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Experimental investigation on ligament formation for molten slag granulation

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HIGHLIGHTS

- Dry granulation for molten blast furnace slag is an attractive alternative to wet granulation.
- Transition equation can be used to identify state of disintegration for molten slag granulation.
- The diameter of slag particles decreased as an increase in angular speed and diameter of rotary cup.
- There was no change in diameter of slag particles with an increase in molten slag temperature.

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ABSTRACT

During the dry granulation for molten blast furnace slag, rotary cup is used to atomize the molten slag. In this study, the mechanism of ligament formation for molten slag granulation was investigated. The results indicated that the transition equations from direct drop formation to ligament formation and ligament formation to sheet formation, obtained from glycerol/water mixture, can identify the type of disintegration for molten blast furnace slag granulation. Due to short wavelength of dilational wave along molten slag ligaments, the diameter of slag particles decreased with an increase in angular speed, and more and more slag particles were far away from the center of rotary cup. The slag particles diameter decreased with an increase in rotary cup diameter. The empirical equation can be used to predict the diameter of slag particles obtained by ligament formation for molten slag granulation at high angular speed. Because of slight change in viscosity and surface tension when the temperature of molten slag was over than 1300 °C, there was no change in diameter and mass fraction of slag particles with an increase in molten slag temperature. All the results could provide guidance for the design of industrial plant for molten blast furnace slag granulation.

1. Introduction

Blast furnace slag, generated by the iron-making process, is quickly quenched by water to form glassy granules which can be used as replacing material for Portland cement. During wet granulation, the waste heat of molten slag discharged at high temperatures, from 1450 to 1650 °C, is usually not recovered. Besides that, a large amount of water is consumed and the waste gas including sulfide is emitted into the around air. Due to considerations regarding energy conservation and environmental protection, dry granulation for blast furnace slag is an attractive alternative to wet granulation [1,2].

From the late 1970s, some techniques of dry granulation for blast furnace slag, rotary cup, rotary disk, rotary drum, air granulation, continuous casting and rolling included, were proposed [3–7]. And there were many laboratory and pilot scale testing of the above methods. However, none of them was used in the iron-making process due to the low recovery efficiency and high cost of investment. As an increase in energy prices, more and more iron and steel enterprises have paid close attention to the technique of dry granulation and waste heat recovery in recent years. Because of high treatment capacity and continuous working, the rotary cup has been extensively studied. Rotary cups are widely used in metallurgical industry, fuel oil atomization, chemical engineering, food processing and agriculture [8–10]. Hinze and his cooperators found three different types of disintegration in rotary cup

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atomization using alcohol/water mixture. During rotary cup atomization, direct drop formation, ligament formation and sheet formation may occur in different technical parameters [11]. Liu et al. found that drop formation may transform into ligament formation and ligament formation may transform into sheet formation with an increase in angular speed for a fixed liquid flow rate. Basing on the experimental data, the transition equations from direct drop formation to ligament formation and ligament formation to sheet formation are derived. And the ligament formation used as the type of disintegration by rotary cup was investigated widely in the present study [12–14]. Ligament formation can provide droplets or particles with uniform diameter compared to sheet formation. In the ligament formation, the liquid flow rate can reach a high value which is unable to reach in direct drop formation. However, the sheet formation for molten slag granulation had been investigated widely by many researchers.

In the present study, the effects of angular speed, cup diameter and molten slag temperature on the disintegration of ligament formation for molten slag granulation were investigated. The dimensionless equation which is used for calculating diameter of slag particles obtained from ligament formation for molten slag granulation was determined.

2. Experimental methods

As shown in Fig. 1, the test unit consists of three parts, including a tundish, rotary device and collectors. The molten blast furnace slag is injected into the rotary cup via tundish, and the flow rate of molten slag can be controlled by the diameter of hole in the center axis of tundish. The rotary cup is connected to an electric motor by flange. During the experiment, the process of granulation is captured by a camera (MotionPro Y3). For security reasons, the vast majority of high temperature slag particles are captured by big circular collector. And the eight 2 cm width rectangular collectors, collecting the slag particles, are used for calculating average diameter of slag particles and mass fraction of slag particles.

In the experimental procedure, the molten slag which is heated by electric furnace is injected into the rotary cup. And the linear velocity of molten slag is the same as that of the rotary cup which is caused by the friction between molten slag and the inner side surface of the rotary cup. Because of centrifugal force, the molten slag reaches the lip of rotary cup, and a circinate molten slag film occurs around the cup. At the edge of the circinate molten slag film, the film is deformed because of disturbances along the circinate molten slag film. And then, the bulges are deformed at the edge of the circinate molten slag film. In the end, the bulges break away from the molten slag film, and the molten slag drops form. The type of disintegration is called direct drop formation. With an increase in angular speed, the bulges do not break away from the molten slag film, and the ligaments occur between bulges and molten slag film. The ligament breaks up into several molten slag drops in the flight. This phenomenon is called ligament formation. With a further increase in angular speed, the bulges combine around the lip of cup when the number of ligaments reaches the maximum value. Then, the ligaments emerge and the thin and wide molten slag film occurs instead. Finally, the molten slag film disintegrates into droplets at the edge of the film. This phenomenon is called sheet formation. The slag droplets are cooled and freeze in the flight.

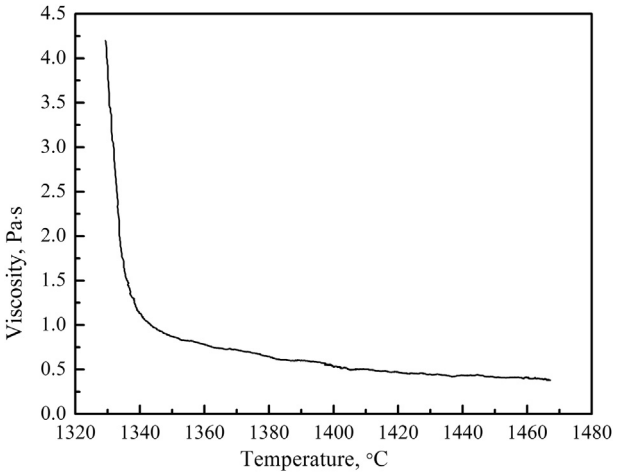

Fig. 2. Viscosity of blast furnace slag at different temperatures.

The main components of blast furnace slags used in the experiment are silica, alumina, lime and magnesium. The viscosity of molten slag with different temperature is shown in Fig. 2.

Kashiwaya and his cooperators found that the surface tension of molten slag had slight change with an increase in temperature when the temperature of molten slag was over than 1300 °C. The empirical equation can be expressed as follows [15]:

$$\sigma = (767.5 - 0.15809T) \times 10^{-3} \quad (1)$$

Where, σ is surface tension of molten slag, N/m, and T is temperature of molten slag, °C.

3. Results and discussions

3.1. Ligament formation for molten slag

In the work of Liu, the mechanism of ligament formation for glycerol/water mixture was investigated [16,17]. The transition

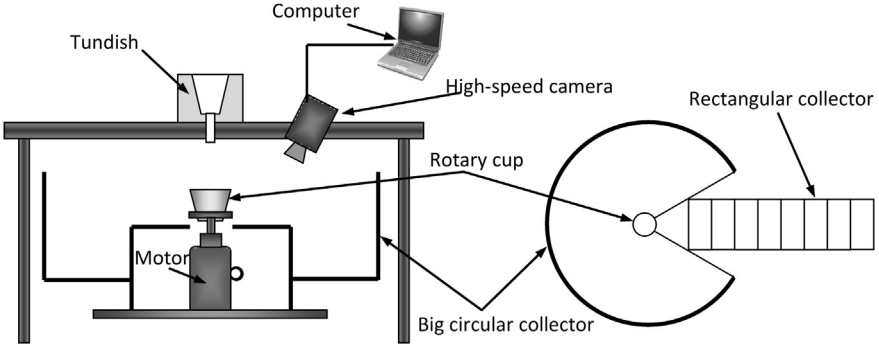

Fig. 1. Schematic diagram of experimental apparatus.