

Ultra-Precise Polishing of Mica Glass Ceramics Using MR Fluids and Nano Abrasives

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MR fluid를 이용한 Mica Glass Ceramics의 초정밀 연마

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(Received 1 August 2017; received in revised form 4 September 2017; accepted 5 September 2017)

ABSTRACT

Mica-glass ceramics has features such as micro-sized crystals, high strength, chemical resistance, semitransparent optical properties, etc. Due to its superior material properties, mica glass ceramics have increasing applications in dental and medical components, insulation boards, chemical devices, etc. In many applications, especially for dental and medical components, ultra-precise polishing is required. However, it is known to be a very difficult-to-grind material because of its high hardness and brittle properties. Thus, in this study, a newly developed ultra-precise polishing method is applied to obtain nano-level surface roughness of the mica glass ceramics using magnetorheological (MR) fluids and nano abrasives. Nano-sized ceria particles were used for the polishing of the mica glass ceramics. A series of experiments were performed under various polishing conditions, and the results were analyzed. A very fine surface roughness of Ra=6.127 nm could be obtained.

Key words : MR Fluid(자기유변유체), Mica Glass Ceramics(운모-유리 세라믹스), Nano Abrasive(나노연마재), Surface Roughness(표면 거칠기), Ultra-precision Polishing(초정밀 연마)

1. Introduction

Recently, ceramic materials have been widely used in dental application fields. Glass ceramics have been much more focused as a dental ceramic material than other general ceramics because of their high strength, high wear resistance, and optical

properties^[1-2]. Glass ceramics have been used already in many engineering applications. Utilization of mica glass ceramics is increasing in research area of biomedical including dental restoration applications. In this study, a newly developed polishing method using magnetorheological fluids (MR fluids) is applied to obtain ultra-precision surface roughness for mica glass ceramics. This method is considered potentially effective solutions to solve problems arising in traditional polishing methods, including

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pressure control, pad wear, subsurface damage, and micro crack propagation problems. MR fluids are suspensions of very small magnetic additives, such as carbonyl iron (CI), and nonmagnetic fluids such as mineral oils or water. MR fluids are known as controllable smart materials, since their flow properties can be easily changed using externally imposed magnetic fields. In the MR finishing process, the surface roughness and material removal rate (MRR) of the workpiece are affected by the process parameters, such as the properties of the employed nonmagnetic abrasives (particle material, size, aspect ratio, density, etc.), rotating wheel speed, imposed magnetic field density, machining depth, etc. In this study, a series of experiments were performed by changing process parameters to investigate the ultra-precision polishing behavior of the prepared mica glass ceramics. As a result, very fine surface roughness of $R_a=6.127\text{nm}$ was obtained.

2. Preparation of experiments

2.1 MR fluids

MR fluids are phase-controllable suspensions comprising a mixture of micro-size magnetic particles (CI particles in this study), and non-magnetic fluids such as mineral oils or water. The MR fluids are known as one of the smart materials since their flow properties can be easily changed by the imposed magnetic field intensity. The MR fluids can form chain-like structures via magnetization of the particles in the fluid; and it can reversibly transform the fluid from a fluid-like state to a solid-like state within milliseconds. As a result of this transformation, the flow properties of the fluid (such as viscosity, etc.) increase due to increased resistance to shear stress according to the imposed magnetic field strength. To use the MR fluid as a polishing media, suitable abrasive particles (nano-size ceria particles in this study) should be

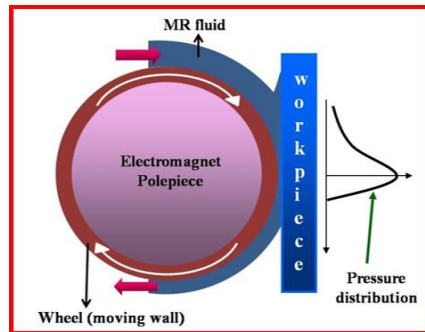
added. Also, other additives are required such as alkaline (Na_2CO_3) to prevent unwanted oxidation of CI particles due to pH drop), and glycerin to stabilize the fluids.

2.1 Polishing principle using MR fluids

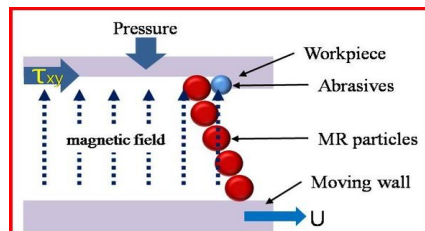
Under the imposed magnetic field, the MR fluids can form chain-like structures with the magnetized CI particles as shown in Fig 1(a). The magnetized MR fluids flow into the gap between a rotating wheel and a workpiece as shown in Fig. 1(b). Thus, the MR fluids and abrasives can perform material removal actions due to relative motions of the abrasives and the workpiece caused by the wheel rotation^[3-6].

2.3 Mica glass ceramics

Required mica glass ceramics for dental and medical applications were sintered using hot-pressing, and their material properties were measured. Measured compositions of the used mica glass ceramics are listed in Table 1.



(a) Schematic of MR fluid polishing



(b) Shear direction of polishing spot

Fig. 1 Principle of MR fluid polishing

Table 1 Composition of mica-glass ceramics

SiO ₂	Al ₂ O ₃	MgO	K ₂ O
50 wt%	20 wt%	15 wt%	8 wt%
Li ₂ O	ZrO ₂	B ₂ O ₂	F
0.9 wt%	4 wt%	2 wt%	6.1 wt%

3. Experiments

3.1 Experimental setup

An illustration of the MR fluid polishing system for the experiment is shown in Fig. 2. The MR fluid polishing system uses only MR fluid which has CI particles, DI water, and stabilizer(Na₂CO₃ and Glycerin). A magnetic field is applied to the rotating wheel (diameter: 120mm), then, is magnetized. entire rim of the In particular, MR fluid and abrasive slurry are separately applied onto the rim of the wheel. The MR fluid is applied onto the rim of a magnetized rotating wheel, and the abrasive slurry is supplied onto the stiffened MR fluid. MR fluid is supplied on the rim via a nozzle in the reformer A. Here, the stiffened MR fluid acts as a polishing pad. Reformer A is to ensure that the thickness of the stiffened MR fluid remains uniform and to fill up and refresh the MR fluid. Then, Reformer B is mainly used to separate the used abrasive slurry for recycling. The experimental setup is shown in Fig. 3. A Rotating wheel with electromagnets is installed on a table. Three-axis motion stages (two linear and one rotational) are assembled on the table for the feeding and the positioning of the workpiece. Compositions of the used MR fluids are listed in the Table 2. Since the MR polishing results are highly affected by the surface conditions of the workpiece, the specimens were pre-polished to have uniform surface roughness of 32nm.

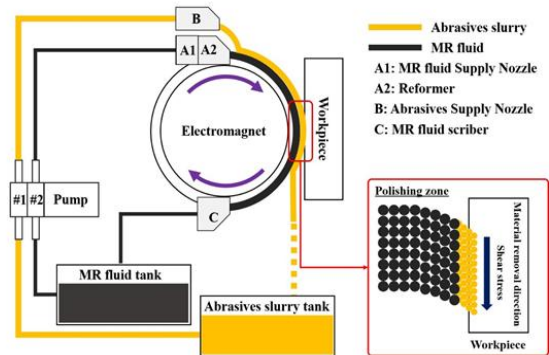


Fig. 2 Schematic of MR fluid polishing

Table 2 Composition of used MR fluids

CIPs	DI water	Na ₂ CO ₃	Glycerin
50 wt%	48 wt%	1 wt%	1 wt%

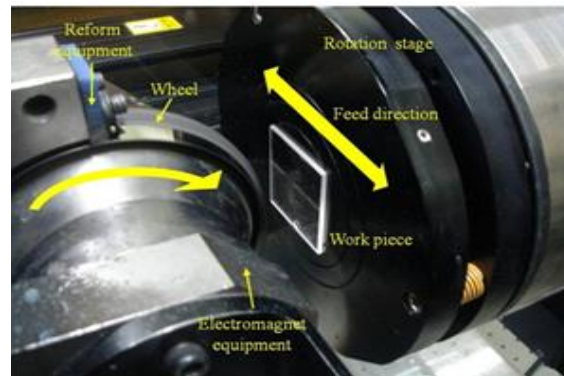
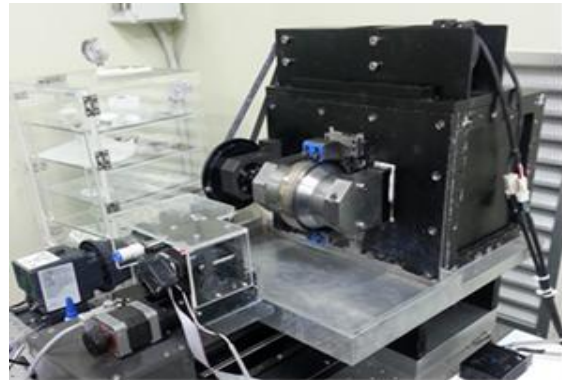


Fig. 3 Experimental setup

3.2 Pre-polishing of mica glass ceramics

Before MR fluid polishing, surface roughness of mica glass ceramics was prepared to a constant level of 32 nm using a sand paper with SiC particles through a mounting process with a diameter of 25mm.

3.3 MR fluid polishing for mica glass ceramics

A series of polishing experiments were performed by changing the process parameters, such as current intensity and wheel speed to investigate the polishing results of the mica glass ceramics. Experimental conditions are listed in Table 3. Polished specimens were measured using a three-dimensional surface profiler (NV6200, Zygo, U.S.A.), and the results were analyzed.

4. Results and Discussions

The surface roughness according to pre-polishing type (lapping and conventional polishing) was 162.575 nm and 32.552 nm. After MR fluid polishing, measured surface roughness variations according to the wheel speeds and magnetic field intensities was compared with polishing types. The measured result is shown in Fig. 4. The surface roughness after MR fluid polishing is shown in Fig. 5. As the results of this experiments, very fine surface roughness of Ra=6.127 nm was obtained. Fig. 6 and Fig. 7 show measured results and SEM images of each polishing type to obtain above result.

Table 3 Experimental conditions

Parameters	Value
Magnetic field (kA/m)	3.8, 4.7, 5.5, 6.2
Wheel speed (mm/s)	308, 616, 1232, 1848
Feed rate (mm/min)	1.0

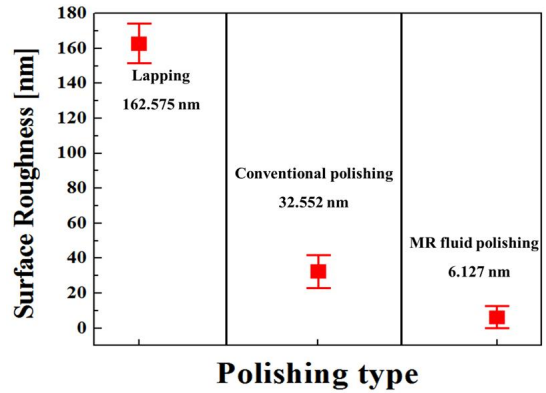
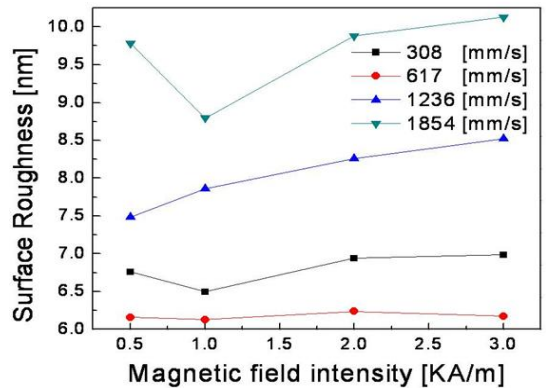
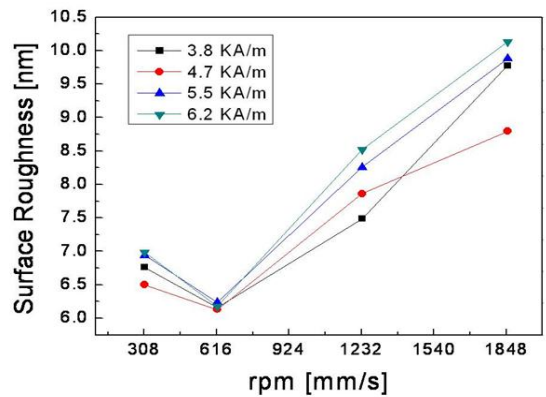


Fig. 4 Results of measured surface roughness according to polishing type

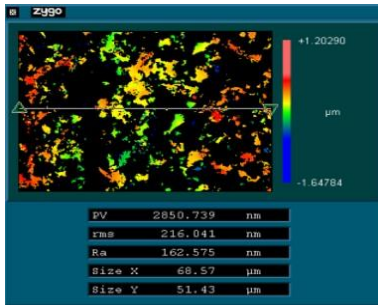


(a) Magnetic field

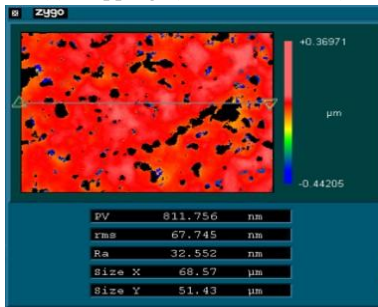


(b) rpm

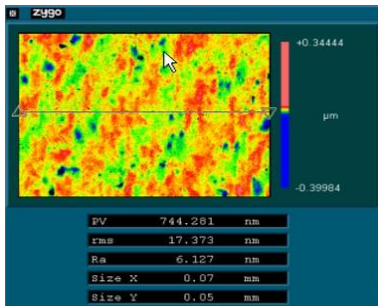
Fig. 5 Results of measured surface roughness according to magnetic field and rpm



(a) Lapping ($R_a=106.575$ nm)

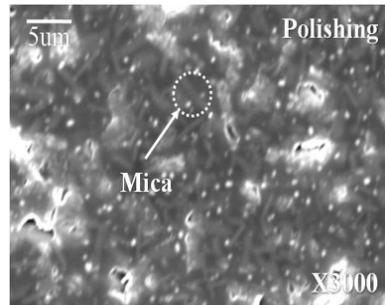


(b) Polishing ($R_a=32.552$ nm)

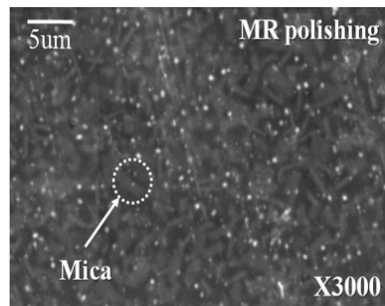


(c) MR polishing ($R_a=6.127$ nm)

Fig. 6 Measured surface roughness of Mica glass ceramics



(b) Polishing



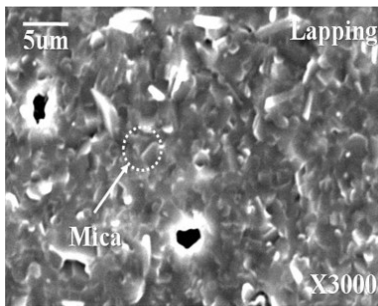
(c) MR fluid polishing

Fig. 7 SEM images according to process

5. Conclusions

In this study, a series of experiments were performed to investigate the ultra-precision polishing characteristics of mica glass-ceramics using MR fluids with nano-size ceria abrasives. The surface roughness variations were measured by changing the process parameters such as magnetic field intensity, wheel rotation speed. The results of this study can be summarized as follows:

1. MR polishing can be adopted as a useful method to improve surface roughness due to its controllable properties and low material removal rate.
2. Very fine surface roughness of $R_a=6.127$ nm was obtained when applied magnetic field intensity of 4.7 kA/m and rotating wheel speed of 616 mm/s.



(a) Lapping

3. MR polishing can be more effective surface finishing method than lapping or conventional polishing methods of hard and brittle materials such as mica glass ceramics.

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Acknowledgement

This study was supported by the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology, Korea (Grant NRF-2015R1A2A2A01005811).

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