An Experimental Study on the Ultra-precision Polishing of Quartz Crystal Using MR Fluids and Micro Abrasives

D W Kim\textsuperscript{1,2}, J W Lee\textsuperscript{1}, M W Cho\textsuperscript{1} and S B Choi\textsuperscript{1}

\textsuperscript{1} Micro Manufacturing Systems Laboratory, Department of Mechanical Engineering, Inha University, Incheon 420-751, KOREA

\textsuperscript{2} Smart Structures and Systems Laboratory, Department of Mechanical Engineering, Inha University, Incheon 420-751, KOREA

E-mail: kdw525@inha.ac.kr

Abstract. This paper presents ultra-precision MR polishing results of quartz crystal, which has been widely used in many applications, such as piezo-electric transducer, surface acoustic wave (SAW) filters and SAW resonators, etc. It is known that smooth surface with sub-nanometer roughness is needed for higher-frequency application. The MR fluids, used for the polishing, consist of DI water based carbonyl iron (CI), nonmagnetic polishing micro abrasives, and required amount of stabilizers. In the process, mixed fluids were supplied into the gap between a rotating wheel (with electromagnetic field) and the workpiece. Then, the micro abrasives contained in the fluids perform material removal action from the workpiece. Such material removal mechanism in the MR polishing is considered as a process governed by the Bingham flow in the contact zone. In this study, material removal characteristics and generated surface roughness of the quartz crystal specimens using the MR polishing process were investigated through a series of experiments. The surface roughness variations of the polished specimens were investigated by changing imposed polishing conditions, such as wheel speed, magnetic field intensity. As a result, very fine surface roughness of $Ra=0.770\text{nm}$ was obtained.

1. Introduction

In this study, variations of the machined surface characteristics of the quartz crystal glass were investigated in a polishing process using MR fluids containing micro alumina abrasives. The quartz crystal has been used in many applications such as optical devices, piezo-electric transducers, surface acoustic wave (SAW) filters and SAW resonators. It is known that ultra-precise surfaces of sub-nanometer roughness with very few surface damages are required for higher frequency applications. The MR polishing method is considered as a potentially effective solution to solve the existing problems arising in traditional polishing methods, such as pressure control, pad wear, subsurface damage, and micro crack propagation problems.

MR fluids, which are known as controllable smart materials, are suspensions of very small magnetic additives, such as carbonyl iron (CI), and nonmagnetic fluids such as mineral oils or water\cite{1-3}. Flow properties of the fluids such as viscosity and flow rate can be easily changed using externally imposed magnetic fields\cite{4}. Such special characteristics of the MR fluids can be applied to polishing processes.
for nonmagnetic parts, such as aspheric lenses, ceramics, etc. In the MR polishing process, the surface roughness and material removal rate of the workpiece are determined by the process parameters such as relative velocity, intensity of the imposed magnetic field, gap size, and used abrasives, etc. Thus, the objective of study is to investigate the effects of the process parameters on the surface roughness in the polishing of quartz crystal glass using the MR fluids and micro abrasives. A series of experiments were performed, and the machined surface qualities were measured using noncontact type measuring instrument. As a result, ultra-precise surface roughness of Ra=0.770nm was obtained using Al₂O₃ (alumina) micro abrasives.

2. Polishing principle using MR fluids
Under the imposed magnetic field, the MR fluid can compose chain-like structures via magnetization of the particles in the fluid. To use the MR fluid as a polishing media, proper abrasives should be added to the fluid: these abrasives adhere to the MR particles as shown in the Figure 1 [5]. A schematic diagram of the MR polishing mechanism is shown in the Figure 2 [6]. As shown in (a), the MR fluid is supplied to the gap between a workpiece and a moving wall (vertically rotating wheel in this study). For the polishing purposes, proper abrasive slurry is incorporated into the fluid, which is supplied to the narrow gap between the wheel and workpiece. Then, the abrasives which are adhered to the MR particles can remove required parts of the workpiece surface.

![Figure 1. Chain cluster formation of MR particles and abrasives.](image1)

3. Experimental setup
Experimental setup for the MR polishing is shown in Figure 3. The MR polishing equipment is composed of a rotating wheel with electromagnetic field and a workpiece fixture, and moving stages. A SEM image of the prepared MR fluid and abrasive slurry mixture is shown in Figure 4(a). Figure

![Figure 2. Applied MR polishing method.](image2)
4(b) illustrates the particle size distribution of the used alumina powder for the polishing. In the Table 1 and 2, compositions of the used MR fluid and abrasive slurry are listed. The experiments were performed by changing the wheel rotating speeds (50~300 rpm) and magnetic field intensities to investigate the surface roughness variations.

![Experimental setup for the MR polishing.](image)

(a) SEM image. (b) Particle size distribution.

**Figure 4.** SEM image and particle size distribution of the alumina abrasive.

**Table 1** Composition of the used MR fluids.

| CI-powder | DI- Water | Na$_2$CO$_3$ | Glycerin |
|-----------|-----------|--------------|----------|
| 50%       | 48%       | 1%           | 1%       |

**Table 2** Composition of the used abrasive slurry.

| Composition | Al$_2$O$_3$ Abrasive | DI- Water |
|-------------|----------------------|-----------|
|             | 17.3%                | 82.7%     |

**4. Results and discussions**

Machined surfaces were measured using a noncontact type three dimensional measuring instrument (Zygo, NV-6200). Surface roughness variations according to the wheel speed and magnetic field intensity variations are shown in the Figure 5. It can be observed that the surface roughness improves with the increase of the wheel rotating speeds, and with the decrease of the imposed magnetic field intensities. As the results of the experiments, very fine surface roughness of Ra=0.770nm was
obtained as shown in Figure 6. Such results insist that the MR polishing method can be an effective method for the polishing of quartz crystal glass.

(a) According to the wheel the speed variations. (b) According to the magnetic field variations.

**Figure 5.** Surface roughness variations according to the applied polishing conditions.

**Figure 6.** Measured results of the machined surfaces (Ra=0.770nm when the wheel speed=300rpm and the magnetic field intensity= 3.8KA/m).

5. Conclusions
In this study, a series of experiments were performed to investigate the ultra-precision polishing characteristics of quartz crystal glass using the MR fluid and polishing slurries with micro alumina abrasives. Surface roughness variation tendencies and polished results of the quartz crystal specimens were investigated by changing the applied process parameters such as the imposed magnetic field intensities and the rotating wheel speeds, etc. The results of this study can be summarized as follows.

- Surface roughness of the specimens improves with the increase of the rotating wheel speeds, and with the decrease of the imposed magnetic field intensities.
- Very fine surface roughness of Ra=0.770nm was obtained.
- MR polishing can be a very effective method for the polishing of quartz crystal glass.

References
[1] Kordonski W I and Jacobs S D 1996 *Int. J. Modn. Phys.* B **10** 2837-48
[2] Kordonski W I and Golini D 1999 *Int. J. Modn. Phys.* B **14, 15 & 16** 2205-12
[3] Kim D W, Cho M W, Seo T I and Shin Y J 2008 Sensors **8** 222-235
[4] Kordonski W I and Golini D 1999 *J. Int. Mate. Sys. and Strus.* **10-Sep** 683-689
[5] Shorey A B, Jacobs S D, Kordonski W I and Gans R F 2001 *Applied Optics* **40** 20-33
[6] Shorey A B, Kordonski W I, Gorodkin S R, Gorodkin S D, Jacobs S D, Gans R F, Kwong K M and Farny C H 1999 *Rev. sci. instum.* **11** 4200-06