A Study of Polishing Parameters to Surface Roughness of Magnetorheological Polishing Methods

Duc-Nam Nguyen, Truong-Giang Nguyen, and Cong-Truyen Duong

Abstract The study aims to determine the effect of polishing parameters as well as polishing speed, abrasive sizes and electric current on surface roughness of titan alloy in the magnetorheological polishing (MRP) methods. When the electric field is applied, the rheological properties of MRP fluid will be changed in the machining process. As a result, the viscosity and shear yield stress of MRP fluid was greatly improved under applied electric current. The workpiece surface can be polished by the abrasive particles with adhering to MR fluid. The influence of polishing parameters on the surface roughness was investigated by experiments. The experimental results indicated that the polishing speed has a great influence on the surface roughness of workpiece. With the increase of the polishing speed, the best surface roughness can be obtained by using the MRP method. The abrasive size had very little effect on surface quality improvement when it was changed in the experimental process. In addition, the electric current also has a strong effect on the surface quality of workpiece. As a result, the surface roughness of ball titan alloy workpiece (Ø32 mm) was reduced rapidly from Ra = 120 nm to Ra = 18 nm under the appropriate machining conditions.

Keywords Magnetorheological polishing · Curve surfaces · Artificial joints · Surface roughness · Titan alloy · MR fluid

1 Introduction

The curved surface plays an important role in a wide range of applications, such as aerospace, astronomy, mould, automobile, biomedical implant and plain spherical bearings [1–5]. In particular, the number of implanted artificial hip joints is increasing significantly in the biomedical field. There are two parts of the hip joint, such as acetabulum or cup and a metalhead attached to the human body. The surfaces of

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artificial joints are mostly spherical shapes. In order to increase the working life of the components, these surfaces need to be machined to achieve better surface roughness.

In addition, materials are also an important factor to improve the biocompatibility of the implant products. Titanium alloys are known as materials with excellent mechanical properties, high corrosion resistance, good hardness, and high applicability. Moreover, these alloys are more biocompatible and support cell attachment as well. Therefore, it is widely used in biomedical fields [6, 7]. However, the machining process of this material faces many difficulties due to unfavorable machining conditions when the chip was generated at elevated temperatures [8–10]. The surface quality of workpieces will not be satisfactory, and especially the surface roughness does not meet the product specifications. In that reason, the polishing process should be performed to improve the surface quality of the product.

There are numerous numbers of conventional machining methods such as grinding, boring shaping, milling and turning etc., used for manufacturing the complex surfaces. These conventional methods have limited application due to generated high stresses and large machining times. As a result, the surface damage and poor topography were generated on the product surfaces. In order to improve the machining efficiency, a computer numerical control (CNC) techniques have been applied to produce workpieces with high dimensional tolerances and perform machining with optimization machining trajectories. Further, many technologies have been carried out to significantly improve the surface roughness of the curved surface, such as chemical mechanical polishing (CMP) [11], magnetic abrasive finishing (MAF) [12], elastic deformation machining [13–16] and so on. However, they have various limitation in processing time and machining cost. In addition, the shear thickening polishing (STP) was also used for increasing the surface quality of the complex surfaces [17–21]. The best surface roughness can be obtained by using the appropriate abrasive sizes, polish-ing speed, and inclination angle of the workpiece, but the viscosity and properties of the polishing fluid were difficult to control during the machining process.

Therefore, the magnetorheological polishing (MRP) methods are considered and applied for processing the curved surfaces [22–24]. MRP is a flexible machining method by using magnetorheological fluid while the magnetic field is applied during the processing. When the electric field is provided, the microstructure and rheological properties of MRP fluid will be changed in the machining process. As a result, the viscosity and shear stress of MRP fluid were greatly improved. The workpiece surface can be polished by the abrasive particles with adhering to MR fluid. In this method, using external field-assisted polishing is a good method to polish curved surfaces.

2 Principle of MRP

The principle of the MRP method for processing the curve surface is presented in Fig. 1. In the MRP process, the machining fluid contains magnetorheological fluid

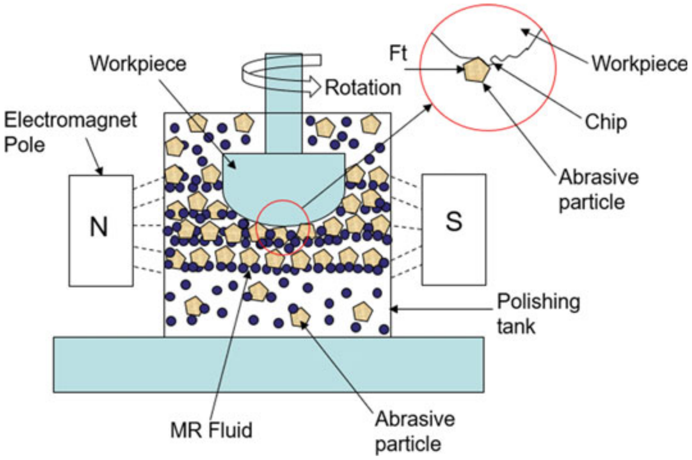

Fig. 1 Mechanism of the MRP process

(MR fluid) combine with abrasive particles. The cutting process will occur when the workpiece was relatively rotated in the MRP fluid. Under the influence of an external magnetic field, the viscosity of MRP fluid was generated and increased with increasing the intensity of the electric current. There, MRP fluid stiffens and forms a flexible magnetic abrasive brush as a polishing cutter. When the workpieces is rotated in the polishing tank, the workpiece surfaces will interact with the polishing fluid. Based on the rotation speed of workpiece and viscosity of the polishing fluid, the shearing stress is generated during the MRP machining.

The benefits of the method are that the viscosity of polishing fluid was easily controlled by the external magnetic field. In the machining process, the viscosity of the polishing fluid and the abrasive particles will be selected in accordance with the shape and material of the workpiece. As a result, the best surface roughness and high efficiency can be obtained during the MRP machining process.

3 Experimental Setup

In the experimental process, the MRP device was set up and developed, which can provide a relative motion between the workpiece and MRP fluid. As shown in Fig. 2, the workpiece was clamped by the spindle, which was driven by a stepping motor. The step motor and spindle were attached on the Z-axis, which can be moved in the vertical direction by a lead screw stage. In addition, two motors were attached on the X and Y axes, which used to control the position of the workpiece during the machining process.

A half-spherical workpiece which made from titan alloy was used in the study. The workpiece diameter of 32 mm was selected. The maximum rotation of the workpiece

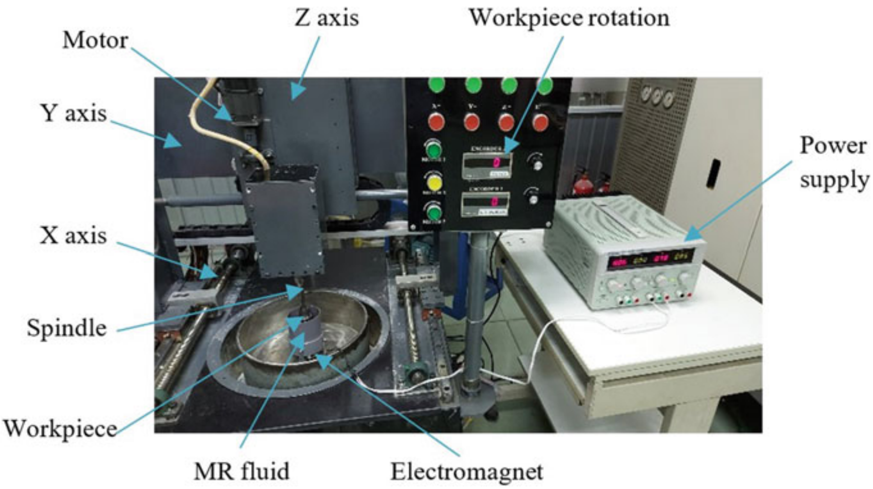

Fig. 2 The magnetorheological polishing (MRP) devices

is 350 rpm. The working gap between the tip of the workpiece and the bottom surface of the polishing tank was chosen of 8 mm. The original surface roughness (Ra) of the workpiece was 120 ± 10 nm. After the polishing process, the MarSurf-M400C measuring device was again used to test the change of surface roughness of the workpiece. After each experiment, five positions on the workpiece surface will be selected to measure the surface roughness. The final value of Ra is calculated by the average of these five positions. The physical properties of titan alloy are presented in Table 1.

In the MRP process, the machining parameters that affect the surface roughness of the workpiece are workpiece rotation, working gap and electric current [25, 26]. Therefore, three polishing parameters such as polishing speed, abrasive sizes and electric current values were chosen and investigated in this study. The single variable method was applied in the experiments. The experimental parameters are listed in Table 2.

Table 1 Physical properties of titan alloy

Items	Parameters
Modulus of elasticity (GPa)	120
Poisson ratio	0.34
Density (kg/m^3)	4500
Thermal conductivity (W/(m × K))	15
Thermal expansion (m/(m × K))	9.2 (300 °C)
Rockwell Hardened (HRC)	33

Table 2 Experimental parameters

Experimental conditions	Parameters
Workpiece	Titan alloy
Workpiece diameter (mm)	32
Abrasive slurry	Al_2O_3
Abrasive concentration (wt%)	25
Abrasive sizes	1000#; 2000#; 4000#
Rotational speed of the workpiece (rpm)	40, 50, 60, 70, 80, 90
Electric current (A)	0.6, 0.8, 1.0, 1.2, 1.4
MR fluid	MRF-132DG
Processing time per trial (min)	30

4 Results and Discussion

4.1 *Effect of Polishing Speed*

The relative movement between the workpiece and MRP fluid is an important factor that affects the surface roughness of the workpieces. The experimental studies were carried out on polishing the titan alloy ball with different polishing speed. The Al_2O_3 abrasive with the size of 4000# and abrasive concentration of 25%, which suspended in MR fluid was chosen in this experimental process. The electric current of 1.2 A was chosen in this section. The rotational speeds of the workpiece were set as 40, 50, 60, 70, 80 and 90 rpm, respectively. The relationship between polishing speed and surface roughness of workpiece is shown in Fig. 3.

As shown in Fig. 3, the surface roughness of workpiece tends to decrease with increasing the polishing speed. The surface roughness decreases rapidly during the first one hours. However, the surface roughness changes slightly during the last two hours of polishing. The best surface roughness with Ra of 18 nm can be obtained under the polishing speed of 70 rpm. When the polishing speed was more than 70 rpm, the surface roughness not only deteriorates but also increases. As a result, the polishing efficiency will not be satisfactory.

In the polishing process, the shear rate is upgraded by the increasing of polishing speed. This will lead to an increase in the contact force between the abrasive slurry and the workpiece. As a result, the cutting ability of the abrasives will be increased. The surface roughness is, therefore, significantly improved.

4.2 *Effect of Abrasive Sizes*

The abrasive sizes are an important specification of the MRP fluid. It determines the surface quality of the workpiece and the performance of the machining process.

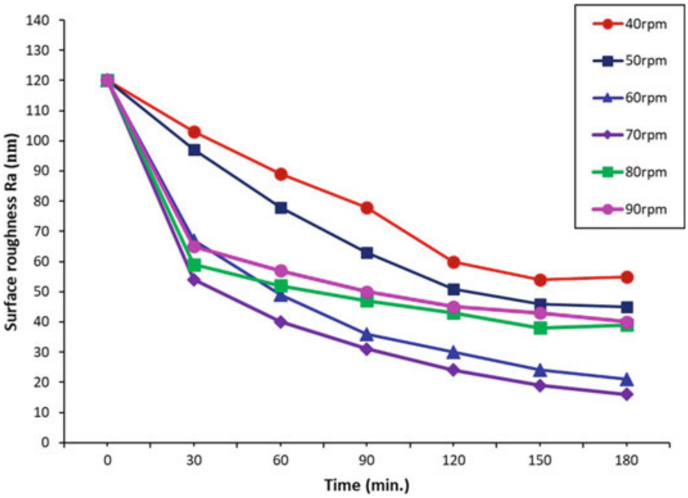

Fig. 3 Relationship between the polishing speed and the surface roughness

In this experimental process, the 1000#, 2000# and 4000# Al_2O_3 abrasives were applied for the experiment with the rotational speed of the workpiece of 70 rpm, the abrasive concentration of 25% and electric current of 1.2 A. The relationship between abrasive sizes and surface roughness of workpiece is shown in Fig. 4.

Base on the experimental results, the curves of surface roughness were almost the same when the workpiece was polished with different abrasive sizes. After three hours of polishing, the surface roughness of workpiece has little change under the

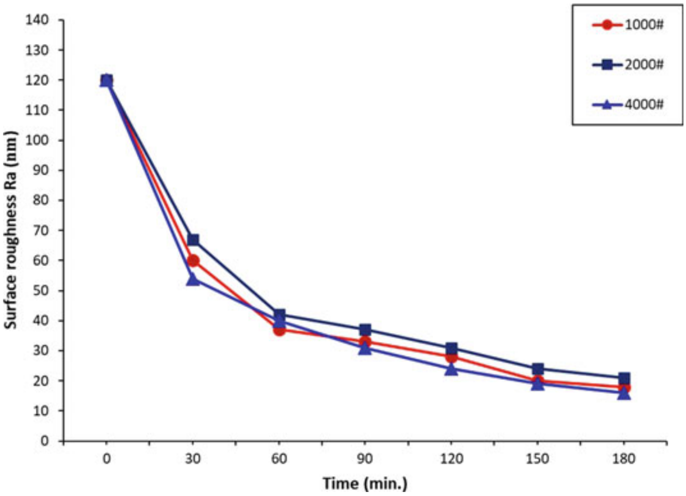

Fig. 4 Relationship between the abrasive sizes and the surface roughness

condition of machining parameters. The surface roughness Ra of 20 nm, 23 nm and 18 nm can be achieved when the abrasive size was 1000#, 2000# and 4000#, respectively.

Basically, the polishing force is the same with different abrasive sizes. The abrasive slurry is applied in the polishing process, so this process is considered as soft. Hence, there is very little difference of micro-scratches on the workpiece surface, which are produced under different abrasive sizes. It means that the abrasive size does not significantly affect the surface roughness of the workpiece.

4.3 *Effect of Electric Current*

The viscosity of MR fluid will be changed under applied electric current through the coil of the electromagnet. As a result, the viscosity of MR fluid is increased and combined with the abrasive particles to arrange into a flexible polishing tool. The rotational speed of the workpiece of 70 rpm, the abrasive size of 4000#, and the abrasive concentration of 25% were applied during the experiments. The electric current of the coil was set as 0.6 A, 0.8 A, 1.0 A, 1.2 A, and 1.4 A, respectively. The relationship between electric current and surface roughness of workpiece is shown in Fig. 5.

From Fig. 5, the surface roughness of workpiece was decreased when the electric current was increased. When the value of electric current is small, the viscosity of the MR fluid is insufficient to create the shear stress for the machining process. As a result, the surface roughness does not reach the desired surface quality. When the value of the electric current is increased, the MR fluid viscosity will be improved.

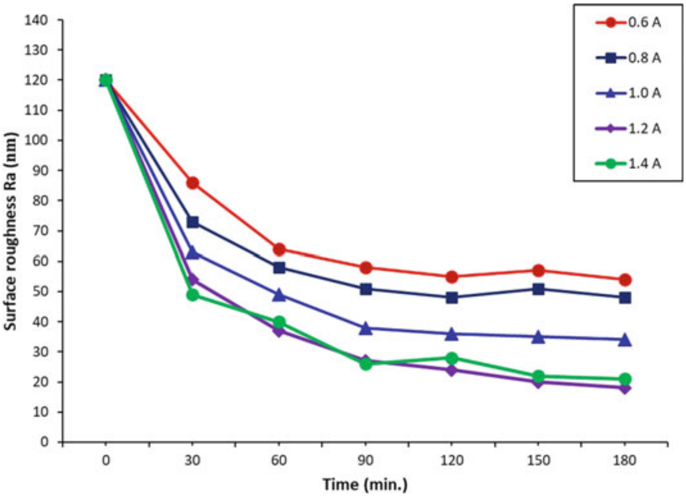

Fig. 5 Relationship between the electric current and the surface roughness

Therefore, the larger cutting force is generated to overcome viscosity resistance when the workpiece is moved in the polishing fluid. The best surface roughness with Ra of 18 nm that can be achieved when the electric current exceeds 1.2 A.

According to the results above, polishing speed and electric current were very important factors in MRP process. In addition, the abrasive size does not seem to affect on the surface roughness of workpiece. The surface topography of workpiece and the pictures of workpiece's surface before and after MR polishing were given in Figs. 6 and 7, respectively.

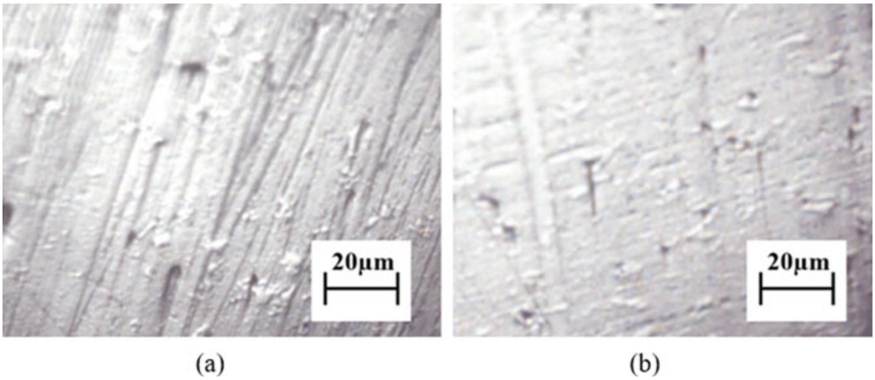

Fig. 6 Surface topography of workpiece: **a** before processing, **b** after processing

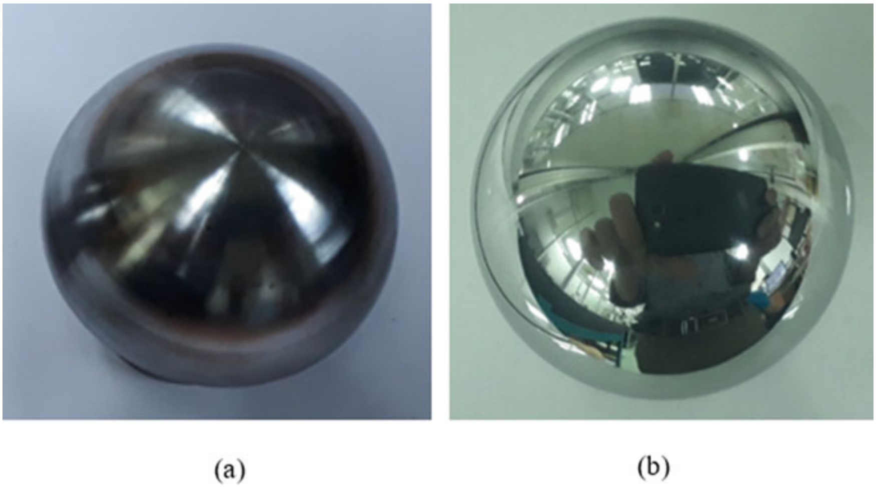

Fig. 7 Picture of workpiece surface: **a** before processing, **b** after processing

5 Conclusions

Experimental studies were carried out to determine the influence of polishing speeds, abrasive sizes and electric current on the surface roughness of workpieces. The conclusions were summarized as follows:

- The polishing speed is an important parameter that greatly influences the surface roughness of the workpiece. The best surface roughness can be achieved under the polishing speed of 70 rpm. When the polishing speed exceeds 70 rpm, the surface quality of workpiece is reduced. As a result, the polishing efficiency will not be satisfactory.
- The abrasive size has very little effect on surface quality improvement when it was changed in the experimental process.
- The electric current also has a strong effect on the surface roughness of workpiece. The best surface roughness Ra can be achieved of 18 nm with the abrasive size of 4000# Al_2O_3 and electric current over 1.2 A.

This proves that the MRP technique is the appropriate method for polishing the curved surfaces.

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Conflicts of Interest The authors have no conflict of interest to declare.

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