EFFECT OF AERATION ON DISPERSION AND SURFACE MODIFICATION OF DIAMOND PARTICLES BY SONOCHEMICAL REACTION

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Abstract

Recently, nanometer sized diamond particles are used as an abrasive in the ultra high precision polishing process and a solid lubricant. However, the diamond particles with average particle sizes of about 5nm aggregate to form cluster diamond particles with average particle sizes of a few microns. Studies have been made on the dispersion of diamond particles in water and modification of their surface properties using sonochemical reactions caused in the suspension medium by ultrasound exposure. An ultrasound exposure system using a vibrating disk with a Langevin type transducer was used in this study. Aggregated cluster diamond particles with average particle sizes of a few microns could be downsized to those with about 40 nm in the aqueous suspension.

Introduction

Recently, nanometer sized diamond particles are used in polishing, texturing, and various other finishing parts [1] and solid lubricants [2]. Dispersing abrasive grains into a medium is important in the manufacturing of abrasive slurry. High precision polishing can be expected if abrasive grains can be homogeneously dispersed into the medium. Diamond particles have been developed for polishing of precision machinery, devices and parts such as magnetic head hard disks, ceramics and metals.

In particular, cluster diamond is expected to have a potential to be used in such precision polishing process mentioned above. Cluster diamond is synthesized from the soot of TNT gunpowder fired in water. It consists of primary particles with sizes of about 5nm, but they aggregate to form particles of a few microns. High precision polishing requires abrasive particles of a uniform size distribution. However, the smaller the particle size is, the greater the difficulties are involved in dispersing particles uniformly in the medium because of the increasing tendency of particle agglomeration. Abrasive particles, when applied in the agglomerated state, may scratch the workpiece or produce an inhomogeneously polished surface on the workpiece, resulting in uneven polishing.

The purpose of this study is to disperse diamond particles in water and modify their surface properties with sonochemical reactions caused in the suspension medium by ultrasound exposure. Two types of ultrasound exposure systems were used in this study. One is a system using an ultrasound horn [3] and the other is a system using a vibrating disk with a Langevin type transducer [4], [5].

The surface modification of diamond particles was evaluated using the zeta potential of the treated diamond particles and through the observation of changes produced on the surface of diamond particles with an FT-IR device.

Experimentals

Figure 1 shows the ultrasound exposure system using a vibrating disk with a Langevin type transducer [4],[5]. A stainless steel vibrating disk (thickness: 2mm and diameter: 180mm) was driven by a bolt clamped Langevin type transducer (Honda electronics CO. LTD. HEC-45402) with a resonant frequency of 40 kHz. The stainless steel vibrating disk was attached to the bottom of the water tank (70mm×70mm, ×150mm) in the system. Output signal of a function generator (HP 8116A) was amplified with a power amplifier (ENI 2100L) of gain 50dB. The output signal was a continuous wave with

an amplitude of 200mV and a frequency of 150 kHz. The amplified signal was applied to the transducer. A 30mg portion of the cluster diamond particles was suspended and stirred in 500mL distilled water in a water tank. The diamond suspension was sonicated using the ultrasound exposure system. Since the purpose of this study is to disperse diamond particles in water and modify their surface properties with sonochemical reactions caused by ultrasound exposure, the effective applied ultrasound frequencies were determined by sonochemical luminescence. Sonochemical luminescence is one of the typical sonochemical reactions. The light intensity of the sonochemical luminescence of luminol solution in a water tank in the ultrasound exposure system was measured with a photomultiplier. Figure 2 shows the measured frequency characteristics of the light intensity of sonochemical luminescence. Figure 3 shows the light pattern. When the sonochemical reaction in the water tank was estimated by sonochemical luminescence, a high light intensity was observed at driving frequencies of 155 kHz and 185 kHz. Brightest horizontal stripe patterns were formed at 185 kHz corresponding to the loop of acoustic sound pressure standing waves in the solution. Light was emitted all over the solution in the water tank at a driving frequency of 155 kHz except for the bottom and center of the solution. A high sensitivity CCD video camera allowed to observe that the light patterns at a driving frequency of 155 kHz were due to the movements of cavitation bubbles by acoustic streaming.

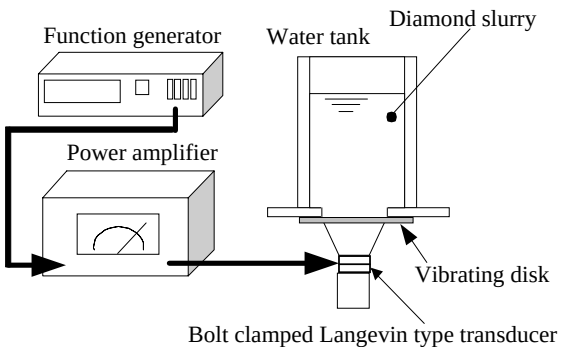


Fig. 1 Ultrasound exposure system using vibrating disk driven by Langevin type transducer used in this study

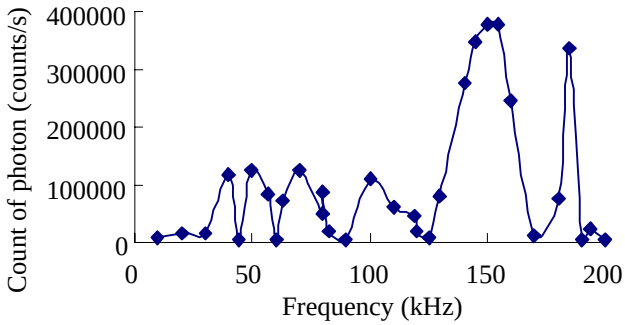
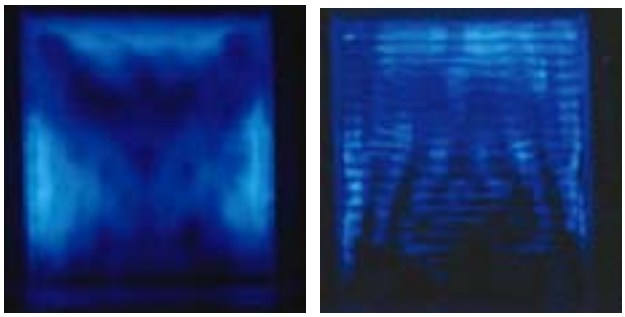


Fig. 2 Frequency characteristics of light intensity of sonochemical luminescence in water tank of ultrasound exposure system



(a) 155kHz (b) 185kHz

Fig. 3 Light pattern of sonochemical luminescence in water tank of ultrasound exposure system

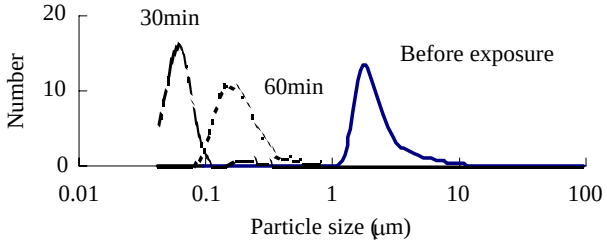
Results and discussion

Changes in particle size distribution

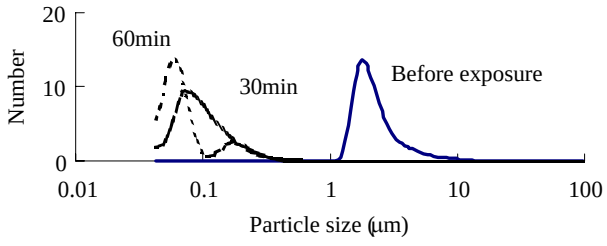
Figures 4 and 5 show changes in the size distribution of the diamond particles before and after being exposed to ultrasound shown in Fig. 1. Figures 4 (a) and (b) show changes of size distributions of the diamond particles after ultrasound exposure without aeration. Figures 5 (a) and (b) show changes in the particle size distribution after ultrasound exposure with aeration. The average size of diamond particles decreased by ultrasound exposure in every case. It is considered that shock waves generated by the collapse of cavitation bubbles broke up and dispersed aggregated diamond particles.

However, the size of diamond particles exposed to ultrasound at 155 kHz were unstable without aeration as in Fig. 4(a). The average size of diamond particles exposed to ultrasound for 30 min once decreased to be about 60 nm, but it increased to 100 nm by ultrasound exposure for 60 min. No such increase in the particle size

occurred by ultrasound exposure with aeration as shown in Fig. 5(a). Liberation of dissolved air from water was considered to cause this phenomenon by ultrasound exposure without aeration. Dissolved air in water acts as the cavitation nucleus. Not fully surface modified diamond particles are considered to aggregate again due to the elimination of the cavitation nucleus in water by ultrasound exposure over 60 min in the case shown in Fig. 4 (a). However, no such increase in particle size was observed for ultrasound exposure at a frequency of 185 kHz even without aeration as shown in Fig. 4 (b). This may be related with the pressure of the sound field generated in the water tank. The maximum sound pressure was 80 kPa for ultrasound exposure at 155 kHz, while that for the exposure at 185 kHz was 40 kPa. It was half maximum sound pressure at 155 kPa. Air (cavitation nucleus) dissolved in water was released rapidly by ultrasound exposure at 155 kHz. On the other hand, air remained as cavitation nuclei in water for a long time at 185 kHz due to the low sound pressure. The size of diamond particles therefore did not increase at ultrasound exposure at 185 kHz.

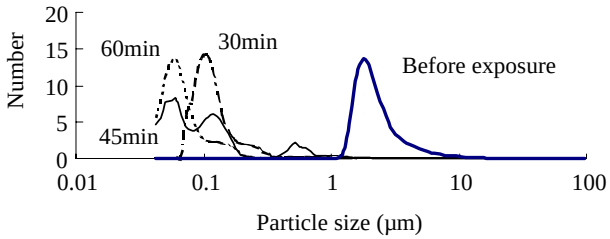


(a) Ultrasound frequency : 155kHz

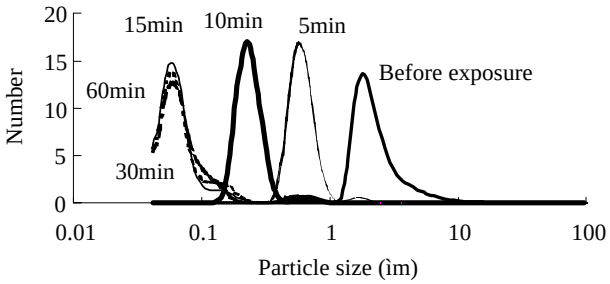


(b) Ultrasound frequency : 185kHz

Fig. 4 Change of size distributions of diamond particles by ultrasound exposure using vibrating disk driven with Langevin transducer (without aeration)



(a) Ultrasound frequency : 155kHz



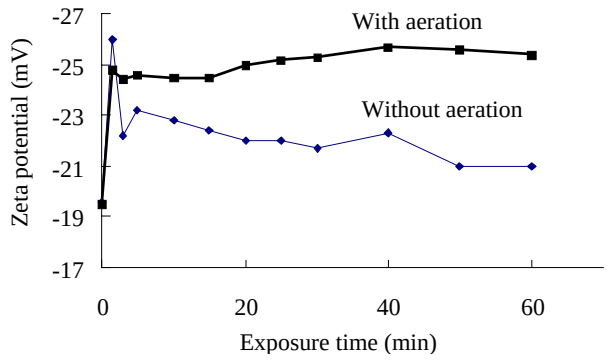
(b) Ultrasound frequency : 185kHz

Fig. 5 Change of size distributions of diamond particles by ultrasound exposure using vibrating disk driven with Langevin transducer (with aeration)

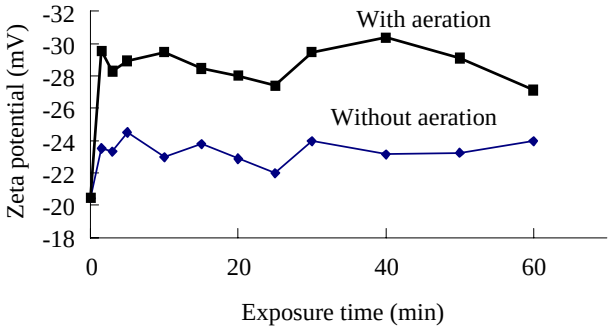
Change in surface conditions

Zeta potential was measured to estimate the extent of change produced on the diamond particle surface exposed to ultrasound. Figure 6 (a) shows the relationship between ultrasound exposure time at 155 kHz and zeta potential for diamond particles with and without aeration. Figure 6 (b) shows the relationship between ultrasound exposure time at 185 kHz and zeta potential for diamond particles with and without aeration.

The maximum zeta potential of diamond particles was observed at ultrasound exposure for 90 s and it decreased after a longer ultrasound exposure time at an operating frequency of 155 kHz without aeration. On the other hand, zeta potential was improved and kept stable for ultrasound exposure at 155 kHz for 90s with aeration. Highest zeta potential was obtained by ultrasound exposure at 185 kHz with aeration. The surface of diamond particles was thus modified effectively by ultrasound exposure with aeration because cavitation nuclei of air could be supplied to generate active oxygen by continuous aeration.



(a) Ultrasound frequency : 155kHz



(b) Ultrasound frequency : 185kHz

Fig. 4 Change of zeta potential of diamond particles by ultrasound exposure and aeration

Conclusion

Cluster diamond particles with primary sizes of 5nm and aggregated to give particles with size of about 3 μm could be dispersed to yield particles of about 40 nm and were surface-modified by ultrasound exposure with aeration. An ultrasound exposure system with a stainless vibrating disk driven with a Langevin type transducer was used in this study.

A standing wave acoustic field was generated in the diamond suspension by the vibrating disk and cavitation nuclei of air were supplied continuously in the diamond suspension by aeration.

Furthermore, the zeta potential of diamond particles could be improved by forming hydroxyl groups on their surface. In addition, no erosion occurred on the surface of the stainless steel vibrating plate in this ultrasound exposure system. The suspension medium was therefore not contaminated by erosion.

Reference

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[2] Noboru Nakayame; Outline of NEDO project entitled “Development of Ultra-Solid Lubricant with Cluster Diamond” in fiscal 1999, 1999.3

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[5] Takeyoshi Uchida, Toshio Sato, Shinichi Takeuchi, Naimu Kuramochi and Norimichi Kawashima; “Basic study on dispersion and surface modification of diamond powders by sonochemical reaction”, Jpn. J. Appl. Phys., vol.42 (2003) pp. 2967-2970, Part 1, No.5B, 2003.5