Influence of Laser Preparation on Surface Integrity and Performance of Cermet Cutting Inserts

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Abstract

Laser machining is successfully applied at tungsten carbide cutting tools in order to produce intricate geometries, which cannot be generated by abrasive methods. In previous investigations it was shown that laser machining, applied to cubic boron nitride (cBN) cutting tools, initiates chemical reactions of nitride and binder material, which may form films of tool protecting hard material. This paper shows the effects of laser machining on phase composition, surface roughness, and residual stresses of cermet cutting tools. Cutting experiments with tools before and after laser machining have been executed in the form of external cylindrical turning of AISI 1045. Tool wear has been investigated and is discussed.

Introduction

Laser machining, here especially laser beam material removal, has been on the upswing in cutting tool preparation recently. This technique can be applied for a great number of materials. Especially those materials, which are mechanically hard to machine offer potential for laser machining, particularly for individual tool geometries, like e. g. flank face undercuts. Besides short pulsed pico- or even femtosecond lasers, also low cost nanosecond lasers or simple marking lasers can be used for the preparation of cutting tools [1]. Influences of laser machining on cemented carbide tools concerning residual stresses, phase transformations etc. have been investigated for several years [2-5]. Some studies highlight that laser machining of cBN tools improves the tool behaviour and increases tool life [6-8].

Comparatively few knowledge exists on laser machining of cermets. Yuxin et al. [9] described a fabrication process of cermets using laser machining. They used powders of nickel, titanium and carbon on a low carbon steel substrate to create TiC-Ni cermets by a 5 kW continuous wave CO$_2$ laser. The nickel amount proved to be responsible for different cermet properties. Sun et al. [10] were able to create ZrB$_2$-Zr cermets by a combined laser sintering/melting technique with the aid of electromagnetic induction heating. The cermet properties, especially hardness, were determined by the ZrB$_2$ and the Zr content. Cermet laser machining in terms of drilling was investigated by Gurauskis et al. [11, 12]. Drilling of the sintered material led to inferior results than machining of the green material. Morimoto et al. [13] conducted a targeted surface modification of thermally sprayed Cr$_3$C$_2$-NiCr cermets by a direct diode laser. The treatment resulted in a distinct increase of Vickers hardness and wear resistance.

Despite an increasing use of cermet cutting tools in industry, the knowledge on tool preparation via laser machining and its influence on tool life is very limited. In the following material properties of laser treated cermet cutting inserts and their wear behaviour during external turning are presented and discussed.
Experimental
For the investigations squared cutting inserts (SNMG120408) of Ti(C,N)-Co cermet have been chosen. Laser machining was performed on a Sauer Lasertec 40 Precision Tool. This machine is equipped with a 13 W Q-switch Nd:YVO$_4$ laser with a wavelength of $\lambda = 1,064$ nm (infrared), a pulse width of 70 ns at 40 kHz and a focus diameter of 40 µm. Two sets of specimens have been prepared. The first one was used for material analyses, the tools from the second set were applied in subsequent cutting experiments. An area of $3 \times 11$ mm$^2$ was laser machined on the flank face of the first set of specimens with the parameters shown in table 1. In case of the second set, the chip breaker was removed by grinding first. Secondly, the complete rake face was treated with the laser parameters at specimen no. 3, 1, and 4. The selected laser parameters were chosen with respect to an increasing heat input (table 1). Fig. 1 depicts the tool geometry and the prepared areas.

<table>
<thead>
<tr>
<th>specimen no.</th>
<th>laser frequency $f_l$ (kHz)</th>
<th>feed velocity $v_f$ (mm/s)</th>
<th>trace offset $o_t$ (µm)</th>
<th>laser power $P_l$ (%)</th>
<th>increasing heat input</th>
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Tab. 1: Laser machining parameters in order of increasing heat input

Aiming to analyse the influence of the laser treatment on tool behaviour and tool life the laser treated cutting inserts (set 2) were used in external turning of AISI 1045. The turning experiments were conducted on a Gildemeister CTX520L lathe. The process parameters were chosen according to a finishing process. Thus, a constant feed ($f = 0.1$ mm), a constant cutting speed ($v_c = 400$ m/min) and constant depth of cut ($a_p = 0.1$ mm) were set. The progression of the tool wear was analysed with a digital video microscope and by scanning electron microscopy (SEM). Additionally, process forces in x-, y- and z-direction have been measured using a Kistler 9121 three-component force dynamometer. The wear criterion was set to a tool life time of $t_c = 5$ min, which is equivalent to a cutting length of $l_c = 600$ m. One repetition was carried out for all cutting tests.

Results of Laser Machining and Discussion
The effects of laser machining can be seen macroscopically as a discoloration, either green or black, depending on the laser parameters. SEM micrographs display the influence of the thermal energy on the tool surface much more detailed (Fig. 2). At lower magnification (left side) the reference tool and tools no. 11 and 3 show undisturbed, smooth surfaces, while in tool no. 10 the first irregularities
appear. Tools no. 9 and 1 possess a fine structured, rough surface, while tool no. 8 shows large structures. Surfaces 6 and 4 again have finer structures, but a little coarser than tools no. 9 and 1.

More details can be seen at higher magnifications (Fig. 2, right). The reference specimen possesses the typical sintered surface. Even the lowest heat input during our experiments causes a melting of surface material, which solidifies again, forming an altered surface (tool no. 11). Increasing heat input shows more distinct laser traces and many cracks in the surface (tool no. 3). Tool no. 10 shows two different surface occurrences: molten and re-solidified traces alternate with completely new shaped traces. The tools no. 9 to no. 4 exhibit completely new shaped surfaces. Interestingly, the structure of tool no. 8 differs significantly from the other surfaces.

**Fig. 2:** SEM micrographs of reference specimen and laser machined surfaces, increasing heat input from top to bottom
In order to get further insight into the formation of new surfaces at a certain heat input, X-ray diffractograms have been made from the machined surfaces. A ground tool is taken as a reference. This diffractogram shows peaks of TiC$_{0.7}$N$_{0.3}$ and of Co (Fig. 3, top). Tools no. 11 and no. 3 show comparable results with a reduced intensity for the cobalt peaks. This is obviously a result of partial melting and re-solidification of surface material. From tool no. 10 to no. 4 additional peaks with increasing intensity by trend appear, which can be assigned to rutile TiO$_2$ (Fig. 3). With further increasing heat input, starting from tool no. 9 or no. 1, another set of additional peaks is observed. This can be correlated to CoTiO$_3$. Consequently, the sharply increasing roughness of the surface at higher heat inputs can be explained by chemical reactions. These reactions are initiated by thermal impacts, which exceed a critical limit.

Fig. 3: X-ray diffractograms of reference specimen and laser machined surfaces, increasing heat input from top to bottom

Fig. 4: Increasing tensile residual stresses with increasing heat input
Residual stress measurements at the Ti(C,N) phase show that the low compressive stresses as a result of the sintering process are converted to tensile residual stresses by laser machining, by trend with an increasing amplitude at higher heat inputs (Fig. 4).

**Results of Cutting Experiments and Discussion**

Abrasive and adhesive wear on rake and flank face occurs in the cutting edge in form of crater and flank wear, respectively. The flank wear shows a comparable wear behaviour with minor increased wear for the laser prepared inserts, which was expected since only the rake face of the inserts had been laser treated. In contrast to this, significant differences regarding the crater wear of specimen no. 3 and the reference specimen could be observed. SEM micrographs clearly show less adhesions on the rake face of the laser treated insert (Fig. 5).

![Fig. 5: Reduced crater wear due to laser preparation of the rake face](image)

With respect to the results presented in Fig. 3 it becomes clear that the reduced tendency toward adhesions can be attributed most likely to the altered surface topography, since no phase transformation has been observed at specimen no. 3. Laser machining obviously generates a 3D micro-pattern in the surface, which under favourable conditions decreases the contact area between tool and chip. Thus, friction decreases as well as the process forces. The latter were measured and are presented in Fig. 6.

![Fig. 6: Decreasing process forces with increasing laser feed velocity \(v_f\)](image)

It can be stated, that the process forces in comparison to the reference inserts decrease with increasing laser feed velocity and thus decreasing heat input, see Figure 6. Thus, the lowest process...
forces result for specimen no. 3. In case of the cutting forces $F_c$ a reduction of 10 % regarding the reference inserts was achieved due to a prepared rake face.

Conclusion
Laser treatment of cutting tools is becoming increasingly noticed in research and industry. However, knowledge on the preparation of cerments is still limited. From the results of this study it is can be concluded that an increasing heat input results in an alteration of the surface due to melting and re-solidification as well as chemical reactions. At higher heat inputs additional phases like CoTiO$_3$ and TiO$_2$ could be detected. Moreover, higher heat input from laser machining leads to increasing tensile stresses next to the surface. With respect to tool behaviour and tool life a reduced tendency toward adhesions and lower process forces could be observed for one of the laser treated specimens compared to the reference inserts. The results indicate that this observation can be attributed to the altered surface topography rather than to chemical modifications. However, further research is necessary to support this finding.

Acknowledgement
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References