BATCH GRINDING OF TALC POWDERS: DEVELOPMENT OF A PROCESS MODEL

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ABSTRACT

Grinding of talc powders has been studied both theoretically and experimentally. The specific rates of breakage of talc powders were measured based on the first-order breakage kinetics model and the cumulative breakage distribution parameters of talc powders were measured from primary breakage products. Based on the measurement results, the specific rate of breakage and cumulative breakage distribution functions were correlated with particle size as $S = 0.007d^{0.57}$ and $B_{ij} = d_i^2 / d_j^2$, repectively. A differential-integral equation was thus build to describe grinding as a rate process and was integrated numerically. Comparisons on size distribution showed that the specific rate of breakage of talc powders increased with grinding time at an increase rate $\partial S/\partial t$ about 0.0066min^{-2}.

KEYWORDS: specific breakage rate; breakage distribution parameter; grinding equation; acceleration behavior.

1. INTRODUCTION

Grinding (comminution) is not only a principal means in size reduction of solids in various industries [1-3], but also is a key technology for synthesis metastable, nano-crystalline materials, amorphous alloys, oxide dispersion strengthened (ODS) superalloys, ceramics and etc. by means of mechanical alloying (MA) [2]. Modeling of grinding process is important for process control and optimum operations [4-5], to achieve tightly controlled particle size distributions in size reduction operations [6], and to understand the mechanisms in materials processing by MA process as well [7].

In this paper, grinding of talc powders in different sizes has been studied both theoretically and experimentally. The specific rates of breakage of talc powders were measured based on the first-order breakage kinetics model [8]. The cumulative breakage distribution parameters of talc powders were measured from primary breakage products [9]. Based on the measurement results, the specific rate of breakage and cumulative breakage distribution functions were obtained by correlations with particle size. From the grinding model [10] and distribution functions of specific rate of breakage and cumulative breakage, a differential-integral equation was build to describe grinding as a rate process. The differential-integral equation was integrated numerically, and comparisons were made with experimental results on the size distribution. And acceleration behavior in grinding process was discussed.

2. EXPERIMENTS AND EXPERIMENTAL RESULTS

Talc powders were used in the experiments. Six batches with mean sizes ranging from 97μm to 1425μm were obtained by sieving from a batch of talc powder. The physical properties of these powders are listed in Table 1.

Table 1 Talc powders used in the experiments and measurement results

Powder	Mean size (μm)	Specific breakage rate (min^{-1})	Breakage distribution constant k (μm $^{-2}$)
Batch 1	1425	0.495	$7.0*10^{-7}$
Batch 2	850	0.256	$3.0*10^{-6}$
Batch 3	258	0.175	$1.7*10^{-5}$
Batch 4	183	0.164	$4.0*10^{-5}$

Batch 5	128	0.104	$6.6*10^{-5}$
Batch 6	97	0.0923	$1.2*10^{-4}$

The experiments were carried out in a planetary ball mill. Two containers of 84mm inner diameter and 75mm high were used in the experiments. The rotating radius of the containers was about 150mm. The rotation speed of the ball mill was operated at 150RPM, and the rotation speed of the containers around its own axis was at 600RPM. The balls are steel ball in 19mm diameter and the ratio of ball to load is about 5:1. The load was about 60grams in each container. The size of the product after each run was analyzed by sieving.

The specific rates of breakage of the talc powders were measured based on the first-order breakage kinetics model [8]. The measured results were also given in Table 1 and were presented graphically in Fig.1. Fig.1 showed that the specific rates of breakage of the talc powders increased as particle sized increased from 97μm up to 1425μm, which has the same size dependence as those of calcite and barite powders [11], but was different from that of B_2O_3 powders as the specific rates of breakage of B_2O_3 powders increased rapidly as particle size increased from 40μm up to about 80μm and decreased hereafter as particle size further increased [7]. The specific rates of breakage of the talc powder could be correlated to particle size as

$$S = 0.007d^{0.57} \qquad (1)$$

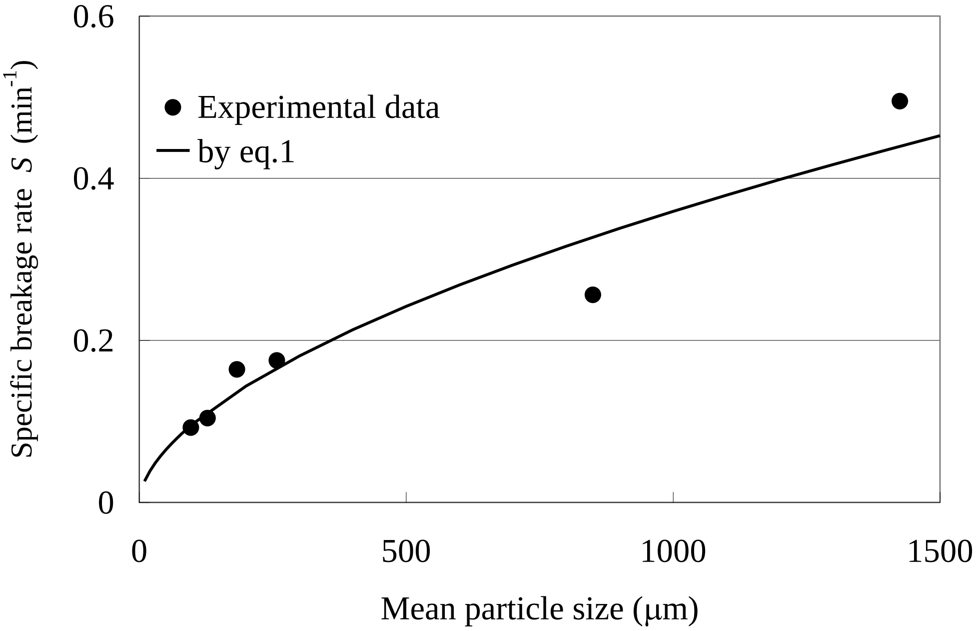

Fig.1 Specific breakage rate vs. particle size

The cumulative breakage distribution parameters of the talc powders were measured from primary breakage products using BIII method with the measured specific rates of breakage [9]. The measured results were plotted in Fig.2 against particle size di. It can be seen that the cumulative breakage distribution parameter Bij could be

taken as proportional to di2 for the talc powders. The proportional constant k for the talc powders was tabulated in Table 1. Then the cumulative breakage distribution parameters can be given by

$$B_{ij} = kd_i^2 \qquad (2)$$

From the definition of the cumulative breakage distribution parameters, it is satisfied $\int_0^{d_j} B_{ij}^{'} dd_i = 1$, which yielded

$$k = \frac{1}{d_j^2} \qquad (3)$$

Fig.3 showed that the relationship (3) agreed with experimental data reasonably well, which could be also seen from Fig.4 as equations (2) and (3) produced

$$B_{ij}^{0.5} d_j = d_i \qquad (4)$$

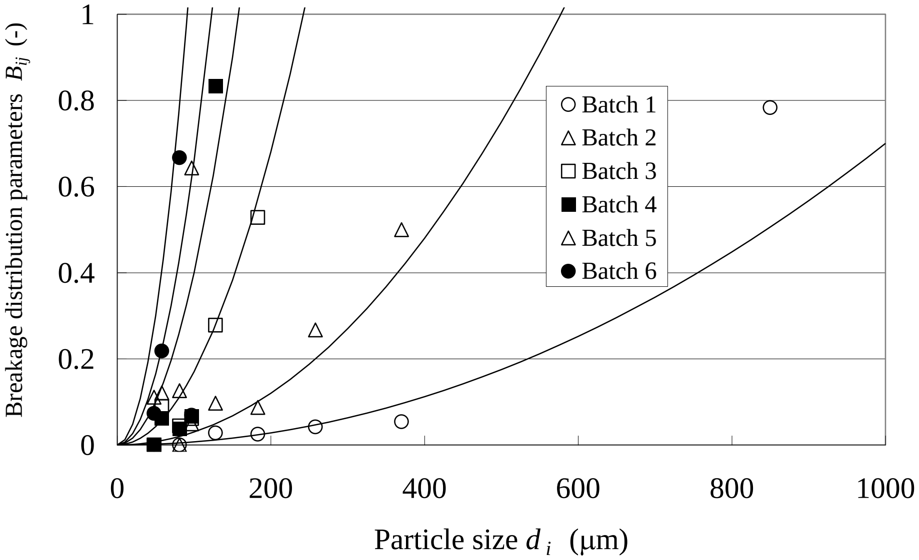

Fig.2 Breakage distribution parameter B_{ij} vs. particle size d_i

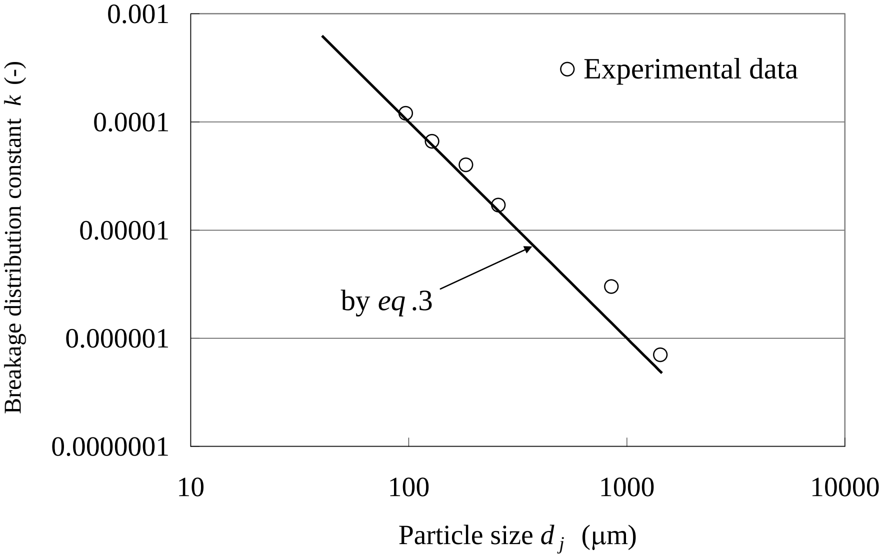

Fig.3 Breakage distribution constant k vs. particle size d_j

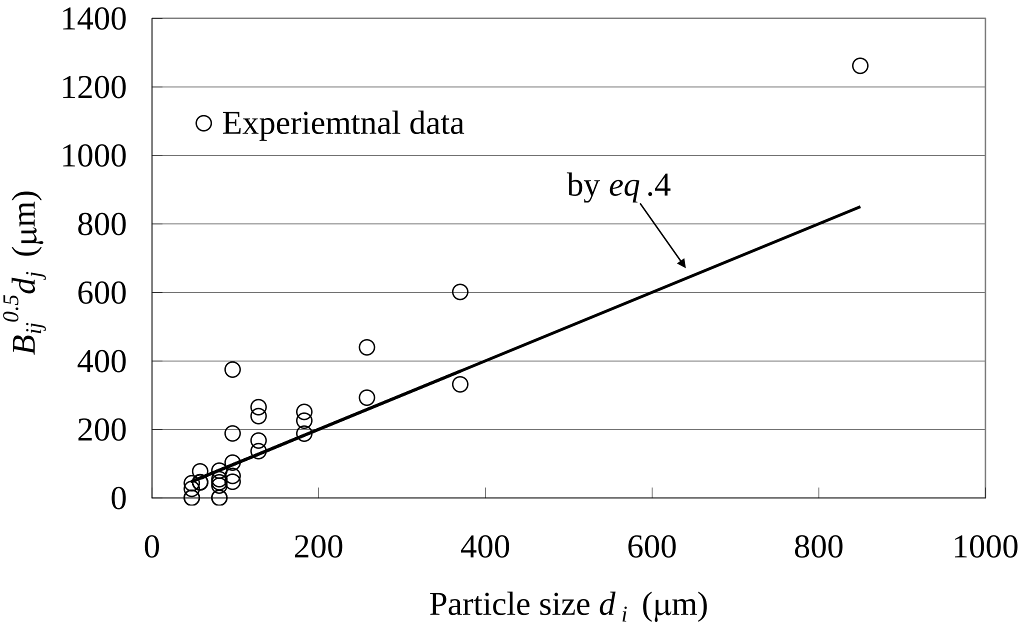

Fig.4 Breakage distribution parameter $B_{ij}^{0.5}d_j$ vs. particle size d_i

3. MODEL AND CALCULATIONS

Many theoretical models have been developed to simulate grinding processes such as population balance model [12-13], discrete element method (DEM) [14-15], dynamic simulation approach [16], stochastic processes approach [17] and etc.. From the specific rate of breakage and the cumulative breakage distribution functions, Austin's grinding model [10,18] could lead to a differential-integral equation describing grinding as a rate process [7] as

$$\partial w(d,t)/\partial t = -S(d)w(d,t) + \int_d^{d_{\max}} S(\phi)B'(d,\phi)w(\phi,t)d\phi \qquad (5)$$

where w is the mass fraction of particles with size d after grinding for time t, d_{max} is the maximum particle size, and ϕ is the integral variable for particle size d_j.

By setting $\eta = \phi/d_{\max}$, $\alpha = d/d_{\max}$, $\beta = S/S_{\max}$, and $\tau = tS_{\max}$, and differentiating equation (2) and substituting it into equation (5), a normalized differential-integral equation describing grinding as a rate process could be obtained as

$$\partial w(\alpha,\tau)/\partial\tau = -\beta(\alpha)w(\alpha,\tau) + 2\int_\alpha^1 \alpha\ S(\eta)w(\eta,\tau)\eta^{-2}\mathrm{d}\eta \qquad (6)$$

where S_{max} is the specific rates of breakage at particles size d_{max}. In the numerical integrations, the particle size d_j was discreted to $\eta=jh$, where h=0.001 and j=1,2,1000, then the normalized differential-integral equation (6) became the following ordinary differential equations [7]

$$\begin{cases} dw_1(\tau)/d\tau = -\beta_1 w_1 + 2\sum_{j=2}^{1000}\beta_j w_j / j^2 \\ \quad\cdots\cdots \\ dw_i(\tau)/d\tau = -\beta_i w_i + 2i\sum_{j=i+1}^{1000}\beta_j w_j / j^2 \\ \quad\cdots\cdots \\ dw_{1000}(\tau)/d\tau = -\beta_{1000}w_{1000} \end{cases} \qquad (7)$$

The ordinary differential equations were integrated by the 4th Runge-Kutta method.

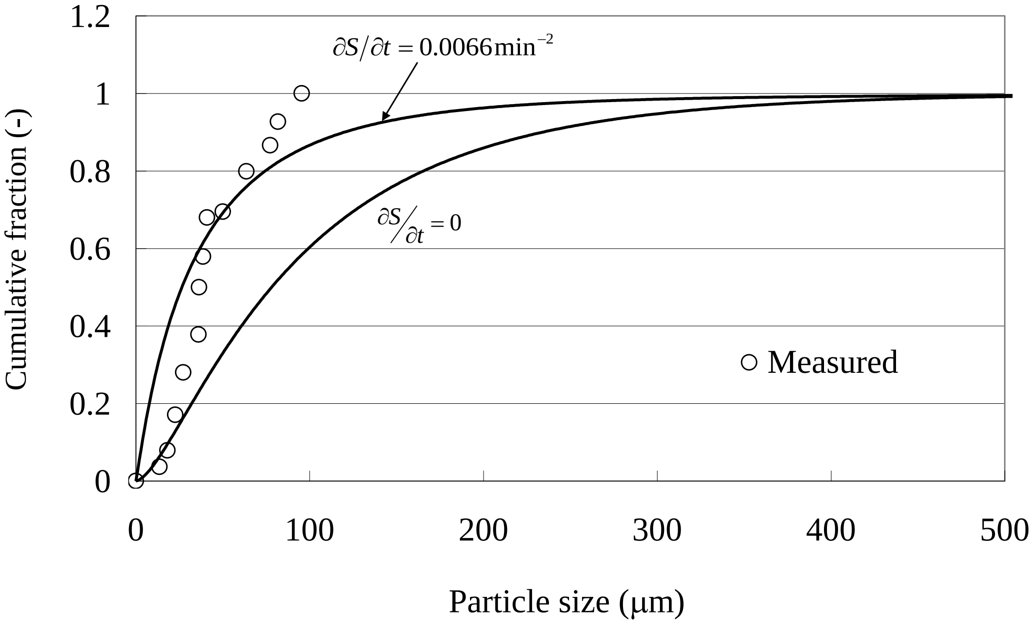

Fig.5 Comparison on particle size distribution between measured and predicted

Fig.5 is a comparison on particle size distribution between measured and predicted by the ordinary differential equations (7). In the experiments, a batch of talc powder ranging from 1250μm to 1600μm with mean size of 1425μm was used as starting powder. The operation conditions were the same as those in the experiments in the measurements of specific rate of breakage and cumulative breakage distribution parameters. The grinding time was 15min and the size distribution after the grinding was analyzed by a sedimentation type particle size analyzer (BT2000). In the calculations, particles uniformly distributed in the range from 1250μm to 1600μm were assumed for the starting powder. The comparison results showed that the specific rate of breakage increased with grinding time, and when the increase rate $\partial S/\partial t$ was taken as 0.0066min^{-2}, the predicted size distribution agreed with the experimental results. Acceleration behavior in grinding process was also reported for quartz in wet grinding for slurry concentrations up to 56 % solids by volume [19].

4. CONCLUSIONS

1. The specific rates of breakage of talc powders measured based on the first-order breakage kinetics model could be correlated to particle size as $S = 0.007d^{0.57}$.
2. The cumulative breakage distribution parameters of talc powders measured from primary breakage products could be given by $B_{ij} = d_i^2 / d_j^2$
3. The comparison results by a differential-integral equation describing grinding as a rate process showed that the specific rate of breakage of talc powders increased with grinding time at the increase rate $\partial S/\partial t$ about 0.0066min^{-2}.

5. ACKNOWLEDGEMENT

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Symbols

B_{ij}	cumulative breakage distribution parameter [-]
d	particle size [μm]
d_i	size of *i*-sized particles [μm
d_j	size of *j*-sized particles [μm]
d_{max}	maximum particle size [μm]
S	specific breakage rate [min^{-1}]
S_{max}	maximum specific breakage rate corresponding to the particle size d_{max}

w	mass fraction [-]
α	normalized particle size [-]
β	normalized specific breakage rate [-]
τ	normalized grinding time [-]

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