A Study on The Inner Wall Spiral Polishing with Magnetic Force

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Abstract - The spiral polishing mechanism in the present experiment employed a turning screw rod to drive the SiC and the steel grits. With a powerful magnet set around the workpiece interacting with the steel grits, the SiC abrasives were driven and then achieve the surface's polishing effects. The best parameters combination was discussed with the control of magnetic flux density, size and weight of SiC particles, weight of steel abrasives, viscosity of silicon oil, turning speed of spindle, as well as machining time and their influences on the surface roughness. The effects of each machining parameter on the appearance of workpiece surface were also studied.

Based on the results of the experiment, with the increase of machining time, the fluidity of the abrasives becomes better, and thus higher quality of polishing surface could be expected after the process of precision spiral polishing. The results also showed that the best polishing surface was found when the magnet of magnetic flux density was controlled at 90mT, particle size at 12μm, 110g of SiC grams, 60 grams of polystyrene balls, silcon oil at 1000 mm^2/s viscosity, and the screw revolution speed at 3500 rpm. The surface roughness was successfully improved from 0.9μm to 0.134μm.

Keywords - Abrasive flow machining, magnetic force, spiral polishing, inner wall polishing

I. INTRODUCTION

With the development of technology, the demands on the surface quality show the importance of micro-energy machining technology when "light, thin, short, and small" products attract more attention and the design of the product surface gets more complicated. In the past, limited by the hardness of the tools, especially varied geometrical shapes and shapes that could almost impossible to be dealt with in a traditional polishing, the micro-machining on bores or grooves was rather valued. However, the higher costs caused by the higher demands on the quality of the surface roughness at the same time accelerated the development of substitute energy, such as electric, chemical, mechanical, and thermal energy, to reduce the limitation of tools, like EDM, ECM, USM, AJM, LBM, and AFM, etc. In order to reach the goal, automation is a solution to saving labor costs and sustaining the stability of machining quality.

From the literature reviewed, Walia et al. [1], by employing a turning rod to generate centrifugal force on abrasives, they discussed the effects of profile shapes, turning speed of the spindle, squeezing pressure, size of the grains, and slurry concentration on changes of surface roughness, and material removal amount. The drill-guided-abrasive approach employed by Sankar et al. [2] was to place a drill into the machining slot so as to generate an axial rotational force by making the grains move upward and downward to raise the material removal rate and to lower surface roughness. Sankaret al. [3-4] used the circulating-abrasive-flow based polishing method. They rotated the workpiece to increase material removal amount by means of the back and forth movement of the grains. Thus, the material removal rate was also raised. Jha et al. [5] created a magnetorheological fluid. By mixing carbonyl iron powder and SiC grains into viscoelastic fat and mineral oils, they got better surface quality through precisely monitored external magnetic field. Singh et al. [6] created a magnetic abrasive, a mixture of Hydrocarbon gel, SiC polymer and a combination of particles. Then, they created a magnetic field by encircling the specimen with electromagnet and examined the effects of magnetic flux density, cycle times and abrasive flow rate on surface roughness and material removal amount.

To obtain good surface quality, traditional or non-traditional bore precision polishing technologies commonly employed include hand-made polishing, boring, reaming, or electro polishing, each with its own machining process, processing characteristics, and its limitation and constraints. For example, traditional polishing is mostly time- and energy-consuming; electro polishing is not suitable for non-conductors for the adverse effects its electro reaction brought to the workpiece. Therefore, the present experiment applied the" Inner Wall Spiral Polishing with Magnetic Force" to effectively improve the inner wall surface quality of bores, debur and remove dusts or metamorphic layers. At the same time, the machined surface was free from residual stress, heat distortion and metamorphic layer, by which the surface roughness was improved and the purpose of surface precision polishing was achieved.

II. EXPERIMENTAL METHOD AND APPARATUS

A. Actuation Mode

The actuation mode of this experiment, as shown in Fig. 1, employed a high-speed turning screw to drive the abrasives for polishing. As the rod revolved at a high speed, the abrasives were driven upward along the groove in the rod and polished the workpiece directly with good fluidity. Meanwhile, the SiC grains in the abrasives continuously squeezed the workpiece surface to achieve the effect of polishing. Because the mold was designed in a hollow shape; as a result, when the abrasives reached the top of the bore, they were pushed aside, flowing to the bottom of the rod, and then moving upward again. The circulation of the abrasives was thus created. Besides, the steel grits in the abrasives were also attracted by the external magnetic field, which provided the Sic grains an extra force toward the workpiece surface, increasing the processing power and effectively removing the asperities. For the repeated cycles of the abrasives in this study, the precision polishing was achieved with the benefits of lower costs and consumption of the abrasives, and removing the burrs and metamorphic layer fast and efficiently.

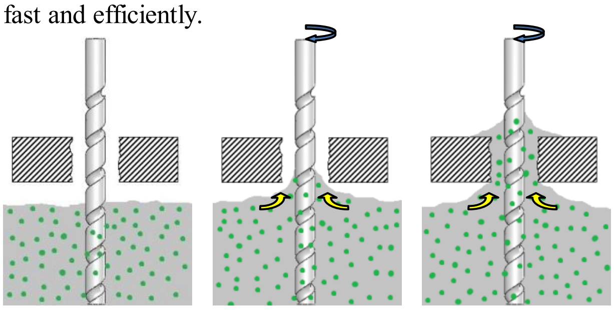


Fig. 1 Mechanism of Spiral Polishing

B. *Processing Characteristics*

The flowing modes of the abrasives included:

1) The abrasives were driven upward along the groove in the rod as the rod turned at a high speed. When the abrasives flowed across the workpiece, the SiC grains would polish the asperities on the workpiece and achieved the effect of polishing.
2) The steel grits in the abrasives were attracted by the magnet around, creating an extra processing power, squeezing the SiC grains onto the workpiece and polishing the workpiece.

C. *Experimental Apparatus*

The present experiment, according to the concept of spiral polishing with abrasives, designed a set of apparatus onto a spindle of a CNC machining tool. With the help of magnetic force, precision spiral polishing was carried out, as illustrated in Fig. 2.

To achieve the purpose of using the abrasives in repetitive cycles, the apparatus was designed as a hollow container with a spindle connected with a CNC or a conventional machining tool. When the abrasives and the workpiece were placed into the hollow container, the abrasives were driven cyclically as the spindle turned spirally and the workpiece was polished. The design not only saved the quantity of the abrasives used but ideally controlled the space the experiment would take up, increasing the convenience of conducting the experiment.

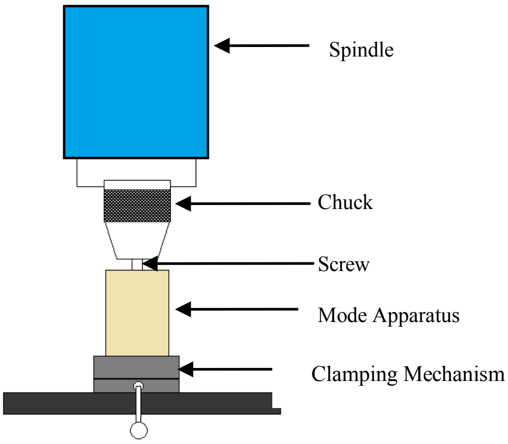


Fig. 2 Illustration of the Mold

D. *Materials*

The abrasive employed in this study was a mixture of SiC particles and silicon oil(100g), steel grits(50g), and polystyrene balls(PS) in different proportions to create good polishing effects. The SiC particle's rough surface and high hardness made it perfect for precision surface polishing. The steel grits and the polystyrene balls benefited the polishing in two aspects. One was that the steel grits would be attracted by the outward magnet and generated an extra force to press the SiC grits onto the inner wall surface for better polishing effects. The other was that the elasticity of the polystyrene balls would absorb the instant impact caused when SiC grits hit the inner wall surface. This helped reduce the impact force and provided continuous sliding and rolling polishing forces, so that the processing time was reduced.

E. *The Workpiece*

The spiral polishing with magnetic force could be employed onto different materials, from ductile materials, like Cu and Al, to those difficult to be polished, like nickel-based alloys and to non-metallic materials, like ceramics and hard plastic materials. The material used in this experiment was a stainless steel tube. Stainless steel features its corrosion resistance, good hot and cold processing, and welding, etc. It is commonly used in food, general chemistry, and atomic energy industries. The workpiece was a stainless steel tube of 13mm O.D., 9.8mm I.D. and 10mm height. Initial surface roughness (Ra) of the inner wall was 0.90 µm.

F. *Experimental parameters*

The parameters in the present experiment included magnetic flux density, size and weight of SiC grains, weight of polystyrene balls, Viscosity of silicone oil, and the speed of the spindle. The appearance and the surface roughness were also discussed (Table 1).

Table 1 The Parameters of the Spiral Polishing with Magnetic Force

Parameters	Experimental Parameter Settings
Magnetic Flux Density (mT)	80、90、120、170
Size of SiC Grains (µm)	7、12、15、22、37
Weight of SiC Grains (g)	70、80、90、100、110
Weight of Polystyrene Balls (g)	40、50、60、70
Viscosity of Silicone Oil (mm^2/s)	1000、2000、3000、5000
Speed of the Spindle (rpm)	2000、2500、3000、3500、4000

III. *RESULTS AND DISCUSSION*

A. *Impact of Magnetic Flux Density on Surface Roughness*

As could be seen in Fig. 3, when magnetic flux density was controlled at 80mT in the processing of spiral polishing with magnetic force, the steel grits were not effectively attracted and squeezed the workpiece, so the polishing effects was limited and a number of irregular s lines were found. When magnetic flux density was added to 90 mT, the deeper lines were no longer seen. However, when magnetic flux density was increased to 120 mT, the greater magnetic force caused greater power but the lines left on the workpiece were found deeper. Then, if we increased the magnetic flux density to 170 mT, greater magnetic force would result in deeper irregular lines on the workpiece from too much magnetic force.

B. Impact of SiC Grains Size on Surface Roughness

According to the results of the experiment, the best surface quality is achieved with SiC grains size of 12 μm. When polishing with smaller SiC grains, the surface roughness was hardly improved in that smaller size of grains would cause finer scratches, failing to remove the dents on the workpiece surface. In addition, when there was great difference between SiC grain size and steel grits, the SiC grains would expose less from the abrasives as the steel grits were attracted to squeeze the workpiece surface, which led to poorer surface quality (Fig. 4).

C. Impact of SiC Grains Weight on Surface Roughness

Based on the results of the experiment, Fig. 5 showed us that the increase of SiC grains weight resulted in better surface quality. This could be explained by the fact that when SiC grains weight increased, the number of the grains also increased. This created more chance for the SiC grains to polish the workpiece, and better polishing effects could be expected. The best surface quality was reached when the weigh of SiC grains was controlled at 110 grams.

D. Impact of PS Weight on Surface Roughness

See Fig. 6, with the adding of PS weight, better surface quality could be expected. The best surface quality was acquired when PS weight was controlled at 60 grams. This might be inferred that when the steel grits increased, the rate for PS to squeeze the workpiece also increased. Therefore, better polishing effects could be seen. However, if we added more PS balls at this time, it would lower the fluidity of the abrasives in the mode. The SiC grains squeezed with each other out of more pressure, more lines on the workpiece surface would be found.

E. Impact of Silicone Oil Viscosity on Surface Roughness

The results of the experiment showed that the best surface quality was found when silicone oil viscosity was controlled at 1000mm^2/s. In fact, greater viscosity of the silicone oil deteriorates the surface quality for the lower fluidity of the abrasives in the mode. Moreover, the thicker protective lubricant on the workpiece surface caused by the greater viscosity stopped the SiC grains from breaking out of the silicone oil, which led to worse polishing effects, as Fig. 7 illustrated.

F. Impact of Spindle Speed on Surface Roughness

As the present experiment showed, the best surface quality could be obtained when rod screw turned at a speed of 3500 rpm (Fig. 8). At this time, stronger centrifugal force as well as faster driving motion was generated when the spindle turned at a higher speed. This helped improve the spiral polishing effect. Under the same processing time, higher turning speed lengthened the flowing distance of the abrasives and provided more chances for abrasives to polish the workpiece. Consequently, better polishing effects was reached. On the contrary, if the spindle turned too fast, the greater pressure deteriorated the surface quality instead of improving it.

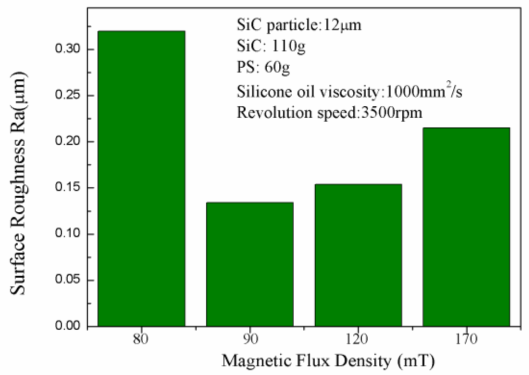


Fig. 3 Impact of Magnetic Flux Density on Surface Roughness

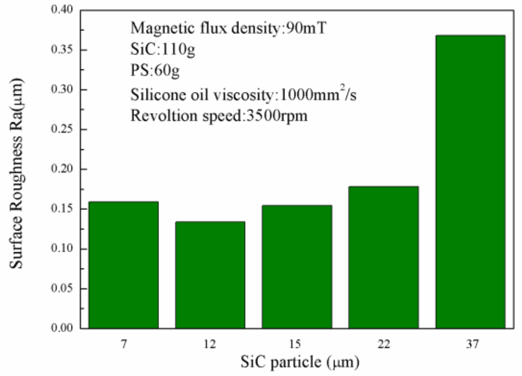


Fig. 4 Impact of SiC Grains Size on Surface Roughness

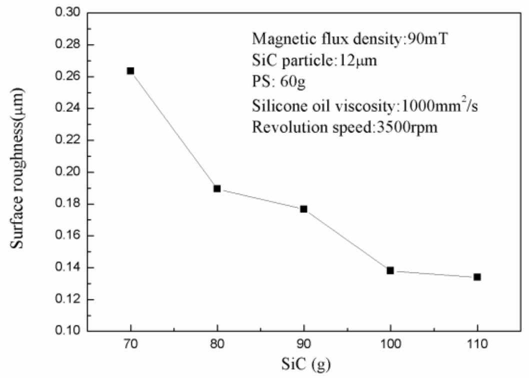


Fig. 5 Impact of SiC Grains Weight on Surface Roughness

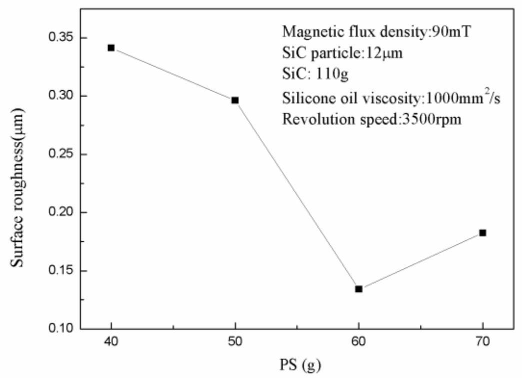


Fig. 6 Impact of PS Weight on Surface Roughness

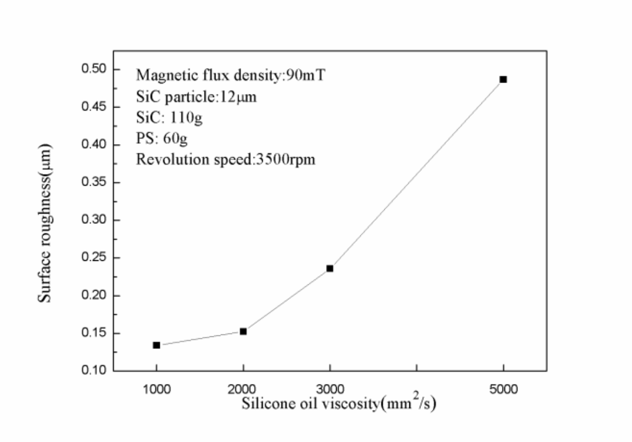


Fig. 7 Impact of Silicone Oil Viscosity on Surface Roughness

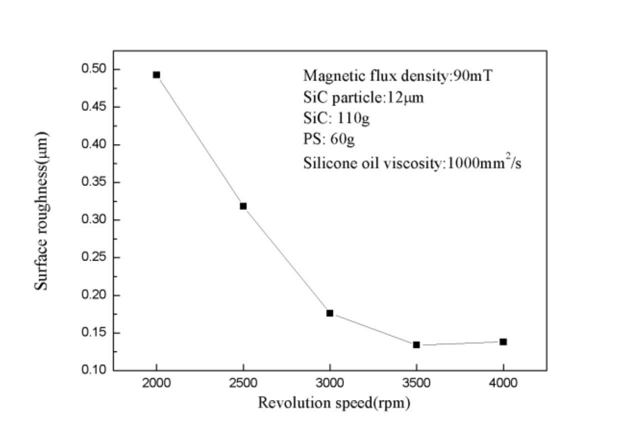
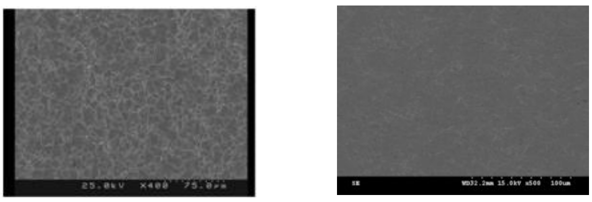


Fig. 8 Impact of Spindle Speed on Surface Roughness

G. SEM Surface Observation

The combination of the parameters on obtaining better polishing effects were particle size at 12 μm, 110 grams of SiC grains, 60 grams of polystyrene balls, silicon oil viscosity at 1000 mm^2/s, spindle turning speed at 3500 rpm, machining gap at 0.6 mm, and 30 minutes of processing time. The surface roughness was successfully improved from 0.9μm to 0.134μm, as shown in the following figure. From Figure 9, we could find that the surface was quite flat.



(a) Before Polishing (b) After Polishing

Fig. 9 The Combination of the Parameters for the Best Spiral Polishing

IV. CONCLUSION

Based on the discussion and analysis of the experiment, the following conclusion can be drawn from the present study:

1) The outward magnet around the workpiece would increase the polishing power of the abrasives. The results of the experiment showed that the surface roughness was significantly improved, with the improvement rate of 85%.

2) The experimental results also suggested that magnetic flux density was better controlled at 90 mT. Too much magnetic force would scratch the workpiece surface.

3) Spiral polishing machining lengthened the polishing route. The surface quality could be greatly improved by means of inner wall polishing machining without the problems of deformation and metamorphism. It not only produced high-quality products, but also lower the costs. This rapid and automated polishing machining made it worthwhile to be developed in the near future.

REFERENCES

[1] R. S. Walia, H. S. Shan, P. Kμmar, “Abrasive flow machining with additional centrifugal force applied to the media.”, Machining Science and Technology, Vol 10, pp.341-354, July-September 2006.

[2] Mamilla Ravi Sankar, S. Mondal, J.Ramkμmar, V. K. Jain, “Experimental investigations and modeling of drill bit-guided abrasive flow finishing (DBG-AFF) process”, International Journal of Advanced Manufacturing Technology, Vol 42, pp.678-688, July 2008.

[3] M. Ravi Sankar, V.K. Jain , J. Ramkμmar, “Rotational abrasive flow finishing (R-AFF) process and its effects on finished surface topography”, International Journal of Machine Tools and Manufacture, Vol 50, pp.637-650, July 2010

[4] Mamilla Ravi Sankar, V.K. Jain, J. Ramkμmar, “Experimental investigations into rotating workpiece abrasive flow finishing”, Wear, Vol 267, pp.43-51, June 2009.

[5] Sunil Jha and V. K. Jain**, “**Design and development of the magnetorheological abrasive flow finishing (MRAFF) process”, International Journal of Machine Tools and Manufacture, Vol 44, pp.1019-1029, August 2004.

[6] Sehijpal Singh, H.S. Shan, “Development of magneto abrasive flow machining process”, International Journal of Machine Tools & Manufacture, Vol 42, pp.953-959, June 2002.