Powder Technology 323 (2018) 195–202

Contents lists available at ScienceDirect

Powder Technology

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

Effect of coal ash on ring behavior of iron-ore pellet powder in kiln

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ARTICLE INFO

Article history:
Received 14 May 2017
Received in revised form 2 September 2017
Accepted 3 October 2017
Available online 04 October 2017

Keywords:
Coal ash
Iron-ore pellet powder
Rotary kiln
Bonding strength
Ring formation

ABSTRACT

Ring formation as a troublesome problem for grate-kiln production of iron-ore oxide pellet makes the quality of pellet declining, production efficiency reducing, and production cost increasing. Pellet powder and coal ash are the raw material of ring. Bonding strength, microstructure and composition of coal ash, iron-ore pellet powder, and their mixed powder were investigated to analyze the effect of coal ash on ring behavior of pellet powder and observe the forming of powder ring in kiln. Results showed that coal ash not only changes chemical composition of pellet powder, but also influences its bonding process. The proportion of hematite decreases while that of mullite and quartz increases with the rise of coal ash. High temperature (not less than 1250 °C) is a necessary condition to make powder form ring. Fe_2O_3 recrystallization of pellet powder is the primary manner for powder briquettes. Pure pellet powder is difficult to form ring because of its insufficient Fe_2O_3 recrystallization at beginning of formation, but their weak bonding can be intensified by coal ash. The combined actions of glassy phase silicide, liquation phase aluminosilicate and liquid phase of low melting substance make the ash briquette with tight structure and high strength in the initial of roasting which is difficult to be destroyed and maintain in rotary kiln as the original ring. Then with the continuous of high temperature roasting, sufficient Fe_2O_3 recrystallization makes the original ring further strong and unbreakable, and evolve to the final ring which is indestructible and malignant.

1. Introduction

Iron ore is one of the most important metal resource and almost all (98%) of it is employed in ironmaking and steelmaking [1,2]. Great mass of iron ore must be agglomerated by sintering and pelletization before ironmaking. With the development of steel industry and the requirement of energy conservation and emissions reduction, pelletization is increasingly important. Grate-rotary kiln with convenience and advancement is applied widely to produce oxidized pellets in China [3–5]. However, the troublesome problem of this technology is ring formation which is inevitable and makes the quality of pellet declining, production efficiency reducing, and production cost increasing [6,7].

At present, ring formation has been the key to make this technology successful to produce oxidized pellets. The raw material of ring formation is iron-ore pellet powder and coal ash which is generated by coal combustion and results in ring formation complicated [8,9]. There have been some publications over the last ten years on the mechanism of ring formation to keep pace with the increase in knowledge of ironmaking and steelmaking. Characterization of process gas particles and deposits was observed to analyze deposit formation in a grate-kiln plant. Degradation mechanisms in the refractory lining were extendedly studied. And thermo-mechanical analysis was employed to assess ash deposition tendency [1,2,7,10–12]. Although considerable research has been devoted to reveal the essence of ring formation, its mechanism is still not completely resolved because ring phenomenon in rotary kiln is very complex, especial for coal-fired kiln which is extensively applied in China.

Our research group has manufactured many research works on ring formation. Fe_2O_3 recrystallization between particles based on solid-state diffusion makes the powders bond and form ring by the research of final ring samples. Furthermore, the mixed powder of iron-ore pellet powder and coal ash was briquetted and their bonding strength was measured to obtain some initial information of ring formation [7, 13–15]. Some knowledge was obtained based on these works, but the ring behavior of powders still doesn't receive clear understanding. Therefore, the bonding strength of iron-ore pellet powder, coal ash, and their mixed powder were measured. Meanwhile, the effect of roasting temperature and time on the powders' bonding behavior was investigated, and their microstructure and composition was observed by XRD, SEM and EDS. With those researches, our object is to clear understand the ring behavior of powders, obtain all initial information of ring formation, reveal the essence of ring formation and restrain it.

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https://doi.org/10.1016/j.powtec.2017.10.005
0032-5910/

2. Experimental

As illustrated in Fig. 1, the whole briquettes production process involves mixing coal ash with pellet powder, blending water with the mixed powder, briquetting the final blended material, drying the green briquettes, preheating the dry briquettes and carbonizing the preheat briquettes.

2.1. Coal ash, iron-ore pellet powder and mixed powder

In drying and preheating processes of pellet production, pellet powder formed from broken pellets is brought into rotary kiln with the unbroken pellets and then meets with coal ash which is generated by coal combustion. The pellet powder and coal ash are mixed, extruded, reacted and ringed in high temperature environment of rotary kiln. In order to research these powder behaviors, a coal powder after grinding and a pellet powder were provided by a steel plant of China. The coal powder had been burnt entirely in muffle furnace to obtain the coal ash sample. The pellet powder got from the connection position of chain grate and rotary kiln had been preheated in production. And the mixed powders with different ash content were manufactured by mixing pellet powder and coal ash whose weight is designed. Because coal ash weight ratio is near 5% of total powder weight in production, we designed four mixed powders in research whose ash content is 2.5%, 5%, 10% and 20%, respectively. Meanwhile, pure pellet powder (0% ash content) and pure coal ash (100% ash content) as two contrast groups are employed in the research.

Chemical compositions of the coal ash, pellet powder and mixed powders are listed in Table 1. Pellet powder has a low content of CaO (0.21%) while a high content of SiO_2 (4.56%), indicating the pellet is a kind of acid pellet, a common pellet in China. The contents of SiO_2 and Al_2O_3 are both increased with the addition of coal ash. For the mixed powders of 10% and 20% coal ash, Their SiO_2 contents are high to 8.68% and 12.79%, whilst the Al_2O_3 are 3.63% and 7.03%. While for pure coal ash, it consists of primarily SiO_2 and Al_2O_3, a small amount of Fe and CaO.

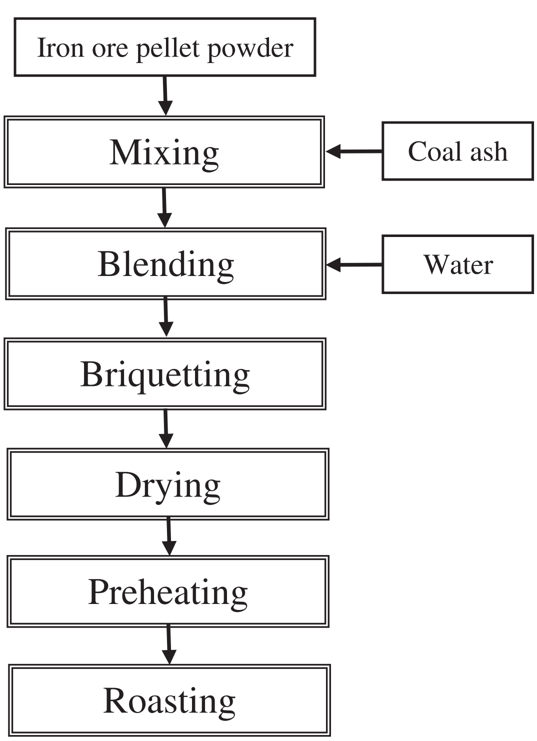

Fig. 1. Scheme of powder briquette production process.

Table 1
Chemical composition of coal ash, iron-ore pellet powder and mixed powder.

Ash content	Chemical composition (mass %)						
	TFe	CaO	SiO_2	Al_2O_3	MgO	K_2O	Na_2O
0%	65.07	0.21	4.56	0.23	0.17	0.03	0.04
2.5%	64.01	0.29	5.64	1.09	0.18	0.04	0.05
5%	62.17	0.42	6.62	1.93	0.19	0.06	0.07
10%	59.27	0.63	8.68	3.63	0.22	0.09	0.10
20%	53.48	1.05	12.79	7.03	0.28	0.16	0.15
100%	7.16	4.42	45.72	34.24	0.75	0.68	0.59

2.2. Blending and briquetting

Sampling was carried out carefully in order to be representative as much as possible. Then the samples of coal ash and pellet powder were dried at 105 °C for 3 h. After drying, they were weighted and mixed gently until all of pellet particles were covered by ash particles. Then water whose proportion was 8% *w*/w of the mixed powder was added in the mixture and they were blended into a final blend material for briquetting. In the end, each briquette was made by pressing 3 g of the blend material in a 10.0 mm internal diameter steel mould at a pressure of 15 MPa with a closely fitting steel plunger under a hydraulic press machine.

2.3. Drying, preheating and roasting

Because the green pellets were treated by the processes of drying, preheating (generally 950 °C for 10 min) and roasting (generally 1250 °C for 10 min) in the pelletizing production [16,17]. All green briquettes were placed in a drying oven and dried at 105 °C for at least 3 h. Afterwards, the briquettes were removed from the drying oven and immediately put in the horizontal tube furnace to fulfill the processes of preheating and roasting. As shown in Fig. 2, the dried briquettes were place in the entrance position of alumina tube whose temperature is near 950 °C for preheating 10 min, and then the briquettes were pushed to the central position of alumina tube for roasting with required time and temperature. Finally, the roasted briquettes were cooled to room temperature with nitrogen atmosphere.

2.4. Measure method

The compressive strength is adopted to evaluate the strength of roasted briquettes. That the compressive strength of briquettes is high indicates the powder is easy to ring. The cylindrical briquette was vertically placed on a horizontal metal plate assembled on the hydraulic press, and then gradually increasing compressive pressure onto the briquette. Meanwhile, a load cell signal connected to a computer continuously recorded the pressure values until the briquette was crushed and the maximum pressure value was stored in the computer. Eight briquettes were measured for each test and their average value divided by the bottom area of the briquette was considered as the compressive strength.

Chemical compositions of the powders were measured by PANalytical X-ray fluorescence spectrograph Axios mAX. And Bruker X-ray diffractometer S0805873 was performed to observe chemical structure of roasting briquettes. Scanning electron microscopy studies were applied using a FEI Quanta 250 FEG microscope equipped with an energy dispersive spectrometer of EDAX Genesis XM2.

3. Results and discussion

3.1. Bonding behavior of different powders

3.1.1. Bonding strength of different powder briquettes

The four briquettes of four mixed powders (2.5%, 5%, 10% and 20% coal ash) and two contrast briquettes of pure pellet powder and coal