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Effect of cooling lubricant on surface roughness for turning stainless steel with binderless-cBN

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Abstract
Binderless-cubic Boron Nitride (cBN) from the company SUMITOMO CORPORATION, Itami, Japan, is one of the most promising cutting materials providing the opportunity for direct cutting of steel with ultra-precision (UP) quality without additional equipment or coating of the workpiece. This work presents the latest development in the field of precision machining of hardened stainless steel with binderless-cBN. In this paper the influence of the feed f and the cooling lubricant on the surface roughness is shown for turning the hardened stainless steel STAVAX ESR (H = 52 HRC) from the company BÖHLER-UDDEHOLM, Düsseldorf, Germany. A surface roughness Ra = 9 nm and Rz = 42 nm could be achieved using binderless-cBN and the cooling lubricant W200SL of the company OPORTET, Duisburg, Germany.

Keywords: Ultraprecision-turning, stainless steel and cBN

1 Introduction

Micro-injection moulding is a key technology for the replication of micro-parts [1]. Therefore hardened steel moulds with a surface roughness Ra ≤ 30 nm and a geometrical accuracy a_g ≤ 5 µm are usually required. By the combination of micro-injection moulding and ultra-precision(UP)-machining it is possible to manufacture plastic parts with high accuracy in shape and surface finish as mass products. These products are required in the fields of medicine, biotechnology, automotive and aviation.

Highest requirements regarding surface finish and accuracy in shape are achievable due to the use of single crystal diamond as cutting material. Cutting ferrous materials with classical UP-equipment leads to an excessive wear of the diamond tool. As a result of this wear behaviour it is not possible to achieve a surface finish which could be compared to cutting non-ferrous materials. Currently pre-machined moulds have to be coated with a nickel-phosphorus-layer to avoid the direct cutting of ferrous materials. To enable the direct cutting of ferrous materials with single crystal diamond various investigations have been done [2]. One approach is the ultrasonic-assisted machining which leads to an intermittent cut. The ultrasonic-assisted machining is commonly used with a cutting speed v_c < 5 m/min [3].

2 Experimental setup and cutting test

To overcome the shown limitations binderless-cubic Boron Nitride(cBN)-tools were investigated for cutting the stainless steel STAVAX ESR (1.2083) of the company BÖHLER-UDDEHOLM DEUTSCHLAND GMBH, Düsseldorf, Germany, with a Rockwell-hardness H = 52 HRC. The cBN was sintered without any binder phase by SUMITOMO CORPORATION, Itami, Japan, and machined by the company MÖSSNER GMBH, Pforzheim, Germany. Further investigations have shown that binderless-cBN offers a great resistance against adhesion, abrasion and attrition [4]. In addition it could be shown that the wear of binderless-cBN-tools could be reduced by the use of cooling lubricant [5].

The investigated tools had a corner radius r_ε = 1,200 µm and a clearance angle α_0 = 5 °. The feed was varied between 3.4 µm ≤ f ≤ 9.7 µm while using a constant cutting speed v_c = 150 m/min and a depth of cut a_p = 5 µm. Investigations were carried out on the machine tool NANOTECH 350 FG of the company MOORE NANOTECHNOLOGY SYSTEMS, LLC, Swanzey, USA. Figure 1 shows the experimental setup for the cutting tests.

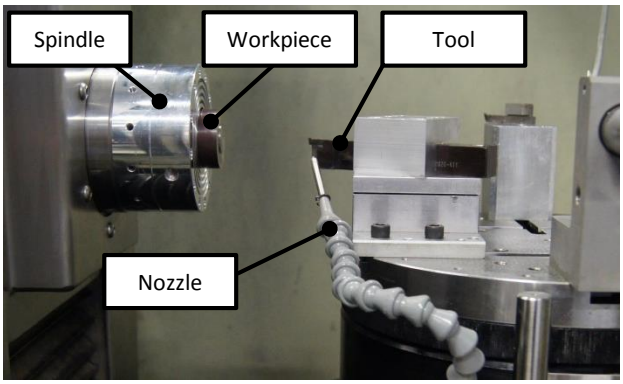

Figure 1. Face turning with binderless-cBN and STAVAX ESR.

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. The cooling lubricant W200SL is composed of petroleum, methyl-oxazolidine, propinylbutylcarbamat, boric acid and water [6]. For measuring the surface roughness the white light interferometer NEWVIEW 5010 from the company ZYGO CORPORATION, Middlefield, USA, was used.

Figure 2 shows the characteristic values of the surface roughness Ra and Rz depending on the feed f and the cooling lubricant. Within the investigated range of the feed f a surface

roughness 10 nm ≤ Ra ≤ 53 nm and 42 nm ≤ Rz ≤ 180 nm could be measured while using compressed air as cooling lubricant. Using W200SL as cooling lubricant a surface roughness 9 nm ≤ Ra ≤ 33 nm and 42 nm ≤ Rz ≤ 148 nm could be documented. Furthermore, figure 2 shows an approximately proportional correlation between the surface roughness Ra, Rz and the feed f while using compressed air. In contrast to this no linear relation between the feed f and the surface roughness could be observed using W200SL as cooling lubricant. According to that the influence of the feed in the range of 3.4 µm ≤ f ≤ 6.9 µm could be rated as low. Using a feed f > 6.9 µm, increased values for the surface roughness Ra and Rz could be documented.

The different progression of the surface roughness in dependency to the feed f could be caused by the reduced minimum chip thickness h_{min} as a result of the cooling lubricant W200SL. The point where the minimum chip thickness h_{min} is reached shifts in the direction of the minor cutting edge S'_W. As a result the amount of workpiece material which is separated by shear increased compared to the workpiece material which is suppressed by plastic and elastic deformation. While using a feed f ≤ 6.9 µm and W200SL as cooling lubricant no decrease of the values for the surface roughness Ra and Rz could be observed. This fact could be explained by the shift of the minimum chip thickness h_{min} in the direction of the major cutting edge S_W for a decreased feed f. After the cutting tests with binderless-cBN and the workpiece material STAVAX ESR a maximum width of flank wear land 12.8 µm ≤ VB_{max} ≤ 28.0 µm for using compressed air and 6.8 µm ≤ VB_{max} ≤ 20.0 µm for using W200SL could be detected after a path length l_c = 50 m.

Face turning of STAVAX ESR with binderless-cBN

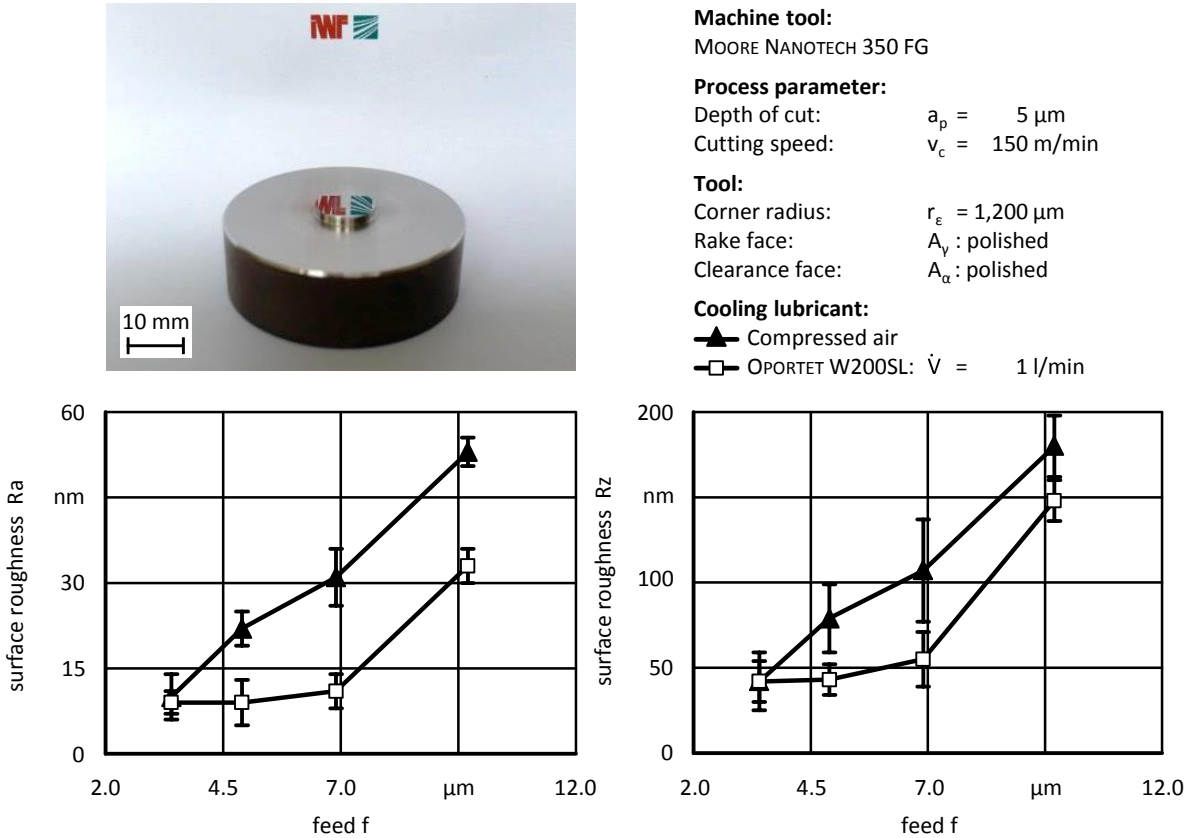

Figure 2. Surface roughness depending on feed f and cooling lubricant for binderless-cBN-tools with a corner radius of r_ε = 1.200 µm.

3 Conclusion and outlook

The findings of this ongoing research show that a surface roughness Ra = 9 nm and Rz = 42 nm could be achieved with binderless-cBN as cutting material. It is also shown that the feed f and the use of the cooling lubricant W200SL influence the surface roughness. Especially for a feed in the range of 3,4 µm < f ≤ 9,7 µm a lower surface roughness could be measured compared to the use of compressed air as cooling lubricant. Further research activities address the wear behaviour of binderless-cBN while cutting the hardened steel STAVAX ESR. This work is funded by the GERMAN RESEARCH FOUNDATION (DFG) within the project “Ultra-precision machining with binderless-cBN”.

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