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

Robert Voss[a,]*, Marcel Henerichs[a], Gianluca Capricano[a], Friedrich Kuster[a], Konrad Wegener[a]

[a] *Institute of Machine Tools and Manufacturing (IWF), ETH Zurich, Leonhardstrasse 21, 8092 Zurich, Switzerland*

* Corresponding author. Tel.: +41 44 6320731 ; fax: +41 446320731. *E-mail address:* voss@iwf.mavt.ethz.ch

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.

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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.

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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.

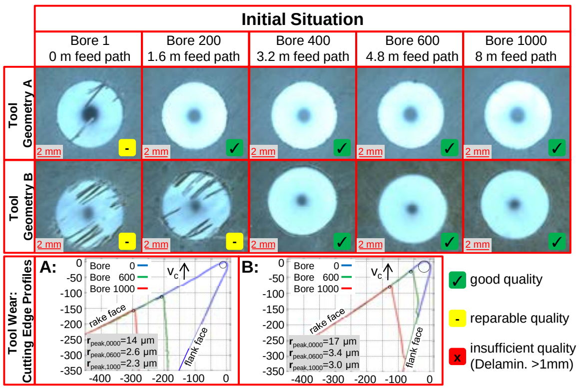

Fig. 1. Initial bore exit quality of diamond coated tools and wear profiles

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

Physical properties	Fibre	Weave/UD	Fibre Mass [g/m^2]	Fibre volume [%]	Laminate Density [g/cm³]	Glass Trans. Temp. [°C]
	IMA	UD	194	59.2	1.58	195
Mech. properties	Tensile	Tensile strength [MPa]	Tensile modulus [GPa]	Compression	Compr. Strength [MPa]	Compr. Modulus [GPa]
	Method EN6032	3050	178	Method EN2561 B	1500	146

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:

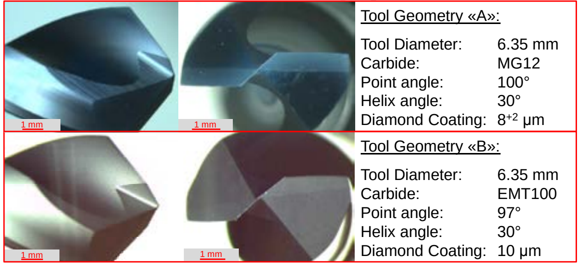

Fig. 2. Tool geometries and coating thickness

3.3. Tangential laser ablation

This treatment method is conducted on a modified *EWAG Laser Line*. The machine is equipped with an Nd:YVO$_4$ 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 one roughing and 10 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$_2$O$_3$ particles with F320 mesh, 15 mm nozzle distance and 2.5 mm sandblast diameter,