxide pellets

There is contradiction between the strength and reducibility of pre-heated and fired pellets containing bentonite. Bentonite is added to improve thermal shock and increase pellet strength by firing, but the reducibility drops because pores are choked by bentonite particles in solid or liquid phase slag bonding.

3.3 Intensifying measures taken to prepare cold-bound pellets

Damp mill was used to disperse and homogenize the highly viscous composite binder for preparation of raw materials, which is of necessity for making good quality cold-bound pellets[8].

Intensified Classification technique has been employed for balling the highly viscous mixture bearing composite binder[10].

3.4 Optimum reduction system

Temperature measurement along the axis of rotary kiln shows that the range of bed temperature over 900 ℃ reaches 70% of the full length of rotary kiln. Metallic iron occurs on the surface of and inside pellets as early as possible by rapid temperature increase at the early stage and keeping high temperature zone long enough during reducing, which gives pellets high resistance against abrasion. The optimum reduction system has been summarized as fast reduction by high temperature performing at full range of the kiln[10].

4 Conclusions

1) The innovative process, compared with the traditional "two step process" for direct reduction of fired pellets, possesses various advantages such as shorter flowsheet, lower investment cost, less energy consumption, lower operation cost, higher economic profits and less environment pollution, and is an unprecedented process which will bring about revolution in the field of direct reduction with coal-fired rotary kiln.

2) Key techniques for the process depend on the addition of composite binder and corresponding measures feasible for pellet making and rapid temperature increase at early stage of direct reduction.

3) The strength decrease and valley width of cold bound pellets are less than that of preheated and fired pellets during reduction in a rotary kiln, although the former is lower than the latter two before reduction. The strength of cold bound pellets therefore can fully meet the requirements for a commercial rotary kiln and there is no existence of low temperature disintegration, eliminating the hidden danger of kiln accretion and higher reducibility.

4) It is of paramount importance to spread and apply the process for it is suitable for our national resources characteristics, such as lack of natural high grade lump iron ores, coking coal and natural gas and abundance in fine ore concentrates with high iron content, and owning a huge market.

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