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Velocity dependent material removal in abrasive subaperture polishing

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Abstract
Polishing processes are an indispensable finishing step in the production of optical glass lenses, mold inserts and other precision components in order to achieve low surface roughness and a high form accuracy. Knowledge of material removal and material removal rate is crucial for the control of corrective polishing processes, especially for dwell time controlled processes.
This paper investigates the influence of rotational speed – or relative speed respectively - and dwell time on material removal in abrasive subaperture polishing. Therefore, footprints were machined into BK7 glass while measuring the process forces and characterising the geometry generated. At lower rotational speeds and dwell times, a nonlinear relationship between relative velocity and material removal was found,, which generally does not correspond to the Preston equation. Furthermore, an influence of the relative velocity on the process forces can be observed.

Abrasive polishing, Material removal, Dwell time

1. Introduction

Abrasive sub-aperture polishing is an indispensable finishing step for generating high form accuracies and low surface roughness in machining of optical glass lenses, mould inserts and other precision components. Due to increasing demands on form accuracy as well as more and more complex geometries, precise control of the polishing process as well as unambiguous knowledge of the material removal are necessary.

Usually, so-called dwell time controls are used, which rely on time-constant material removal functions that have to be determined experimentally. The material removal is controlled by the dwell time of the polishing tool and realized in the polishing process by the feed rate [1-5].

An analytical approach to describe the material removal and the material removal rate dz/dt in polishing is the equation, which was derived by Preston already in 1927 [6]:

$$dz/dt = k_p \times p \times v_r$$

According to the Preston equation, material removal is proportional to polishing time t, polishing pressure p, relative velocity v_r and the Preston coefficient k_p. In this context, the Preston coefficient summarizes all remaining process-relevant variables [6].

Studies by Téllez-Arriaga et al. [7] show an influence of the relative velocity on the coefficient of friction between the polishing tool and the workpiece. This influences the dragging force, which is the sum of the frictional forces exerted on all points of the tool, as well as the material removal. Based on these results, they therefore extended the Preston equation. Further investigations by Cordero-Dávila et al. [8] show that the dragging force is also dependent on the density of the polishing tool and, thus, modified Téllez-Arriaga's model. In our own work [9], the nonlinear influence of the relative velocity on the material removal described by Téllez-Arriaga et al. could also be reproduced and mapped. Therefore, a transferability to other polishing systems and a general correlation can be assumed.

In this work, a different polishing system is investigated for the relationship between relative speed and material removal In order to verify the transferability of the described correlations. A possible influence of the relative speed on the contact force is also considered.

2. Experimental setup and methods

The experimental investigations are carried out using cylindrical N-BK7 glass lenses. The glass lenses have a diameter of 80 mm and were surface ground on the Cranfield Precision TTG350 ultraprecision grinding machine. Polishing experiments are performed on a Microfinish 300 from Precitech. A 10 mm diameter cylindrical polishing pin covered with polyurethane foam is applied together with an oil-based polishing paste with diamond abrasive grains, which have a grain size of 3 µm as the polishing tool. A piezoelectric dynamometer from Kistler is used to measure the contact force, which is mounted underneath the workpiece holder. The experimental setup is shown in Figure 1.

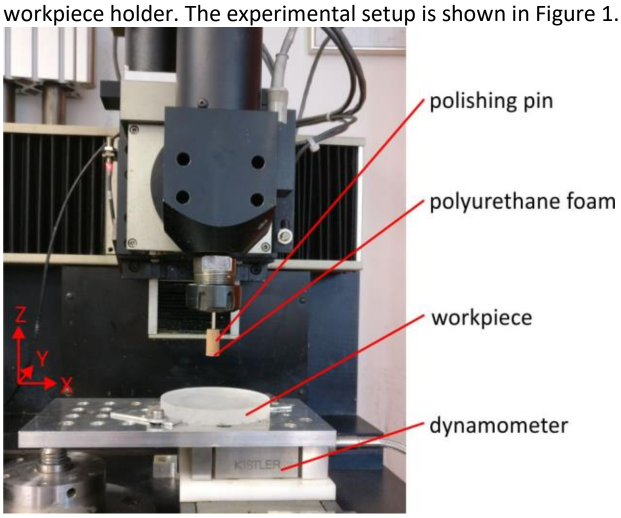

Figure 1. Experimental setup

Footprints are generated to investigate the influence of relative speed on material removal. The rotational speed n is varied between 100 rpm and 200 rpm and the dwell time t_d is varied in 30 second steps from 30 seconds to 120 seconds. The selected contact force F_p is set to 5.66 N as determined by preparatory experiments. In the polishing system studied, this is controlled through the axial infeed of the polishing pin, until the desired contact force is reached. The process parameters are summarized in Table 1. Each set of process parameter is performed three times.

Table 1 Process parameters

workpiece material	N-BK7 glass
polishing slurry	oil-based, diamond abrasives, grain size 3 µm
rotational speed *n*	100 rpm; 200 rpm
relative velocity v_r	0.05 m/s; 0.1 m/s
dwell time t_d	30 s; 60 s; 90 s; 120 s
contact force F_p	5.66 N

Material removal is determined with the white light interferometer Talysurf CCI HD from Taylor Hobson. Here the removal depth z of the generated footprints is measured on basis of profile sections.

3. Results

Figure 2 shows the average depth of material removal of three measurements for rotational speeds of 100 rpm and 200 rpm plotted over the dwell time. It can be seen that the removal depth increases with increasing dwell time for both rotational speeds investigated. Since in dwell time controls the feed rate is derived from the dwell time, it can therefore also be concluded that the material removal rate decreases with increasing feed rate. Furthermore, it can be observed that a doubling of the speed leads to at least a doubling up to a quadrupling of the material removal depth. This influencing factor decreases with increasing dwell time and a decreasing influence of the rotational speed on the material removal can be concluded with increasing dwell time or decreasing feed rate. An exponential relationship between dwell time and material removal depth can be seen at a rotational speed of 100 rpm and dwell times of 30 to 90 seconds. This relationship cannot be explained by the Preston equation, which describes a linear relationship.

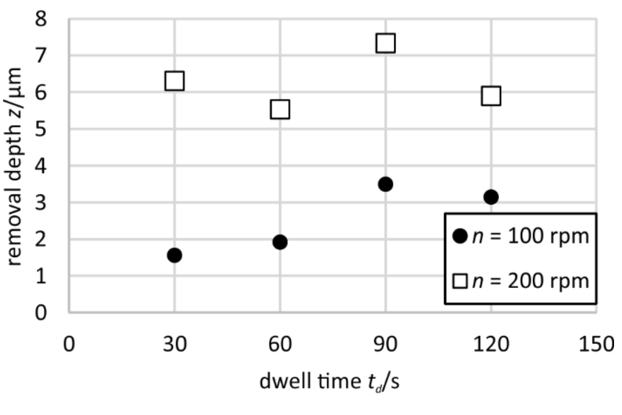

Figure 2. Correlation between rotational speed, dwell time and material removal depth

Figure 3 shows the influence of the rotational speed on the contact force and the axial infeed. As described, the polishing system controls the contact force via the infeed. It can be seen that at a speed of 200 rpm, the target contact force of F_p = 5.66 N or in some cases higher forces are already achieved with lower axial infeed. An influence of the dwell time on the contact force could not be observed, therefore a presentation is omitted.

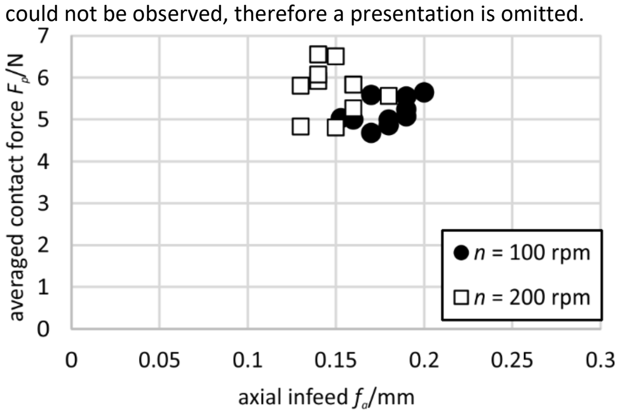

Figure 3. Correlation between rotational speed, contact force and axial infeed

4. Conclusions

The aim of this work was to investigate the relationship between relative speed, material removal and contact force of a polishing system. It was shown that the rotational speed as a component of the relative speed has an influence on the material removal depth as well as on the contact force. The influence of the rotational speed on the material removal depth is also dependent on the dwell time respectively the feed rate. In addition, an exponential relationship between dwell time and material removal depth can be observed at low rotational speed.

In future work, the relationships shown are to be further quantified in order to obtain a database for modifying the Preston equation. This can lead to a more deterministic description of the material removal in polishing as well as to the improvement of dwell time controls.

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