

A NANOMETROLOGICAL MANAGEMENT APPROACH TO ASSESS THE PROFILE AND THE SURFACE CHARACTERISTICS OF THE END MILLING TOOLS BY MULTI-MEASUREMENT ANALYSIS

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Abstract: The competitive machining industry requires modern milling tools and their flexible, high quality and powerful industrial implementations. The main factors effecting the operational quality of the end milling tools are tool material, coating and edge geometry. This study represents the assessment of the coating and the surface characteristics of the end milling tools by contact (stylus profilograph) and non-contact mode nanometrological devices (digital microscope, 3D laser scanner) to establish a methodology to assess the micro/nanogeometry of the coated and uncoated tools with an effort to predict the surface roughness effect. This approach introduces a wide application of knowledge extraction to supervise the end milling operation by ensuring the operational quality of the tools where high accuracy and good quality surface is demanded.

Keywords: End milling tool, coating, surface characteristics, roughness, quality, environment

1. INTRODUCTION

The advanced metrology methods integrated into development of modern milling tools and their industrial implementations are vital to maintain a competitive operation in today's machining industry. The usage of nanomultilayer coatings on end milling tools establishes a novel approach to the state-of-art technology. Moreover the cutting tool surface profile and the geometrical product specification have proved to be one of the major effects on cutting tool lifetime and quality of the process. With the industrial requirement of flexible, high quality and powerful machining operations, the nanometrological measurements and investigations have become an integrated aspect of their research and development strategy [1].

There has been much prior research conducted to improve fatigue strength, corrosion resistance, tool lifetime and that will eventuate in a major influence for the economical and environmental performance of the milling machines. The major influence of the micro/nanogeometry (surface roughness, cutting edge coating) has been investigated so far by means of diverse numerical modeling

[2-5]. However, the characterization of the micro/nanogeometry of the cutting edge of the end milling tools is often challenging due to the experimental precision measurements. In this study, the surface roughness characterization process was carried out by nanometrology devices in order to overcome the challenges by predefined limits in compliant with the international standards. The advanced metrology methods are used to make measurements by both contact mode (stylus profilograph [6] and non-contact mode (digital microscope [7], 3D laser scanner [8]) devices on both coated and uncoated pair of the end milling types.

The coating industry were developed in the 1970s by introducing physical vapour deposition (PVD) coating usually applied in 1-15 μm thicknesses on tools made of steel and hard metals. Chemical vapour deposition (CVD) coatings were commercialized after 30 years [9]. The new coating compositions such as titanium-nitride, titanium-carbon-nitride, titanium-aluminium-nitride or titanium-aluminium-carbon-nitride deploy higher hardness, thermal stability, wear resistance, oxidational resistance, frictional behavior, cutting performance and are used according to the requirements of the processed material. The utilization of the coated tools varies with the applications. Therefore, the statements about the tool lifetime or the quality of the operations depend on each end milling and its process, machining properties that can be evaluated peculiarly.

The demand of the machining industry to operate competitively focuses on the above mentioned improved performance of the end milling tools coupled with the high quality and environmentally sound operation. Due to the high costs of such separate activities, this study proposes an integrated management system to be implemented introducing efficiency, savings and environmentally sound process utilizing a professional process management toolbox (iGrafx) as represented in Figure 1. The proposed methodology targets the assessment of the surface characteristics of the end milling tools to establish a nanometrological process management under the guidance of quality and environmental management systems in compliant with the standards and guidelines [10, 11]. The process management contributes to the research study

exhibiting an advantage over traditional methods through real-time process control, analysis, reporting and standardization.

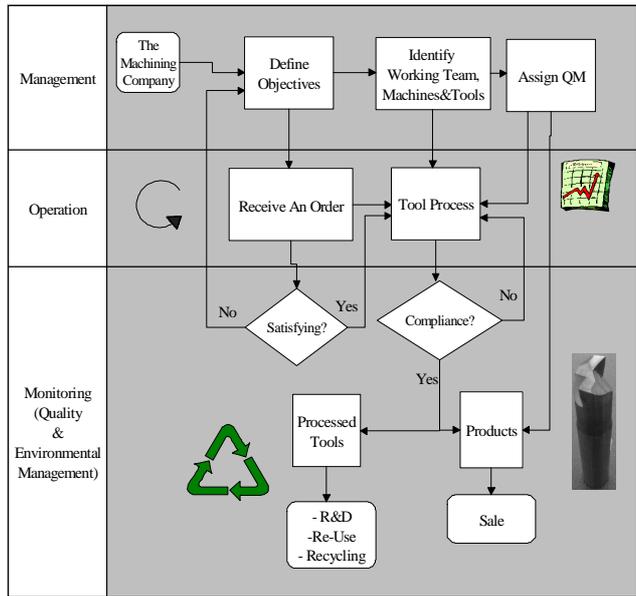


Figure 1. The proposal of an integrated management system in the machining industry

2. THE END MILLING TOOL MEASUREMENTS

The end milling tools are chosen from 16 mm diameter with two teeth with both coated and uncoated samples (Figure 2). The dimensions of the end milling tool samples are shown in the Table 1. The coating technology used on the tools is one of the newest PVD hard coating processed via ARC-vaporization (arc assisted vaporization) at temperature up to 450°Celsius. The ARC-technology has the advantages of friction-reducing surface, stable bonding with the uncoated surface, and longer hardness lifetime minimizing the micro-changes during operation. In the samples, the coating PVD is conducted by a process of collecting the cathode AlTiN and an additional element's atomized and afterwards vaporized materials. This process is performed under vacuum by many layers of nano scale coatings with an average thickness of 1 – 3 μm.

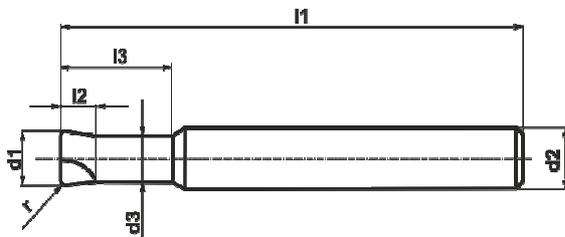


Figure 2. The end milling tool of 16 mm diameter with two teeth

Table 1. The dimensions of the cutting end mill (in mm)

Ød1	Ød2h5	Ød3	l1	l2	l3	R	Z
16	16	15	90	5,5	30	1.0	2

The uncoated and coated cutting mill samples have the similar surface structure except the coating layer observed in the color of Anthracite as represented in the Figure 3.

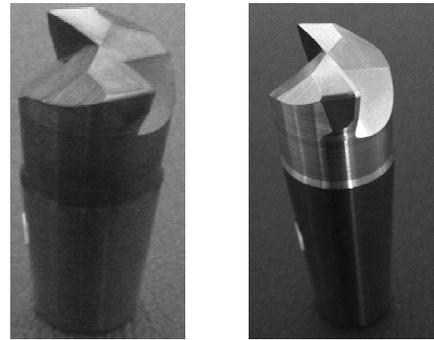


Figure 3. The end milling tools: The coated and uncoated samples

In this study, the nanometrological measurements are performed to analyze the characteristics of the coating surfaces of the end milling tools under the guidance of the standards. The roughness profile is sampled to evaluate some roughness parameters like Ra, the area between the roughness profile and its central line, or the integral of the absolute value of the roughness profile height over the sampling length. This accurate measurement and judgment processes of this research work were performed at Vienna University of Technology, Department of Interchangeable Manufacturing and Industrial Metrology, Nanotechnology Laboratory.

2.1 The contact mode assessment of the end milling tools

The contact measurement is carried out by the profilograph of Form Talysurf Intra 50 with ultra software (FTS Iμ) according to the ISO 4287 and ISO 4288 [12, 13]. The measurements are taken by the perpendicular direction profilometric scans on the end milling tool cutting edge surfaces. The scan length is chosen as a total of 1.25mm with a number of 5 scans on each sample. The tactile system has a high resolution of 16nm in 1.0mm with the stylus arm length of 60 mm, the conisphere diamond stylus tip radius of 2 μm. A force of 1 mN (speed = 1 mm/s) and the high-pass Gaussian filter with a 0,25mm cutoff value were applied in all measurements by the stylus instrument that is represented in the Figure 4 and Table 2 [6]. The Ra roughness parameters were calculated based on a standard spectrum of roughness (ISO 25178-601:2010) [14]. The results were processed in TalySurf Intra software.

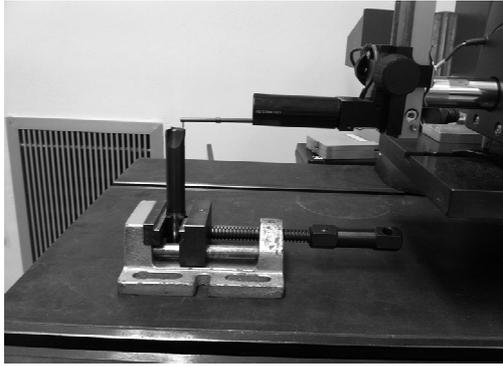


Figure 4. Measurement setup of the profilograph (Form Talysurf Intra 50) during the contact measurement of the end milling tools

Table 2. The specifications of the stylus profilometer

Measurement Method	Spatial resolution	Z Resolution	Range Z
Stylus Profilometer	1-2 μm	3 -16 nm	0.2-1 mm

2.2 Optical assessment of the end milling tools

The digital microscope (Keyence VHX-2000) illustrated in Figure 5 is a high resolution CCD camera based system with a high intensity halogen lamp and image processing capabilities that integrates observation, recording, and determination of measurement functions [7].

The evaluation processes have been carried out by software (Keyence VHX-2000) developed for imaging purposes. This investigation was performed with a 20x objectives, as 20x objective has smaller deviations in the measurement results. Actually, the instrument has from 20x to 500x and 500x to 5000x objectives, i.e. enlargement capability of the objective part of the microscope. These properties enable the instrument to get different depth of views of surface structure.

The specifications of the digital microscope are indicated in the Table 3.

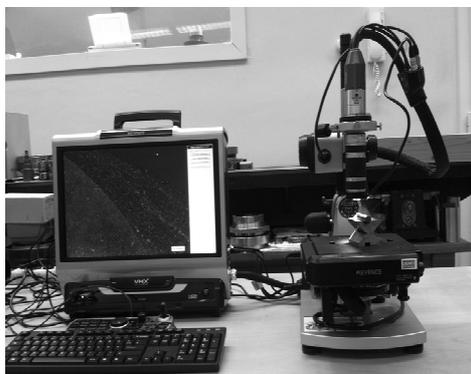


Figure 5. Measurement setup of the digital microscope (Keyence VHX-2000) during the optical measurement of the end milling tools

Table 3. The specifications of the digital microscope [7]

Model	VH-Z20R				VH-Z500R		
Magnification	20x	30x	100x	200x	500x	1000x	
Field of view (mm)	Horizontal	15,24	10,16	3,05	1,52	610	305
	Vertical	11,40	7,60	2,28	1,14	457	229
	Diagonal	19,05	12,70	3,81	1,91	762	381
Depth of field (mm) ²	34	15,5	1,6	0,44	-	-	
Evaluation distance (mm)			25,5				4.5

While carrying out the measurement with the digital microscope, the evaluation process is complemented with the 3D laser scanning microscope (Keyence VK-X100/X200) [8] to monitor surface topography in detail. The measurement setup and the specifications of the 3D laser scanning microscope are indicated in Figure 6 and Table 4 respectively.



Figure 6. Measurement setup of the 3D laser scanning microscope (Keyence VK-X100/X200) during the contact measurement of the end milling tools

Table 4. The specifications of the 3D laser scanning microscope [8]

Measurement Method	Spatial resolution	Z Resolution	Range Z
3D Laser Scanning Microscope	120 nm	0,5 nm	100 mm

High precise measurement techniques and surface structure analysis are required in advanced fields of interchangeable manufacturing and precision engineering. This study presents the characterization of the surface roughness of the end milling tools by experimental precision measurements.

The experimental tool life determination for real applications of the machine industry is more complex than its suggested mathematical models. The ISO Standard 8688 guides us on the deterioration of tools due to the tool wear [15]. However, the end milling tool deterioration must be investigated as a total effect of wear, edge fracture and deformation. After the optical assessment of the end milling tools, the surface investigation of the coating effect were investigated by machining the end milling samples by a linear industrial type CNC universal milling machine

(Deckel Maho DMC 64V). The orthogonal cutting processes are performed with two cutting tools with different coating specifications at the cutting speed of 220 m/min, 5800 rpm, feed rate of 4600 mm/min (Vf), depth of cut of 0.5 mm (Ap), 3.5 mm (Ae). GS-2312 Mould Steel was machined using coated and uncoated tools in different time durations which are 5, 25 and 45 minutes [16]. The surface quality of the end milling tools were detected optically as represented in Figure 7, Figure 8 and Figure 9. The system is established to define the tool lifetime in terms of operational constants that varies depending on the machining equipment and industry additionally.

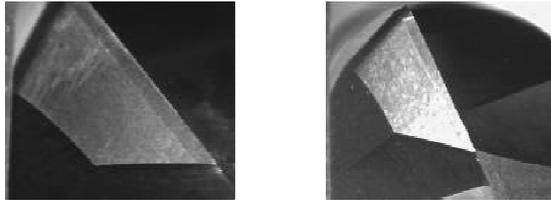


Figure 7. Before Machining (Uncoated vs Coated)

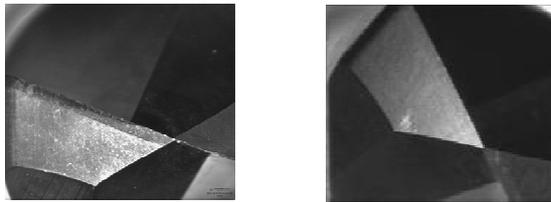


Figure 8. Machining after 5 min (Uncoated vs Coated)

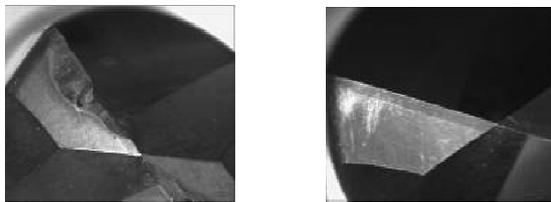


Figure 9. Machining after 25 min (Uncoated vs Coated)

The results indicates that coating cutting tools with PVD technique both improved the quality of machining and surface finish and extended the tool life. For the coated cutting tools, the values of surface parameters and geometrical profile did not show significant variations comparing with the uncoated ones in the first 15 minutes. However as the experimental machining process time increased, Ra values have increased drastically. The uncoated end mill was worn out totally after reaching the process time of 26 minutes.

The tool life as one of the most important criteria of machinability in terms of the tool material is the stable amount of machining time until deterioration. It is vital to define the tool life as the total cutting time to attain a specific value of tool-life criteria. The main numerical values of tool deterioration require testing material that is specifically assigned for the process.

3. THE ANALYSIS AND CONCLUSION

In this study, surface quality of selected high precision cylindrical end mills was measured in micro/nano scale. Surface characteristics of coatings were investigated. The effects of coatings on surfaces of cutting tools were determined by comparing to uncoated version of the coated tool. These mentioned surface investigations consist of two techniques: contact and non-contact mode devices. The measurement results presented are the surface roughness measurements in micro/nano scale by the profilometer (Figure 10 and Figure 11) and the capturing of the magnified surface images measuring the micro/nanogeometry of the cutting edge (Figure 12, Figure 13) by the 3D laser scanning microscope.

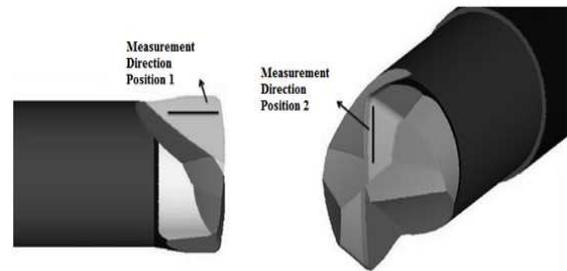
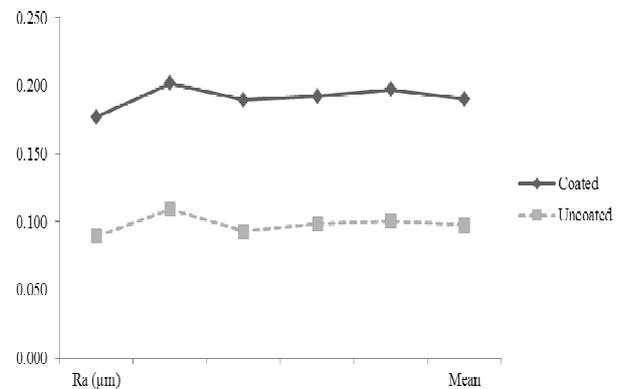


Figure 10. The measurement surface area indication on the end milling tools



	Ra (µm)					Mean
Coated	0,177	0,2019	0,1896	0,1922	0,1973	0,190
Uncoated	0,0893	0,1092	0,0932	0,0985	0,1006	0,098

Figure 11. R_a values belonging to the coated and uncoated end mill cutting tool

The results for the end milling cutting tool samples represent smooth surface topography in terms of R_a values. R_a values are around 293 nm for uncoated end mill sample and 362 nm for coated end mill sample.

A set of macro-geometric variables of the end mills has been experimentally defined with the angle and radius measurement of the end milling tools that have a complex surface geometry. The 3D laser scanning microscope is used

to evaluate the cutting tool surface topography as well as the geometrical profile and investigate the surface topography in 3D. The micro rectangular areas taken from the milling tools on the surface of the cutting edge has been measured to have an angle of 82.3395° represented in the Figure 12. The measurement also results the radius of a high precise spherical sample with a radius of 8.322 mm is indicated in the Figure 13.

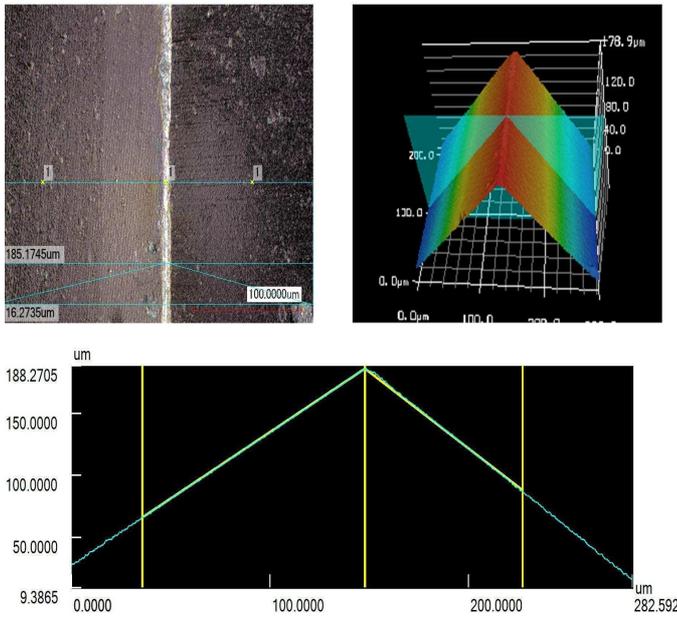


Figure 12. Angle measurement of the Cutting Tool End using the 3D Laser Scanning Microscope

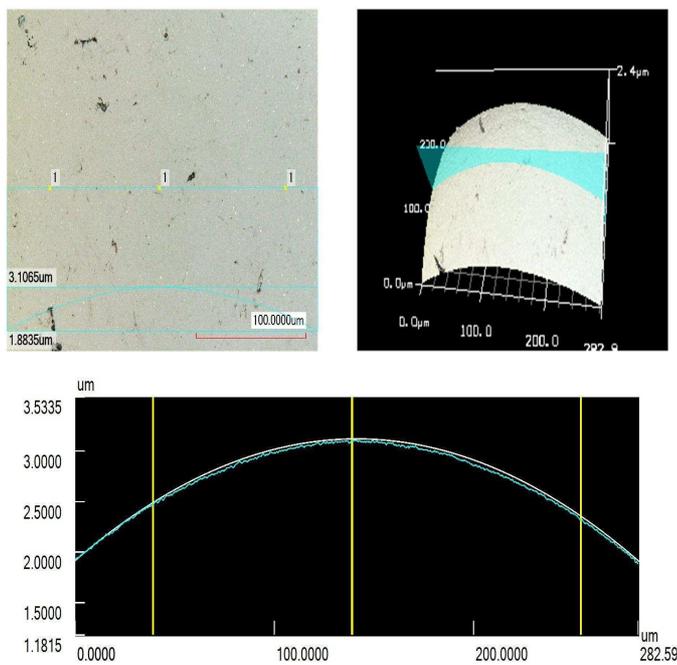


Figure 13. Radius measurement of the High Precise Spherical Surface using the 3D laser scanning microscope

The digital microscope is used for both micro/nanogeometry (Figure 14) and also the profile (Figure 15) evaluation of the end milling tool cutting edges.

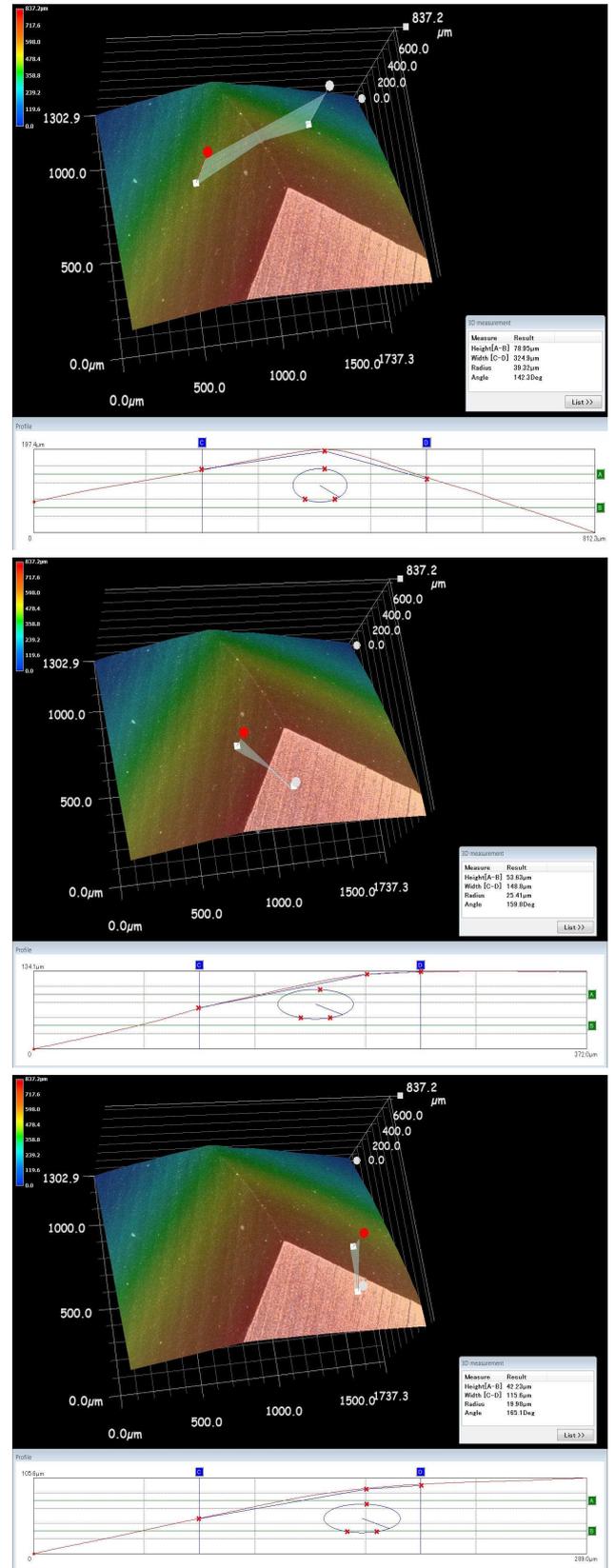


Figure 14. The micro/nanogeometry measurement of the end milling cutting edge using the digital microscope

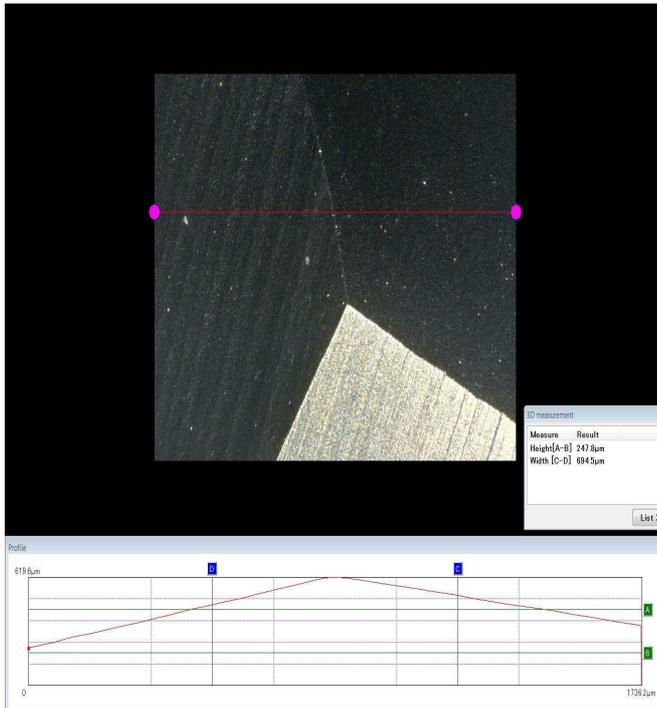


Figure 15. The profile measurement of the end milling cutting edge using the digital microscope

This study represents the assessment of the profile and the surface characteristics of the end milling tools by contact (stylus profilograph) and non-contact mode nanometrological devices (digital microscope, 3D laser scanner) in order to create a database to evaluate the tool investigation using multi-parameter analyse and 3D. This approach introduces a wide application of knowledge extraction to supervise the end milling operation and intelligently manage the operation quality of the tools coupled with environmental management and performance improvement of the cutting tool operations.

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