Geometry and Wear Measurement of Cutting Tools

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Abstract: In order to judge the quality of cutting tools it is necessary to measure their geometry and wear during their use in the industrial process. This allows taking measures to improve the quality and durability of the tools as well as to increase the machining speed. In the following we demonstrate how the 3D metrology device InfiniteFocus can be used for such complex geometry and wear measurements. Due to its special technology it is able to measure even very steep surface slopes and delivers highly accurate 3D data together with perfectly registered true color information. We demonstrate the performance of the system by geometry measurements on different cutting tools with radii down to 3µm. By using special registration algorithms the system is able to compare the three-dimensional structure of the tools before and after their usage and to determine important parameters such as the total volume of worn and accumulated material.
Keywords: 3D metrology, cutting tools, measurement, wear

1. INTRODUCTION

The three-dimensional measurement of cutting tools, drill bits and milling cutters is an important aspect of quality control in the industrial process, since the form and wear of cutting edges have a significant influence on the quality of machined parts. Among others the edge geometry influences the possible cutting speed as well as the lifetime of the tools. Since these tools often have a very complex geometry including steep flanks and undercuts, their 3D measurement is a big challenge for optical 3D metrology devices.

Traditionally cutting tools are either measured with tactile measurement devices or by analysis of 2D images containing profiles of the cutting edge. The disadvantages of tactile devices are, that on the one hand they need very long for the measurement of a whole tool, on the other hand the geometry of the stylus can influence the measurement result. Additionally some measurements on the edge are not economic due to the hardness of the tool material and the subsequent wear of the stylus tip. The evaluation of 2D images is possible for simple measurements where no occlusions occur, however it is not possible for measurements where real 3D information is necessary. This includes tools with concave regions and complex tools such as drill bits and milling cutters.

In the last years optical 3D measurement methods have become more and more popular in various fields [Jiang, 2007]. The 3D measurement of drill bits and cutting tools however is often hardly possible with optical devices due to their complex geometry and their steep surface flanks. White light interferometers e.g. only allow the measurement of flank angles up to about 30°, which typically is not enough for the evaluation of cutting tool radii.
An optical measurement technology which is suitable for the measurement of steep edges is Focus-Variation [ISO 25178-6, Draft]. In this paper we demonstrate, how a measurement device based on Focus-Variation can be used for the three dimensional measurement of cutting tools. This device fulfils on the one hand the requirement to measure steep flanks and on the other it allows the measurement of quite large areas with very good resolution. After describing the device and its analysis possibilities in Section 2 with demonstrate geometry and wear measurements on different tools in Section 3.

2. 3D MEASUREMENT AND ANALYSIS OF CUTTING TOOLS

The optical 3D measurement device based on Focus-Variation, which is used for the measurements introduced in this article, is InfiniteFocus by Alicona (Fig. 1). In order to perform 3D measurements the device vertically scans the specimen by the sensor while continuously acquiring data. Since the system has a limited depth of field only small parts of the object are imaged sharply at the same time. By analyzing the variation of focus during the scanning process for each measurement a complete 3D model is obtained. A detailed description of the measurement principle can be found in [Scherer, 2007].
In addition to the 3D data, the measurement device also delivers true colour information for each measurement position, which is perfectly registered to the height data. This colour information often enables the user to classify regions that have not been used, and those where wear has occurred. Additionally a repeatability measure is analytically estimated for each measurement point. This repeatability measure is an estimation of the standard deviation of the z-coordinate of the measurement point as it would occur in a measurement series. This measure can be used for different investigations such as the estimation of the quality of the measurement points, the filtering of measurement points with bad repeatability, the detection of vibrations or other exterior influences during the measurement.
In order to analyze the geometry of a cutting edge, a special software module is available (Fig. 2) that analyzes cutting edges on a surface profile based basis. First profile paths are defined in the true colour image of the cutting tool either automatically or manually (region 1. in Fig. 2). Then a height profile is extracted from a specified profile path (marked blue) and the resulting height diagram is visualized in region 2. This profile typically consists of two steep flanks and a rounded top region. In order to quantify the quality of the cutting edge a series of different parameters can be extracted

as described in region 4 of Fig. 2. The most important parameter is the cutting edge radius which is obtained by the following automatic procedure:

- Fit a straight line into the left and right surface flank of the cutting edge.
- Determine the top region of the edge by extracting those surface points where the deviation to the corresponding fitted line increases above a certain threshold.
- Fit a circle robustly into the segmented top region of the height profile.

The extracted parameters such as the edge radius or the angle between the fitted lines are then listed in the table in region 3 of Fig. 2. By switching between the different surface profiles, a good impression of the change of the height parameters across the edge is obtained.

Another important parameter for the description of the quality of a tool is the roughness of the surface. This can be either calculated according to the draft of the ISO standard 25178 [ISO 25178-2, Draft] in an area-based matter or on a profile based basis according to [ISO 4287, ISO 4288]. The knowledge of the surface roughness has a significant influence on the production since it influences among others how well the material can be chipped.

A third important parameter is the volume of the material that has been worn during the manufacturing process. This can be obtained using the following procedure:

1. 3D measurement of the tool before usage.
2. 3D measurement of the tool after usage.
3. Automatic registration of the 3D models to each other.
4. Calculation of the difference of the two 3D models.
5. Calculation of the volume of the difference model.

The automatic registration of the 3D models is necessary in order to assure that the difference is correctly calculated from corresponding points. A detailed description of this process can be found in [Danzl, 2006].

Figure 1: The InfiniteFocus system.

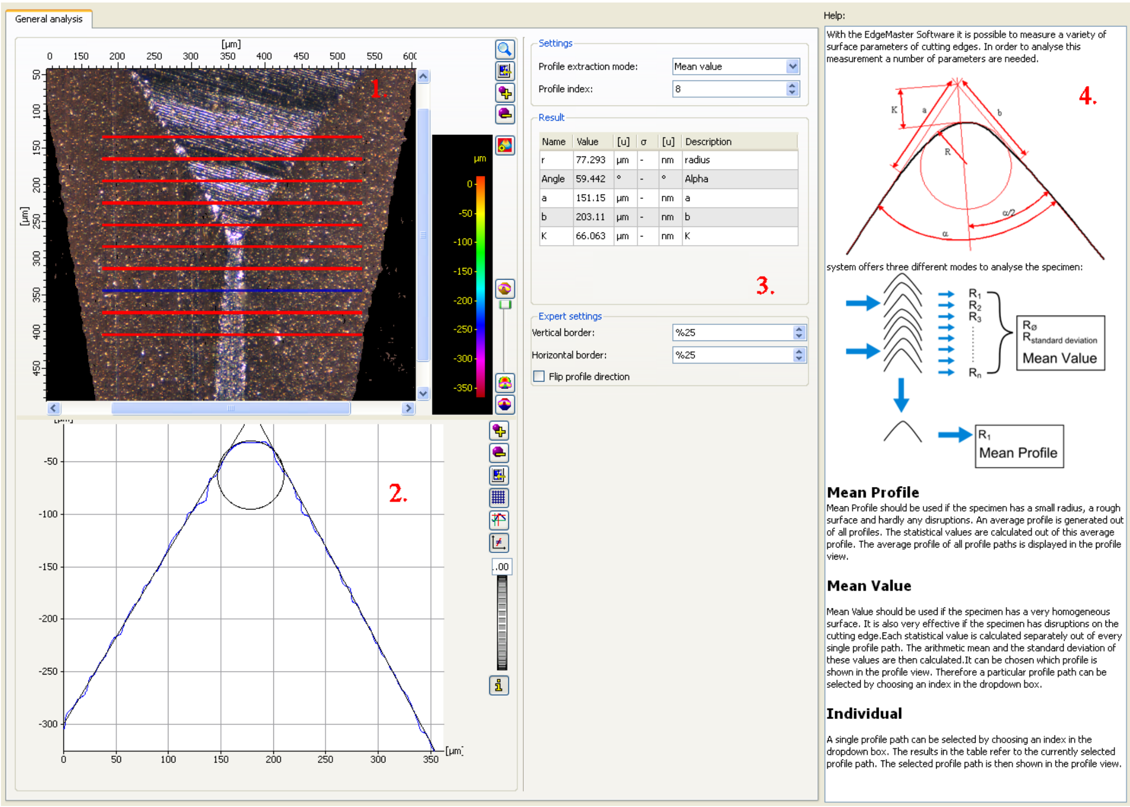


Figure 2: Screenshot of the edge analysis software. The analysis module consists of: (1) True color image of the 3D model with profile paths. (2) An extracted surface profile with superimposed fitted lines at the surface flanks and fitted edge radius. (3) Edge parameters. (4) Help showing the meaning of the different parameters.

3. RESULTS

In the following geometry and wear measurements of milling cutters are described that have been carried out with the InfiniteFocus system. On the one hand we provide wear measurements on cutting edges and on the other hand measurements on corners of the milling cutter. An overview 3D model of the milling cutter measured by InfiniteFocus is provided in Fig. 3. The parts used for the wear measurement are marked with black circles.

3.1. Wear Measurement of Edges

In order to measure the wear on a cutting edge, first a 3D model of the edge of the original milling cutter has been measured with the InfiniteFocus system (Fig. 4a). The 3D model shows the shape of the slightly rounded edge as well as sloped structures on a flank of the tool. After using the milling cutter for manufacturing, the edge has been measured a second time. The resulting 3D model of the worn edge in Fig. 4b shows a significantly larger amount of wear which in addition has become more inhomogeneous.

In order to measure the amount of wear ten height profiles have been extracted and analysed at equidistant distances perpendicular to the edge. Two exemplary height profiles of the original and the used cutting edge are provided in Fig. 5a and 5b. Into these profiles two lines have been fitted along the flanks in order to calculate the angles. Into the uppermost part circles have been fitted in order to determine the radius of the edge. Both profiles in Fig. 5 have similar axis scaling and show how the wear (and thus the cutting edge radius) has increased by usage of the cutting tool.

In Table I the measured radii of the 10 horizontal profiles are provided for both 3D models. Additionally, statistical parameters of the measurements such as the mean and the standard deviation have been calculated. The table shows that the original part has a very small mean radius of about 4.7µm whereas the worn part has a radius about twice as large. An interesting aspect is the increase of the standard deviation by a factor of three which shows the inhomogeneous wear on the edge.

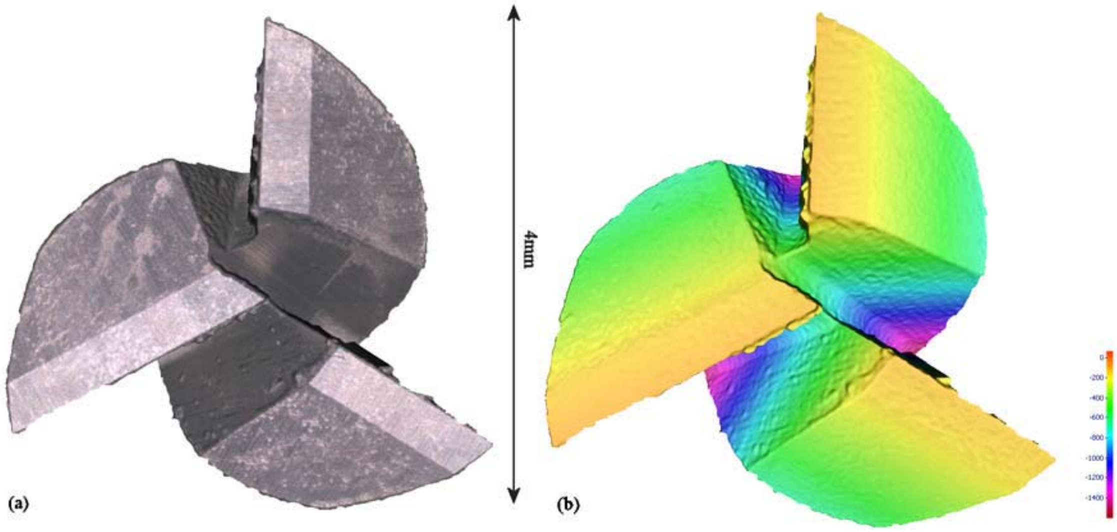


Figure 2: 3D model of a milling cutter measured by InfiniteFocus. The parts that have been investigated in detail are marked with black circles. (a) 3D model with superimposed true color image. (b) 3D model with pseudo colors where each colour represents a different height.

#	1	2	3	4	5	6	7	8	9	10	Mean	Std.
Org	3,55	3,95	5,77	4,66	5,4	3,59	3,61	7,33	4,49	5,22	4,76	1,23
Used	11,1	8,18	16,6	6,01	10,08	4,96	8,02	7,23	16,2	8,46	9,68	3,95

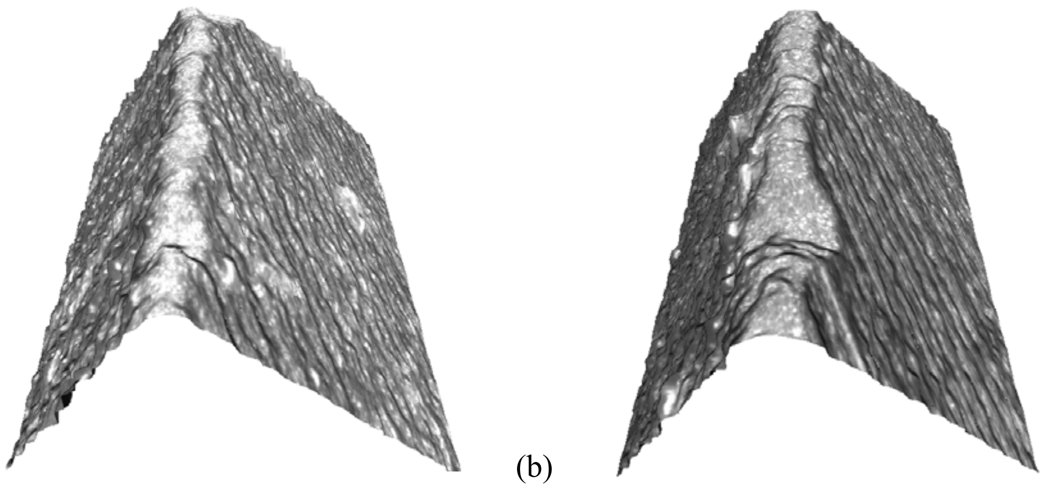
Table I; Edge radii (µm) for 10 extracted height profiles with mean and standard deviation (std) before and after usage of the tool.

3.2. Wear Measurement on Corners

Additionally the wear has been measured on corners of the milling cutter. First 3D models of the corner have been measured before and after usage. Afterwards the difference between the two 3D models has been calculated which contains the worn material. In order to assure that the difference is calculated from corresponding surface regions, the two 3D models have been registered to each other before difference calculation.

In Fig. 6a a 3D model of the original corner is provided, whereas Fig. 6b contains a 3D model of the used corner. Both 3D models have been overlaid with the true color image measured by InfiniteFocus. This allows a classification into original regions (dark) and worn regions (bright).

After the two 3D models have been registered to each other, a difference height model has been calculated (Fig. 7a) which allows the quantification of the worn volume (~601400μm^3). Another possibility to measure the amount of the worn volume is to extract height profiles of the original and the worn part and to overlay them (Fig. 7b) in a single diagram. This allows a good visualization of regions where much and regions where little material has been removed.



(a) (b)

Figure 4: 3D model of the edge (a) before and (b) after usage in the industrial process.

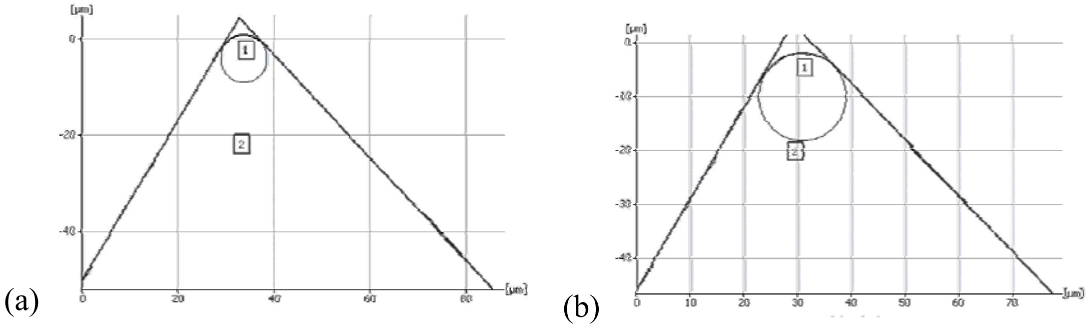


Figure 5: Surface profile extracted perpendicular to the cutting edge; (a) before and (b) after usage in the manufacturing process. The radius of the cutting edge increases approximately by a factor of two.

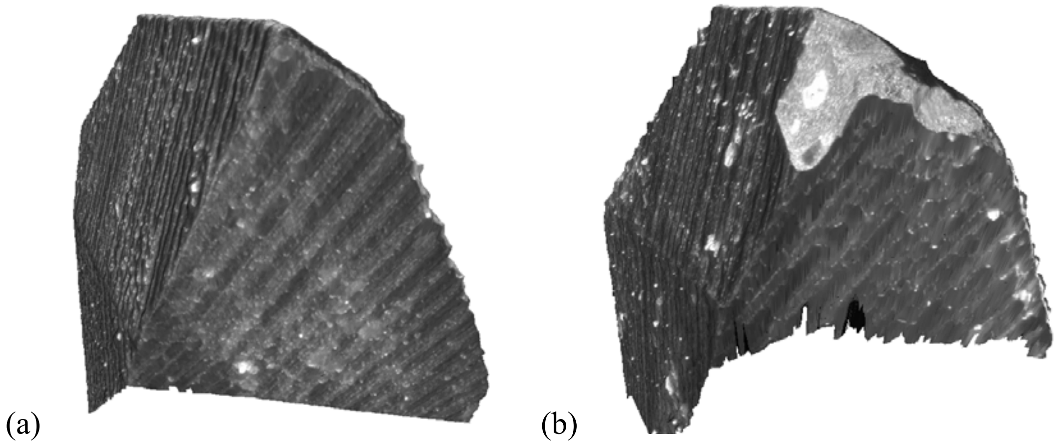


Figure 6: 3D model of the tool corner (a) before and (b) after usage in the manufacturing process. The bright regions in Figure (b) allow a classification of worn regions.

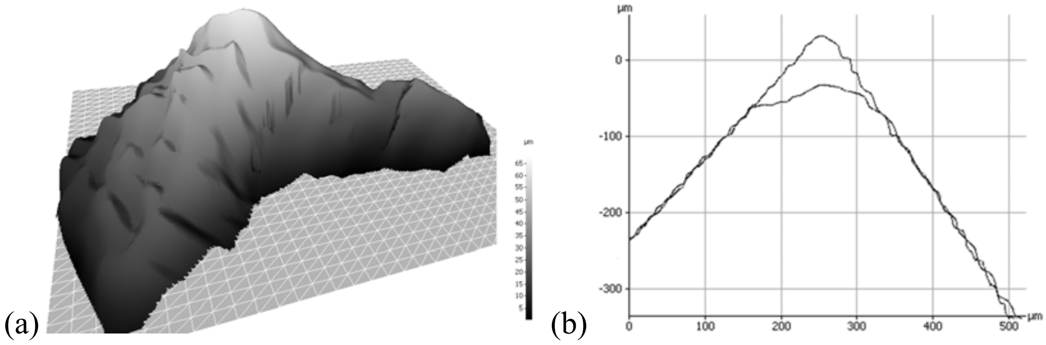


Figure 7: (a) 3D model of the worn volume at the tool corner; (b) overlay of a surface profile of the original and the used milling cutter. The profiles show the amount of the worn material.

4. SUMMARY

A method has been proposed that allows measuring the 3D shape of cutting tools using an optical metrology device. In contrast to many other 3D measurement devices InfiniteFocus is able to measure steep flanks. Additionally it does not only deliver 3D data but also perfectly registered true color information.
By using different analysis methods it has been shown, how the device can be used to measure the geometry and the wear of cutting edges from cutting tools. Besides, it has been demonstrated that the device is able to measure large areas (whole milling cutters) as well as very small regions such as edge radii with a few microns.
This combination of high accurate 3D measurement over large areas even at steep edges, as well as robust analysis functions makes the device ideally suited for the measurement of various cutting, milling and drilling tools.

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