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The Effects of Cut Thickening Polishing Parameters on the Curved Surface Roughness of an Acrylic Workpiece

Nguyen Ngoc Quan[1*], Nguyen Tien Thai[1], Nguyen Minh Hieu[1], Pham Van Thang[1], Dang Duc Tuyen[1]
[1]Department of Mechatronics, Hanoi University of Industry, 298 Cau Dien, Bac Tu Liem District, Ha Noi, Vietnam
*Email: ngocquan1982002@gmail.com

Abstract— *To investigate the effect of cut thickening polishing (CTP) parameters on the surface roughness of the curved arcrylic workpiece, which is used in partial pulp mechanism of wind-power generator, a series of related cut thickening polishing experiments using different abrasive concentrations, particle sizes and polishing velocities were carried out. The surface roughness and topography of the processed workpiece were investigated by microscopy and roughness tester. It is concluded that the polishing velocity followed by abrasive concentration and particle size has the greatest influence on finial surface roughness. The surface roughness Ra decreases from 580 nm to 18 nm in 20 minutes polishing.*

Keywords— *Thickening polishing process; Arcrylic curved surface; Abrasive concentration; Particle size; Polishing velocity.*

I. INTRODUCTION

Curved surface [1, 2] plays a key role in a wide range of applications, such as aerospace, astronomy, mould, and automobile. In order to obtain a better performance of imaging optical systems and to reduce the size and weight of lenses, aspheric optical components are used in mirror and lens assemblies. These applications brought an increasing demand for curved surfaces in recent years. What's more, the shapes of curved surfaces are becoming more complicated, when higher surface quality and forming accuracy are required.

Polishing as the one of the most important procedures of ultra-precision machining [3, 4] for curved surface, its main function is to remove the damaged surface layer which occurred in the early stage of the processing, correct shape error, reduce the surface roughness of workpiece. A variety of polishing processes using a special fluid whose viscosity can be adjusted by an external field have been developed, such as magnetorheological finishing [5-7], electrorheological fluid-assisted polishing [7, 8], electrophoretic polishing [9, 10], magnetic fluid float polishing [11, 12], magnetic abrasive polishing [13, 14]. Polishing method based on the shear thickening effect of non Newtonian fluid is a new technology which was proposed [15, 16]. Sufficient works have already been done to research the performance of shear-thickening polishing (STP). Lyu Binghai et al [17]. Theoretically described the principle of cut thickening polishing, and its feasibility was verified by the experiments. Li 687 Proceedings of the 20th International Symposium on Advances in Abrasive Technology 3-6 December, Okinawa, Japan Min et al [18]. Established material removal model and governing equations of fluid flow in cut thickening polishing process. The cut thickening polishing (CTP) has solved many problems of traditional processing technology for curved surface, such as complex processing equipment, high cost, poor consistency processing, difficult to meet processing requirements of high efficiency and high quality for various curved surface especially complex shaped surface.

In the present study, a series of related experiments were carried out to investigate the effect of abrasive concentration, particle size and polishing velocity on spherical surface of arcrylic workpiece. Finally, the surface roughness decreased rapidly from 580 nm to 18 nm in 30 min polishing.

II. PRINCIPLE OF CUT THICKENING POLISHING PROCESS

Thickening polishing process method utilizes cut thickening fluid as the base fluid of the polishing slurry, in which the fine abrasives are dispersed. A non Newtonian cut thickening polishing (CTP) with shear thickening effect [10,11] is prepared by adding particles or powders in a non Newtonian power law fluid. The principle of cut thickening polishing process is shown in figure 1.

In the process of polishing, cut thickening phenomenon occurs when the cut thickening polishing moved relatively between the polishing liquid and the workpiece. At the same time, the solid colloidal particle dispersed in the slurry will aggregate to particle clusters, in which abrasive grit will be surrounded by solid colloidal particle. The cut elastic layer which caused by increasing viscosity enhances the holding effect of solid particles on the abrasive grains. a flexible "fixed abrasive tool" is formed in the contacting area and abrasives or micro powders produce micro cutting on the surface of workpiece. As a result, the material removal rate and polishing effect are achieved. On the other hand, the flow properties of the non-Newtonian fluid guarantee that the "fixed abrasive tool" [12] can fit well with different curved surfaces. It means that complex curved surfaces can be polished conveniently in cut thickening polishing process. The cut thickening phenomenon is reversible as the cuting force is removed, and the slurry will revert to the original flow properties.

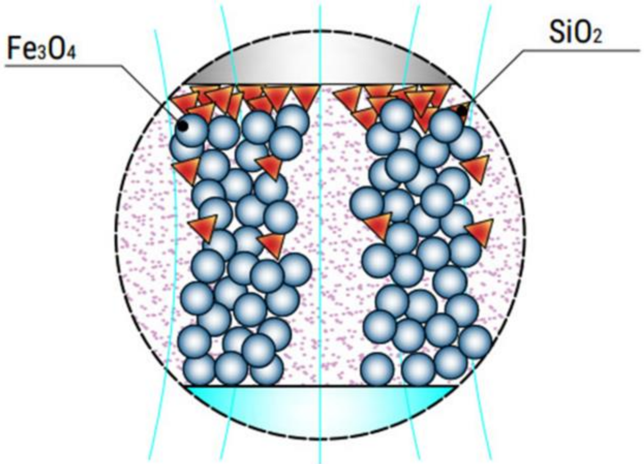

Fig. 1. Material removal mechanism of cut-thickening polishing process

III. EXPERIMENTS

3.1 Experimental setup and conditions

An experimental device, developed for cut thickening polishing process in cut-thickening conditions, is shown in Fig. 2. The whole experiment device is controlled by 688 Advances in Abrasive Technology XX industrial PC. The device can be achieved four-axis linkage, which X axis moving left and right feed, Y axis moving before and after the feed, Z axis moving up and down feed, B axis can be driven by the worm gear drive axis. The workpiece can be fixed on the axis, and all of the axes are driven by servo motors. The rotational speed of the motor can exceed 3000 rpm. Diameter of the polishing pool with cut thickening polishing slurry can be up o Ø800 mm, which is driven by a servo motor at the bottom of the device. And the otational speed of the motor can exceed 400 rpm. To sum up, the workpiece can move laterally, longitudinally, vertically, and rotate, and complex surface polishing can be achieved.

The influence of various machining parameters on the surface roughness of arcrylic workpiece include abrasive concentration, particle size and polishing velocity were investigated. A single variable method was used in the experiments, and contact roughness tester was used to measure the surface roughness. Detailed experimental parameters are shown in Table 1.

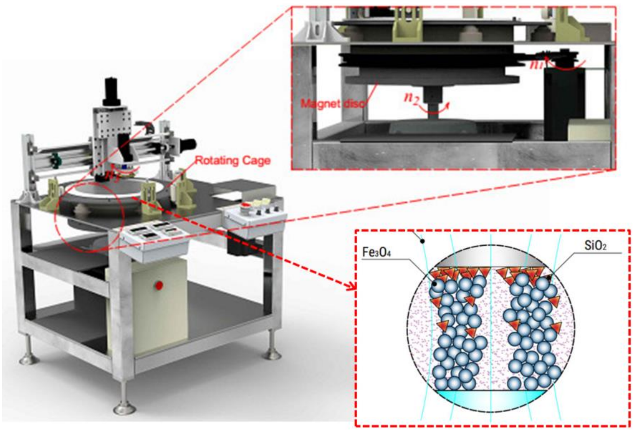

Fig. 2. Experimental device for CTP

TABLE 1. Experimental parameters

Numerical order	Experimental conditions	Parameter
1	Abrasive	Al_2O_3
2	Workpiece	Acrylic
3	Rotational speed of workpiece (rpm)	80
4	Particle size (μm)	13.5, 15.0, 17.5, 25
5	Abrasive concentration (wt%)	20, 25, 30, 35
6	Polishing velocity (m/s)	5.26, 5.47, 5.67, 5.88

3.2 Results and discussion

3.2.1 Effect of abrasive concentration

Cut-thickening effect is a very important factor in CTP, which depends on the abrasive concentrations of the CTPS. Thus, the effect of CTPS with different abrasive concentration plays an important part in the CTP effect. Four groups abrasive concentration of the CTPS had been experimented in the processing of arcrylic workpiece when the particle size was 15μm and the polishing velocity was 5.47 m/s.

Fig. 3 shows the curve of the surface roughness under different abrasive concentrations. It was clear that the surface roughness of acrylic workpiece decreases and the surface quality becomes better with the increase of the abrasive concentration. This result is similar to the traditional polishing, the increase in abrasive concentration, which means that the increase in abrasive grains involved in surface processing, can more effectively improve the polishing efficiency. However abrasives will be agglomerated when the abrasive concentration is too high which will damage the surface of the workpiece.

3.2.2 Effect of particle size

Four groups of different particle sizes had been experimented, and the processing time per trial was 5 minutes when abrasive concentration was 25wt%, and the polishing velocity was 5.47 m/s. The average particle size 13.5, 15.0, 17.5, 25 microns on the surface roughness of arcrylic workpiece was investigated. Fig. 4 show that the law is different from traditional polishing. The experimental results obtained in different abrasive grain sizes conditions, the roughness changes are basically the same. In other words, the grinding particle size changes have little effect on surface roughness.

This is because the removal of the material is mainly due to the micro-cutting effect of the abrasive grains in the CTP. At the same abrasive concentration, the number of abrasive grains increase as the abrasive grain size decreases. On the other hand, in the traditional mechanical grinding and polishing process, the abrasive grain rigid contact with the tool. The greater the particle size of the abrasive, the less the number of particles involved in the removal of abrasive particles, the deeper the depth of the abrasive cut into the workpiece. As a result the surface roughness of the workpiece is higher than that of the workpiece with a small particle size. In the process of CTP, the abrasive grains are flexibly constrained by the dispersed particles in the polishing solution. The depth of the abrasive grains depends on the flow of the polishing fluid Variable characteristics instead of the particle size of the abrasive grains. With the same processing conditions, the rheological properties of the abrasive grains with different particle sizes (13.5-25 μm)

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are similar, so that the abrasive grains without particle size exhibit similar cutting ability.

3.2.3. Effect of polishing velocity

Polishing velocity is a significant index of effective and efficient CTP. Four groups of different polishing velocities had been experimented, and the processing time per trial was 5 minutes when abrasive concentration was 25wt%, and the particle size was 15µm.

The polishing speed has a great influence on the surface roughness of the workpiece. The low surface roughness can be achieved quickly, which is mainly because with the increase of polishing speed, cut thickening effect is enhanced. The effect of the polishing solution on the wear of the abrasive grains is improved, thereby significantly improving the ability of the abrasive grains to remove the material. It is possible to more effectively remove the small bumps on the surface so as to obtain a better surface roughness during the same polishing time. At higher polishing speeds, the workpiece surface roughness drops from 570 nm to 21.1nm.

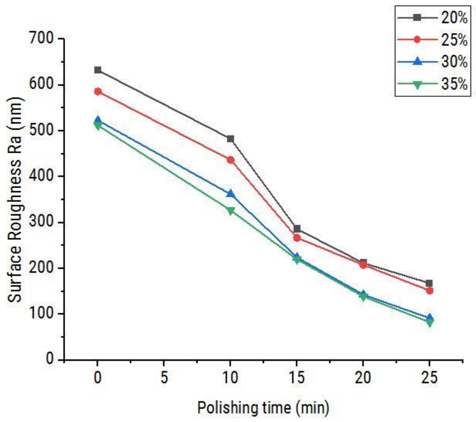

Fig. 3. Abrasive concentration

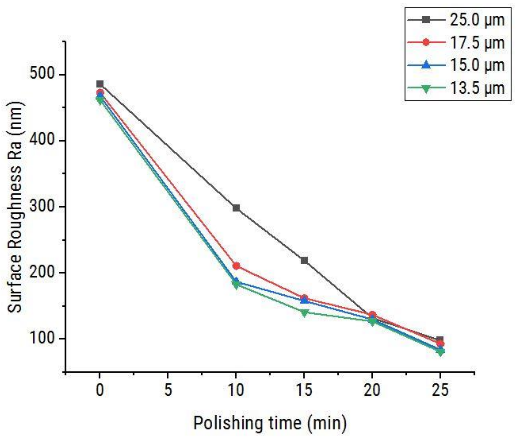

Fig. 4. Particle size

3.2.4 Polishing results under optimized experimental condition

In conclusion, the higher polishing velocity and abrasive concentration are good for the higher polishing efficiency and lower surface roughness. The higher polishing velocity means stronger cut thickening effect of polishing slurry. The increase in abrasive concentration means that the more abrasive particles act on the surface of the workpiece.

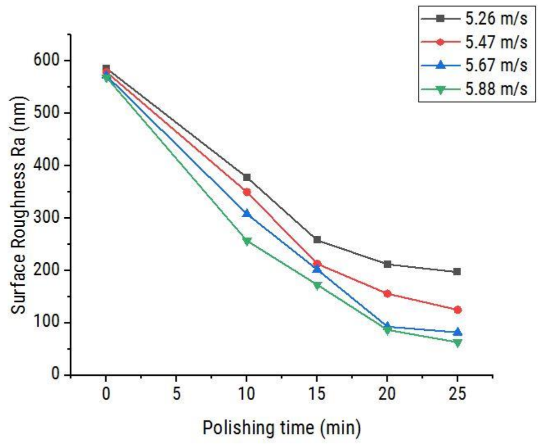

Fig. 5. Polishing velocity

Finally appropriate parameters for processing are selected as the polishing velocity was 5.88 m/s, the abrasive concentration was 20wt% and the particle size was 15.0 µm. Under this condition, the cut thickening effect of the polishing solution and the grinding grain of the abrasive grains is better so that workpiece can be polished more efficiently. The surface roughness of arcrylic workpiece decreased from 580 nm to 68 nm in 20 min polishing. Fig. 6 shows an image of 2-Dimensional texture of the workpiece surface.

(a) Original surface (b) Surface of processed 20 minutes

Fig. 6. SEM surface of the workpiece surface

IV. CONCLUSIONS

A new polishing method, Cut Thickening Polishing (CTP), was proposed in this study to obtain extreme smooth curved surface. Experiments were carried out to reveal the influence of abrasive concentration, particle size and polishing velocity on the surface roughness. The main results are summarized as follows:

- The abrasive concentration is a significant factor influencing polishing effect. The higher the abrasive concentration is, the better the results are.
- The effect of different particle size on surface roughness is not obvious.
- The polishing velocity has the greatest influence on the surface roughness. With the polishing velocity of 5.88 m/s, the smoothest surface with best roughness can be obtained quickly.
- A fine workpiece surface with nearly no scratches was obtained, and surface roughness was reduced rapidly from Ra = 580 nm to Ra = 18 nm after 20 min processing, under

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the optimized CTP conditions. Better results of the CTP were achieved.

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