Original
Received April 22, 2002
Accepted for Publication September 4, 2002

A Fundamental Study of Dry and Wet Grinding from the Viewpoint of Bending Tests by Drop Weight Method

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The preparation of fine powders by grinding may be accomplished by either a wet or a dry process and the differences between these have been discussed. The difference of breaking strength in different atmospheres affects the grindabilities. In this study, bending tests were carried out using a drop weight method on glass material in order to investigate the quantitative effect of water atmosphere on strength. The influence of the crack length of the glass surface on the difference of fracture probability in water and in air was also studied. As a result, it was found that the fracture probability in water was larger than that in air when the input energy in specimen was constant. Then, the difference of the fracture energy in water and in air increased with decreasing the crack length.

Key Words : Dry and wet grinding, Bending test, Drop weight method, Glass

1. Introduction

The preparation of fine powders is an important operation in the field of mineral processing, the ceramic industry, the electronics industry and so on, and may be accomplished either by breaking down or by building up. Breaking down process, that is size reduction, is an important step in many industries in which raw materials are converted into intermediate or final products, and is very widely applicable. In the design, construction, operation and control of size reduction process, it is essential to understand the mechanical properties of the feed materials. Mechanical properties are especially related to the grindabilities and breaking properties[1-10]. In a study of size reduction, it is therefore important to understand these properties but there is no universal methods. In addition, a practical grinding operation involves various stress or breaking conditions, such as impact, compression, tension, bending, shear, torsion, tearing, attrition and so on. These stresses or breaking conditions are complex and cannot be measured directly. It is also difficult to evaluate correctly all the mechanical properties which are related to a grinding process. Grinding process may be classified into wet and dry processes and the differences between these has been discussed. The wetting agent is usually water. The authors discussed the difference between the two processes using a small ball mill, from a kinetic and energy point of view[11-14]. The primary advantage for wet grinding compared with dry grinding is that a production of sub-micron particles is easy. Therefore, fine or ultrafine particles are mainly produced by a wet grinding process. It has been considered that the difference in grindabilities between wet and dry processes may arise from the change of surface energy, the degree of dispersion and other reasons[15-19]. However, the effects of these causes are not fully understand. The difference in breaking strength in different atmospheres has long been known[20]. In bending tests, breaking starts from a minute flaw on a specimen surface and then, the difference could be easily understand. The static bending test had been carried out on glass material and the results were reviewed[21].

In this study, a dynamic bending test was carried out on glass to understand the effect of atmosphere on fracture probability.

Table 1 Size of test pieces (100 pieces).

	Average	Standard deviation
Length [mm]	76.0	0.0165
Width [mm]	26.0	0.0103
Thickness [mm]	1.01	0.0121

2. Sample used and experimental procedure

The sample used was silica glass, i.e. commercial slide glass for microscopes. Table 1 shows the average size of 100 test pieces. A set of tests was performed for 50 pieces. After washing with water and drying at 45℃ for a day, the test pieces were kept in a desiccator until the bending tests were performed. The tests were carried out in water (wet strength) and in air with about 56-78 % relative humidity (dry strength).

In the wet grinding processes, the formation of a new fracture surface or a crack and the adsorption of water on the new surface or its penetration into the crack occur simultaneously. The procedure for wet bending tests was as follows :

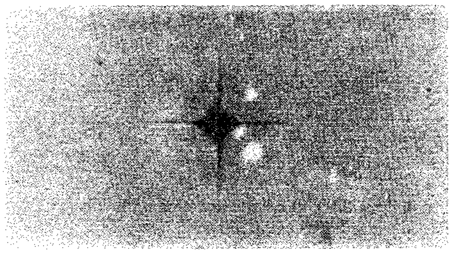

Table 2 Indenter load and crack length.

load [N]	length C_1 [μm]	length C [μm]
9.80	Dry ; 59.9 (1.6) Wet ; 61.2 (1.4)	Dry ; 163.7 (9.1) Wet ; 179.5 (6.8)
4.90	Dry ; 43.2 (1.9) Wet ; 44.1 (1.2)	Dry ; 109.0 (4.9) Wet ; 115.4 (5.4)
2.94	Dry ; 32.8 (1.2) Wet ; 33.8 (1.0)	Dry ; 77.8 (4.4) Wet ; 82.3 (3.3)

( ) ; Standard deviation, 400-700 test pieces

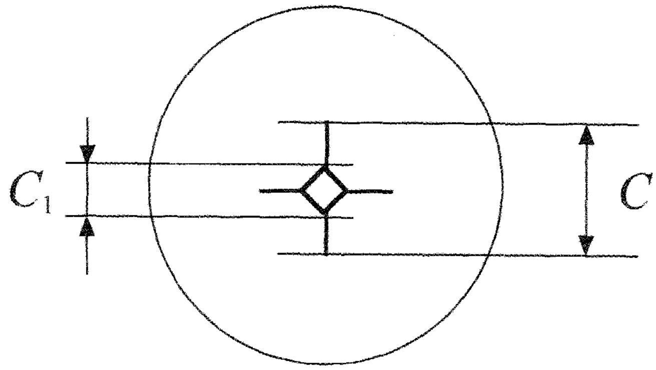

Figure 1 Typical pattern of crack formation.

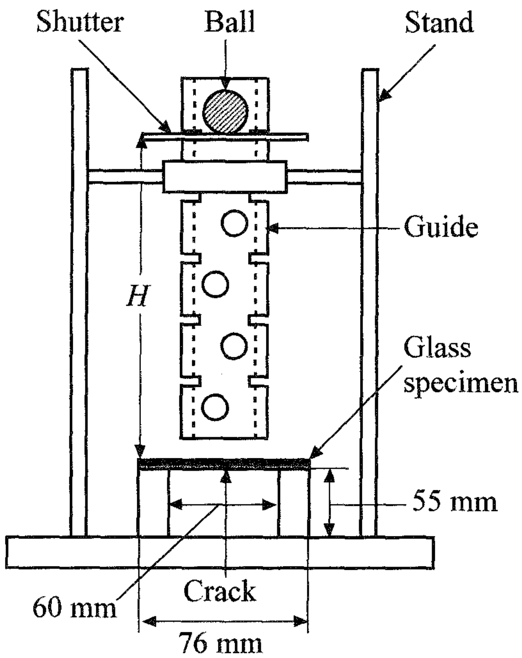

Figure 2 Drop weight method.

1) A drop of distilled water is carefully dropped on the center of the tention side of the test piece.
2) The center is pressed by the Vickers diamond of an Akashi Micro Hardness Tester with an automatic loading system so that a crack is formed.
3) The bending tests are achieved with a drop weight method.

The dry bending tests were performed with the same procedure as that for the wet ones except for the first step of the above procedure. The crack was formed by the Vickers diamond of right quadrangular pyramid, which had an angle of 136° between the opposite faces. Figure 1 shows the typical crack pattern. Two kinds of crack length were defined as C_1 and C, and were measured under the microscope at a magnification of 400× using a micrometer which was an accessory of the Tester. The length could be varied by changing the indenter load in the range of 2.94-9.80 N. In any load, the loading time during which the piece was indented was 5 seconds. Table 2 shows the indenter load and crack length.

Figure 2 shows the measuring device. Assuming that the potential energy of a ball was the energy input to a glass specimen as shown in Eq.(1).

$$E = m_B g H \tag{1}$$

where m_B (6.36×10^{-3} kg) is mass of a ball, g, gravitational acceleration and H, height of ball. The ball is made of alumina with diameter 0.015 m and density 3.6×10^3 kg·m^{-3}. The potential energy of a ball was changed by a position of the shutter from 0.025 m to 0.5 m height.

The fracture probability, P_f ,was defined :

$$P_f = \frac{N}{N_f} \tag{2}$$

where N and N_f (=50) are number of fractured and feed specimens.

3. Experimental results

Figures 3, 4 and 5 show the relationship between fracture probability, P_f, and input energy, E, when the crack length is changed. These figures show that the fracture probabililty in water is larger than that in air when the input energy is constant.

Figure 6 shows the relationship between ratio of fracture energy, E_w/E_a, and fracture probability, P_f. Where, E_w and P_a are the input energy which is required to get the same fracture probability in water and air atmosphere, respectively and they are calculated from Figures 3, 4 and 5. From Figure 6 it is found that fracture enegy in water is less than that in air irrespective of the crack length, and it is confirmed that E_w/E_a decreases with decreasing the crack length.

4. Conclusion

In this paper, a fundamental study of dry and wet grinding was discussed from the viewpoint of bending tests.

The results are summarized as follows :

1) The fracture probability in water was larger than that in air when the input energy in glass specimen was constant.

2) The above difference increased with decreasing the crack length.

3) It was confirmed that a wet grinding process is useful from the points of view of fracture energy.

Acknowledgements

Authers gratefully acknowledge the financial support from Johoku Chemical CO., LTD.

Nomenclature

C and C_1 : crack length [μm]

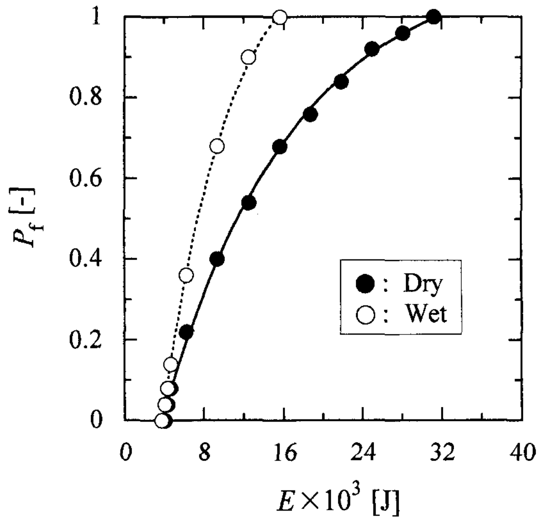

Figure 3 Relationship between fracture probability P_f and input energy E (Indenter load =2.94 N).

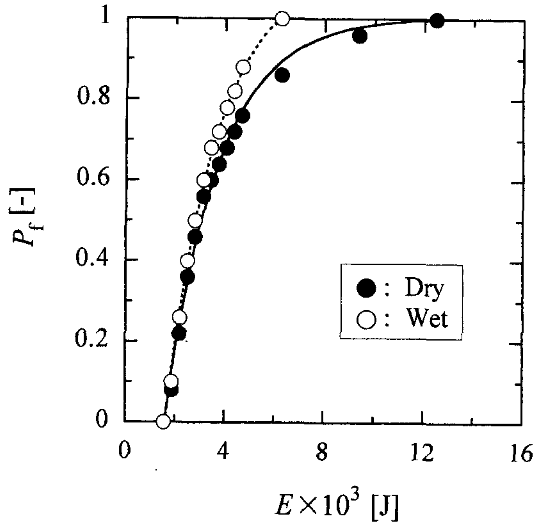

Figure 5 Relationship between fracture probability P_f and input energy E (Indenter load =9.80 N).

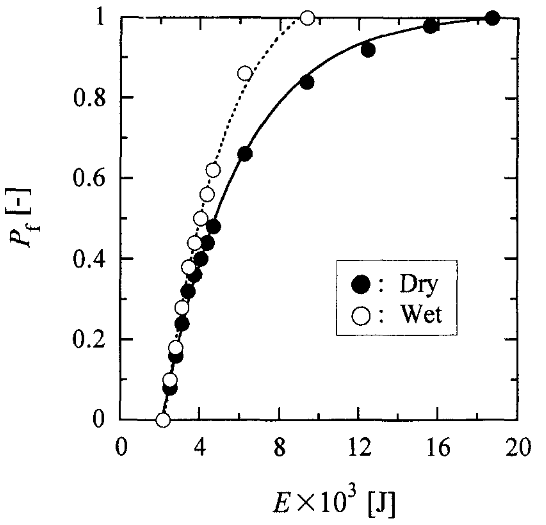

Figure 4 Relationship between fracture probability P_f and input energy E (Indenter load =4.90 N).

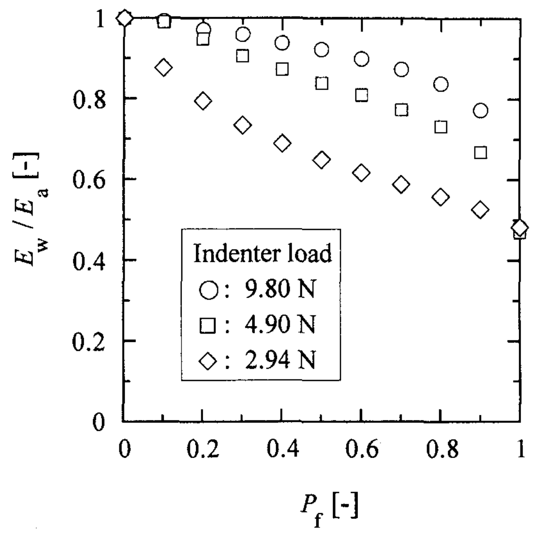

Figure 6 Relationship between ratio of fracture energy E_w/E_a and fracture probability P_f.

E : input energy [J]
E_a : input energy in air atomosphere [J]
E_w : input energy in water atomosphere [J]
g : gravitational acceleration (=9.8) [m•s^{-2}]
H : height of ball [m]
m_B : mass of ball [kg]
N : number of fractured specimen [-]
N_f : number of feed specimen (=50) [-]
P_f : fracture probability [-]

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