euspen's 23rd International Conference & Exhibition, Copenhagen, DK, June 2023
www.euspen.eu

The influence of an energetic field on the diamond turning process of distinct metals

T. Zielinski[1], O. Riemer[1]

[1]*Leibniz Institute for Materials Engineering, Laboratory for Precision Machining, Badgasteiner Str. 3, 28359 Bremen, Germany*

zielinski@iwt.uni-bremen.com

Abstract
Ultrasonic-assisted manufacturing processes are regarded as key technology for reducing tool wear of diamond tools when machining steel. Previous investigations show, that the economical machining of different steel materials is possible since tool wear is significantly reduced by vibrating the tool at ultrasonic frequencies. How far the ultrasonic assisted cutting of metals with diamond tools is governed by the changing process kinematics only or by the additional energy introduced into the material through the ultrasound has not yet been investigated.
In this context, the present investigation is dedicated to diamond machining of distinct metals with an ultrasonic excitation on the workpiece side. The aim of the study is to investigate to which extent the modification introduced into the material can be attributed solely to the superimposed energetic field of the ultrasound. For the realization of a processing in the ultrasonic field a dedicated experimental set-up was designed and the machining process with varying ultrasonic excitations is carried out on steel, copper, brass and aluminium samples; carbide and monocrystalline diamond tools are applied in the machining. The evaluation of the experiments is based on process forces.

Diamond machining, Ultrasonic softening, Process Forces, Topography

1. Introduction

Due to the technical advancements in the last years the demand of components with optical functions grew significantly. Examples are lenses for mobile phones as well as headlights and head-up-displays for the automotive industry. To produce large numbers of those components typically injection molding is used. A high durability of supplied molds is desirable, which can be archieved with steel as mold material. Unfortunately, a surface with certain optical properties can only be machined with diamond tools, although their use in the machining of steel results in catastrophic tool wear [1]. Ultrasonic-assisted manufacturing processes are regarded as key technology for reducing tool wear of diamond tools when machining steel. Previous investigations show, that the economical machining of different steel materials is possible since tool wear is significantly reduced by vibrating the tool on an elliptical path at ultrasonic frequencies [2, 3, 4]. However, the exact removal mechanisms and influences of the ultrasonic assisted machining are not yet known. A possible influence of the ultrasonic excitation on the machining process is given by the ultrasonic induced softening.

2. Ultrasonic induced softening

As early as 1955, Blaha and Langenecker found that an ultrasonic field has a significant impact on existing material properties [5]. They observed a reduction of the critical shear stress in tensile stress tests on zinc monocrystals as soon as the workpiece is exposed to an ultrasonic field. Here, the the workpiece was exposed to the energy of an ultrasonic field through a surrounding liquid medium. In subsequent research, the reduction of the critical shear stress was proven for a variety of materials. In addition to zinc, it also occurs with many other materials, including glass [6], steel [7, 8], copper [9] and aluminium [10]. An influence of the amplitude of the ultrasonic exposition on the shear stress reduction at constant frequency was also noted [Wan16]. However, it is not yet investigated, if the ultrasonic softening has any influence on a cutting process.

3. Objective

In this context, the presented investigation is dedicated to diamond machining of distinct metals with an ultrasonic excitation on the workpiece side. The aim of this investigation is to determine to which extent the effects of the ultrasonic assisted machining on the process can be attributed solely to the superimposed energetic field of the ultrasound with the effect of ultrasonic induced softening.

As a relevant indicator for analyzing a cutting process, the characterization is focused on the process forces in this first machining experiments with an ultrasonic excitation.

4. Experimental setup

For the machining an experimental setup was realised, which exposes the tool and workpiece to an ultrasonic field through a liquid medium similar to the tensile tests performed by Blaha and Langenecker.

4.1. Ultrasonic field

The ultrasonic field is generated in an ultrasonic cleaning unit (Type: ELMA P30H) originally designed for cleaning purposes in medical applications. A mounting unit for the workpiece was incorporated in the device (Figure 1). The frequency level of the ultrasonic unit can be varied at 37 kHz and 80 kHz. On the other hand, the intensity and thus the energy density of the ultrasonic field can be set unrestricted between 30 % and 100 %. As liquid medium distilled and de-ionised water with accordance to VDE 0510 was used. For analyzing the impact of the ultrasonic field an the machining process, the static process forces were measured on the tool side with a piezoelectric dynamometer (Type: Kister 9254).

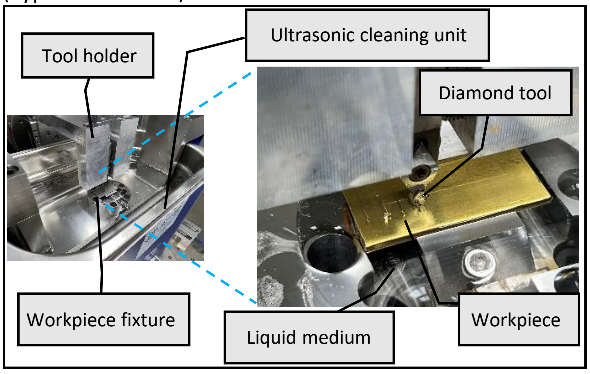

Figure 1. Experimental setup

4.2. Machining

The machining experiments were carried out on an ultraprecision machine (Type: Moore Nanotech 500FG), in which the diamond tool (r_ε = 750 µm; γ = 0°) was mounted in the tool holder, which was attached to the dynamometer and the main spindle respectively. The cutting motion for the grooving experiments with an increasing depth of cut ($a_{p,max}$ = 15 µm) was realised solely using the linear axes of the machine with a cutting velocity of v_c = 30 mm/min. The resulting process forces for the grooving experiments while machining steel (42CrMo4), copper (Cu-OF), aluminium (AlMg4.5Mn0.7) and brass (CuZn37) were obtained for a depth of cut of a_p = 7.5 µm.

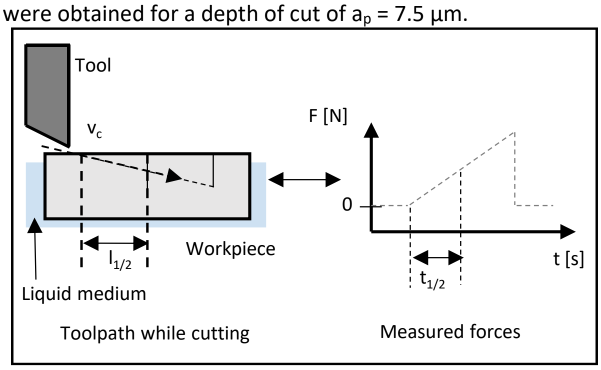

Figure 2. Maching process and process force analysis

5. Analysis of the impact of an ultrasonic field on cutting

The resulting data for both cutting and thrust forces are visualized in Figure 3 for all investigated materials with the exception of steel. Opposite to ultrasonic assisted machining of steel with diamond tools the tool wear occurred to be catastrophic. Therefore the experiments with steel workpieces were not further carried out.

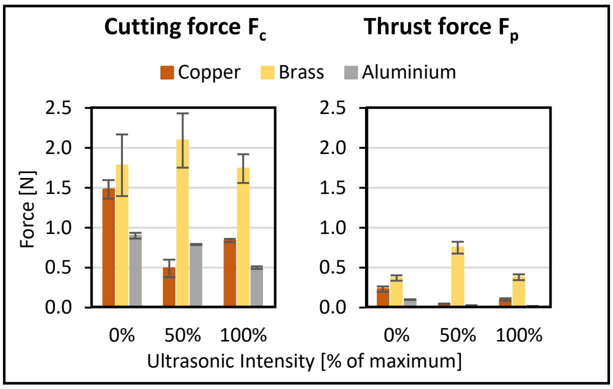

Figure 2. Resulting process forces

The relation between the cutting and thrust forces is indepentend from the machined metal generally the same for all cutting experiments. For copper and aluminium the exposition of the machining process to an ultrasonic field results in lower process forces. Especially aluminium exhibits an increasing intensity of the ultrasoning field continuously decreasing the process forces by up to 45 %; for copper the decrease is still significant and up to 66 %, but not continously. Machining brass on the other hand is not observably affected by the ultrasonic field. A possible explanation is an insufficient flatness of the workpieces, as the brass workpieces were not premachined. However, an influence of the ultrasonic field on the machining process can be claimed.

6. Conclusions

Machining experiments under different ultrasonic fields were carried out on different metals using diamond tools. It was observed, that with an increased intensity of the ultrasonic field, nearly all process forces decreased. A linear correlation could not be made for all cases, which might be attributed to not sufficient workpiece preparation. Future experiments will therefore include improved premachined workpieces, as well as an investigation, whether the resulting surface topography in the ground of grooving experiments or the tool wear are influenced by the superpositioning of an ultrasonic field. Perspectively, the decrease of process forces due to an increase of the ultrasonic induced energy offers potential to improve the machining of brittle and hard-to-cut materials, which is the aim of future works.

Acknowledgements

The work is funded by the German Research Foundation (DFG), project number 511868434.

References

[1] Brinksmeier, E., Gläbe, R.: Diamond Machining of Steel Molds for Optical Applications. *Key Engineering Materials* **364-366** (2008) 701-706.
[2] Moriwaki, T., Shamoto, E.: Ultraprecision Diamond Turning of Stainless Steel by Applying Ultrasonic Vibration. *CIRP Annals* **40**, Issue 1 (1991) 559-562.
[3] Gläbe, R.: Prozess- und Schneidstoffentwicklungen zur ultra-präzisen Drehbearbeitung von Stahl. Bremen (2003), Dissertation.
[4] Zielinski, T.; Rickens, K.; Riemer, O.; Karpuschewski, B.: Ultrasonic assisted diamond turning of conventional and additive manufactured steel materials for optical components. *euspen 20th International Conference Proceedings* (2020) 421-422.
[5] Blaha, F.; Langenecker, B.: Dehnung von Zink-Kristallen unter Ultraschalleinwirkung. *Naturwissenschaften* **42** (1955) 556–559.
[6] Zhang, C.; Rentsch, R.; Brinksmeier, E.: Advances in micro ultrasonic assisted lapping of microstructures in hard–brittle materials: a brief review and outlook. *International Journal of Machine Tools & Manufacture* **45** (2005) 881–890.
[7] Harada, K.; Sasahara, H.: Effect of dynamic response and displacement/stress amplitude on ultrasonic vibration cutting. *Journal of Materials Processing Technology* **209** (2009) 4490–4495.
[8] Dutta, R.K.; Petrov, R.H.; Delhez, R.; Hermans, M.J.M.; Richardson, I.M.; Böttger, A.J.: The effect of tensile deformation by in situ ultrasonic treatment on the microstructure of low-carbon steel. *Acta Materialia* **61** (2013) 1592–1602.
[9] Hu, J.; Shimizu, T.; Yang, M.: Impact effect of superimposed ultrasonic vibration on material characteristics in compression tests. *Procedia Engineering* **207** (2017) 1063–1068.
[10] Wang, C.J.; Liu, Y.; Gou, B.; Shan, D.B.; Zhang, B.: Acoustic softening and stress superposition in ultrasonic vibration assisted uniaxial tension of copper foil: Experiments and modeling. *Materials and Design* **112** (2016) 246–253.