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Experimental Investigation of Slag Particles of Ligament Mode Disintegration in Spinning Disk Atomizing

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Abstract

As the main by-product of steel production process, blast furnace slag is rich in high-temperature waste heat. Aiming at emission reduction and waste heat recovery, the dry granulation method by various atomizers appears to attract growing attention. However, the heat recovery efficiency is determined by the cooled slag particles with high quality. In this paper, the centrifugal granulation in spinning disk was performed experimentally. The slag particles size of ligament disintegration was studied using photos taken by means of high-speed camera. A mixture of rosin and paraffin with a mass ratio of 4:1 and two kinds of disks (flat disk and slotted disk) were discussed in the experiment. The results indicate that at a higher angular speed and slotted disk, smaller particles can be obtained easily. In general, the surface structure of disk not only has influence on particle average diameter but also gives consideration to mass fraction of particles. The results in this paper can be applicable for designing and optimizing the dry granulation method of spinning disk atomization.

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Keyward: Ligament formation; Particles size;Waste heat; Spinning disk; Molten slag

1. Introduction

In the past few decades, the iron and steel industries is one of the most energy intensive industries. According to statistics of World Steel Association, global blast furnace pig iron production reached 1165 million tons in 2015[1]. What's more, the blast furnace (BF) slag is produced about 300kg per ton of pig iron in the blast furnace process. The BF slag discharge temperature is up to 1450-1550°C and not recovered [2], resulting in wasting a large amount of thermal energy [3]. Therefore, waste heat recovery will be a method to achieve sustainable development and energy conservation and emission reduction for the steelmaking industries.

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Nomenclature

d	Diameter of particle [m]	We	Weber number
D	Depth of groove [m]	ω	Angular speed [rad/s]
Oh	Ohnesorge number	ρ	Density [kg/m^3]
Q	Mass flow rate [g/s]	σ	Surface tension [N/m]
R	Disk radius [m]	μ	Dynamic viscosity [Pa · s]
Re	Reynolds number	ν	Kinematic viscosity [m^2/s]
W	Width of groove [m]		

Nowadays, spinning disk [4,5] and cup atomizer [6] have been successfully applied in the molten slag reprocessing, which is known as the centrifugal granulation method [7]. When reaching the spinning atomizer, liquid film will be turned into droplets under the action of centrifugal and adhesive forces. This process produces uniform slag particles, realizing effective heat recovery and reuse of material. For such atomizers, the mechanism of atomization can be defined as direct drop, ligament and sheet formation mode [8]. Moreover, ligament formation mode is considered to be the most appropriate process in centrifugal granulation study [9]. Wang [10], Ahmed [11] and Purwanto [5] researched the slag properties produced from spinning disk atomizer. Kashiwaya and In-nami [3] developed the production of amorphous slag particles with different structures of rotary cylinder. However, there are few studies in the influence of disk structure on granulation process, it is indispensable to make further research on the structure of spinning disk.

In present work, the centrifugal granulation in spinning disk was investigated experimentally by means of high-speed camera visualization. With changing the surface structure of disks, the exploration of average particle size and particles distribution were analyzed for a deep understanding of ligament type disintegration. The present work should contribute to the designing and optimization of centrifugal granulation using spinning disk atomizer.

2. Physical model of atomizing

The composition of BF slag mainly includes CaO, SiO_2, Al_2O_3, MgO, which is very complicated [12, 13]. Liu et al. [14] investigated the molten slag granulation for waste heat recovery from various metallurgical slags including BF slag. In the paper, physical simulation of molten slag granulation by spinning disk was analyzed, choosing a mixture of rosin and paraffin to be analogue of BF slag. The mixture of rosin and paraffin was proved to be an ideal simulacrum [15]. The physical property parameters of the analogue and the experimental conditions were determined by the similarity theory.

For the centrifugal granulation process, the diameter of particles produced can be expressed as the experimental correlation [15].

$$\frac{d}{R}=1.6(Re)^{0.26}(Oh)^{0.38}(We)^{-0.42} \tag{1}$$

Where the non-dimensional Re number, Oh number, We number are defined as:

$$Re=\frac{Q}{\nu R} \qquad Oh=\frac{\mu}{\sqrt{\rho\sigma R}} \qquad We=\frac{\rho\omega^2 R^3}{\sigma} \tag{2}$$