

Experimental investigation and analytical modelling of the effects of process parameters on material removal rate for bonnet polishing of cobalt chrome alloy

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ABSTRACT

Cobalt chrome alloys are the most extensively used material in the field of total hip and total knee implants, both of which need highly accurate form and low surface roughness for longevity in vivo. In order to achieve the desired form, it is extremely important to understand how process parameters of the final finishing process affect the material removal rate. This paper reports a modified Preston equation model combining process parameters to allow prediction of the material removal rate during bonnet polishing of a medical grade cobalt chrome alloy. The model created is based on experiments which were carried out on a bonnet polishing machine to investigate the effects of process parameters, including precess angle, head speed, tool offset and tool pressure, on material removal rate. The characteristic of material removal is termed influence function and assessed in terms of width, maximal depth and material removal rate. Experimental results show that the width of the influence function increases significantly with the increase of the precess angle and the tool offset; the depth of the influence function increases with the increase of the head speed, increases first and then decrease with the increase of the tool offset; the material removal rate increases with the increase of the precess angle non-linearly, with the increase of the head speed linearly, and increases first then decreases with the increase of the tool offset because of the bonnet distortion; the tool pressure has a slight effect on the influence function. The proposed model has been verified experimentally by using different Preston coefficients from literature. The close values of the experimental data and predicted data indicate that the model is viable when applied to the prediction of the material removal rate in bonnet polishing.

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1. Introduction

Conventional polishing of bearing surfaces for artificial joints is usually carried out by semi-automated polishing or in some instances manual polishing, both of which are labour-intensive and time consuming. To minimise the processing time and improve the surface quality, a technique of computer numerical control (CNC) known as bonnet polishing has been applied to such polishing tasks in the present study. Bonnet polishing, originally developed by Walker and co-workers [1], was primarily developed for polishing optical materials used in large optical devices such as telescopes. Aspheres and freeform optical surfaces have been processed using the bonnet polishing technology [2], but it represents a new and attractive option when applied to the manufacture and finishing of the bearing surfaces of prosthetic hip or knee implants. In such devices form control of the bearing surface is a critical determinant

of implant life [3]. To achieve the desired form, it is of paramount importance to understand how the various machining parameters affect the ability to achieve optimal form to facilitate the extended lifespan of implants. The material removal rate (MRR) is clearly a fundamental element in optimising the machining. It is therefore non-trivial to establish the link between the MRR and machine process parameters.

The MRR has been widely investigated in various polishing processes. The earliest investigation was carried out by Preston [4] who proposed the well-known Preston equation which assumes that the MRR is proportional to the contact pressure, and the relative velocity:

$$\text{MRR} = K \times P \times V \quad (1)$$

where K is the Preston coefficient, including the effects of abrasive size and material, slurry concentration, workpiece material, polishing cloths/pads, etc.; P is the contact pressure between the polishing tool and the workpiece; V represents the velocity of the polishing tool relative to the workpiece.

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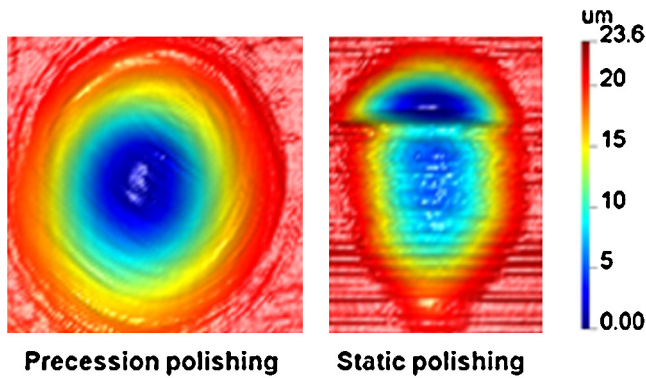


Fig. 1. Influence function polished by different modes.

The Preston equation is widely accepted and has become the basis of the subsequently proposed MRR models. Buijs and Houten [5] presented an MRR model by incorporating Young's modulus, hardness and fracture toughness in lapping of glass. Compared with Preston equation, this model only investigated the Preston coefficient instead of wholly changing the modes of contact pressure and relative velocity. Matsuo et al. [6] proposed a modified Preston's equation by substituting frictional force for polishing pressure. This model created the connection of frictional force with MRR, indicating that the material removal in polishing process was achieved by polishing force rather than contact pressure, which was contributed to a better understanding of the material removal mechanism. Another model similar to Matsuo's was developed by Shorey [7]. Shorey's model described the MRR using the shear stress to replace the pressure or the frictional force. The above models confirmed that the MRR was linearly proportional to the contact pressure and the relative velocity but other researchers, such as Wang et al. [8], presented another approach. Wang et al. proposed a revised model by introducing the exponents to the contact pressure and the relative velocity. The limit of Wang's model was that it needed a huge amount of experimental data to ascertain the exponents for the contact pressure and relative velocity, which would be costly in terms of time and machining effort. Cheung et al. [9] proposed an MRR model based on the assumption of Gaussian distribution of the contact pressure in bonnet polishing. However, the present authors found that the Gaussian shape of the influence function was created by the precession mode polishing (i.e. revolving the polishing tool around the normal of the workpiece) rather than by a genuine Gaussian distribution of the contact pressure as shown in Fig. 1 (the left influence function polished in precession

mode is Gaussian shape, the right one polished in static mode is not Gaussian shape).

As can be seen, all the models based on the Preston equation described above only consider the contact pressure and the relative velocity. However, there are many other factors that may affect the MRR for different polishing processes. When considering the bonnet polishing, the main process parameters which potentially affect the MRR include precess angle, head speed, tool offset and tool pressure. Therefore, the current models are unsuitable to be used to predict the MRR in a bonnet polishing process which becomes the key motivation of this work. The aim of the present study is to empirically establish the link between the MRR and the process parameters based on the Preston equation and experimental data.

2. Experimental setup

In the present study, the workpiece material applied throughout was a medical grade cobalt chrome (CoCr) alloy, the most commonly used biomaterial for artificial implants. The polishing medium was GR35 polyurethane polishing pad with 3 μm alumina slurry whose specific gravity was 1.025. The samples were 23 mm diameter and 8 mm height cylindrical CoCr alloy. In this investigation, the precession mode, in which the inclined rotating polishing tool is rotating slowly around the normal of the workpiece, was used to polish the influence function (IF) so that the created IF was Gaussian shape.

The experiments were carried out on a typical 7-axis bonnet polishing machine, Zeeko IRP200 (Fig. 2). This machine uses a rotating bulged bonnet with internal pressure as the polishing tool. The bonnet is flexible and covered with a polishing cloth/pad. The inflated bonnet can conform to the variable curvature of the curved surface of the component during the polishing process. An outstanding feature of this machine is that it has a higher polishing efficiency as well as the ability to generate smooth surface textures [10]. Bonnet polishing predominantly depends on the following four process parameters: precess angle α , head speed ω , tool offset d and tool pressure t_p (Fig. 2).

3. The effects of process parameters

This section investigates the characteristics of material removal through polishing different IFs by varying the values of the process parameters. The IF can be defined as a dimple produced by rotating the polishing tool on a fixed location of the workpiece surface for a fixed set of machine parameters [11]. When one parameter was studied, the values of other parameters were kept constant as in Table 1. After polishing, the 3D maps of the IF were measured by

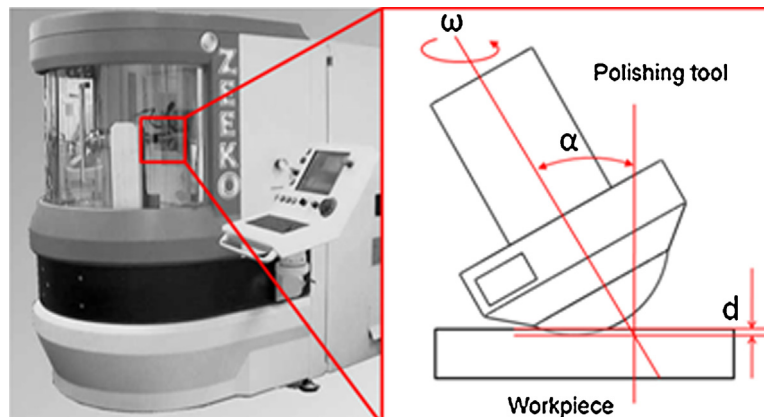


Fig. 2. Experimental setup and process parameters.

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