Influence on the ductile behaviour of binderless tungsten carbide applying ultrasonic assisted diamond turning

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Abstract

For the production of mould inserts for precision glass moulding, the ultra precision grinding technique with a subsequent manual polishing operation is typically applied. These processes are time consuming and have a relatively low reproducibility. An alternative manufacturing technology, with a high predictability and efficiency, which additionally allows a higher geometrical flexibility, is the diamond turning technique. In addition the ultrasonic assisted ultra precision cutting process has already proven its potential for machining difficult-to-cut materials, such as steel and glass. By applying the ultrasonic assistance, the classic constraints of the process can be widened significantly. In this publication the process is applied on binderless, nano crystalline tungsten carbide.

1 Experimental setup

The experiments were divided into two blocks with different objectives. The first block included basic ruling experiments, which served as an indicator of ductile material behaviour of the nano-grain tungsten carbide (Figure 1 left). In these experiments, the tool performed a linear movement with a steadily increasing depth of cut. The strategy is similar to the well known nanoindenter tests, however, the tests have a more practical transferability, since real diamond tools are used. The experiments enabled a comparison of the processes with and without ultrasonic assistance. There were used two different frequencies of 60 and 80 kHz.

Additional face turning experiments were conducted in order to identify the process limits regarding tool wear and roughness depending on the processing parameters The strategy is shown in Figure 1 right. The experiments were performed on an ultra precision machine with a son-x ultrasonic tooling system (UTS one) and diamond tools from Contour Fine Tooling.

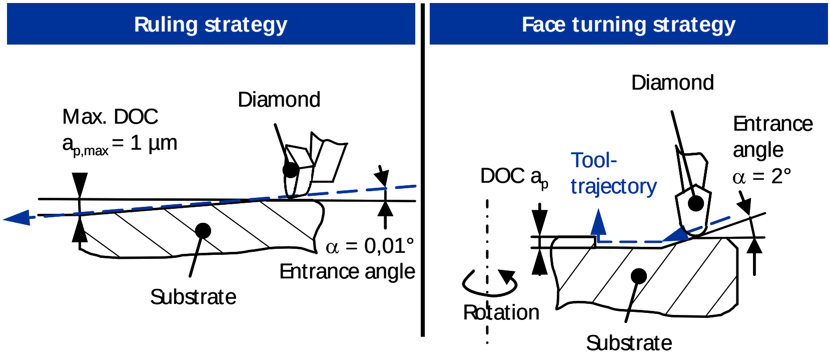

Figure 1: Machining strategies

Detailed material analysis of the machined nano grain tungsten carbide grade (CTN01L) revealed a critical depth of cut at a undeformed chip thickness of $h_{cu,crit}$ = 165 nm. The value was estimated based on the theoretical assumptions from Bifano et. al and Blackley et. al [1, 2], where the critical depth of cut is calculated from the material hardness, the elastic modulus, the fracture toughness and a specific constant.

2 Machining results of ruling tests

The ruling operations were conducted at three different configurations: without ultrasonic assistance (conventional), with a ultrasonic assistance of 60 kHz and with 80 kHz. The generated surfaces are shown in Fig. 1 in the described order.

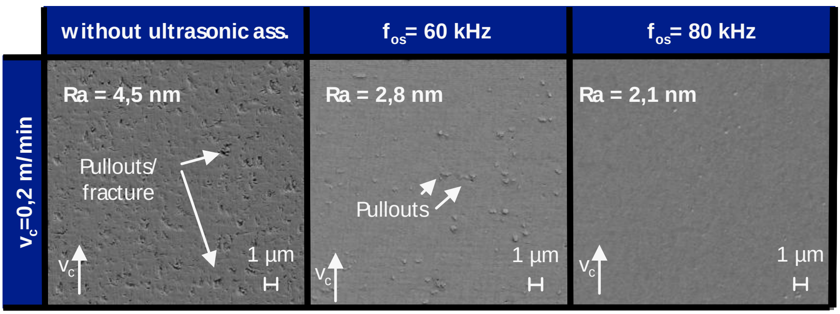

Figure 2: Surface topography after ruling tests with different configurations

Several pullouts and micro fractures can be identified at the ruled surface without ultrasonic assistance. The cutting depth at the measurements is at about 0.5 µm and hence above the critical depth of cut, which leads to brittle fracture. Applying the ultrasonic assisted process with 60 kHz (Fig. 2 centre) the fracture is reduced. By increasing the frequency to 80 kHz (Fig. 2 right) the fracture cannot be identified anymore. Hence an increase in the critical depth of cut by applying the ultrasonic assistance can be derived. A higher frequency seems beneficial for the ductile mechanisms in the tungsten carbide material.

3 Machining results of face turning tests

The face turning experiments revealed the influence of the feed rate on the surface roughness values, shown in Figure 3. The lower the feed, the lower the roughness. Specially a feed of 5 µm, which exceeds the critical depth of cut leads to excessive brittle fracture during the cutting process and a high roughness. The topography is shown in detail for each feed rate in Figure 4.

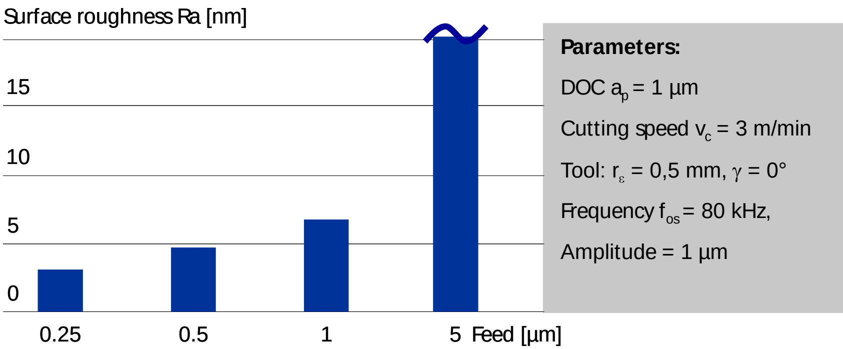

Figure 3: Surface roughness after face turning with ultrasonic assistance

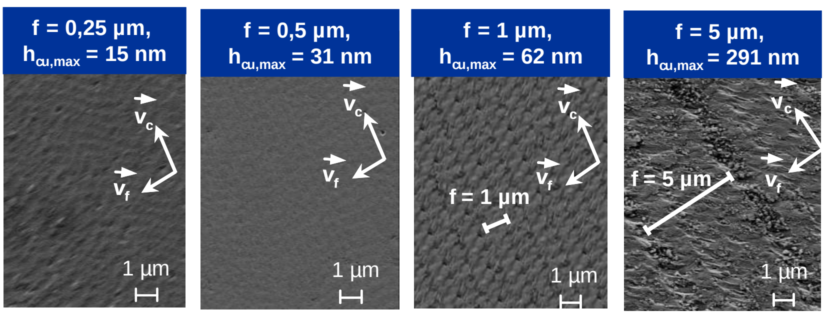

Figure 4: Surface topography after face turninig with different feed rates

4 Near surface analysis

The influence of the ultrasonic assistance on the cutting mechanisms was detected based on the surface roughness measurements of the described experiments. Further near surface analysis (TEM) were performed in order to verify the assumption, that the ultrasonic assistance induces a higher compression strength into the shear zone in comparison to the conventional process. Representative measurements are shown in Figure 5, which verify this assumption. A strong surface deformation can be detected at the near surface zone of the experiment with an ultrasonic assistance of 80 kHz (right) up to a depth of approx. 600 nm, whereas the surface deformation without ultrasonic assistance is almost not measurable (left).

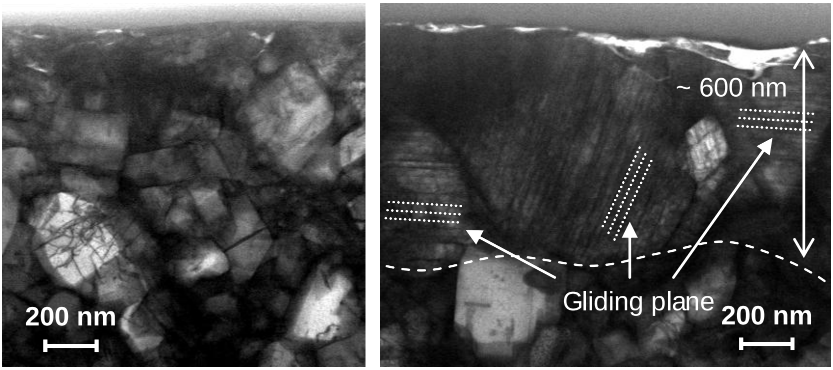

Figure 5: Near surface zone analysis with TEM, left: conventionally machined, right: machined with ultrasonic assistance

5 Summary and conclusion

In the presented experiments the ductile machining of the hard and brittle material nano grain tungsten carbide was proven applying single point diamond cutting. An ultrasonic assisted process improves the ductile machinability of the material. The explanation for this mechanism is the increased compressive stress and hence the increased energetic density in the shearing zone. This leads to an improved ductile behaviour of the brittle material tungsten carbide.

References:

[1] Bifano, T. G.; Dow, T.; Scattergood, R.: Ductile-Regime Grinding: a New Technology for Machining Brittle Materials, ASME Journal, 113, p.184-189, 1991

[2] Blackley, W.S.; Scattergood, R.O., Ductile Regime Machining Model for Diamond Turning of Brittle Materials, Prec. Eng., Vol. 13 No 2, 1991, S. 252-257