Conference Paper

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Post-Coating Treatment of Cutting Edge for Drilling Carbon Fibre Reinforced Plastics (CFRP)

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Abstract

Drilling of highly abrasive carbon fibre reinforced plastics (CFRP) requires carbide tools with geometrical highly adaptable tool geometries and wear resistant diamond coatings. To counteract the tradeoff between long tool lifetime by preferably thick diamond layers leading to large cutting edge radii (bluntness), and the sharpest possible cutting edge to generate flawless machining qualities, the following post-coating cutting edge treatment methods are compared: Laser-ablation and selective sandblasting. It is shown that laser treatment generates cutting edge radii of 3-4 µm leading to outstanding bore exit qualities in CFRP from the first bore on, while diamond still protects the rake face.

Keywords: CFRP; Cutting Edge Treatment; Drilling; Diamond Coating; Laser; Sandblast

1. Introduction

Driven by the aviation and automotive industry drilling and milling carbon fibre reinforced plastics (CFRP) is heavily investigated. Besides an increase of machining quality the optimisation of tool lifetime is in focus of research. The main thrusts are on tool geometry and coating [1-3].

This study proves that cutting edge preparation is an option to increase the machining quality as well as the tool lifetime not only in metal machining [4, 5] but also in drilling CFRP. Due to the abrasiveness of CFRP with high fibre content, diamond tools are increasingly used for high volume drilling operations in the aerospace industry. The hard and sliding-wear-resistant diamond protects the comparatively soft cutting edge from rapidly getting worn and rounded, among others presented by Wang et al. [1]. Although PCD tools possess a much thicker layer of diamond and nominal could stand the tool wear longer, at least for drilling operations, diamond coated carbide drills have become established due to currently higher geometry flexibility [3]. According to Gilpin [6] adjustments of the tools macro and micro geometry play a decisive role in drilling CFRP, where chip formation and transport have a huge influence on the machining quality.

The diamond coating represents an extra layer on top of the grinded carbide tool, usually with a thickness in the range of 6-12.5 µm [1-3]. Assuming a minimum grindable cutting edge radius of about 4 µm, depending on the carbide composition and the grinding process, a cutting edge radius after coating of 10-16.5 µm will arise. Most of the carbon fibres for the aerospace industry show diameters in the range of 5-7 µm. Consequently the post-coating cutting edge radius is up to triple the size of the fibre diameter, resulting in rather blunt tools. According to extensive studies by Tsao and Hocheng [7] and analyses by Henerichs [8], tools should be as sharp as possible to reach acceptable machining quality with low forces. Despite coating companies use edge finishing techniques before the coating process to improve the cutting edge sharpness, experiments by Henerichs et al. [3] and Wang et al. [1] show that diamond coated carbide tools exhibit poor bore exit quality until the coating smoothens within the first bores (run-in period): The quantity of poor bores depends on tool geometry, coating and CFRP material.
It aims to develop diamond coated CFRP drilling tools which create initially a good bore quality. Therefore the following trade-off needs to be addressed: On the one hand to benefit from the enhanced tool lifetime by diamond coatings and on the other hand to reduce large peak radii of diamond coated tools. In this study two cutting edge treatment methods subsequent to the diamond coating process of CFRP drilling tools are presented: Tangential laser ablation and abrasive sandblasting. The treated cutting edges are tested in CFRP and compared to non-treated diamond coated tools. Analyses with infinite focus microscopy, force measurement and optical microscopy enable evaluation of the different methods.

2. Initial Situation

Fig. 1 shows the bore exit quality development of two exemplary diamond coated carbide drilling tools, namely geometry A and geometry B, for 1000 bores. These tools show a so called run-in period: It takes about 150 bores for geometry A and 250 bores for geometry B to generate good bore exit quality. Afterwards the bore exits are free from uncut fibres or delamination at least until the 1000th bore. Measurements of the cutting edge radius after coating, after 600th and 1000th bore in cutting edge profiles at 80% of the tool radius show a strong decrease with tool wear. Obviously the cutting edge sharpness increases with wear and the bore quality becomes better. Entrance delamination does not occur in general with these drills.

3. Experimental Setup

3.1. CFRP material in test

Unidirectional CFRP M21/34%/UD194/IMA-12K with 8 mm thickness, which is widely utilized in the aerospace industry, is used in this study. It contains of 66% (by weight) IMA-fibres and high performance matrix material HexPly<sup>®</sup> M21. A top layer of woven glass fibre, which is known to lower delamination defects, is absent in the experiments to ensure all tool wear and material defects are being generated only by the CFRP. Table 1 displays the mechanical properties of the machined work piece material:

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Fibre Weave/UD</th>
<th>Fibre Mass [g/m²]</th>
<th>Fibre Volume [%]</th>
<th>Laminate Density [g/cm³]</th>
<th>Glass Trans. Temp. [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMA</td>
<td>UD</td>
<td>194</td>
<td>59.2</td>
<td>1.58</td>
<td>195</td>
</tr>
</tbody>
</table>

Table 1. Physical and mechanical properties of IMA-12K fibres

3.2. Drilling Tools

Two different drilling tool geometries, namely A and B, with the same nano-crystalline diamond coating of slightly different thickness and different carbide material (both 6% Co) are tested. Fig. 2 shows the tool properties:

![Tool geometries and coating thickness](image)

3.3. Tangential laser ablation

This treatment method is conducted on a modified EWAG Laser Line. The machine is equipped with an Nd:YVO<sub>4</sub> ultrashort pulsed laser of the company Time-Bandwidth (Fuego™) which emits light in a wavelength of 1064 nm. The laser beam is guided through a hurrySCAN II® scan head of Scanlab with two axes and feed speeds up to 7 m/s.

The material at the cutting edge is removed by tangential laser ablation process from the tools flank face with reciprocating movement of the laser beam parallel to the cutting edge; see Fig. 3 (a). The infeed in x-direction between the three separate tangential ablation processes is 15 µm for each of the two dressing steps. Laser parameters used: Power of 28.3 W, 800 kHz pulse frequency, 0.6 mm/s vertical feed and 500 mm/s scanner feed, ~0.5 mm Rayleigh length, ~30 µm focus diameter.

3.4. Sandblasting

Selective sandblasting of the cutting edges has been applied to induce cracks in the coating on the flank face or erode it locally to shorten the run-in period. The jet nozzle with 1.8 mm diameter is mounted onto a six axes robot, which orients the sandblast vertically on one cutting edge flank face. During sandblasting the robot performs a reciprocating motion parallel to the cutting edge. This serves for 2D distribution of fluctuations in the abrasive grain density of the sandblast. The following sandblasting parameters have been set: 6 bar air pressure, Al<sub>2</sub>O<sub>3</sub> particles with F320 mesh, 15 mm nozzle distance and 2.5 mm sandblast diameter,
5 mm/s feed parallel to the cutting edge, 360 times overrun results in 3 min duration of sandblasting per position.

The 3rd and 4th row in Fig. 4 show the wear status of A2L, A3S and B2L after drilling 200 bores in 8 mm thick CFRP. The analysis of the micro-geometry at 80% of the radius of each tool is presented in the 5th row after coating (blue), cutting edge preparation (green) and machining (red). Coloured bars in the pictures of the 1st and 4th row mark the respective profile analysis position. The breakouts of A3S become worse after drilling 200 bores and the exposed carbide shows rounding up to 10 µm radius. The lasered tools show an even wear on the flank face being proportional to the length of cut. A break out of the 82° µm thick coating of A2L occurs on the rake face at the cutting edge corner which certainly affects the machining quality. In this area of the cutting edge, which generates the final bore surface, the carbide is no longer protected by the coating and it starts to be rounded. Tool B2L does not show such an error. It cannot conclusively be stated if initial damages in the coating are introduced by the laser operation, process forces exceed the coating stability due to specific tool geometry A, or the different substrate materials of geometry A and B influence the coating adhesion. Besides this single defect the remaining diamond coated cutting edge of A2L becomes even sharper with wear: $r_{\text{peak,200}} = 2.2 \mu m$ (not displayed) and $r_{\text{peak,200}} = 2.3 \mu m$. The same effect -increasingly getting sharper cutting edge with tool wear- occurs at tool B2L. The cutting edge radius after laser preparation is about 3 µm and after drilling 200 bores even smaller with $r_{\text{peak,200}} = 2.8 \mu m$.

The drilling experiments are conducted on a Mikron VC1000 3-axes machine. Force measurement is conducted at the workpiece using a Kistler dynamometer type 9272.

Table 2 shows the drilling parameters and test procedure.

<table>
<thead>
<tr>
<th>Tool name</th>
<th>Preparation method</th>
<th>Cutting velocity [m/min]</th>
<th>Rev. [1/min]</th>
<th>Feed Rate [mm/rev]</th>
<th>Test procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1R</td>
<td>Reference</td>
<td>90</td>
<td>4511</td>
<td>0.06</td>
<td>C, M, [d_{ab} f_{M}, f_{ab}]</td>
</tr>
<tr>
<td>A2L</td>
<td>Laser</td>
<td>90</td>
<td>4511</td>
<td>0.06</td>
<td>C, L, M, [d_{ab} f_{M}, f_{ab}]</td>
</tr>
<tr>
<td>A3S</td>
<td>Sand</td>
<td>90</td>
<td>4511</td>
<td>0.06</td>
<td>C, S, M, [d_{ab} f_{M}, f_{ab}]</td>
</tr>
<tr>
<td>B1R</td>
<td>Reference</td>
<td>100</td>
<td>5013</td>
<td>0.05</td>
<td>C, M, [d_{ab} f_{M}, f_{ab}]</td>
</tr>
<tr>
<td>B2L</td>
<td>Laser</td>
<td>100</td>
<td>5013</td>
<td>0.05</td>
<td>C, L, M, [d_{ab} f_{M}, f_{ab}]</td>
</tr>
</tbody>
</table>

C=Coated, L= Laser preparation, S=sandblasting, d=drilling of i bores, f=periodical force measurement, M=3D- and light optical-microscopy of cutting edge, f=periodical repetition until bore i

4. Experimental Results

Standard diamond coated drilling tools are compared with those treated by the two methods explained above subsequent to the coating process. The first two rows in Fig. 4 show the diamond coated tools after treatment. While the tangentially lasered tools A2L and B2L show an evenly reset cutting edge with exposed carbide material shining on the flank face and faultless diamond coating on the rake face, the sandblasted tool A3S has multiple irregular break-outs of the diamond coating all along the cutting edge. The diamond coating on the rake face of the tool, being averted to the sandblast, shows chipping defects up to 30 µm distant to the original cutting edge. It is hardly possible to fit a peak radius in the cutting edge profile (bottom of Fig. 4) after sandblasting ($r_{\text{peak}} = 5.7 \mu m$). Although the sandblast ($\phi=2.5 \text{ mm}$) treated a 2.5 mm wide zone parallel to the cutting edge, the diamond coating in the residual zone of the flank face seems not to be affected.
prepared tool B2L are constantly 15-20 N below the reference B1R. The laser treated tool A2L is 10-17 N below the reference A1R for the first 100 bores and subsequently equal to A1R. While the torque of the tool B2L is reduced by 1 - 2.3 Ncm during first 200 bores, the torque of A2L reduced by even 5 - 6 Ncm for 50 bores. Subsequently the effect of laser treatment on the torque fades and the tool is equal to the reference. The feed force of the sandblasted tool A3S starts on the same level as the reference tool A1R but increases rapidly within 50 bores from 59.6 N to 85.1 N (+43%) due to adverse wear and cutting edge rounding; The same effect but on a weaker scale can be recognized for the torque of A3S.

5. Conclusion

Precondition for the presented results is that the tool macro-geometry is basically suitable for machining the chosen CFRP material. Best results will be achieved if the tool shows a sharpening effect with progressing wear, based on different wear progressions of coating and carbide, described by Maegawa et al. [9]. It is possible to increase the sharpness of diamond coated cutting tools by picosecond laser ablation: Cutting edge radii of 3-4 μm are achievable with diamond coating still protecting the rake face, resulting in outstanding bore qualities in CFRP. The phase with poor bore quality during initial bores of diamond coated tools can be completely skipped. The feed forces can be reduced durably by 20 - 30% (-14 N to -21 N) compared to a diamond coated reference tool. The presented selective sandblasting process harms the coating along the cutting edge and rake face, resulting in declining bore quality. The study shows that sandblasting with the described process is unsuitable to improve the tool micro geometry of the cutting edge. The influence of the treatment method on the tool lifetime has not been examined but is part of further research.

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