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ABSTRACT

To investigate the material removal characteristic of paste polishing, experimental investigations based on Taguchi method have been carried out. In the experiments, the dwell time was fixed 300 seconds and the bonnet position was 4. The four variable factors (precess angles, head speed, head pressure and tool offset) with 3 levels were chosen to design the orthogonal array. With the designed orthogonal array, two groups of experiments have been implemented to verify the repeatability of paste polishing. The experimental results indicated that the sizes and shapes of polishing spot varied with polishing parameters, the most influential parameter was precess angle and its contribution was 37.39%. However, the results of material removal rates did not coincide with the principle of Preston equation. This meant that the paste polishing was not a deterministic polishing and cannot be used to correct the form polishing.

Key words material removal characteristic, CoCr alloy, paste polishing

1 INTRODUCTION

Material removal mechanism of polishing is a considerable complicated process. The influence on the material removal characteristics which was termed as influence function may be the parameters of polishing machine such as tool pressure and tool speed, or material of workpiece or shape and size of polishing abrasives. Traditionally, the material removal rate (MRR) was described by Preston equation as the following [1]:

$$\frac{dz}{dt} = K_p P V_r \quad (1)$$

Where P is polishing pressure, V_r is the relative velocity, t is polishing time, and K_p is the Preston coefficient. K_p is the summation of grain size, concentration of abrasives, materials of polishing tool and workpiece. Therefore, the Preston coefficient K_p has to be determined by experiment for each polishing system.

Much research has been carried out to investigate the material removal mechanism of polishing. A large amount of models of material removal based on the Preston equation have been created to investigate the material removal rate. L Zhang et al investigated the material removal of fixed abrasives polishing and developed a method to calculate the material removal based on the wear index [2]. According to the model, it was found that the shape of material removal profile was parabolic and the material removal was related to the following factors: the normal polishing force, the geometry of polishing tool and workpiece, the spindle speed and feedrate of the polishing tool, the material of workpiece and polishing tool. Markus Schinhaerl et al predicted the distribution of material removal rate within the influence function which was calculated in reference [3, 4]. The prediction model was based on Preston's equation and used to predict Magneto-rheological finishing (MRF) influence functions. This model was suitable for planar and convex workpiece and was able to utilize the influence function with very high removal rates. Reference [5] proposed a model which described the relationship between the material removal rate and primary polishing parameters. Experimental results showed that the material removal rate mainly depended on the pressure applied.

The purpose of this research is to investigate the material removal characteristic of paste polishing and to find the contribution of each parameter. The experiments design were based on Taguchi method. The samples used in the experiments was cylindrical CoCr alloy and the diameter of planar surface was 26mm.

2 POLISHING SYSTEM

This experimental research was carried out on the Zeeko IRP200 polishing machine (Figure 1). This machine has 7-axis: X, Y, Z are linear axes and A, B, C, H are rotational axes. IRP 200 has the ability to polish flat,spherical, aspheric and free-form surface [6-8]. The machine axes can be used for traditional spiral polishing or raster polishing within a total envelope size of 300×260×130mm. This machine uses a spinning, bulged and compliant tool covered with a suitable polishing cloth as the lap medium in combination with water based polishing slurries. The inflated bonnet can be modulated to vary the polished spot size. The mechanical movement is controlled by CNC machine tool principles, moving the polishing tool relative to workpiece surface in three linear axes (X, Y and Z) and three rotational axes (A,B and C). With the control software, excellent surface texture with almost no directional properties can be obtained. In this polishing system, the following parameters will be used.

(1) Precess angle: This parameter described the angle of the centre line of bonnet and the perpendicular line of the workpiece. The unit of precess angle was degrees.
(2) Head speed: This parameter related to the speed of the rotation of polishing tool (bonnet). The unit was measured in revolutions per minute (rpm).
(3) Head pressure: This is the pressure of bonnet which inflates the bonnet into a spherical shape. The pressure was measured in bar.
(4) Tool offset: This parameter related to the deformation deep of bonnet when the bonnet touched the workpiece. The unit of tool offset was millimetres.
(5) Point spacing and track spacing: The parameters of point spacing and track spacing can also be described as X spacing and Y spacing. The point spacing was related to the spacing of polishing points along the X-direction while the track spacing depicted the spacing of polishing points along the Y-direction. Both of these parameters were measured in millimetres.
(6) Surface feed: This parameter depicted the feedrate of the polishing tool. The unit of surface feed was millimetres per minute.

3 Experimental methods

The CoCr samples (Figure 2) were first turned and then polished by manual until the basic topographies were obtained. Because of polishing uncertainty by manual, pre-polishing should be implemented. After pre-polishing, the three areas of these samples were measured by CCI (Figure 3). Some of the samples were polished again in order to control all of their roughness level below 40nm (Sa). Both pre-polishing and influence function polishing were carried out by Zeeko IRP200 machine tool. The polishing medium used in polishing was Silicon Carbide paste whose size is 17 μm and the polishing cloth is 37 hardness of Zirconium Oxide. The design of the experiments was based on Taguchi method. In these experiments, the dwell time was fixed as 300 seconds and bonnet position was 4. The four variable factors and 3 levels of each factor chosen were shown in table 2. With the table 2 mentioned factors, at least 9 trials must be carried out to optimise the polishing processes. The designed orthogonal array was shown in table 3.

4 Conclusions and discussion

With the table 3 experimental designs, two groups of trials were carried out to find the maximal and minimal material removal rate and to verify the repeatability of paste polishing. The 3D maps of polishing spots were measured by Talysurf PGI. The volumes of material removal were calculated with aid of the Zeeko accessory software Precession. Both of the polishing spots and their models were displayed in table 4(In Taguchi method, the experimental results were called response). The static volumes of material removal were shown in figure 4. Table 5 was the results of ANOVA (Analysis of Variance).

As can be seen in the table 4 and figure 4, the sizes and shapes of polishing spot varied with the different parameters. This meant that material removal rate changed with the parameters correspondingly. The contributions of different parameter were shown in table 5. In these experiments, the most influential parameter was precess angle and its contribution was 37.39%, followed by tool offset (16.73%), tool pressure (14%) and head speed (1.13%). From Preston equation, the material removal rate was proportional to tool pressure and head speed, but this principle cannot be seen from figure 4. For example, from trial 1 to trial 3 in the first group of experiments, the precess angle was fixed and the head speed increased from 800 rpm to 1600 rpm, the tool offset from 0.1mm to 0.2mm and tool pressure from 0.5 bar to 1.5 bar. According to Preston equation, from trial 1 to trial 3, the material removal rate should increase but figure 4 did not show these results. Comparing with the response 1 and response 2 in figure 4, the repeatability of the two groups of experiments were not displayed. In the first group, the maximum and minimum material removal rates were trial 2 and trial 9 but in the second group were trial 3 and trial 4 respectively. This result indicated that paste polishing were not suitable for corrective polishing which the material removal rate must be controlled precisely. The main reason for that was the paste polishing was not a deterministic process because the amount of paste decreased with time consuming. In other words, the material removal rate decreased from the beginning to the end of polishing. In addition, because the paste was coated manually, it was very hard to control the amount of paste in the same level at each polishing.

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Figure 1 Zeeko IRP200

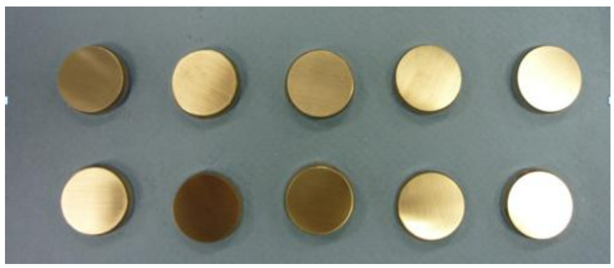


Figure 2 CoCr Samples

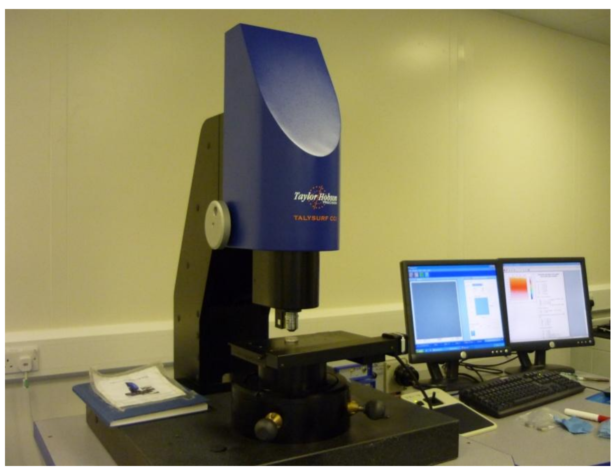


Figure 3 CCI

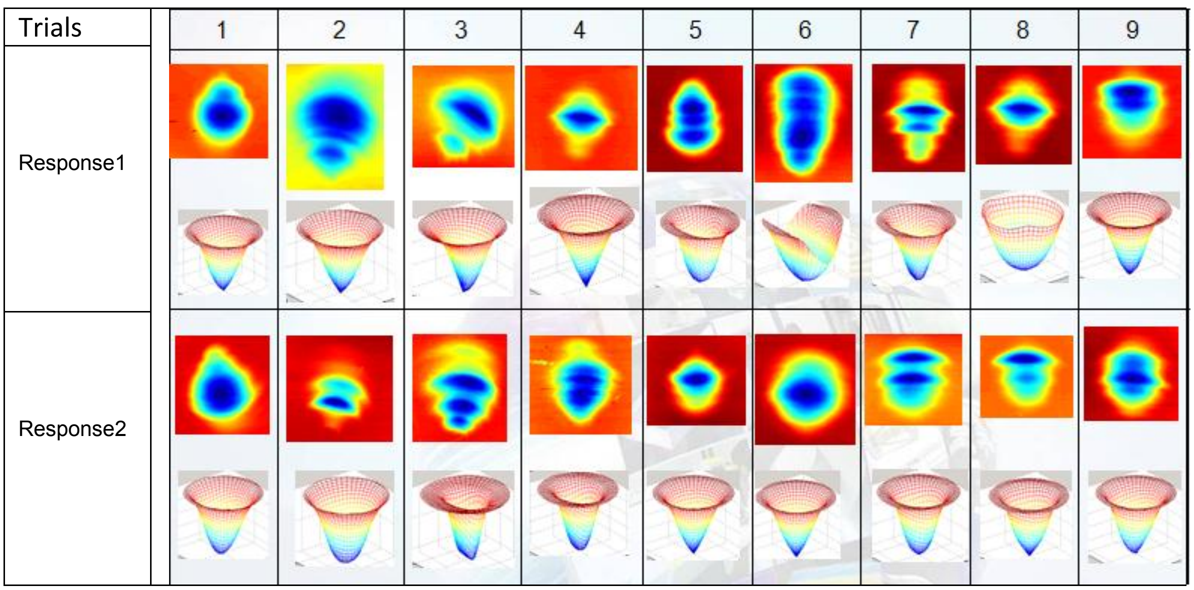
Table 2 Four factors with 3 levels

Parameters \ level	1	2	3
Precess angle(degs)	5	10	15
Head speed(rpm)	800	1200	1600
Tool offset (mm)	0.1	0.15	0.2
Tool pressure (bar)	0.5	1.0	1.5

Table 3 Orthogonal Array

Parameters / Trials	Precess angle (degs)	Head speed (rpm)	Tool offset (mm)	Tool Pressure (bar)
1	Level 1	Level 1	Level 1	Level 1
2	Level 1	Level 2	Level 2	Level 2
3	Level 1	Level 3	Level 3	Level 3
4	Level 2	Level 1	Level 2	Level 3
5	Level 2	Level 2	Level 3	Level 1
6	Level 2	Level 3	Level 1	Level 2
7	Level 3	Level 1	Level 3	Level 2
8	Level 3	Level 2	Level 1	Level 3
9	Level 3	Level 3	Level 2	Level 1

Table 4 Polishing spots and their models



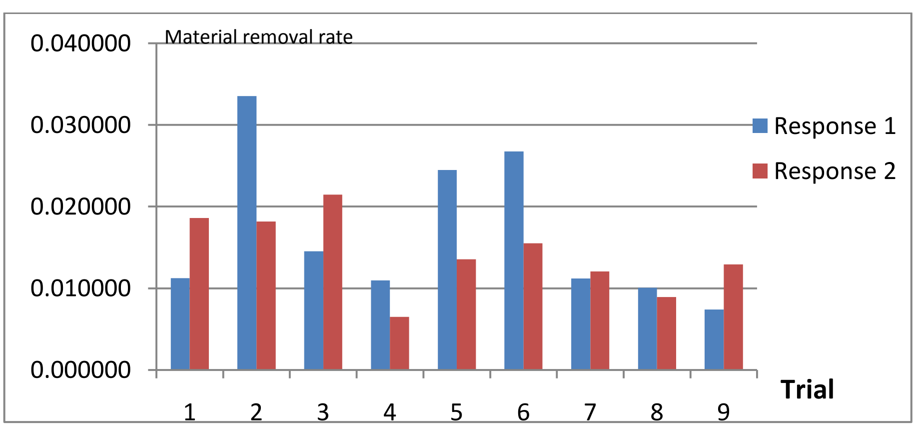


Figure 4 Bar chart of material removal volume

Table 5 Results of ANOVA

ANOVA					
Columns	Factor Name	Sum of square	Variance	Contribution	Rank
1	Precess angle (degs)	31.0313000000	15.51565	37.39%	1
2	Head speed (rpm)	0.9399000000	0.46995	1.13%	4
3	Tool offset (mm)	27.7702000000	13.8851	16.73%	2
4	Tool pressure (bar)	23.2419000000	11.62095	14.00%	3