Roughness Prediction for Elastic Polishing of Complex Ceramic Workpieces

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Abstract

The durability of complex implants can be improved by the application of ceramics for the knee prostheses [1]. Hard-hard-pairings like a ceramic knee joint have to be machined in an automated high-precision process on one machine and clamping due to high geometrical and surface quality requirements. In this paper, the polishing process with elastic diamond polishing tools for the application to complex ceramic workpieces is modelled and verified by polishing experiments.

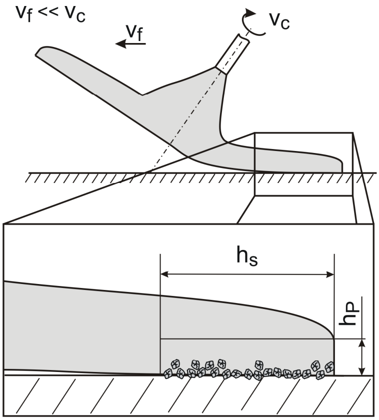
1 Introduction

In general, ceramic materials are machined using abrasive processes with diamond particles [2]. A polishing method was developed in [3] to compensate the disadvantages of polishing with loose abrasives, e.g. non-constant material removal and disposal of diamond lubricants by usage of polyethylene bond diamond tools. Elastic tools are able to adapt to the geometries of the complex surfaces. In combination with CAD/CAM controlled tool path generation the workpiece can be machined with a force control for minimized form deviations by the adaption of the elastic tool. The aim of the polishing step is to smooth the roughness peaks of the pre-ground surface in order to achieve high ratios of the bearing contact areas.

With the knowledge concerning the relation between the bonding deformation and the contact forces, it is possible to achieve defined contact forces by a variation of the infeed. Consequently, complex shaped ceramic surfaces can be polished within the desired form tolerances.

2 Modelling method

The influece of the process parameters on the machined surface topography shall be predicted by a model. It is assumed that the removal of the roughness peaks depends on the number of grains, which slide over the workpiece in a discrete period of time ($\dot{N}_{KP}''$) and on the contact pressure of the grains on the workpiece (F_g). A higher number of grains lead to decreased peak heights and a higher contact pressure of the polishing grains on the workpiece leads to an increased smoothening up to a certain degree. The calculation of the number of grains which affects the workpiece surface is shown in Figure 1 [3].



Calculation:

$$\dot{N}_{Kp}'' = \frac{3 \cdot C_p \cdot s(r_p - h_s) \cdot v_{cp}}{\pi^2 \cdot \rho_g \cdot q_e \cdot d_g^3}$$

with:

$\dot{N}_{Kp}''$ number of diamond grains in the overlaid tool area
C_p concentration
ρ_g density of the diamond grain
q_e factor for the grain form
d_{gp} diamond grain size
v_{cp} cutting speed
r_p radius of the polish tool

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Figure 1: Modelling number of diamond grains which slides over the surface

3 Stiffness of resilient tools

The polish tool stiffness was determined in relation to the lead angle β and the diamond concentration in the bonding to extend the model with the contact forces. The polish tool stiffness is calculated with the relationship of the measured normal force F_N to the infeed f_t and describes the resistance of the tool against deformation. The force measurement was carried out by means of a rotating dynamometer of type Kistler 9125 on tool side. A significant influence of the diamond concentration to the stiffness is detected in the investigations (Figure 2). The normal force increases linearly with rising infeed for C50 and C100, it increases progressive for a C200. A higher concentration leads to an increase of the tool stiffness due to the lower amount of the elastic bonding material connecting the grains. Furthermore, the stiffness raises by an increasing lead angle due to higher deformation of the elastic tool.

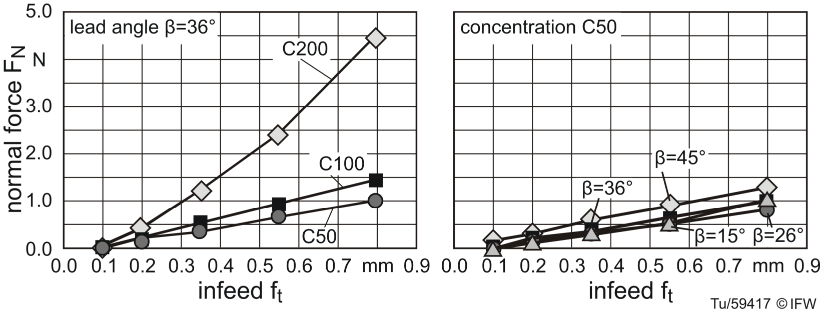

Figure 2: Relationship between infeed and normal force

4 Influence of machining parameters to the surface topography

In further investigations the influence of the concentration, the lead angle as well as feed speed, cutting speed and infeed on the smoothing of the roughness peaks was determined in dry polishing with polyethylene bond polish tools.

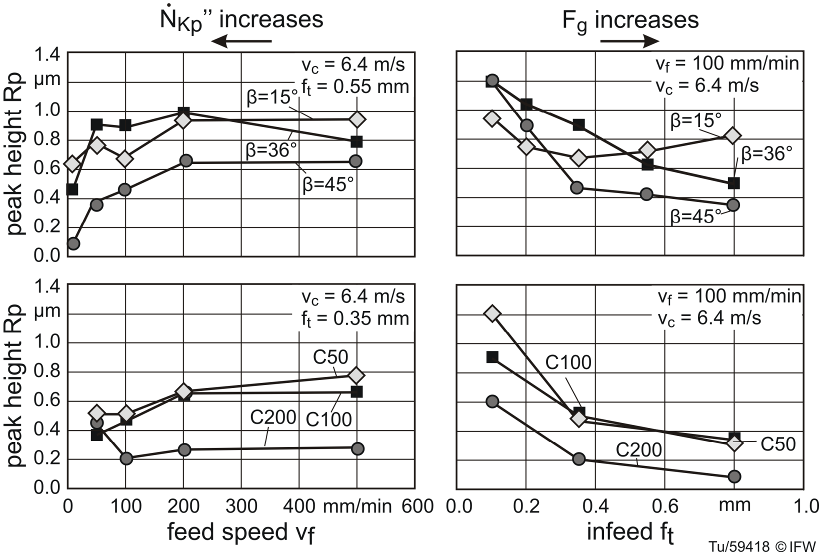

Figure 3: Influence of the process parameters on surface quality

An optimum for the cutting speed is detected at approximately 6.4 m/s. Smaller values increase the stress to the bonding and the grains brake out. Higher values create higher contact zone temperatures so that the bonding is burned. In Figure 3 the influence of the lead angle is faced to the influence of the diamond concentration. A lead angle of 45° smoothes the workpiece surface more than flat lead angles due to higher normal forces affecting the diamond grains. A higher concentration causes smaller peak heights too, due to a higher number of grains which slide over the workpiece surface. The slower the feed rate and the higher the infeed the smaller the peak height is because of an increased number of diamond grains and a raised normal force per grain.

5 Conclusion and future work

The investigations verified the assumptions of the theoretical model. Thus, a high number of grains in the elastic diamond bonding achieves better smoothing of the roughness peaks than low concentrations. A lead angle of 45° is preferred. Furthermore, small feed rates enable high surface qualities. However, the feed rate influences the tool wear significantly and has to be chosen in relation to the wear. A middle cutting speed should be used to avoid high tool wear. However, the cutting speed does not influence the main roughness significantly, as assumed.

In further investigations the influence of the normal force affecting the diamond grains will be integrated in the prediction model. Moreover, the influence of the properties of the pre-ground surface will be considered. Therefore, a defined process design for the polishing of complex ceramic is enabled.

6 Acknowledgement

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