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Industrial Paper

Ultrashort-pulsed laser processing of hard and ultrahard helical cutting tools

Gregory Eberle[a,*], Shoshana Huber[a], Claus Dold[a], Bruno Frei[a], Christoph Pluess[a]

[a]*Ewag AG, Industriestrasse 4, Etziken 4554, Switzerland*

Abstract

The advantages of using infrared ultrashort laser pulses ($\lambda = 1064$ nm, $\tau_p \leq 10$ ps) in industrial applications has been growing more and more apparent in the past five years. Within the cutting tool industry, ultrashort-pulsed laser technology is developing into a competing manufacturing method owing to advantages such as high surface quality, minimal cutting edge chipping, high material removal rates, no detectable material transformations and the ability to generate new and complex geometries regardless of the materials mechanical properties. However, the industrialization of ultrashort-pulsed laser technology not only implies a stable laser source or machine tool, but it also implies the ability to apply its associated advantages in a user-friendly manner. This paper will demonstrate the application of ultrashort laser pulses in fabricating polycrystalline diamond and tungsten carbide drill bit geometries with the goal of enabling a greater acceptance of adopting laser technology within the cutting tool industry.

Keywords: picosecond laser; cutting tools; drill; diamond; tungsten carbide; software

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1. Introduction

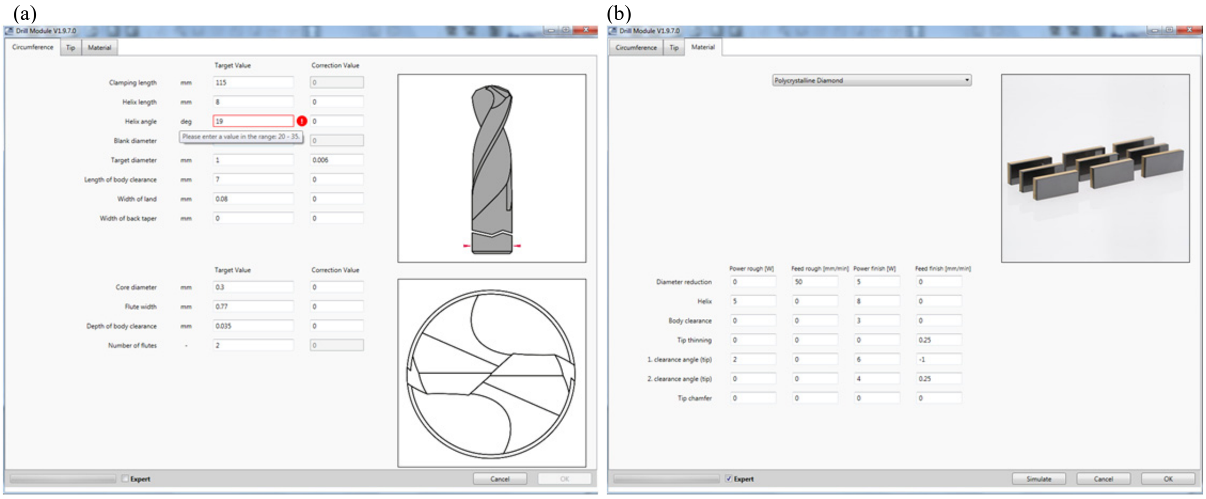
The majority of cutting tools used in milling, drilling, turning and other machining processes are made of either tungsten carbide or high-speed steel. Owing to a growing trend towards increased wear resistance and improved machinability, a growing share of cutting tools are now being made out of ultrahard materials such as diamond and cubic boron nitride. There are however difficulties in fabricating ultrahard cutting tools using conventional techniques such as erosion and grinding. In erosion, the material must be electrically conductive. In grinding, the grinding wheel must exhibit equal or greater hardness than the tool it must grind. Additionally in both cases, the smallest feature which can be produced is based on the utilized wheel or wire. To overcome this, an alternative using ultrashort-pulsed laser technology is proposed.

The first account of applying laser technology on ultrahard materials is demonstrated by Konov et al. (1994) where an ultraviolet nanosecond laser is used to process polycrystalline diamond films. Shortly thereafter, Miyazawa et al. (1996) fabricated chip breakers in polycrystalline diamond composites using an infrared nanosecond laser. The fabrication of cutting edges without pre- or post-processing followed almost a decade later when Weikert and Dausinger (2004) processed various derivatives of diamond using infrared laser sources ranging between nanosecond down to femtosecond. Recently, Warhanek et al. (2018) emphasized that by using picosecond laser sources, the processed cutting tool exhibited longer service life, improved surface quality, lower processing forces during machining and could machine materials deemed difficult by conventionally processed cutting tools. More interestingly, Hajri et al. (2018) demonstrate the fabrication of a cutting tool with a diameter Ø = 0.1 mm with high geometrical resolution showing that ultrashort pulsed laser technology can be especially attractive compared to conventional techniques.

In this paper, the approach and results of fabricating drill bits from cylindrical blanks using the *EWAG LASER LINE ULTRA* will be discussed. This machine is equipped with five mechanical axes, three optical axes and an industrial picosecond laser source ($\lambda = 1064$ nm, $\tau_p \leq 10$ ps, $P_{avg} =$ up to 50 W, $d_{4\sigma} = 25$ µm, $f_{rep} =$ up to 1000 kHz). This enables high geometrical freedom while at the same time significantly mitigating residual heat input.

2. Computer-aided Manufacturing (CAM) Module

Laser technology in the cutting tool industry has been in constant development for the past ten years. Efforts have been extensively applied in determining a robust parameter set in order to machine ultrahard materials. To further develop and industrialize laser technology, a corresponding CAM module must also be developed. A CAM module is considered the back end of the software while the front end consists of a graphical user interface (local or web-based). The responsibility of the back end is to convert the input derived from the front end into information which can be used to carry out calculations. Images showing the parameterized programming environment of the *EWAG Drill Module* front end are shown in Fig. 1.



		Target Value	Correction Value
Clamping length	mm	115	0
Helix length	mm	8	0
Helix angle	deg	19	0
Blank diameter			0
Target diameter	mm	1	0.006
Length of body clearance	mm	7	0
Width of land	mm	0.08	0
Width of back taper	mm	0	0

Please enter a value in the range: 20 - 35.

		Target Value	Correction Value
Core diameter	mm	0.3	0
Flute width	mm	0.77	0
Depth of body clearance	mm	0.035	0
Number of flutes	-	2	0

☐ Expert

Polycrystalline Diamond

	Power rough [W]	Feed rough [mm/min]	Power finish [W]	Feed finish [mm/min]
Diameter reduction	0	50	5	0
Helix	5	0	8	0
Body clearance	0	0	3	0
Tip thinning	0	0	0	0.25
1. clearance angle (tip)	2	0	6	-1
2. clearance angle (tip)	0	0	4	0.25
Tip chamfer	0	0	0	0

☑ Expert

Fig. 1. Screenshots depicting the programming environment of the *EWAG Drill Module*: (a) user inputs to define circumferential properties of the drill bit; (b) user inputs to define material and optionally to influence process parameters.

Programming of a drill bit is carried out in three steps. Firstly, the circumferential properties of the drill bit is defined in the circumference tab (see Fig. 2a), followed by the tip properties and finally the material is defined. Through the material and other geometrical properties, a laser parameter set, i.e. laser power, frequency, etc., is automatically determined. Owing to a wide variety of hard and ultrahard materials available, e.g. different grain sizes or different binder materials, the programmer is able to fine-tune a select few parameters when the “expert mode” is activated (see Fig. 3b). After programming is carried out, the back end, i.e. the CAM module is triggered and generates the code which can be interpreted by the control system of the mechanical and optical axes of the machine tool.

3. Results

The features of a drill bit which can be fabricated using the *EWAG Drill Module* together with the *EWAG LASERLINE ULTRA* machine tool are noted below:

- Tip thinning
- Tip chamfer
- Primary and secondary clearance face
- Diameter and back taper
- Body clearance
- Helix flute

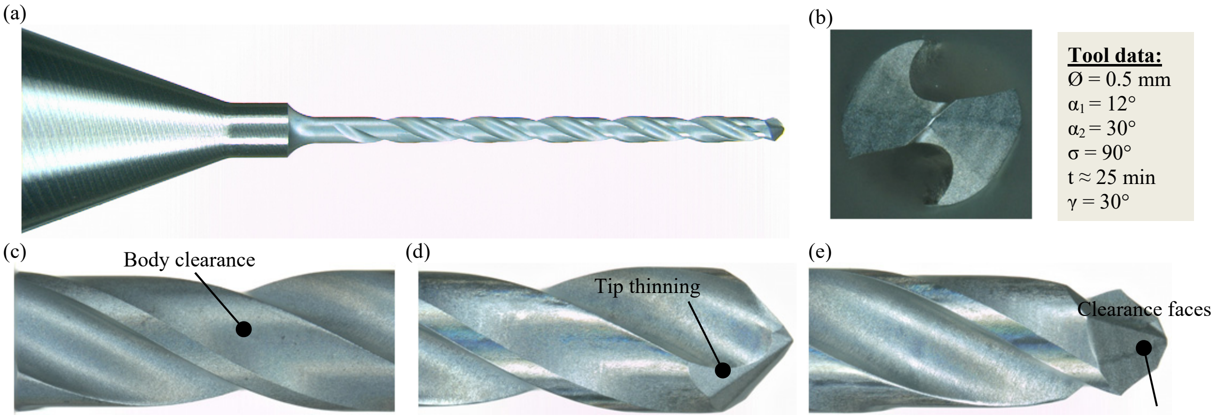
It must be emphasized that fabrication of the drill bit starts from a cylindrical blank whereby no pre-processing or reclamping of the tool takes place. The above geometrical features can also be tuned according to the application of the drill bit. The geometrical ranges which have been thus far tested are outlined in Table 1.

Table 1. Valid geometrical ranges of the *EWAG Drill Module*.

Geometrical feature	Min. value	Max. value	Unit
Primary clearance angle, α_1	8	18	°
Secondary clearance angle, α_2	20	34	°
Point angle, σ	90	145	°
Helix angle, γ	20	32	°
Diameter	0.5	3	mm
Diameter to flute length / length of body clearance ratio	1:2	1:10	-
Tip thinning form	Form A and C (accord. to DIN 1412:2001-03)		-

3.1 Tungsten Carbide Composites

Tungsten carbide (WC) tools are typically a homogeneous composite of tungsten carbide grains in the order of ≤ 5 µm which are sintered together by cobalt. Several images showing the various features of a laser-fabricated WC composite drill bit are shown in Fig. 4 with the design parameters given in the upper right hand corner.

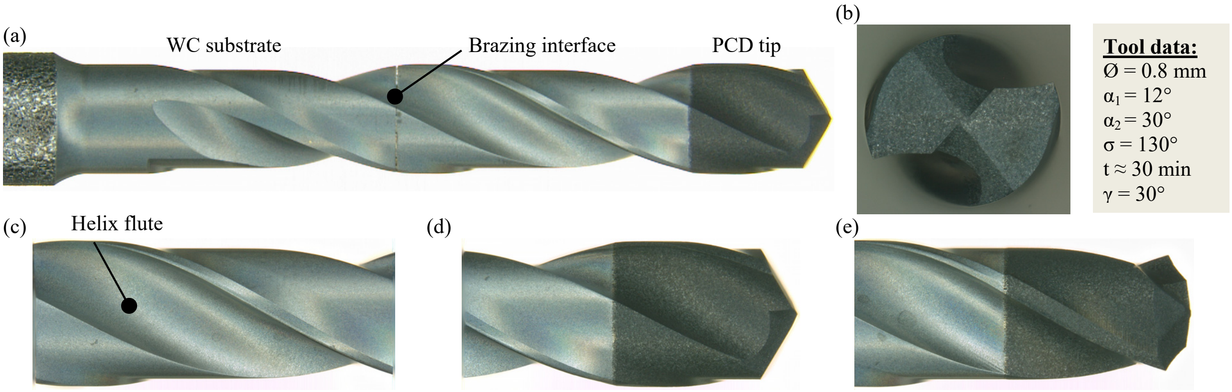


Tool data:
Ø = 0.5 mm
$\alpha_1 = 12°$
$\alpha_2 = 30°$
$\sigma = 90°$
t ≈ 25 min
$\gamma = 30°$

Fig. 4. Optical microscope images of a Ø0.5mm WC composite drill bit: (a) Overview of the drill bit; (b) top view; (c) side view with close-up of the body clearance; (d) side view with close-up of the tip thinning; (e) side view with close-up of the clearance faces.

3.2 Polycrystalline Diamond Composites

Polycrystalline diamond (PCD) tools are typically a homogeneous composite of single crystal diamond grains in the order of ≤ 5 µm which are sintered together by cobalt. Additionally, the diamond is almost always locally brazed on a WC tool substrate. On a drill bit, the only section necessary to be made of diamond is the section which carries out cutting during the drilling process, i.e. the tip. Several images showing the various features of a laser-fabricated PCD composite drill bit are shown in Fig. 5 with the design parameters given in the upper right hand corner.



Tool data:
Ø = 0.8 mm
$\alpha_1 = 12°$
$\alpha_2 = 30°$
$\sigma = 130°$
t ≈ 30 min
$\gamma = 30°$

Fig. 5. Optical microscope images of a Ø0.8mm PCD composite drill bit: (a) Overview of the drill bit; (b) top view; (c) side view with close-up of the WC composite substrate; (d) side view with close-up of the PCD composite showing tip thinning; (e) side view with close-up of the PCD composite showing the clearance faces.

3.3 Quality

Two qualities of a cutting tool, which often dictates its performance in a machining process are surface roughness and cutting edge radius. This is because they influence friction and cutting forces which the tool will experience during machining. In the case of a drill bit, the surface quality of the helix flute on both PCD composites and WC composites are measured using a 3D optical surface profiler. After measurement, the area of interest is cropped, the form is removed using a 10th order plane and a fixed fast Fourier transform filter is applied with a cut-off frequency of $\lambda_c = 0.25$ mm. The cutting edge radius is measured using a 3D focus-variation microscope. After measurement, a cross-sectional profile averaged over a width of 200 μm is extracted from the 3D data and an ellipse is applied according to algorithms defined by the Alicona MeasureSuite 5.3.1 software. A summary of the results are shown in Fig. 6.

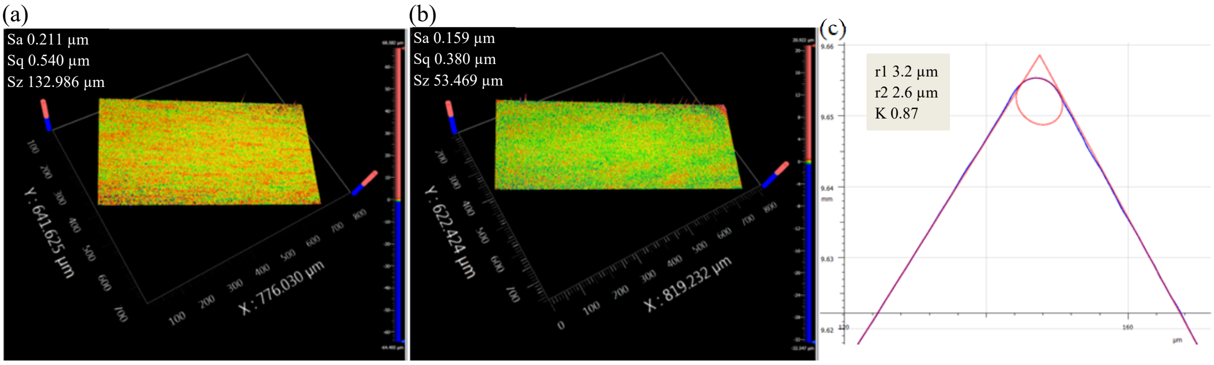


Fig. 6. Quality of laser processed drill bits: (a) PCD composite surface roughness of the helix flute; (b) WC composite surface roughness of the helix flute; (c) a typical cutting edge profile.

Profile surface roughness values (R_a) of a drill bit are difficult to measure since the required measurement length outlined by ISO DIN 4288 cannot be achieved. For this reason, area surface roughness values (S_a) are given and lie below ≤ 250 μm. The cutting edge radius typically lies below ≤ 5 μm with a K-factor in the order of 1 ± 0.2. Such sharp cutting edge radii are favorable in the machining of materials such as plastics, aluminum and carbon/glass fiber reinforced polymers.

4. Conclusions and Outlook

In conclusion, this paper demonstrates the fabrication of drill bits made of tungsten carbide and polycrystalline diamond composites using an easy to use programming environment. In this way, the complexity and broadness associated with laser technology is kept to a minimum while at the same time the ability to produce complex tools of high surface and cutting edge quality is made possible. In the future, the CAM module will be extended to include additional drill bit features, e.g. double margin, and other helical cutting tool types, e.g. end mill while at the same time investigations are ongoing in producing cutting tools less than Ø0.5mm.

References

Hajri, M., Pfaff, J., Büttner, H., Wegener, H., 2018. Fabrication of a Ball End Nose Micro Milling Tool by Tangential Laser Ablation. 8th CIRP Conference on High Performance Cutting: Budapest, Hungary.

Konov, V.I., Ralchenko V.G., Pimenov, S.M., Smolin, A.A., Kononenko T.V., 1994. Laser Microprocessing of Diamond and Diamond-like Films. SPIE 2045.

Miyazawa, H., Takeuchi, S., Miyake, S., Murakawa, M., 1996. Sintered Diamond Cutting Inserts with Chip Breaker Prepared by Laser Technique. Surface and Coatings Technology 86-87, 797-802.

Warhanek, M., Walter, C., Hirschi, M., Boos, J., Bucourt, J.F., Wegener, K., 2016. Comparative Analysis of Tangentially Laser-processed Fluted Polycrystalline Diamond Drilling Tools. Journal of Manufacturing Processes 23, 157-164.

Weikert, M., Dausinger, F., 2004. Cutting of Diamond, in "*Femtosecond Technology for Technical and Medical Applications. Topics in Applied Physics*". In: Dausinger, F., Lubatschowski H., Lichtner, F. (Eds.). Springer, New York, pp. 155.