Material removal investigation in bonnet polishing of CoCr alloy

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ABSTRACT

The manufacture of orthopaedic joint bearings surfaces requires exceptionally high levels of control of not only the surface finish but also the surface form. In the case of hip joints, the form of femoral head should be controlled to within ± 50μm from a given diameter. It has been shown that a better form control of bearing component could enhance clearances creating the correct volume of lubrication to fill the bearing surface gap and reduce wear particle generation. This element is especially critical for the new generation non-spherical head designs.
Bonnet polishing which is used successfully in the area of optics is potentially an excellent finishing process to control the form and finish of artificial joints. In the process of form control polishing an "influence function" which defines the material removal rate is of vital importance in developing a corrective polishing procedure. However, the effects of polishing parameters (such as precess angle, head speed, tool pressure and tool offset) on influence function are not very clear for CoCr alloys. These elements must be assessed if a deterministic polishing process is to be developed. Therefore, it is of paramount importance to understand the contribution of each polishing factors to influence function and consequent part polishing. This study has investigated the effects of polishing parameters on influence function, including geometric size and volumetric material removal rate (MRR). The experimental results indicate that the polishing parameter of precess angle and tool offset affect the geometric size of influence function significantly; the polishing parameter of head speed and tool pressure affect the geometric size of influence function to a lesser degree; the polishing parameter of precess angle, head speed and tool offset affect MRR greatly.

Keywords bonnet polishing; influence function; material removal

1 Introduction

The characteristic of material removal has been termed as the influence function[1]. The influence function was defined by Walker D. et al as the contour of a dimple (or called polishing spot) produced by a spinning polishing tool exerting a cutting action on a specific location of a workpiece surface. The influence function is closely related to the material removal characteristic of the polishing tool involving the geometric size and the distribution of the material removal of the specified polishing tool [2, 3]. In CNC controlled polishing an influence function is of vital importance for defining a polishing procedure. Obtaining an influence function is a considerable significant step in corrective polishing. However, the effects of polishing parameters (such as precess angle, head speed, tool offset and tool pressure[4]) on influence function are not very clear for CoCr alloys used in artificial joint replacements. The present investigation has studied the relationship of the above mentioned factors on the influence function.

The material removal in the area of optics fabrication has been investigated extensively. The earliest investigation concerning material removal was carried out by Preston [5]. The achievement of Preston was known as Preston equation. Now most researchers' material removal models are based on Preston equation. Buijs et al. presented a revised Preston equation by incorporating Young's modulus, hardness and fracture toughness in lapping of glass [6]. Matsuo et al. proposed a modified Preston's equation by substituting frictional force for polishing pressure [7]. Another model similar to Matsuo's model is developed by Shorey [8]. Shorey's model described the MRR using the shear stress to replace the pressure or the frictional force. Shorey uses this model to depict the material removal rate in Magnetorhological Finishing (MRF) process, where the Preston coefficient contains the chemistry of the carrier fluid, abrasive type and glass type. He also showed that the material removal increases with the addition of cerium oxide, alumina oxide and diamond. With the consideration of near surface mechanical properties, modified Preston's equation, abrasive size and concentration, glass chemistry and durability and glass average single bond strength, DeGroote et al. use peak MRR to substitute MRR and create a considerably complex model [9].This model has been validated firstly term by term firstly and then combined together to examine mechanics, fluid properties and chemistry in MRF material removal process. Lambropoulos et al.'s model shows the volume removal rate has a linear relationship with the workpiece's Young's modulus, an inversely proportional relationship with the fracture toughness and the square of Knoop hardness [10]. Through introducing the mechanical properties of workpiece, the Preston's model can be more accurately modified according to different material of workpiece. Through review of material removal modes in the field of polishing, the authors find that there are few material removal models for metal polishing, especially for bonnet polishing of CoCr. Therefore, it is beneficial to investigate the effect of each polishing factor on influence function, including both geometric size and MRR.

The cylindrical samples used in these experiments are CoCr alloy which is the most commonly used material in artificial implant. They are 23mm diameter and 7mm height. The polishing clothes are polyurethane GR-35, with 3μm Alumina slurry whose specific gravity is 1.025. All experiments were carried out on the Zeeko IRP200 polishing machine. After spots were polished, the 3D maps of influence functions were measured by a Somicronic Surface instrument. The volumetric material removal rates (MRRs) were calculated by Precession software which was developed by Zeeko Company Ltd.

2 THE EFFECTS OF PRECESS ANGLE

The polishing parameter of precess angle affects the contacting area of polishing tool on the surface of workpiece. Different contacting area can hold different amount of abrasives in the same concentration of slurry. Otherwise, the linear speed of polishing tool in different part of bonnet is different, i.e. the speed in the centre is always slower than in the periphery. The material of workpiece in polishing is removed by abrasives. Therefore, precess angle should influence the MRR. But how does precess angle affect the MRR and what relationship of them is ambiguous. This investigation has tried to find the relationship of precess angle and MRR.

The experimental conditions for the effects of precess angle are given in table 1. The precess angle was increased from 5^0 to 30^0 with an increment of 5^0. Other parameters were kept constant. The photographs of influence function were given in Fig. 1. As can be seen in Fig. 1, all influence functions are circular and precess angle affects the geometric size of influence functions obviously. The geometric size of influence function increases significantly with the increase of precess angle when precess angle increases from 5^0 to 20^0; the increase rate decreases when precess angle increases from 20^0 to 30^0. The reason for this is that when precess angle is small, the contacting area of polishing tool is near the centre of bonnet. In this situation, the polishing speed is small and the MRR is consequently low.

Fig. 2 shows the 3D maps and their related 2D profiles of the influence function in the precess angle experiments. As given in Fig. 2, all influence functions comply with a basic Gaussian shape and are uniform except for the last experiment where precess angle is 30^0. In all 2D profiles, when precess angle is 10^0, 15^0, 20^0 and 25^0, the profiles are regular while in 5^0 and 30^0, the profiles are irregular. Fig. 3 gives the relationship of MRR and precess angle. As can be seen in Fig. 3, the MRR increases with the increase of precess angle. When precess angle is 5^0, the MRR is lowest (0.006mm^3/min). Then the MRR increase sharply with the increase of precess angle up to the highest (0.061mm^3/min). The exact relationship of MRR and precess angle is not yet fully clear. This needs more experimental data to determine the MRR model. However, these results indicate that precess angle is one of the main parameters affecting the material removal rate and the geometric size of influence function.

3 THE EFFECTS OF HEAD SPEED

According to Preston equation, the MRR is linearly proportional to the polishing speed. The higher speed will always result in more material removal in the same period of time. In bonnet polishing, the polishing speed is the velocity of bonnet revolution (Units: rpm). This investigation tried to establish the relationship of head speed and MRR in bonnet polishing of CoCr. The experimental conditions are given in table 1. The polishing speeds ranged from 300rpm to 1800rpm with an increment of 300rpm. Fig. 4 shows the influence function changes with the increase of polishing speed. The geometric size of influence function doesn't change obviously with the change of polishing speed. Fig. 5 shows that the polishing speeds change from 300rpm to 1800rpm, all influence functions comply with Gaussian shape. Therefore, polishing speed influences the shape of influence function only slightly. Fig. 6 shows the fitting results of polishing speed and MRR. The fitting line of the polishing speed and MRR shows that the relationship of them is linear. This set of experiments indicates that polishing speed doesn't affect the shape of influence function greatly and affects the MRR linearly.

4 THE EFFECTS OF TOOL OFFSET

Tool offset is the deformation depth of bonnet when it contacts on the surface of workpiece in polishing. Obviously, different tool offset generates different contacting area in polishing. Contacting areas hold the abrasives which in turn remove the material of workpiece. Therefore, when tool offsets are changed, the geometric size of influence function should change. However, how much the tool offset affects the influence function needs to be investigated. The experimental conditions for this investigation are given in Table 1.

Fig. 7 shows the photographs of influence function when the tool offsets are changed from 0.1mm to 0.7mm. As shown in Fig. 7, the geometric size of influence function increases significantly with the increase of tool offset. This means tool offset affects the geometric size of influence function greatly. Fig. 8 shows the shift of influence function when tool offset changes from 0.1mm to 0.7mm. It can be seen that from 0.1mm to 0.3mm, the influence functions are Gaussian shape, but from 0.4mm to 0.7mm, the influence functions are no longer Gaussian shape. The reason for this is that the material of bonnet which is a neoprene rubber would appear to be deformed under the loads needed to maintain the large offsets. With the increase of tool offset, the bonnet deforms continuously when tool offset is less than 0.3mm, but when tool offset is greater than 0.4mm, the bonnet warps slightly. In this situation, the centre of contacting area departs from the surface of workpiece. The material of workpiece in this area is not removed. Therefore, a protrusion is created in the centre of polishing spot. This phenomenon is harmful for deterministic corrective polishing and should be avoided.

Fig. 9 shows the relationship of tool offset and the MRR when tool pressure is 1bar. As can be seen in Fig. 9, the MRR reaches a maximum around 0.5mm before reducing due to the bonnet deformation.

5 THE EFFECTS OF TOOL PRESSURE

As mentioned above, tool pressure in bonnet polishing is not the contacting pressure on the workpiece. This pressure relates to the “hardness” of the polishing tool. If the tool offset is constant, the increase of pressure will results in the increase of contacting pressure, vice versa. If the tool pressure is constant, the increase of tool offset will also results in the increase of contacting pressure. So in bonnet polishing, the contacting pressure relates to both the tool offset and pressure. The tool offset was kept constant as 0.15mm in this investigation and the tool pressure was changed from 0.4bar to 2.0bar with an increment of 0.4bar. Other polishing parameters were given in table 1.

Fig. 10 shows the geometric size of influence function varies with the change of tool pressure. It can be seen in Fig. 10 that the geometric size of influence function nearly doesn’t change with the increase of tool pressure. Fig. 11 shows that when the tool pressure increases, the influence function always complies with Gaussian shape. Fig. 12 shows the effects of tool pressure on the MRR. The MRR increases with the increase of tool pressure slightly. This indicates that if precess angle, head speed and tool offset are kept constant, tool pressure has little effect on MRR.

6 CONCLUSIONS

This study has investigated the effects of processing parameters on the influence function. The research results indicate that the MRR increases with the increase of precess angle non-linearly, increases with the increase of tool speed linearly, increases firstly and than decreases with the increase of tool offset and increases slightly with the increase of tool pressure. When all processing parameters are kept constant, the Influence function nearly doesn’t change. This would verify that the MRR of bonnet polishing is stable and the polishing process is deterministic. Both the geometric size of influence function and the MRR increase with the increase of precess angle obviously. The head speed nearly does not change the geometric size of influence function but the MRR increase linearly with the increase of tool speed. The size of influence function increases obviously with the increase of tool offset, but the MRR increases firstly and then decreases due to tool distortion. The tool pressure doesn’t change the geometric size of influence function and only slightly changes the MRR. Further studies will use the information generated above to investigate models of material removal for the bonnet polishing used here.

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Table 1: Experimental conditions

Factors	Dwell time	Precess angle	Head speed	Tool offset	Tool pressure
Value	300 s	15deg	1200rpm	0.15mm	1bar

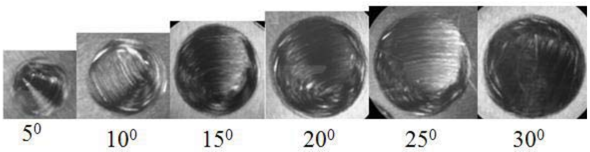

Figure 1: The photographs of influence function for precess angle

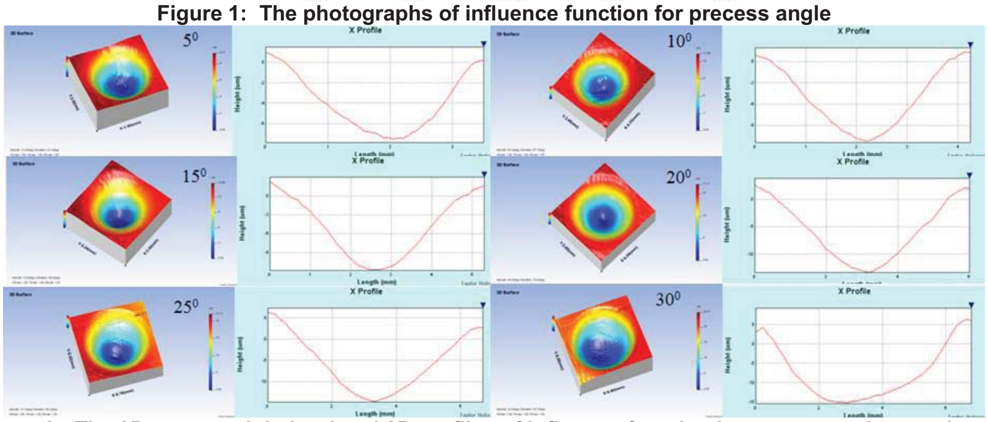

Figure 2: The 3D maps and their related 2D profiles of influence function in precess angle experiments

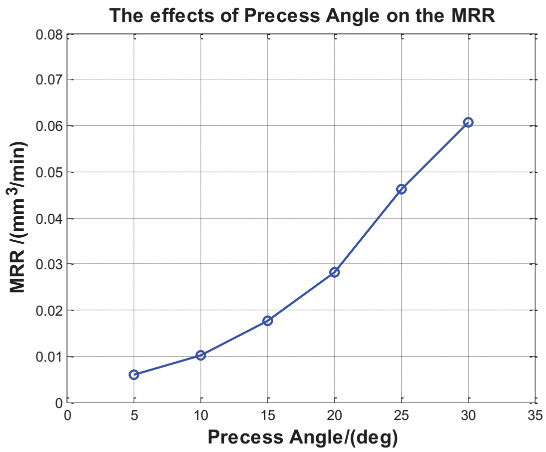

Figure 3: The effects of precess angle on MRR

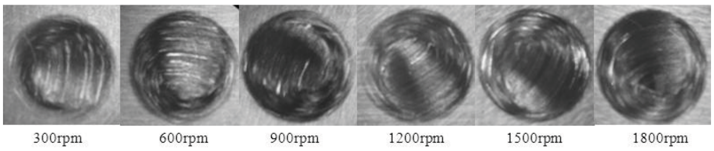

Figure 4: The photographs of influence function for tool speed experiments

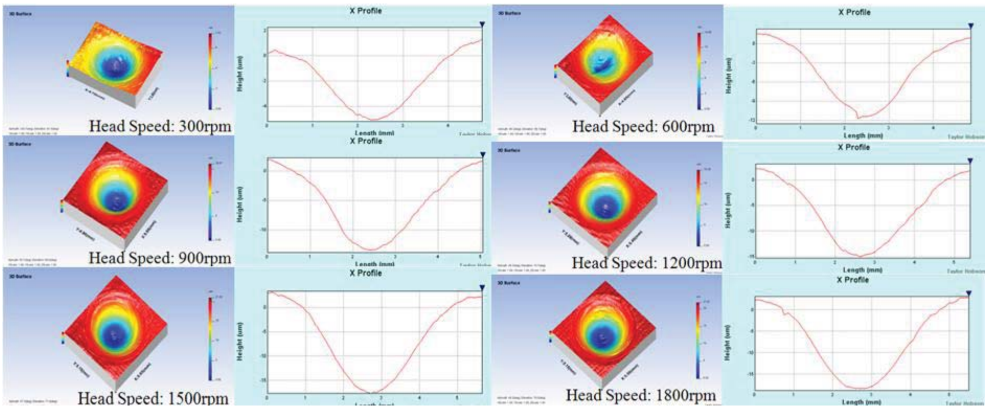

Figure 5: 3D maps and their related 2D profiles of polishing spots in tool speed experiments

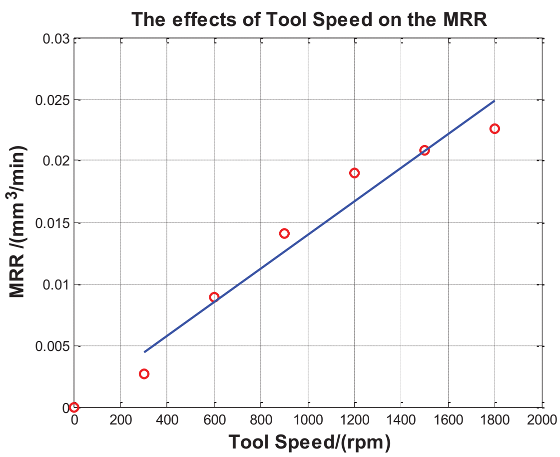

Figure 6: The effects of Head speed on the MRR

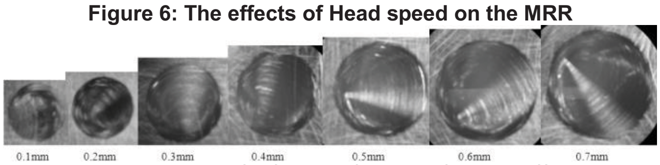

Figure 7: The photographs of influence function for tool offset experiments

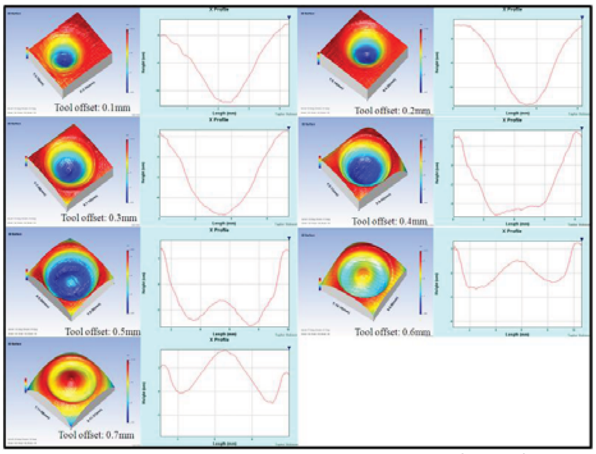

Figure 8: 3D maps and their related 2D profiles of influence functions in tool offset experiments

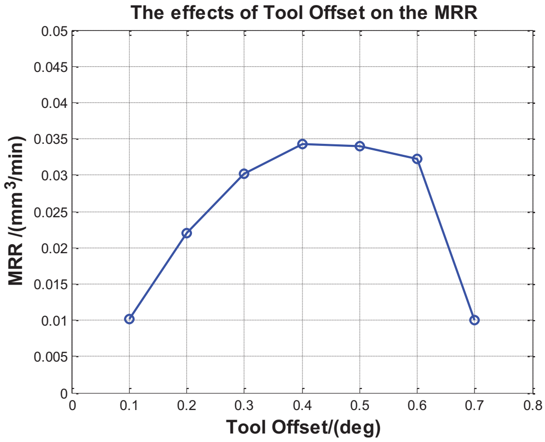

Figure 9: The effects of tool offset on MRR

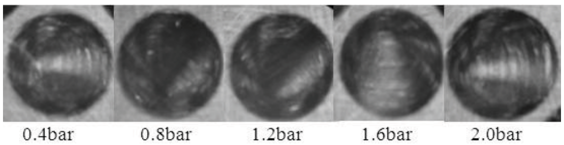

Figure 10: The photographs of influence function for tool pressure experiments

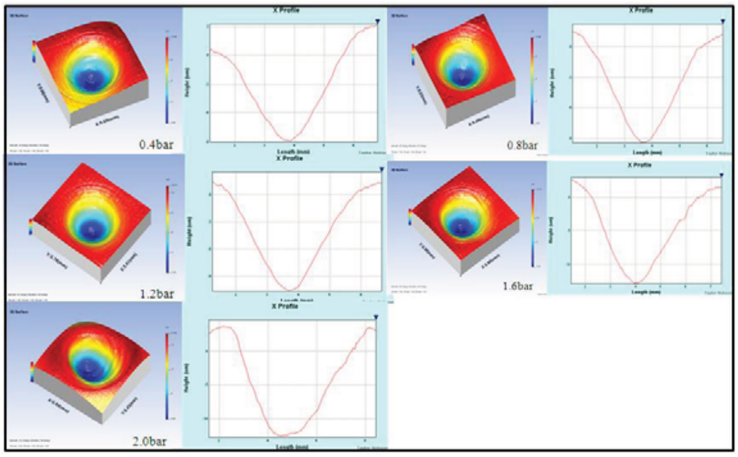

Figure 11: 3D maps and their related 2D profiles of influence function in tool pressure experiments

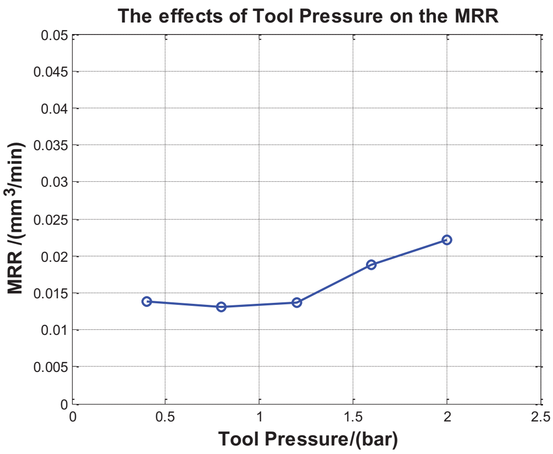

Figure 12: The effects of tool pressure on MRR