Plate Topography Influence on the Nanogrinding Process

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Abstract --- Nanogrinding is an ultraprecision process capable of creating surfaces with an average roughness R_a in the subnanometer range. Since the nanogrinding process is very dependent on the grinding plate's topography, the creation of this topography has been investigated. An initial conditioning process creates an average plate roughness R_a in the order of 1 µm. A consecutive diamond impregnation process truncates the peaks by creating mesa surfaces. Differences in surface topography also influence the cutting rate of the nanogrinding process.

Introduction

Nanogrinding is an ultraprecision surface machining process similar to fixed abrasive lapping. It is applied to machining ultrasmooth surfaces on ceramic microparts [1]. The grinding tool is a soft metal plate in which diamond grit used for the nanogrinding cutting process is embedded. To accommodate a fluid film thickness necessary to support the workpiece, nanogrinding requires a considerable plate roughness. It is achieved by conditioning the plate with an abrasive medium. After the conditioning, diamond impregnation with a coplanar alignment of the diamonds' summits takes place. As in the case of other surface finishing techniques like polishing and lapping, for nanogrinding the plate conditioning process is one of the key factors for achieving an optimal workpiece surface finish.

Grinding Plate Creation and Nanogrinding Process

The nanogrinding plate has a diameter of 400 mm. For conditioning, the plate was first moistened with the conditioning slurry. The slurry consisted of a conditioning medium, dispersed in DI-water with a ratio of 250 g/λ. Next, a cast iron conditioning ring was positioned on the plate. Driving the plate resulted in its rotation and a revolving of the conditioning ring. The conditioning ring forced the plate's shape to conform to the negative of its envelope, thus controlling flatness. It also machined the plate by removing its top layer and roughen its surface. The surface roughness may be controlled by the appropriate choice of the conditioning medium's material and grain size.

The conditioning media used for this investigation were pumice (a mineral consisting of Al_2O_3 and SiO_2), pure alumina (Al_2O_3), and silicon carbide (SiC). Furthermore, not only the grain size of the three conditioning media was chosen differently but also the grain size of the same medium was varied (s. Tab. I).

The grinding material for nanogrinding is diamond grain which is impregnated in the nanogrinding plate. The diamond impregnation process was executed after the completion of plate conditioning. It was accomplished by running a conditioning ring with ceramic pellets on the plate surface while applying the diamond slurry. The slurry consisted by volume of 70% DI water, 20% ethylene glycol, and 10% ethanol, plus 0.3 g/λ of 0.5-1 micron size diamond powder. The same fluid sans diamond was later used for the nanogrinding process. After diamond impregnation, the nanogrinding plate is carefully decontaminated in an ultrasonic cleaner to remove all loose grit.

Following the reinstallation of the nanogrinding plate, 60 min. of nanogrinding experiments were conducted. The workpiece material was Altic, a material extensively used in data peripherals and consisting of 70% Al_2O_3 and 30% TiC.

Table I

Conditioning Media

Conditioning Medium	Grain Size [μm]
Pumice (Al_2O_3 / SiO_2)	0 – 50
Al_2O_3	5 - 7
Al_2O_3	9 - 12
Al_2O_3	15 - 18
SiC	4 - 6
SiC	8 - 11
SiC	15 - 18

Plate Topography

To determine the plate's topography, i.e. its flatness, roughness, and texture, various analysis methods may be applied [2]. Scanning electron microscopy (SEM) was used for gaining qualitative topography information. Plate topography measurements were conducted by white light interferometry in the vertical scanning mode (VSI). Atomic force microscopy (AFM) was applied whenever nanometer scale resolution was required.

Fig. 1 depicts the average roughness R_a of the grinding plate over the duration of the experiment for the various conditioning materials. The starting value for each curve is the roughness after conditioning, the value for t=0 min. after diamond impregnation. The following values are the respective plate roughness conditions during the consecutive nanogrinding process with the changes caused by plate wear.

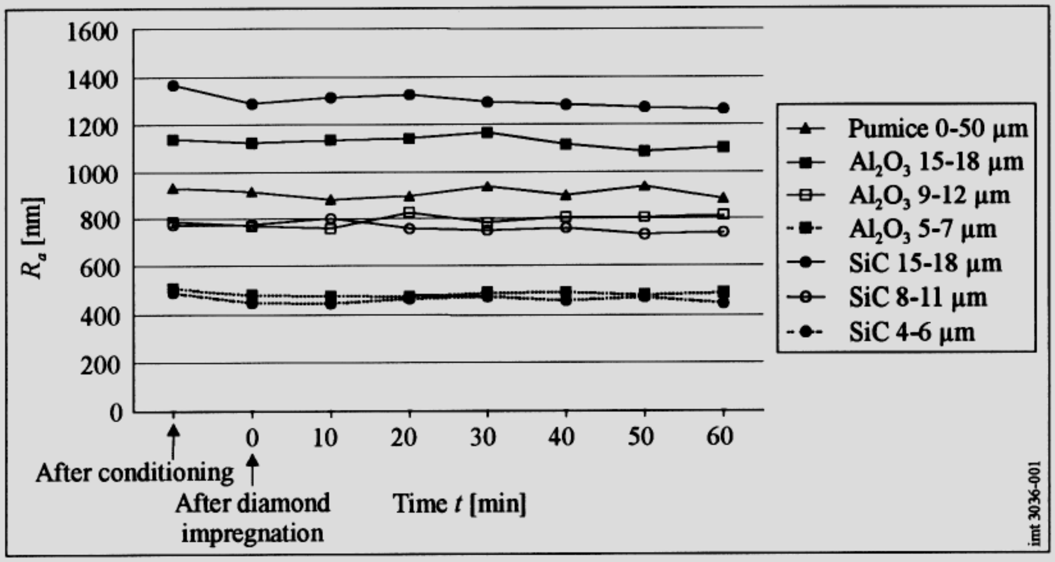

Fig. 1 Plate roughness R_a versus time as a function of the condition media (WLI measurements)

Fig. 3 sheds some light on the nature of surface topography change during the course of the experiment. It presents AFM micro topography graphs of exactly the same region of the plate surface at different states of the plate after conditioning. Left, it depicts the virgin plate after conditioning, at the center it shows the plate after diamond impregnation, and right it presents the plate at the end of the experiment after 60 min of nanogrinding. After conditioning, the plate started out with a random profile. However, the diamond impregnation process caused a very distinctive change to the topography: the conditioning ring apparently was truncating the peaks, creating some mesa type plateau surfaces in which the diamond grains are embedded. The consecutive machining process resulted in a further flattening of the peaks and thus in an increase of the mesa surface areas.

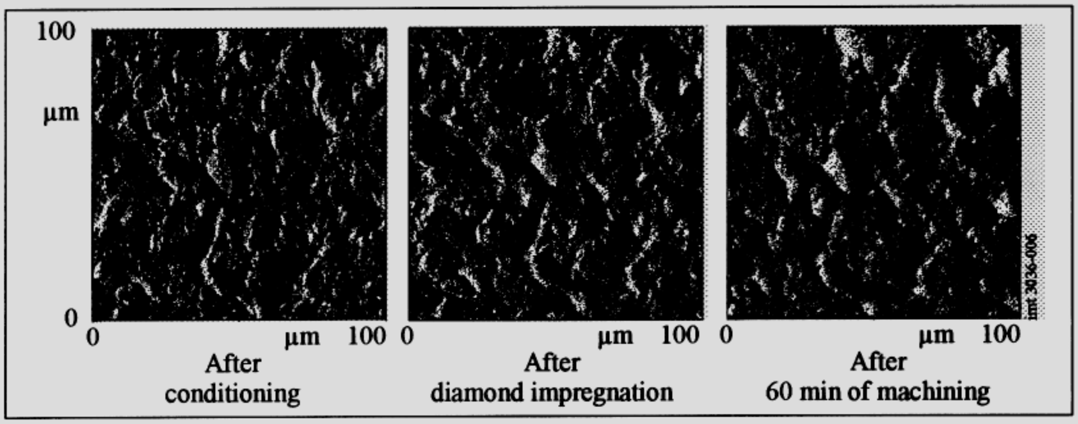

Fig. 3 Different states of the plate's surface topography (AFM measurements)

The distinctive formation of mesa surfaces provides us with a measurement challenge. The average roughness R_a is well suited to describe the plate's state after the conditioning. However, it does not lend itself to classify the changes the plate is exposed to during diamond impregnation and during the nanogrinding process. While the average roughness stays more or less constant over the machining time, the size of the mesa surfaces in which the diamond grain is embedded, does change. To describe the changes in the mesa areas the reduced peak height R_{pk} is chosen.

Fig. 4 depicts the relationship between R_{pk} and the Abbott curve. The Abbott curve represents the density distribution of material M_r in the depth of the roughness profile and povides information on the shape of the profile [3, 4]. The Abbott curve was originally developed to describe tribological properties of surfaces.

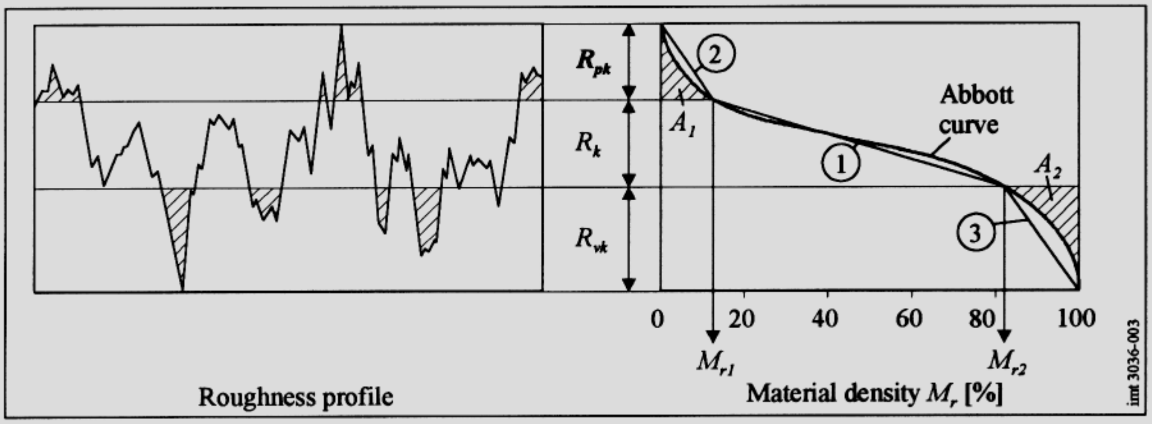

Fig. 4 Roughness profile and Abbott curve

Fig. 6 depicts the reduced peak height R_{pk} as a function of plate life. To describe the changes the plate is experiencing during the duration of the experiment the reduced peak height R_{pk}.

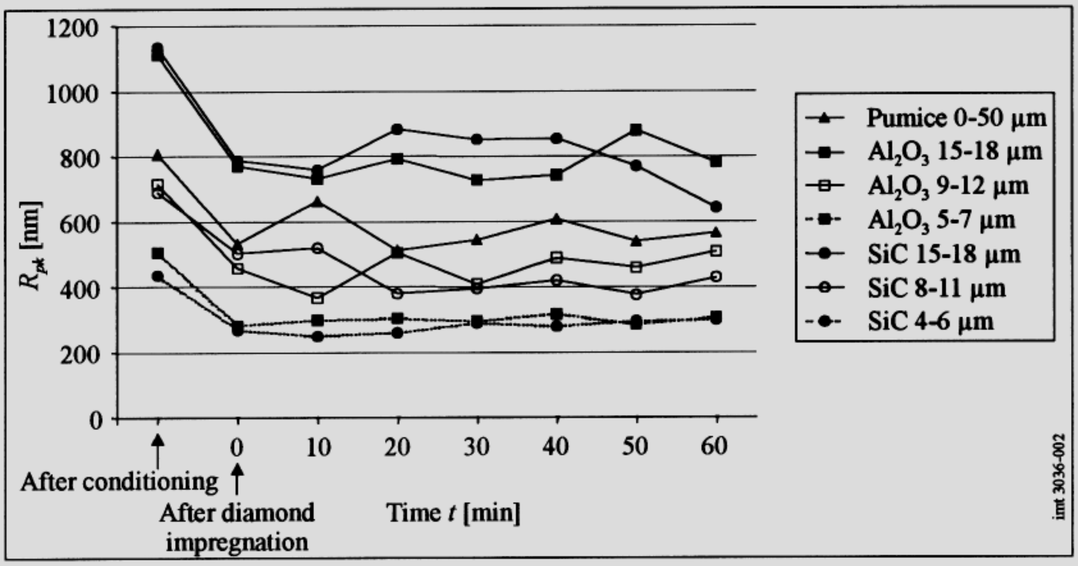

Fig. 6 Reduced peak hight R_{pk} versus time as a function of the applied conditioning media (WLI measurements)

The importance of plate conditioning apparently is to provide a plate topography with very distinctive features. First of all, the plate surface has to be rather rough. This roughness is both required to allow a peak truncation and to form mesa surfaces in which the embedded diamonds ultimately are doing the cutting. The height between mesa surface and valley has to match the thickness of the fluid film used for nanogrinding. During the nanogrinding process, the mesa surfaces are increasing their size, which means the distance "mesa to valley" is continually decreasing. Since the fluid film thickness is constant, this wear results in a lack of engagement of diamond grains at the workpiece.

Cutting Rates

To determine the cutting rates as a function of the conditioning process, nanogrinding tests were performed. Four samples of Altic with a size of 2.5 mm x 15 mm were mounted on a workpiece holder. By applying weights, a workpiece pressure of 420 kPa was achieved. The rotational velocity of the grinding plate and the workpiece holder were 45 RPM and 65 RPM, respectively.

Fig. 8 shows the cutting rate results. Depending on the applied conditioning medium it differed by a factor of five between 0.2 and 1 µm/min. Apparently the variation in conditioning media result in surface topography differences causing a variance in diamond impregnation behavior.

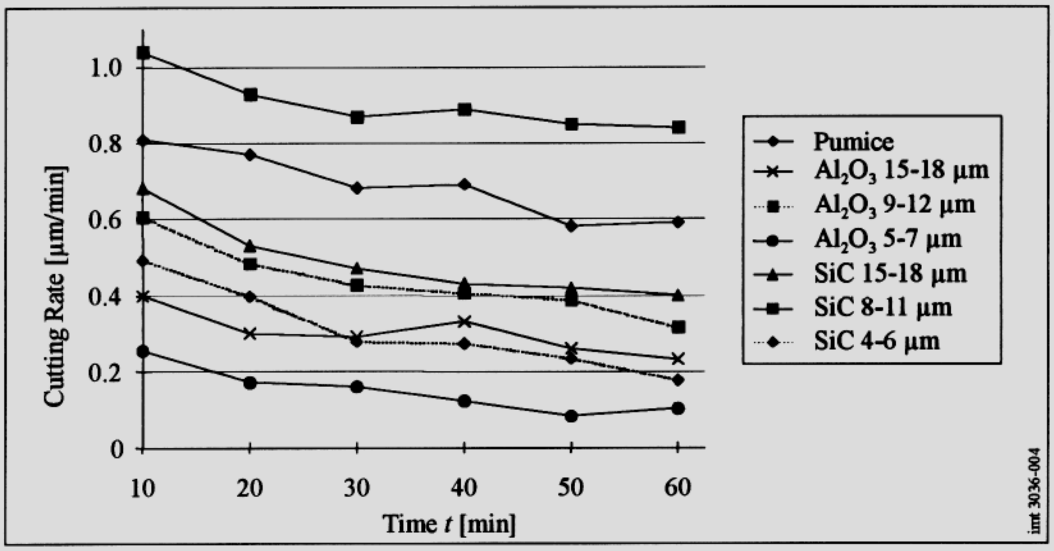

Fig. 8 Cutting rates for different conditioning media

Conclusion

By varying the conditioning media a range of plate average roughness between appr. 0.5 and 1.5 µm may be achieved. The differences in surface topography ultimately also result in different cutting rates during the nanogrinding process. While the average roughness R_a is a value appropriate to describe the plate surface topography after conditioning, this roughness value is not suited to specify the plate topography changes occurring after conditioning. A roughness value better suited to characterize the change of profile during diamond impregnation is the reduced peak height R_{pk}. This roughness value, originating from the Abbott curve, decreases during diamond impregnation and stays more or less constant during workpiece machining.

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