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Experimental Study in Order to Get the Spherical Particles of Silica Glass by Autogenous Grinding with a Stirred Mill

Naoya Kotake[1], Naoyuki Toida[1], Yosuke Sato[1], Yoshiteru Kanda[1]
Junichiro Tsubaki[2], Tsuyoshi Ishikawa[3] and Osamu Nagaoka[3]

[1] Department of Chemistry and Chemical Engineering, Yamagata University, Japan
[2] Department of Molecular Design and Engineering, Graduate School of Engineerng, Nagoya University, Japan
[3] Mistui Mining, Co., LTD., Japan

A demand for the aggregates is increasing in the field of civil and architectural industry and so on. In these industries, the particle size and shape of aggregates are important factors and especially spherical or rounded particles are desired. In Japan, waste glass is used as one of the aggregate materials for the pavement or the construction.

In this study based on the frictional action of material on each other, an autogenous grinding of silica glass with a stirred mill were carried out in order to eliminate flakelike or squarish particles and get spherical or rounded ones for aggregate materials. The autogenous grinding experiments were conducted by applying loads to the particle layer of silica glass. The particle shape was evaluated by the shape index, N/T and the degree of circularity, ψ_{ci}. The unfractured particles (20~13 mm) were evaluated by N/T and ψ_{ci}, and the products (finer than 10 μm) by ψ_{ci}. As a result, N/T of the unfractured particles decreased with an increase of grinding time. ψ_{ci} of the unfractured particles and the products increased with an increase of grinding time (; progress of grinding), and became almost constant in the long time grinding. These tendencies were not changed by the applied load on the particle layer, but the limit value of ψ_{ci} at the products were varied with the applied load.

Keywords : Autogenous grinding, Silica glass, Shape index, Degree of circularity

1. Introduction

Waste glass bottle in life is increasing with an increase of the consumption of drinks, almost of the glass bottles were broken or damaged, and it is difficult to use as the returnable glass bottle.

The production of the crushed stone and the manufactured sand which are used as aggregates for the construction material are yearly increasing because of decrease of natural stone and sand. From the view points of recycling of waste materials and enviromental protection, a part of the broken or damaged glass bottle is recently used as aggregates of the pavement after the crushing and grinding in place of the crushed stone and the manufactured sand. The fragments and the particles of the crushed and ground glass bottle for aggregates have some problems, such as sharp corners. Then, the shape of aggregates is necessary to round the corners of ones.

In this study, silica glass which was produced at a steady condition and had a stable property was used as a sample material. The autogenous grinding experiment of silica glass with a stirred mill was performed in order to obtain spherical or rounded particles which are suitable for the aggregate material. The evaluation of particle shape was examined at unfractured particles of sample and products finer than 10 μm by using the shape index [1,2] and the degree of circularity.

2. Experiment

2.1 Preparation of sample

The properties of silica glass used in this experiment are tabulated in Table 1. In order to obtain the sample of 20~13 mm, fragments of silica glass were classified by sieving by hand carefully.

Table1 Properties of silica glass

Density	:	2,150 kg · m^{-3}
Young's modulus	:	7.35 × 10^4 MPa
Poisson's ratio	:	0.16
Work index	:	14.8 kWh · t^{-1}
Vicker's hardness	:	465 kgf · mm^{-2}
Moh's hardness	:	6-7

2.2 Experimental apparatus

The stirred mill used was an Attritor-Type D (Mitsui Mining Co., LTD.) as shown in Fig. 1. The mill was made of stainless steel and its volume was about 5.5 liters, and included a double wall which acted as a water jacket. A torque meter was mounted on the driving shaft between the motor and the mill. Fig. 2 shows a detail diagram of the grinding apparatus.

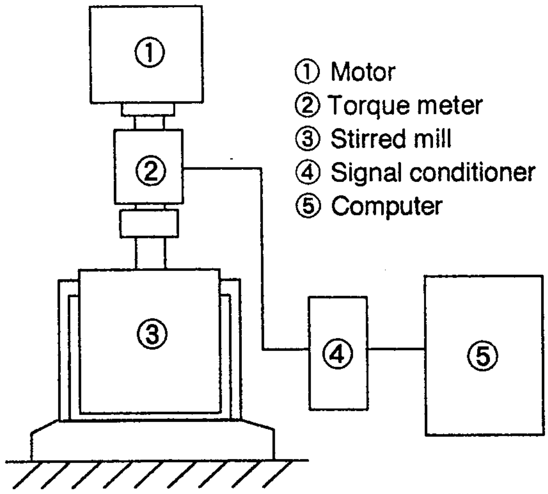

Fig.1 Schematic diagram of experimental apparatus

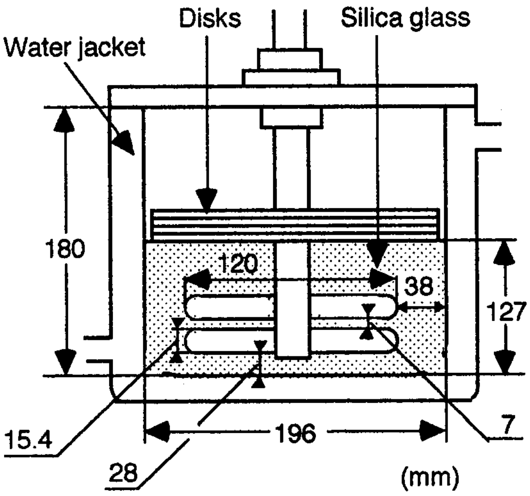

Fig. 2 Grinding apparatus

2.3 Experimental method

The autogenous grinding experiments were performed by applying loads to the particle layer of silica glass using the disks which were made of zirconia and steel as shown in Fig. 3. The feed samples were charged flatly into the grinding vessel by hand, and the disks were put on the particle layer as shown in Fig. 2. The feed size of the sample was 20~13 mm and the feed mass was 4 kg. The impeller speed of the stirred mill was always run at 55 rpm. The applied loads (mass of the disks) were changed in 0, 1 and 4 kg. The grinding times were 2, 4, 10, 25, 40, 60 and 180 minutes. These experimental conditions are tabulated in Table 2. After the grinding tests, ground products were sieved manually from feed size to 4.76 mm and by using a rotating and tapping shaker from 3.36 mm to 0.15 mm. The particles finer than 10 μm were obtained by wet sieving of the products finer than 0.15 mm, and were photographed through a scanning electron microscope. One hundred particles of the unfractured feed sample and three hundred particles of the products finer than 10 μm were sampled in order to measure the particle shape respectively.

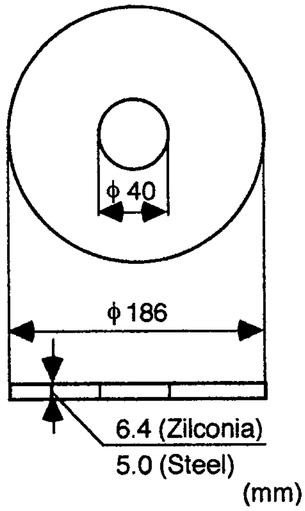

Fig. 3 Dimensions of disk

Table 2 Experimental conditions

Feed size	:	20~13 mm
Feed mass	:	4 kg
Impeller speed	:	55 rpm
Applied load (Mass of disk)	:	0, 1, 4 kg
Grinding time	:	2, 4, 10, 25, 40, 60, 180 min

2.4 Evaluation of particle shape

The particle shape of unfractured particles were evaluated by the shape index, N/T [1,2] and the degree of circularity, ψ_{ci}, and the particle shape of the products finer than 10 μm by ψ_{ci}. Fig. 4 shows definitions of the shape index and the degree of circularity, respectively. The shape index defined by Eq. (1) was measured manually with great care by a slide caliper, and the degree of circularity defined by Eq. (2) by an area-line meter.

$$\frac{N}{T} = \frac{\text{diameter of circumcircle}}{\text{thickness}} \geqq 1 \qquad (1)$$

$$\psi_{ci} = \frac{\text{perimeter of circle of equal projected area}}{\text{perimeter of particle}} \leqq 1 \qquad (2)$$

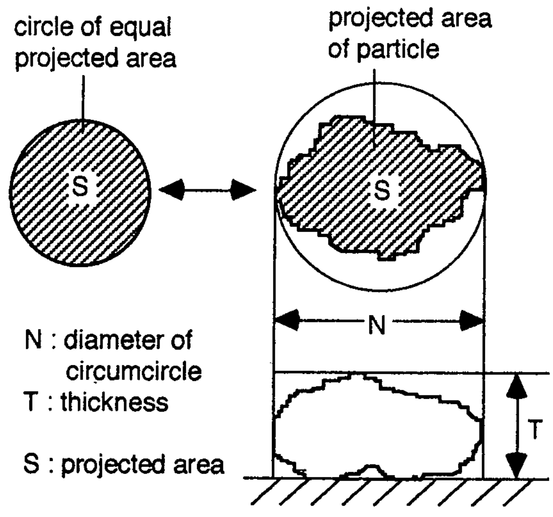

Fig.4 Evalulation of particle shape

3. Results and discussions

3.1 Particle shape of unfractured particles (feed size ; 20 ~13 mm)

Fig. 5 shows the relationship between the average of the shape index of unfractured particles and the mass fraction of feed size, when the applied loads (the mass of disks) were 0, 1 and 4 kg. The shape indices decrease with a decrease of the mass fraction of feed size, and these changes are not depend on the mass of disk. The minimum values of the indecies at the different applied loads were similar.

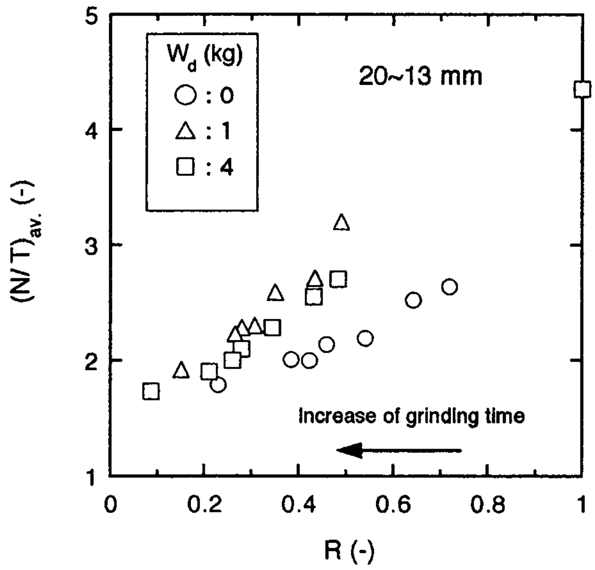

Fig.5 Relationship between average of shape index and mass fraction of feed size

Fig. 6 shows the relationship between $(N/T)_{av.}/(N/T)_{f,av.}$ (= (average of the shape index)/ (average of the shape index of feed)) and the mass fraction of feed size. From this figure, it was found that the maximum decrease of the shape index is about 60 % of feed. The minimum value of the shape index of unfractured particles are hardly affected by the applied load.

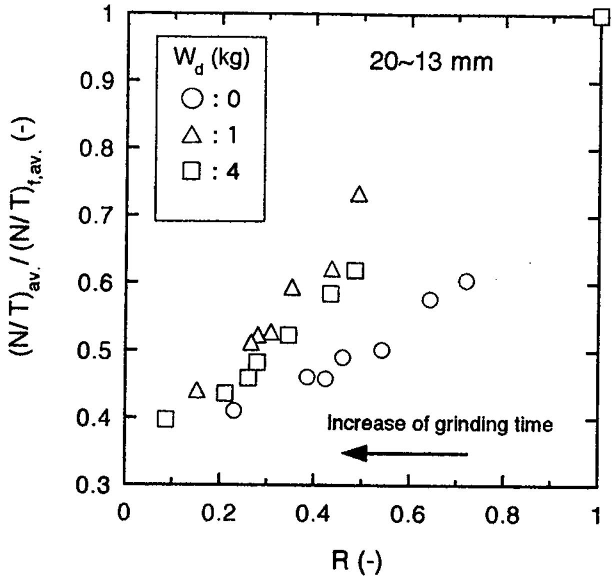

Fig.6 Relationship between $(N/T)_{av.} / (N/T)_{f,av.}$ and mass fraction of feed size

The relationship between the average of the degree of circularity of unfractured particles and the mass fraction of feed size is shown in Fig. 7.
This figure shows that the degree of circularity of unfractured particles increase with a decrease of the mass fraction of feed size, and there was little effect of the applied load on the degree of circularity.

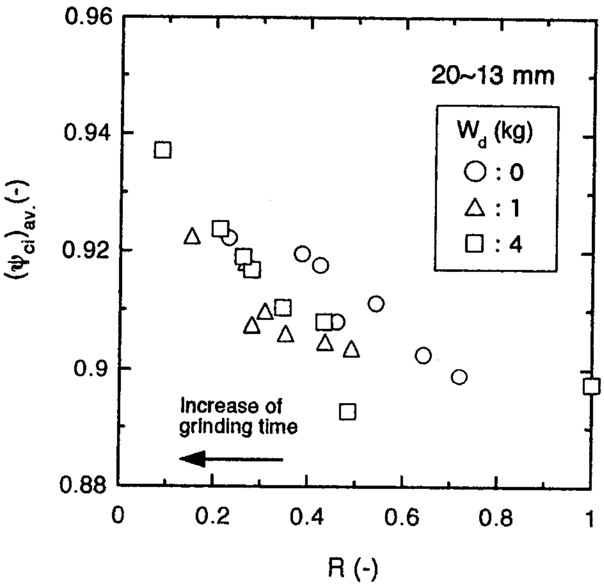

Fig.7 Relationship between average of degree of circularity and mass fraction of feed size

Fig. 8 shows the relationship between $(\psi_{ci})_{av.}/(\psi_{ci})_{f,av.}$ (= (average of the degree of circularity)/ (average of the degree of circularity of feed)) and the mass fraction of feed size. This figure shows that the maximum increase of the degree of circularity is a few percent of feed. As same as the result in Fig. 6, there was also little effect of the applied load on the degree of circularity of unfractured particles. These results indicate that the autogenous grinding with the stirred mill is effective for a decrease of the shape index and an increase of the degree of circularity in the feed size. The above result is almost independent of the applied load.

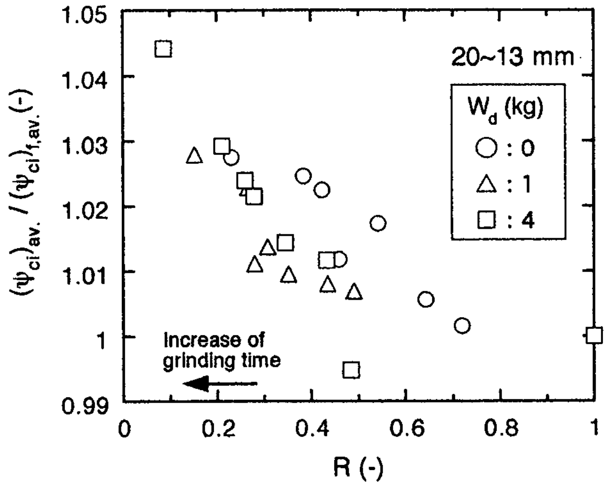

Fig.8 Relationship between $(\psi_{ci})_{av.} / (\psi_{ci})_{f,av.}$ and mass fraction of feed size

3.2 Particle shape of products (particles finer than 10 μm)

The relationship between the average of the degree of circularity and the mass fraction of the products is shown in Fig. 9. In this figure, there is an effect of the applied load at 4 kg on the degree of circularity. It was considered that the increase of compressive force was acted efficiently for the grinding of edges of the fine particles which were produced by the autogenous grinding.

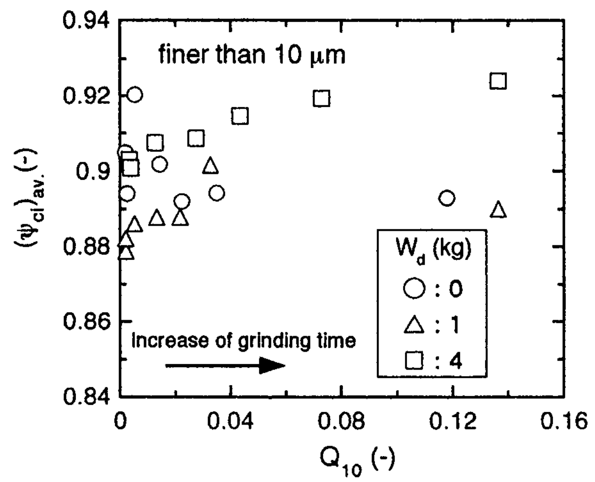

Fig.9 Relationship between average of degree of circularity and mass fraction finer than 10 μm

4. Conclusion

In this study, the autogenous grinding of silica glass with a stirred mill was carried out in order to obtain spherical or rounded particles.

The results were summarized as follows :

(1) The shape index of unfractured particles in 20~13 mm decreased with an increase of the grinding time, and the degreee of circulality increased with an increase of the grinding time, but the effect of the applied load to the particle layer on the particle shape was little.

(2) The shape of products finer than 10 μm was improved with an increase of the applied load to the particle layer.

Nomenclature

N : diameter of circumcircle (mm)
N/T : shape index (-)
Q_{10} : mass fraction of products finer than 10 μm (-)
R : mass fraction of unfractured particles in 20~13 mm (-)
S : projected area of particle (mm^2)
T : thickness (mm)
W_d : applied load (mass of disk) (kg)
ψ_{ci} : degree of circularity (-)

Subscript

av. : average
d : disk
f : feed sample

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