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An investigation of material removal characteristics in multi-jet polishing of cylindrical surfaces

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Abstract

Precision cylindrical surfaces including internal and external surfaces have been widely used in moulding dies, precision slides and bearings, etc. The final polishing process can directly determine the surface quality of the cylindrical surfaces which are critical for their functionality. This paper presents the development of a novel linear array multi-jet polishing (LAMJP) tool and a process for polishing of precision cylindrical surfaces. A nozzle with a line array of orifices is purposely designed while its material removal characteristics have been analysed experimentally. The results show that the LAMJP process not only possesses high polishing efficiency, but also is effective in improving surface roughness of the precision cylindrical surfaces.

Keywords: Multi-jet polishing, material removal characteristics, cylindrical surface, fluid jet polishing

1. Introduction

Precision cylindrical surfaces including internal and external surfaces have been widely used in moulding dies, precision slides and bearings, etc [1-3]. The surface integrity of them is critical for their functionality, which is mainly determined by the final polishing process.

In recent years, fluid jet polishing (FJP) has been widely used in precision polishing of freeform optical glass and moulds, ceramics, etc. FJP possesses unique advantages, such as high machining accuracy, suitability for polishing of various complex surfaces, minimal tool wear and no increase of the temperature of the workpiece [4-6]. Beaucamp, et al. [3] combined FJP and bonnet polishing to implement super-smooth finishing of diamond turned hard X-ray moulding dies. However, the main drawback of this process is its low material removal rate. Some researchers [7, 8] conducted their studies to solve this problem. The authors proposed a novel multi-jet polishing process [9] largely enhance polishing efficiency and improve surface finishing in machining different types of surfaces such as internal surfaces [10], microstructure surfaces [11], etc.

In this paper, a line array multi-jet polishing (LAMJP) process and a purposely designed MJP nozzle have been developed while the material removal characteristics of the LAMJP have been investigated for precision polishing of cylindrical surfaces.

2. Line array multi-jet polishing (LAMJP) of cylindrical surfaces

Fig. 1(a) shows the schematic diagram of the LAMJP method which attempts to polish external cylindrical surfaces. During the polishing process, the cylindrical surface is mounted on the chuck rotating in a certain rotational speed, and the LAMJP nozzle is moved along the generatrix of the cylindrical surfaces. A rod-shaped LAMJP nozzle with a linear array of orifices at the side face is designed as shown in Fig. 1(b). The pressurized premixed slurry is pumped out from the slurry tank through the nozzle to the cylindrical surface of the workpiece. An array of slurry jets is ejected out of the nozzle, and impinge multiple regions on the target surface simultaneously. Its polishing efficiency is increased as compared with single jet polishing (SJP) process as determined by the number of orifices incorporated.

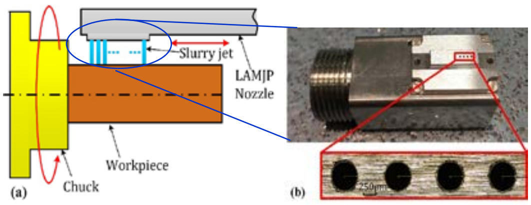

Figure 1. Schematic diagram of (a) the line array multi-jet polishing (LAMJP) on cylindrical surfaces, and (b) snapshot of the LAMJP nozzle

3. Experimental investigation work

3.1. Experimental setup

As shown in Fig. 2, the experiments were conducted on an IRP200 7-axis ultra-precision polishing machine from ZEEKO Ltd, UK. The LAMJP nozzle was mounted at the tool spindle through a connection component.

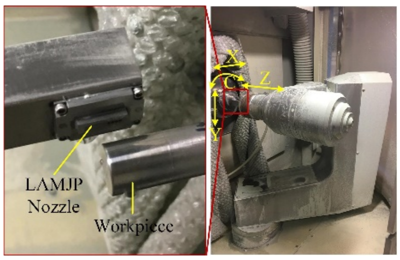

Figure 2. Snapshots of the experimental setup

Hence, the workpiece was mounted on the chuck of the work spindle which was controlled to move in X/Y/Z directions relative to the LAMJP nozzle. The workpiece was rotated through the control of the C axis. The workpiece was an external cylindrical surface made of 304 stainless steel. A LAMJP nozzle with four linear distributed orifices was purposely designed in this study.

The diameter of the orifice is 0.5 mm, and the interval between each orifice is 1 mm.

3.2. Material removal characterization

To further investigate the material removal characteristics on cylindrical surface of LAMJP, experiments were conducted to study the tool influence function (TIF) under different polishing conditions as shown in Table 1.

Table 1 Polishing conditions for tool influence function test

Conditions	Group 1	Group 2
Fluid pressure (bar)	5,6,7,8	6
Tool offset (mm)	5	2.5,5.0,7.5,10
Dwell time (min)	2	2

1000 silicon carbide polishing slurry was used in this experiment. The material of the workpiece is 304 stainless steel. Fig. 3 shows the sectional profile of the TIFs generated under various polishing conditions. The volume removal rate and peak-to-valley height value of the TIFs were determined to evaluate the material removal rate (MRR) under various polishing conditions (see Fig. 4). The results indicate that the fluid pressure has a larger influence on the MRR than that of the tool offset. A larger fluid pressure leads to a higher MRR.

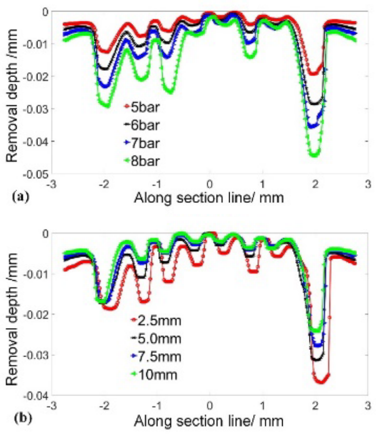

Figure 3. Sectional profiles of TIFs under different conditions. (a) Different fluid pressure and (b) different tool offset

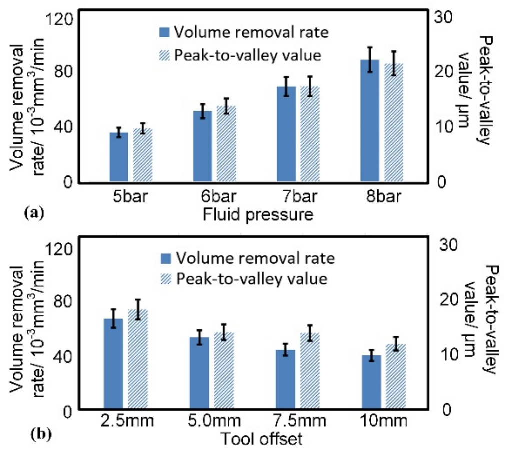

Figure 4. Material removal rate comparison. (a) Different fluid pressure, and (b) different tool offset.

3.3. Polishing experiments on external cylindrical surfaces

Polishing experiments were conducted on external cylindrical surfaces with a diameter of 12.5 mm. Table 2 shows the polishing conditions. Fig. 5 shows the snapshots of the surface generated before and after polishing. The surface finish was greatly improved to mirror finished surface after polishing. Their surface roughness were also measured by the Zygo Nexview white light interferometer. As shown in Fig. 6, the arithmetic roughness of the cylindrical surface was reduced from 116 nm to 22 nm after polishing, which demonstrates the effectiveness of the LAMJP.

Table 2 Polishing conditions in polishing of cylindrical surfaces

Conditions	Value
Fluid pressure (bar)	6
Tool offset (mm)	5
C-axis speed (rpm)	10
Z-axis speed (mm/min)	1
Polishing length along Z direction (mm)	15

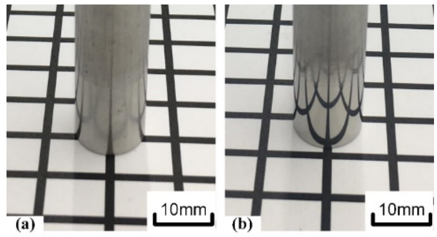

Figure 5. Snapshots of cylindrical surface: (a) Before polishing and (b) after polishing.

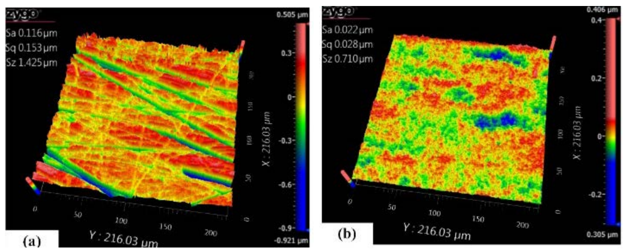

Figure 6. Measured surface roughness. (a) Before polishing and (b) after polishing.

4. Summary

In this paper, a novel linear array multi-jet polishing (LAMJP) method has been developed for precision polishing of cylindrical surfaces. The results of the experimental investigation of the material removal characteristics of the LAMJP indicate that the fluid pressure has a larger impact than the tool offset on the material removal rate. A higher fluid pressure leads to a higher MRR. Moreover, the results of the polishing experiment on external cylindrical surface show that the LAMJP possesses a high polishing efficiency and is effective in improving surface roughness of the cylindrical surfaces.

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