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Cutting forces while machining STAVAX ESU with binderless-cBN

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Abstract
Binderless-cubic-Boron-Nitride(cBN) from the company SUMITOMO CORPORATION, Itami, Japan, provides the opportunity for direct cutting of steel with ultra-precision quality without additional equipment or coating of the workpiece. This work presents the latest results in the field of ultra-precision machining of hardened stainless steel with binderless-cBN. In this paper the influence of the cutting speed v_c, the feed f, the depth of cut a_p, and the cooling lubricant on the cutting force F_c is shown for turning the stainless steel STAVAX ESU. The cutting speed, the feed and the depth of cut were varied between $3\ m/min \leq v_c \leq 450\ m/min$, $0.9\ \mu m \leq f \leq 9.7\ \mu m$, and $5\ \mu m \leq a_p \leq 30\ \mu m$ respectively. As cooling lubricants compressed air and W200SL of the company OPORTET, Duisburg, Germany, with a volumetric flow rate $\dot{V} = 1\ l/min$ were used. For measuring the cutting forces F_c the piezoelectric dynamometer MINIDYN 9256C2 from the KISTLER INSTRUMENTE AG, Middlefield, USA, was used. As a result of this work cutting forces $F_c \leq 4.9$ N could be observed with an inconstant progression over the varied process parameters.

Keywords: Ultraprecision-turning, stainless steel and cBN

1 Introduction

Micro-injection moulds with an arithmetical mean deviation $Ra \leq 30$ nm and a geometrical accuracy $a_g \leq 5\ \mu m$ are often required to fulfil the markets demands from the biotechnology, medicine and the automotive industry. Micro-injection moulding is a key technology for replication of low-priced plastic parts [1]. Especially the growing market of the medicine technology needs an increasing number of these products [2].

Ultra-precision-(UP)machining of non-ferrous workpiece materials is well known for the mentioned application. To increase the economic efficiency of the replication process mould and die making industry prefers the use of hardened steel as mould material. UP-machining of ferrous materials with single crystal diamond as cutting material leads to an excessive tool wear. To overcome this limitation several investigations have been done [3]. The ultrasonic assisted machining (UAM) is one approach which is currently applied in industry. Usually this process technology leads to a limited cutting speed $v_c < 5$ m/min and requires an additional device [4]. An often used technology to avoid the direct cutting of hardened steel is a coating with a layer made of Nickel-Phosphorus (NiP). Pre-machined steel moulds are electroless coated with a layer with a thickness $d \geq 50\ \mu m$. Both technologies increase the development time t_d for the moulds and make the process insufficient.

A different approach to enable the direct cutting of hardened steel is the substitution of the diamond through binderless-cubic-Boron Nitrid (cBN). UHLMANN ET AL. [5] and POLTE ET AL. [6] showed with preliminary investigations that the wear of binderless-cBN is influenced by oxygen (O_2) through the formation of Boron Oxide (B_2O_3). UHLMANN ET AL. [7] also showed that an arithmetical mean deviation $Ra = 9$ nm is achievable.

2 Experimental setup

To investigate the cutting forces F_c while maching the steel material STAVAX ESU from the company BÖHLER-UDDEHOLM DEUTSCHLAND GMBH, Düsseldorf, Germany, face turning test were carried out on the machine tool NANOTECH 350 FG from the company MOORE NANOTECHNOLOGY SYSTEMS, LLC, Swanzey, USA. The binderless-cBN-tools had a corner radius $r_\varepsilon = 1{,}200\ \mu m$ and a clearance angle $\alpha_0 = 5\ °$. The tools also showed a polished rake face A_γ and polished flank face A_α. The cutting speed was varied between $3\ m/min \leq v_c \leq 450\ m/min$, the depth of cut between $5\ \mu m \leq a_p \leq 30\ \mu m$ and the feed between $3.4\ \mu m \leq f \leq 9.7\ \mu m$. A piezoelectric dynamometer MINIDYN 9256C2 from the company KISTLER INSTRUMENTE AG, Winterthur, Switzerland, was used for cutting force acquisition. Figure 1. shows the experimental setup for the cutting test.

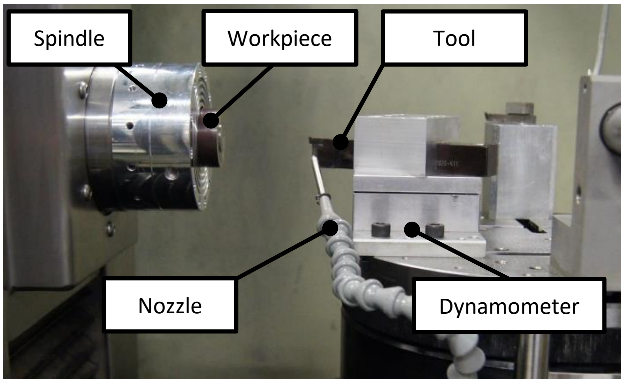

Figure 1. Experimental setup for face turning tests

As cooling lubricants compressed air and the liquid cooling lubricant W200SL from the company OPORTET®, Duisburg, Germany, were compared. W200SL was used with a volumetric flow rate $\dot{V} = 1$ l/min.

3 Cutting test

Knowledge of cutting forces F_c is important for a holistic process understanding. Figure 2. shows the measured values for the cutting forces F_c depending on the cutting speed v_c, the depth of cut a_p, and the feed f. Regarding the cutting speed v_c it could be observed that the cutting force varies between $0.8 \text{ N} \leq F_c \leq 1.4 \text{ N}$ when compressed air was used and between $1.1 \text{ N} \leq F_c \leq 1.9 \text{ N}$ when W200SL was used as cooling lubricant. A comparison between the cooling lubricants shows that compressed air leads to lower cutting forces F_c because of the decreasing hardness of the steel material with increasing cutting temperatures ϑ_Z. This effect could also be observed regarding the depth of cut a_p and the feed f. Figure 2 shows also an almost linear increase of the cutting forces F_c between $1.0 \text{ N} \leq F_c \leq 3.7 \text{ N}$ and $1.4 \text{ N} \leq F_c \leq 4.9 \text{ N}$ regarding the depth of cut a_p. This fact could be explained by an increasing cross-section of undeformed chip A. The feed shows a small influence on the cutting force F_c between $3.4 \text{ µm} \leq f \leq 6.9 \text{ µm}$ which could be explained by a shift of the point where the minimum chip thickness h_{min} is reached. This affects the cutting forces F_c because of a changed frictional behaviour between the workpiece and the tool. Using a cutting speed $v_c = 150$ m/min, a depth of cut $a_p = 5$ µm, a feed f = 4.9 µm, and W200SL as cutting lubricant a surface roughness Ra = 9 nm and Rz = 43 nm could be achieved. The cutting material shows a high potential for the application in the mould and die making industry, e.g. for illumination optics and sealing elements.

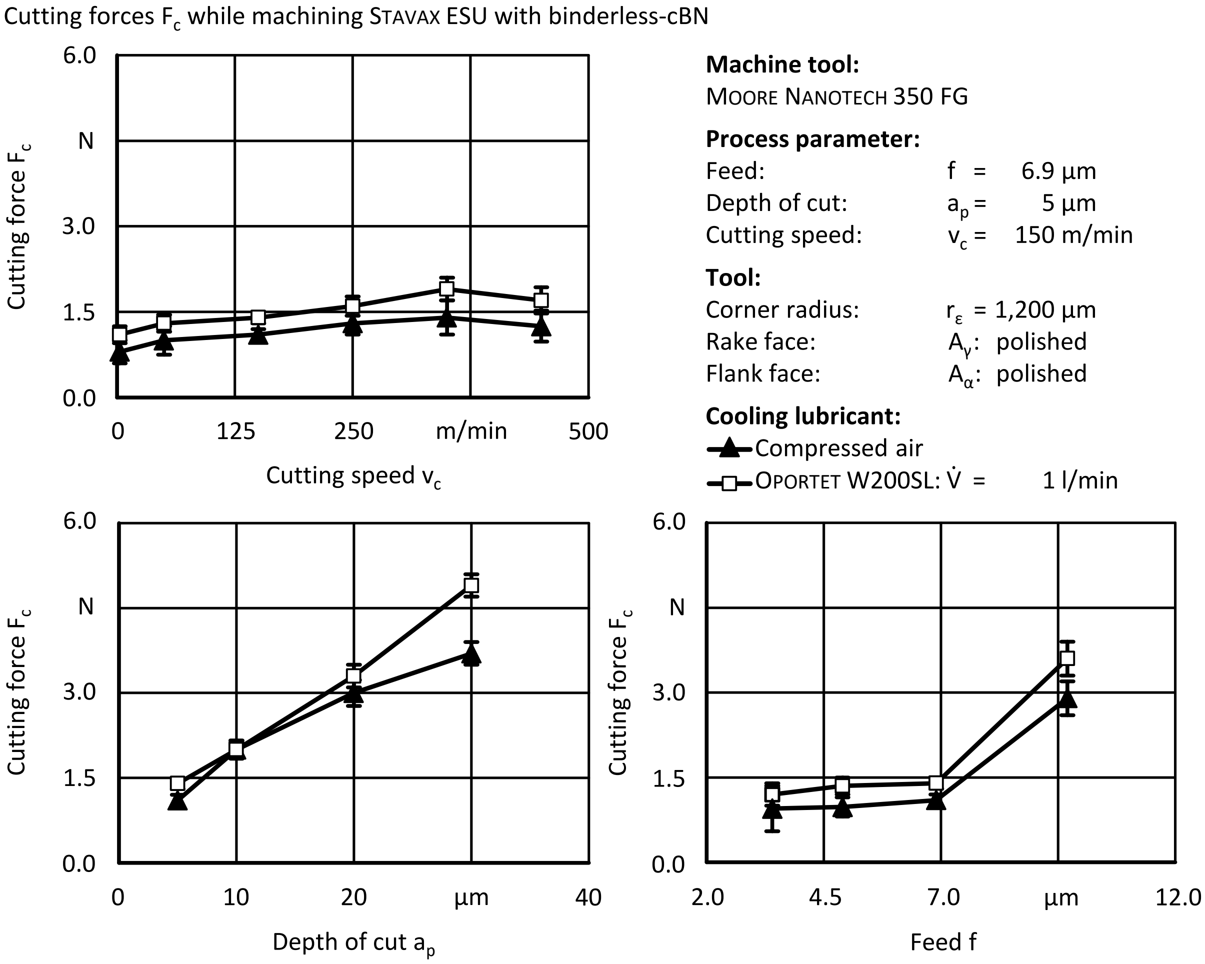

Figure 2. Cutting forces in dependency of the cutting speed v_c, the depth of cut a_p, and the feed f with respect to the cooling lubricants compressed air and W200SL

4 Summary

The findings of this ongoing research show that the cutting forces F_c are in the range $0.8 \text{ N} \leq F_c \leq 4.9 \text{ N}$ for the investigated set of parameters. It is also shown that the influence of the cutting speed v_c and the feed between $3.4 \text{ µm} \leq f \leq 6.9 \text{ µm}$ is less compared to the depth of cut a_p and a feed f > 6.9 µm. This work is funded by the GERMAN RESEARCH FOUNDATION (DFG) within the project “Ultra-precision maching with binderless-cBN”.

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