Effect of the Surface Properties of Particle on the Classification Performance of a Dry-Cyclone

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Abstract

The purpose of the present study was to investigate the effect of the surface properties of silica particles on the classification performance of a dry-cyclone. As a result, it was clear that the separation force between the surface of particle and the silicon was decreased by the AFM measurement when the surface of the silica particles could be modified with ethanol or acetone treatment. Fine particles in the original silica particles with the treatments were easily collected by the filter in a dry-cyclone system; hence, the particle classification performance was enhanced.

***Keywords*:** Classification, Cyclone, AFM, Separation Force, Surface Property

1. Introduction

The development of a classification technique has been indispensable for industrial applications, because performance of the products is expected to be enhanced through control of the size distribution of the material particles. The classification methods were classified into 2 types: wet and dry. In our recent research, the zeta potential of silica particles treated with a bead mill (Yamamoto et al., 2010) displayed size dependency — smaller particles had a more negative zeta potential. This phenomenon and the flow with electrophoresis were used to enable particles with sizes below submicron to be classified in the wet system (Yamamoto et al., 2009, 2011, 2012). Thus, it was possible to think that the properties of the particle surface were important factors for classification. A lot of studies of surface modification of particles using were reported. For example, silane coupling agents were used to make hydrophobic surfaces (Jesionowski et al., 2001), alcohols were utilized for surface alkoxylation of silicas (Shioji et al., 1992), and organic materials were removed from the surfaces to make hydrophilic surfaces by plasma treatment (Donose et al., 2005). However, the influence of these surface modifications on classification of a dry-cyclone was not clarified. Hence, the present study was focused on effect of the surface properties of silica particles, which was evaluated using atomic force microscopy, on the classification performance of a dry-cyclone.

2. Experimental

2.1 Materials

Silica powder (Denka Fused Silica, Denki Kagaku Kogyo, Co., Ltd.) with a mass median diameter of 2.01 μm was used as the test powder in the present study. The particle size distributions of the fine and coarse classified particles were measured using a particle size distribution analyzer (LA-950, Horiba Co., Ltd.) according to its standard operation procedure. The size distribution of the original silica test powder for the classification experiments was measured using the same method and is shown (Figure 1).

Acetone (Wako Pure Chemical Industries Co., Ltd.) and ethanol (Wako Pure Chemical Industries Co., Ltd.) were used as typical organic solvents to modify the surface of the silica particles. The silica particles and organic solvent, with a weight of silica particle to organic solvent of 36 wt%, were stirred for 1 hour at room temperature. The solvent was then evaporated to prepare the dried silica particles. This surface modification by each organic solvent was referred to either as ethanol or acetone treatment.

2.2 Measurement of separation force by AFM

An atomic force microscope (AFM) (Nanoscope IIIa, Digital Instruments) was used to evaluate the surface properties of the tested silica particles and the effect of the surface modifications. Using a contact-mode procedure, cantilevers with tips made of silicon with a nominal spring constant of 9 N/m were used. The surface of a silica particle put on the freshly cleaved mica surface was pushed by the probe tip (Figure 2a) to obtain the force curve (Figure 2b) when the tip was separated from the particle surface. The absolute value of a minimum separating force was defined as the separation force of the particle, F. The contact area between the tip and particle surface was so small that the separation force defined in this study was independent of the particle size. The average and the distribution of F were calculated by measuring the separation forces of 150 sample particles on a mica surface. To measure the interactions, the approaching speed of the probe was fixed at 4000 nm/s. All AFM measurements were carried out at room temperature: i.e., 20 ± 2 ºC.

2.3 Classification of particles using a dry-cyclone

Classification experiments were carried out using the dry-cyclone system (Figure 3). The total flow rate was fixed at 40 L/min using a flow meter and a blower. The linear velocity in the inlet of the cyclone was calculated to be 8.89 m/s, which meant that the velocity in the present study was much slower than that of the typical use of a cyclone (Yoshida et al., 1991, 2005, 2009, 2010). Hence, we clarified the effect of the surface properties of the silica particles on the classification performance of the cyclone because of longer residence time of the particles in the cyclone. The original powders with a mass of 0.7 g were supplied into the cyclone for 1 minute from a feeder. This classification apparatus was operated for 10 minutes.

The finer particles were collected from the filter. The larger (coarser) particles were collected from the dust box of the cyclone. Partial separation efficiency, $\Delta\eta$, which is defined by Eq. (1), was used to evaluate the classification performance of the cyclone. The mass and distributions of the fine and coarse particles were measured.

$$\Delta\eta = \frac{m_c f_c(D_p)\Delta D_p}{m_f f_f(D_p)\Delta D_p + m_c f_c(D_p)\Delta D_p} \qquad (1)$$

In the above equation, mc and mf represent the mass of the coarse silica powder and the classified fine powder, while f_c and f_f represent the size distributions of the coarse silica powder and the classified fine powder, respectively.

3. Results and Discussion

3.1 Surface properties of silica particles

First, to investigate the influence of the treatment by organic solvents on the surface properties of the tested silica particles, the separation forces between the particles and the probe tip were measured. The averages of *F* are summarized in Table 1, and the distributions of *F* are shown (Figure 4). Acetone or ethanol treatment decreased the separation force of the silica particle. Water molecules on the silica surface usually increase the separation force through the liquid bridging (Fukunishi et al., 2006; Jones et al., 2002). It was conceivable that the surface of silica particles without modification were hydrophilic and that water molecules in the air were adsorbed by them, however, some of them were removed by treatment with an organic solvent. Hence, the separation forces were lessened by the surface modifications using ethanol and acetone. This effect on the classification performance was investigated in the next section.

3.2 Effect of the surface properties of particles on the classification performance of a dry-cyclone

The effect of the organic solvent treatment to silica particles on the partial separation efficiency curves of a dry-cyclone at the total flow rate of 40 L/min is shown (Figure 5). Classification performance was improved by the treatments of the particle surface by organic solvents. In the case of acetone treatment, the classification performance was much better because acetone was more hydrophobic than ethanol. One of the reasons was that the dispersion of the powders was enhanced by the reduction of the separation force by the surface modification (Figure 4). It was possible to think that much more fine particles were collected by the filter because of the prevention of the coagulation between particles.

The interactions between the probe tip and the fine particles collected by the filter were measured to evaluate the particle properties of the fine powders. Particles on the small cleaved mica surface set on the filter were used as a sample to measure interactions by AFM because the property of the particles collected directly by the filter were consolidated by the blower. The results are listed in Table 2. As compared with Table 1, the separation force of each sample became smaller. Thus, fine particles with smaller separation force, which were hard to be coagulated with each other, were easily collected by the filter. Surface treatment of silica particle by organic solvent was effective for reduction of the separation force between particles and enhancement of the classification performance of a dry-cyclone.

4. Conclusions

The purpose of the present study was to investigate the effect of the surface properties of silica particles on the classification performance of a dry-cyclone by measuring the interactions of particles by AFM. As a result, it was clear that the separation force between the surface and the silicon was decreased by modification treatment with either ethanol or acetone. The effect of the decrease in separation force might have contributed to the dispersion of the silica powder at the inlet in the cyclone. And also, the surface treatment of silica particle with the organic solvent was effective for enhancement of the classification performance of a dry-cyclone.

Acknowledgement

This study was financially supported in part by the Hosokawa Powder Technology Foundation and by Grants-in-Aid for Young Scientists (B) from the Ministry of Education, Culture, Sports, Science and Technology of Japan (No. 23760721).

References

Donose B. C., I. U. Vakarelski, and K. Higashitani. 2005. Silica Surfaces Lubrication by Hydrated Cations Adsorption from Electrolyte Solutions, *Langmuir*, 21, 1834-1839.

Fukunishi, A. and Y. Mori. 2006. Adhesion force between particles and substrate in a humid atmosphere studied by atomic force microscopy, *Advanced Powder Technology*, 17, 567-580.

Jesionowski T., A. Krysztafkiewicz. 2001. Influence of silane coupling agents on surface properties of precipitated silicas, *Applied Surface Science*, 172, 18-32.

Jones R., H. M. Pollock, J. A. S. Cleaver and C. S. Hodges. 2002. Adhesion Forces between Glass and Silicon Surfaces in Air Studied by AFM: Effects of Relative Humidity, Particle Size, Roughness, and Surface Treatment, *Langmuir*, 18, 8045-8055.

Shioji S., K. Tokami, and H. Yamamoto 1992. Surface Alkoxylation of Silicas by Mild Reactions with Alcohols, *Bull. Chem. Soc. Japan*, 65, 728-734.

Yamamoto, T., Y. Harada, K. Fukui and H. Yoshida. 2009. Classification of Particles Dispersed by Bead Milling Using Electrical Field-Flow Fractionation, *Journal of Chemical Engineering Japan*, 42, 720-727.

Yamamoto, T., Y. Harada, K. Fukui and H. Yoshida. 2010. AFM Investigation of the Surface Properties of Silica Particles Dispersed by Bead Milling, *Colloids and Surfaces A*, 362, 97-101.

Yamamoto, T., T. Tatekawa, K. Fukui and H. Yoshida. 2011. Enhancement of the Classification Performance of Electrical Field-Flow Fractionation Using Horizontal Electrophoresis, *Journal of Chemical Engineering Japan*, 44, 398-404.

Yamamoto, T., Y. Harada, T. Tsuyama, K. Fukui and H. Yoshida. 2012. Classification of Particles Dispersed by Bead Milling Using Electrical Field-Flow Fractionation, *Kona Powder and Particle Journal*, 42, 720-727.

Yoshida H., T. Saeki, K. Hashimoto, and T. Fujioka. 1991. Size Classification of Submicron Powder by Air Cyclone and Three-dimensional Analysis, *Journal of Chemical Engineering of Japan*, 24, 640-647.

Yoshida H., K. Ono, and K. Fukui. 2005. The Effect of a New Method of Fluid Flow Control on Submicron Particle Classification in Gas-cyclones, *Powder Technology*, 149, 139-147.

Yoshida H., Y. Inada, K. Fukui, and T. Yamamoto. 2009. Improvement of gas-cyclone performance by use of local fluid flow control method, *Powder Technology*, 193, 6-14.

Yoshida, H., Y. Nishimura, K. Fukui and T. Yamamoto. 2010. Effect of apex cone shape on fine particle classification of gas-cyclone, *Powder Technology*, 204, 54-62.

Nomenclature

D_p particle diameter (μm)

$f_c(D_p)$, $f_f(D_p)$ particle size distributions of the classified coarse silica and fine particles, respectively (%)

h separation distance between the silica particle on top of the probe tip and the mica plate (nm)

m_c, m_f masses of the classified coarse and fine particles, respectively (g)

ΔD_p small difference in particle diameter (μm)

$\Delta\eta$ partial separation efficiency (-)

Table 1 Average separation forces of silica particles with surface modifications

	Without treatment	Ethanol	Acetone
Average of F [nN]	216.7	121.9	114.6

Table 2 Average separation forces of fine silica particles

	Standard	Acetone treatment
Average of F [nN]	113.0	88.8

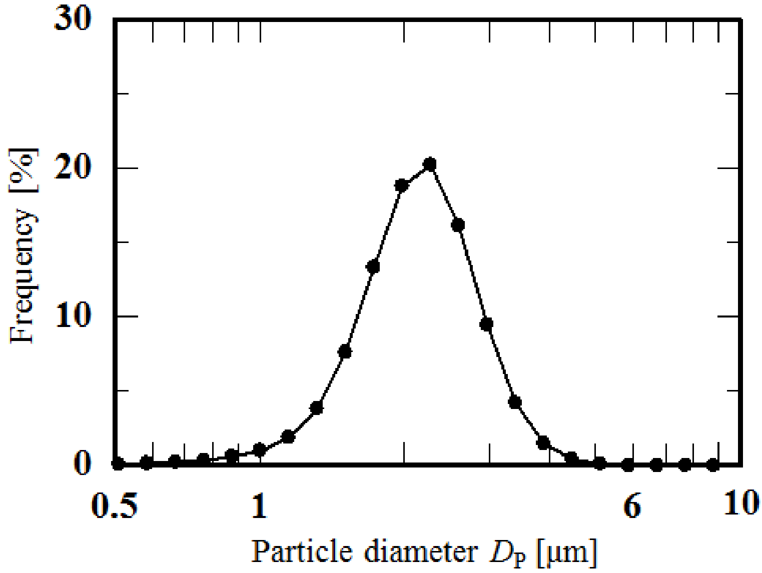

Figure 1 Particle size distribution of the original silica powder.

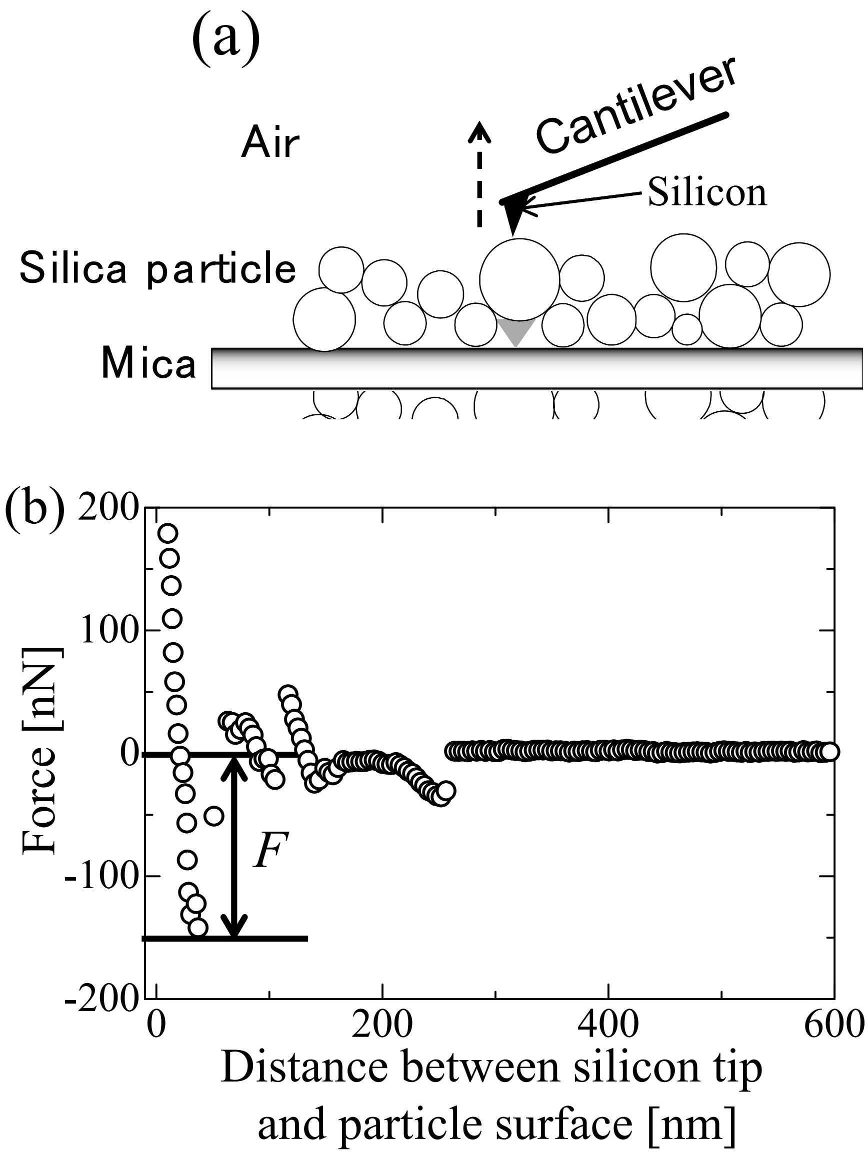

Figure 2 Measurement of interaction by AFM; (a) between cantilever tip and silica particle in the air and (b) its separating force curve.

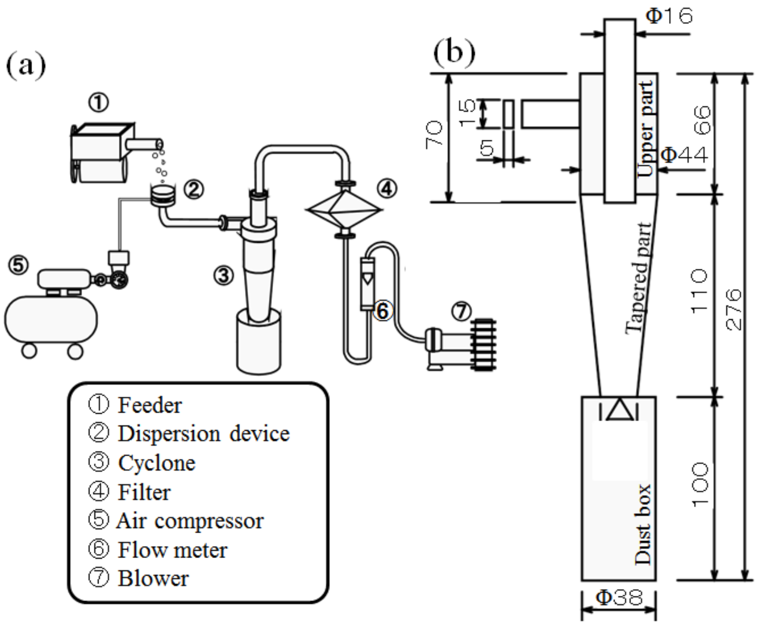

Figure 3 Cyclone system for classification: (a) overview and (b) details of the cyclone.

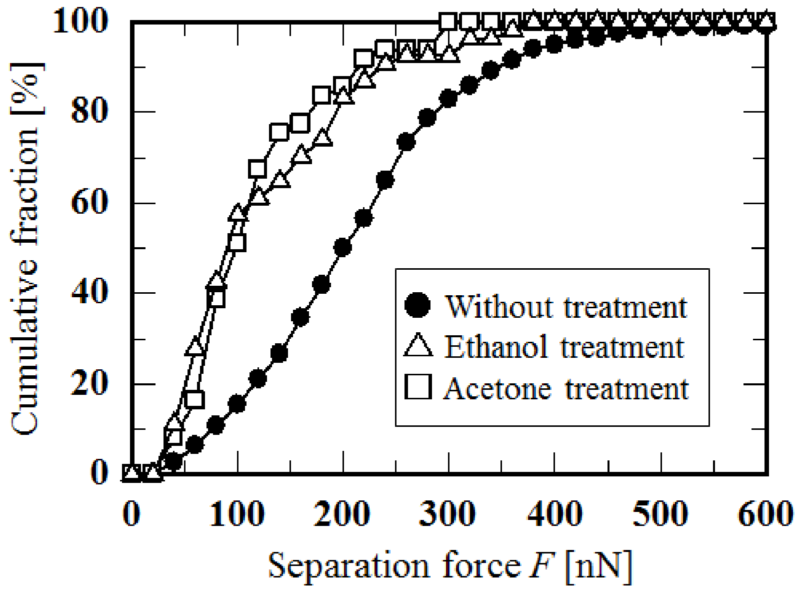

Figure 4 The effect of the surface modification on the separation force of the silica particle.

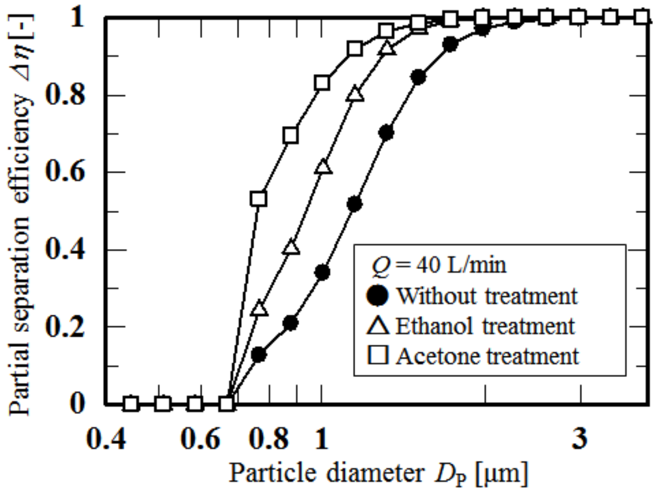

Figure 5 The effect of the surface modification on the classification performance of the cyclone at the total flow rate of 40 L/min.