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Evaluation of flow properties of toner powder using conical rotor

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Abstract

In order to accurately evaluate the dynamic flow properties of toner powder, a new rotary shearing tester with a conical rotor was developed. This instrument was equipped with an automatic pressing system to compress toner powder. The tester could simultaneously measure torque and compression load during the intrusion and rotation of the conical rotor into the same packed toner powder. The optimum rotational speed and intrusion rate of the conical rotor for the characterization of the flow properties of toner powder were discussed based on test results; their values were calculated as 0.017 s^{-1} and 0.083 mm/s, respectively. The torque of toner powder changed in proportion to the cube of the depth of intrusion in the toner powder bed. The surfaces of toner powder samples prepared from polymer resin and carbon pigment particles were coated with fine particles (SiO_2, TiO_2) under a different condition. The flow characteristics of toner powder with a different particle surface were evaluated based on the relationship between the shearing torque and the void fraction of packed toner. In the present case, the Rumpf model was applied to estimate the shearing force H at the contact point between two particles of toner powder. The value of H for toner powder with a rough particle surface, which was covered with fine particles (SiO_2, TiO_2), was 41 nN, while that for toner powder with a smooth particle surface, which was not covered with fine particles, was 357 nN. Further the effects of the particle shape of the toner on the torque of toner powder after compression under the same conditions were investigated. The torque of toner powder decreased with an increase in circularity.

Keywords: Toner; Conical rotor; Rotary shearing tester; Flow property of toner powder; Torque; Shearing force

1. Introduction

Recently, electrophotographic technologies for printers and copy machines were developed. In order to enhance the image quality, it is important to control various properties of toner powder, such as the particle size, shape, triboelectric charging behavior, thermal melting behavior, adhesive behavior, and flowability. Since toner powder is generally conveyed on a developing roller and is dusted on the electric latent image of a photoconductor during the developing process, the image quality, which depends on image density and resolution, is affected by the flowability of toner powder. Different types of evaluation methods based on the angle of repose, loose bulk density, cohesion level, etc., have been employed to characterize the flowability of toner powder. However, the reproducibility, quantitativity, and accuracy of such simple methods are insufficient.

Various types of test devices have been developed for the actual and quantitative characterization of the flow behavior of powder. For example, the direct shear tester [1–4], coaxial double-cylinder-type shear tester [5–7], rotational shear tester [8], and tensile strength tester [9–12] have been used to evaluate the flow properties. In particular, because the structure and operation of the device are simple, an evaluation of the liquidity of powder based on friction characteristics has been attempted in a comparative manner using a mechanical stirrer and rotor. In the coaxial double-cylinder-type shear tester, longitudinal grooves are carved on the inner surface of a cylinder in order to increase the stress between the metallic surface and powder. However, since it is difficult to determine the shearing plane and maintain the stationary state of the shearing torque, the reproducibility of measurements is poor and they are influenced by changes in the initial and filled states of the sample.

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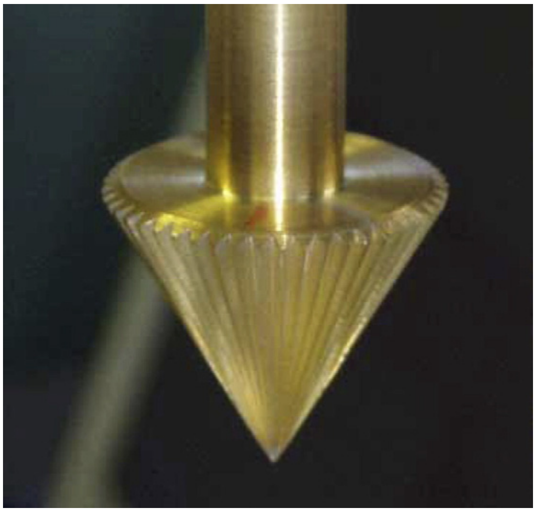

Fig. 1. Photograph of the conical rotor with notches in the vertical direction.

The effects of the shape of a rotating rotor on the evaluated friction characteristics of powder have been investigated [13]. A device with a conical rotor that can intrude into powder can detect a slight change in its friction characteristics when different wax coatings are used [14]. The friction characteristics of powder have been evaluated based on shearing and intrusive characteristics by employing the intrusion method using a conical rotor [15–18]. However, the difference in the measured value due to the initial state of powder poses a problem.

In the case of toner powder, little quantitative research has been conducted on the effects of metal oxide surface additives of toner particles on toner flow [19,20].

In this study, a new rotary shearing tester with a conical rotor is developed in order to evaluate the flow properties of toner powder with high accuracy. This instrument is equipped with an automatic pressing system for stabilizing the initial state of toner powder. Measurement conditions suitable for toner powder are examined, and the flow properties of toner powder with different particle surfaces are characterized and discussed using the new tester.

2. Experimental procedures

2.1. Rotary shearing tester with conical rotor

The newly developed rotary shearing tester could simultaneously measure the torque and vertical load during the rotation and intrusion of the conical rotor into a layer of toner powder. The flow properties of toner powder were evaluated using the tester. Notches were cut on the surface of the conical rotor in the vertical direction for rotation, as shown in Fig. 1. The friction element between the powder that entered into the notches and the powder in the surrounding area of the rotor was measured.

Fig. 2 shows a schematic diagram of the rotary shearing tester. It consists of a compression zone and a measurement zone. In the compression zone, when the test cell that contains toner powder is raised, the powder is compressed by the piston and weights. During compression, the rising speed of the test cell is controlled in order to prevent the leakage of the toner powder from the space between the piston and the wall of the test cell. The compression load is varied by changing the number of weights in the range of 1.25–10.86 kPa.

After compression for 1 min, the test cell was moved into the measurement zone. In this zone, the conical rotor was connected with a torque meter, and the compression load during the shear test was measured using a load sensor installed at the bottom of the test cell. The test cell was raised by the elevating stage such that the rotating conical rotor intruded into the center of the powder layer. The torque and compression load produced by the rotation and intrusion of the conical rotor into the pre-compressed powder layer were measured using the torque meter and load sensor, respectively. The movement distance in the elevating stage was measured with a displacement sensor.

When the top of the conical rotor was contacted with the surface of compressed toner powder by raising the test cell, the rotor was begun to rotate and intruded into the powder at a constant rotational speed and intrusion rate, which were determined beforehand. The torque and compression load were measured continuously until the intrusion depth of the rotor was 23 mm.

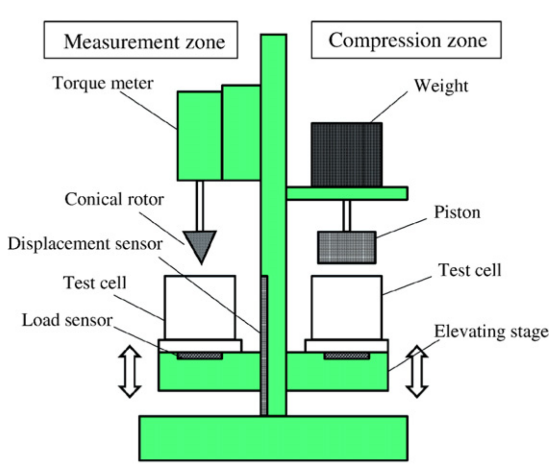

Fig. 2. Schematic diagram of the rotary shearing tester with the conical rotor and automatic compressing system.

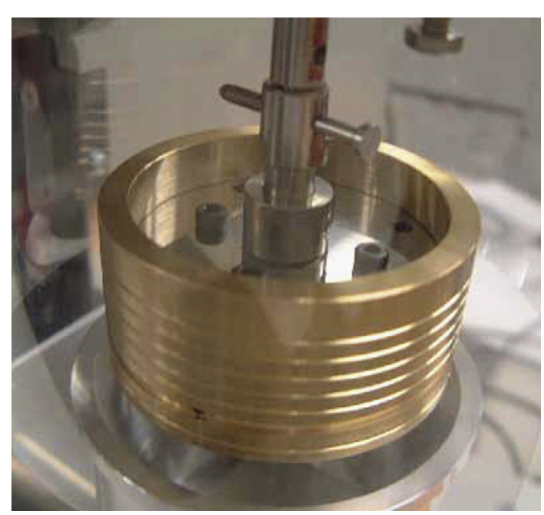

Fig. 3. Photograph of the compressing piston with air holes on the side.