Effect of Water Supply Using Ultrasonic Atomization on MCF (Magnetic Compound Fluid) Slurry Working Life in MCF Polishing

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Abstract. Magnetic compound fluid (MCF) polishing process is a precision finishing method that has been applied to a large variety of materials, ranging from soft optical polymers to hard ceramics. The biggest effort toward practical use of the MCF polishing is to prolong the working life of MCF slurry. In this paper, we focused on the drying phenomenon of MCF slurry during polishing, and developed a new water supply system using an ultrasonic atomization mechanism. This system can humidify the MCF polishing area locally. Polishing experiments with water supply to MCF slurry have been carried out and the prolongation of MCF slurry working life is discussed.

Introduction

In recent years, the demand for clean energy such as solar photovoltaic is increasing with the development and the increase in application of renewable energies. In order to concentrate sunlight and raise the efficiency of the power generation in the solar cell system, Fresnel lenses are commonly employed as the key parts in the system. This kind of lens is in general created by generating micro shape on optical glass or plastic, and in practice produced by injection molding or/and hot press process with micro structured molds/dies. As the transmitted light energy of lenses is closely related to the geometrical quality, i.e., the form accuracy and surface roughness of the lens, and the quality of lenses depends on that of the molds/dies used, the generation of high form accuracy and high precision micro structured molds is a stringent requirement.

Exiting precision machining processes such as diamond machining and precision grinding are well suited for the manufacture of micro structured surfaces. However, in some cases subsequent polishing of the micro structures must be performed to improve surface roughness and form accuracy or to remove cutter-marks caused by pre-machining which may result in light scattering effects [1]. One promising advanced finishing technique is abrasive polishing which is considered to be one of the effective manufacturing [2]. Gessenharter et al. [3] proposed abrasive flow machining method to improve the surface quality. Abrasive polishing using pin type and wheel type polishing tools made of polyamide was applied to improve the surface roughness of micro structured molds [4]. In these methods, however, it is hard to achieve the uniform distribution of abrasive gains within the polishing zone which blocks the further improvement of work-surface quality. Under this situation, magnetic fluid (MF) or/and magnetorheological (MR) fluid mixed with abrasives as a polishing tool was introduced for the finishing of three-dimensional surfaces [5-7]. However, magnetic field, magnetic pressure and apparent viscosity of the MF are smaller than that of an MR fluid, whereas the particles are more stably distributed in the former than in the latter [8].

Against these problems, a novel slurry is produced by mixing the MF containing nanometer size magnetite particles and MR fluid containing micron size carbonyl iron powder (CIP) in the same base solvent, and exhibits higher magnetic pressure and apparent viscosity and a more stable and uniform distribution of particles under a magnetic field, while maintaining a fluid-like behavior [9]. Once a magnetic field is applied, chain-shaped magnetic clusters composed of nanometer sized magnetite particles and micron sized CIPs are formed along the magnetic lines of force immediately, and abrasive grains are entrapped into the clusters or distributed between clusters, and α-cellulose fibers have interwoven with the clusters. When a relative motion is given between the work-surface and abrasive grains, a polishing force is imposed on the workpiece owing to the induced friction between the workpiece and abrasive grains, and the micro-cutting action of abrasive particles occurs to remove materials. The MCF slurry has been successfully used for polishing flat surfaces with nano-precision and scratch-free work-surfaces under a static and/or dynamic magnetic field [10-11]. However, in the MCF polishing, there is a problem that the working life of the MCF slurry is short due to the centrifugal force resulting from the rotation of the polishing tool and the moisture evaporation due to the processing heat. In addition, a method of discarding MCF slurry after polishing is a big problem.

Therefore, in this study, a novel MCF polishing method using an ultrasonic atomization is proposed, and the effects of the ultrasonic atomization on the MCF polishing are investigated. For this purpose, an experimental apparatus primarily consisting of the ultrasonic atomization unit are designed and manufactured, and investigations of the MCF polishing under the ultrasonic atomization is also conducted in this paper. In addition, in order to make it possible to reuse the MCF slurry, it also investigate the examination experimentally.

Polishing principle and experimental details

Fig. 1 schematically illustrates the MCF polishing process. A disk-shaped permanent magnet is attached on the end face of its holder with an eccentricity of d. An MCF carrier made of an aluminum plate is located the magnet with a clearance. When the magnet holder is rotated at speed n_1, the magnet revolves around the axis of the holder. The magnetic flux density is constant but the magnetic lines of force constantly revolve around the magnet holder axis.

Once the clearance Δ between the workpiece and the carrier has received a certain volume of MCF slurry, as shown in Fig. 1, chain-shaped magnetic clusters composed of nanometer sized magnetite particles and micron sized CIPs (Carbonyl-iron-particles) are formed along the magnetic lines of force immediately; non-magnetic abrasive particles are entrapped into the clusters or distributed between clusters and α-cellulose fibers have interwoven with the clusters. Therefore, under the combined effect of both magnetic levitation and gravitational forces, majority of nonmagnetic abrasive grains within the MCF slurry move towards the work surface. In addition, all of the clusters are collected forcibly by the magnetic attraction force and they are gathered in the area where the magnetic field is stronger. When the MCF slurry is given to the rotational speed, a large polishing force is imposed on the workpiece owing to the induced friction between the workpiece and abrasive grains, and the micro-cutting action of abrasive grains occurs to remove materials.

For realizing the polishing principle, an experimental rig was constructed as shown in Fig. 2. A polishing unit was composed mainly of an aluminum-made MCF carrier and a motor used for rotationally driving the MCF carrier via a belt/pulley mechanism is attached. In addition, another motor is employed as the magnet holder, on the end face of which a neodymium permanent magnet is attached with an eccentricity. In addition, in order to suppress the drying of the MCF slurry and prolong the working life, a local humidification system in the polishing area using the ultrasonic humidifier was attached. Polishing experiments were performed on the constructed experimental rig. The purpose of this research was to investigate the effects of ultrasonic atomization. Therefore, the water-based MCF slurry was prepared with given compositions as shown in Table 1. Table 2 shows the experimental parameters. Zirconia ceramics was used for the workpiece, and the water supply amount of the ultrasonic atomizer was 0 to 0.40 ml / min. In addition, by prolonging supply of abrasive grains constituting MCF slurry and α cellulose, the working life was extended and the reuse was evaluated. In order to evaluate the polishing characteristics of the MCF slurry, the workpiece was exchanged every 30 minutes, and the surface roughness Ra and the amount of material removal were measured. For each workpiece before polishing, the initial surface roughness Ra was set to about 150 nm using a lapping machine.

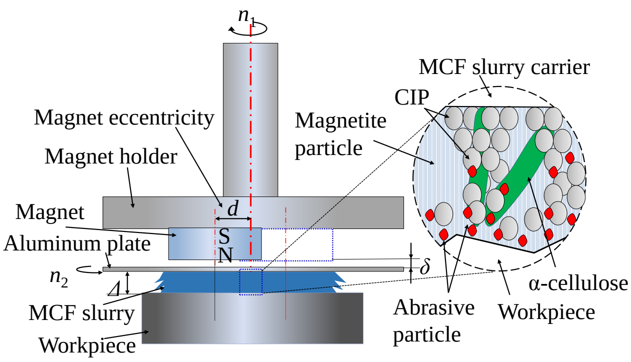

Fig. 1 Illustration of the ultrasonic vibration assisted MCF polishing process

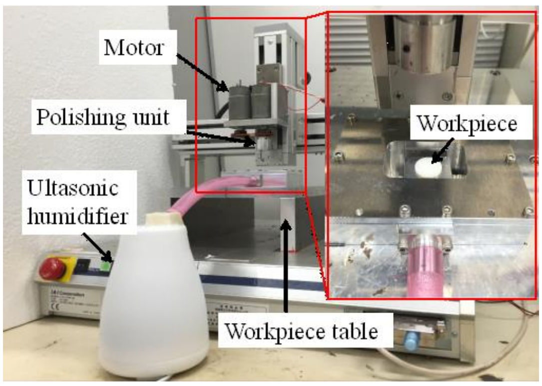

Fig. 2 Photograph of the experimental rig

Table 1 Compositions of MCF slurry

	Concentration
Abrasive: Diamond (Mean diameter :1.0 μm)	12 wt.%
Carbonyl iron powder: (Mean diameter: 7.0 μm)	40 wt.%
MF: WSG W11	40 wt.%
α-cellulose	3 wt.%

Table 2 Experimental conditions

Workpiece		ZrO_2
Permanent magnet	φ [mm]	2×5
	d [mm]	Revolution radius : 2
	n_1 [min^{-1}]	Rotational speed : 1,000
Aluminum plate n_2 [min^{-1}]		Rotational speed : 1,000
x-axis feed	Stroke [mm]	5
	Feed rate [mm/s]	5
Supply of MCF slurry [ml]		0.17
Clearance [mm]		0.1
Ultrasonic humidifier [ml/min]		None, 0.20, 0.30, 0.40
Supply amount	[ml/min]	0.30
	[mg/30min]	Abrasive : 3.0
	[mg/150min]	α -cellulose : 3.0
Polishing time [min]		180

Experimental results and discussion

Fig. 3 shows the temporal change of the surface roughness in the supply of water. As a result, in the case of no moisture supply (None), the polishing characteristics can not be maintained by drying the MCF slurry. However, when water is supplied, the slurry can be used up to 180 min. The surface roughness Ra increases as the cumulative working time of the slurry increases in all the water supply. Also, at 0.30 ml / min, the polishing performance can be maintained up to 120 min and has increased since 150 min. This may be caused by scattering or wear of the slurry during polishing. Because the permanent magnet is used for polishing, the decrease of the iron powder, which is the magnetic material of the slurry component, is small. Therefore, it is thought that it is caused by non-magnetic abrasive grains of slurry constituents and α cellulose. To clarify the cause, abrasive grains and α cellulose were supplied and conduct experiments. In the following experiments, water supply is performed at 0.30 ml / min at which the polishing characteristics can be maintained most.

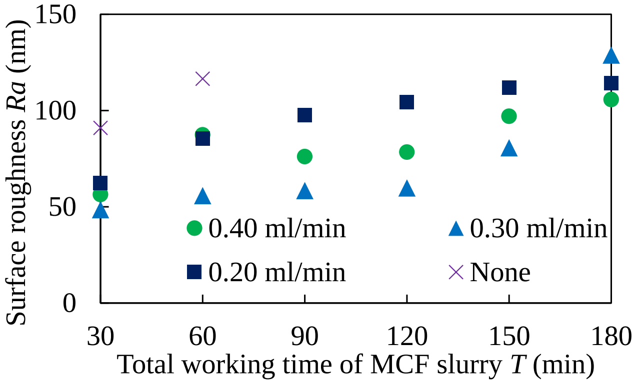

Fig. 3 Changes of the surface roughness in each condition

Fig. 4 shows the change in the mass of the slurry when there is no water supply without polishing and the slurry is air-dried. As shown in Fig. 4, the mass of 0.02 g is reduced at 180 min by attaching the slurry to the experimental equipment. It is considered that this is due to the reduction of the components of the slurry due to the rotation of the polishing tool. Therefore, 0.02 g of abrasive grains or α cellulose will be supplied. Fig. 5 shows temporal changes in surface roughness when water + abrasive grains and water + α cellulose are supplied. For water + abrasive grain, 0.003 g of abrasive grain was supplied every 30 min. There was no significant change in water + abrasive grain compared with only water supply. From this result, since the polishing characteristics can be maintained only by supplying water up to 120 min, experiments were carried out by feeding α cellulose from 150 min to 0.003 g of α cellulose. From the Fig. 5, it was possible to suppress increase in surface roughness by supplying α cellulose. Fig. 6 shows the amount of material removed in Fig. 5. From Fig. 6, in the case of water and water + abrasive grains, the amount of material removed decreases at 150 min, but it is maintained up to 180 min by supplying α cellulose.

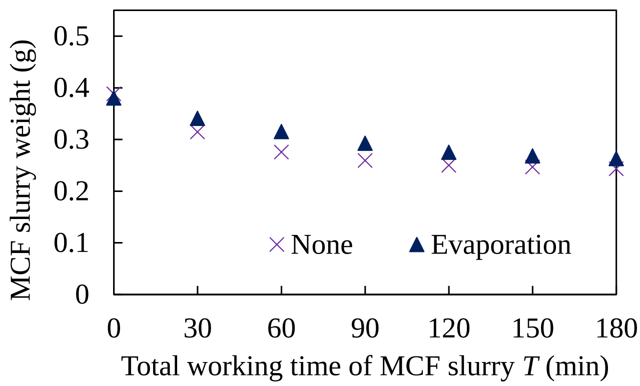

Fig. 4 Changes of the MCF slurry weight in each condition

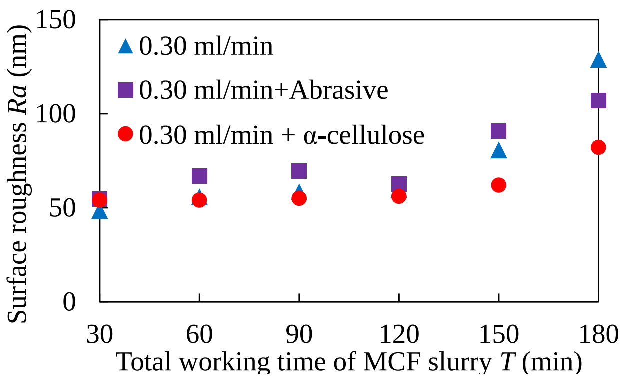

Fig. 5 Changes of the surface roughness in each condition

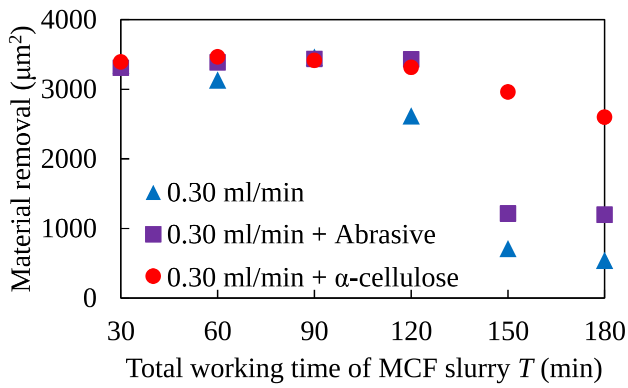

Fig. 6 Changes of the material removal in each condition

Conclusions

For the purpose of prolonging the life of slurry in MCF polishing, a local humidification system in the polishing region using an ultrasonic atomizer was proposed and the influence of the water supply amount on the polishing characteristics was evaluated. Drying of MCF slurry was suppressed by supplying water in the polishing experiment and it was shown that polishing for a long time is possible. It also clarified that slurry can be recycled by maintaining the polishing characteristics of slurry by supplying α-cellulose.

Acknowledgments

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