

SURFACE CHARACTERIZATION BY ACCURATE MEASUREMENT AND IMAGE PROCESSING SYSTEMS ON MACHINED SURFACES OF PRECISION CUTTING TOOLS

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Abstract:

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 machined milling cutters by experimental precision measurements and the image processing tool. The data obtained are compared to assess the surface characterization parameters and computational data in terms of precision, accuracy, sensitivity, repeatability and resolution.

In the experimental measurement phase, the roughness measurements and surface topography characterization were performed in the nanotechnology laboratory using the stylus profilometry and digital microscopy. The computational phase was performed using an image processing toolbox with precise evaluation of the roughness for the machined metal surfaces of the end mill cutting tool. The surface parameter database is established exhibiting an advantage over the traditional method. This study reveals a comparison methodology of the end mill surface parameters using both stylus readings and image processing software for widely used end mill cutting tools that have considerable effect on characterization of sensitive manufacturing surface of millings.

Keywords: surface roughness, end milling, image processing, precision machining

1. Introduction

The experimental precision measurements are one of the key methods for characterization of the roughness conducted by nanometrology devices to serve the manufacturing industry. However, the characterization of the surface of the machined metal milling is often challenging due to its complex surface structure, its effect on the end-product and predefined limits in accordance with the standards.

Surface roughness is a measure of the texture of a surface. Roughness is evaluated by means of some parameters: R_a , 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, and R_z , average maximum height of roughness profile are the most preferred parameters measured commonly by a stylus profilometer [1] in surface roughness evaluation, as the most of the surface finish standards in the world are written for these profilometers. As a complementary of the stylus method, the digital microscopy makes

a notable contribution to the development of the field of dimensional measurement. The other important property of the digital microscopes is to monitor high quality recorded images easily, since the optical image is projected directly on the charge-coupled device (CCD) in a digital camera.

This study focuses on establishing a methodology for the surface roughness characterization by managing an evaluation process after comparison of both experimental measurements utilizing the stylus method, the digital microscopy and also image process technique implementing an image recognition algorithm. The samples used for this study were chosen according to the factors of the shape, size, material, process parameters, the stiffness, macro-geometry, coating specifications determining the mechanical properties of the machined metal millings. The uncoated and coated machined cutting mill samples were observed, measured and their images were processed to serve a solution to the problems of two basic complications in manufacturing tools; operational surface abuse and life time. Roughness of the cutting mills' surface is one of the most important considerations affecting the desired surface quality and the functional behavior of the part moreover preventing these complications. The aim of this application was to see the differences between the end mill cutting tools with and without coatings, when measuring roughness of the end mill surfaces, because such surfaces are being measured after a series of machining processes in general.

The evaluation process flow as represented in below Fig. 1 consists of two main phases that reveals the detailed scientific, collaborative research process. The two main phases, namely the measurement phase and the computational phase were managed by using the professional process management software toolbox (iGrafx). The process management contributed to the research study exhibiting an advantage over traditional methods through real-time process control, analysis, reporting and standardization.

2. Material

The coating technology called "Physical Vapor Deposition (PVD)" is conducted by a process of collecting the cathode AlTiN and an additional element's atomized and afterwards vaporized materials. This process takes place at 500 °C and then the cutting mill is covered under vacuum. The coating process is performed by many layers of nano scale coatings with an average thickness of 1 – 3 μm.

The uncoated and coated cutting mill samples have the similar surface structure except the coating layer observed

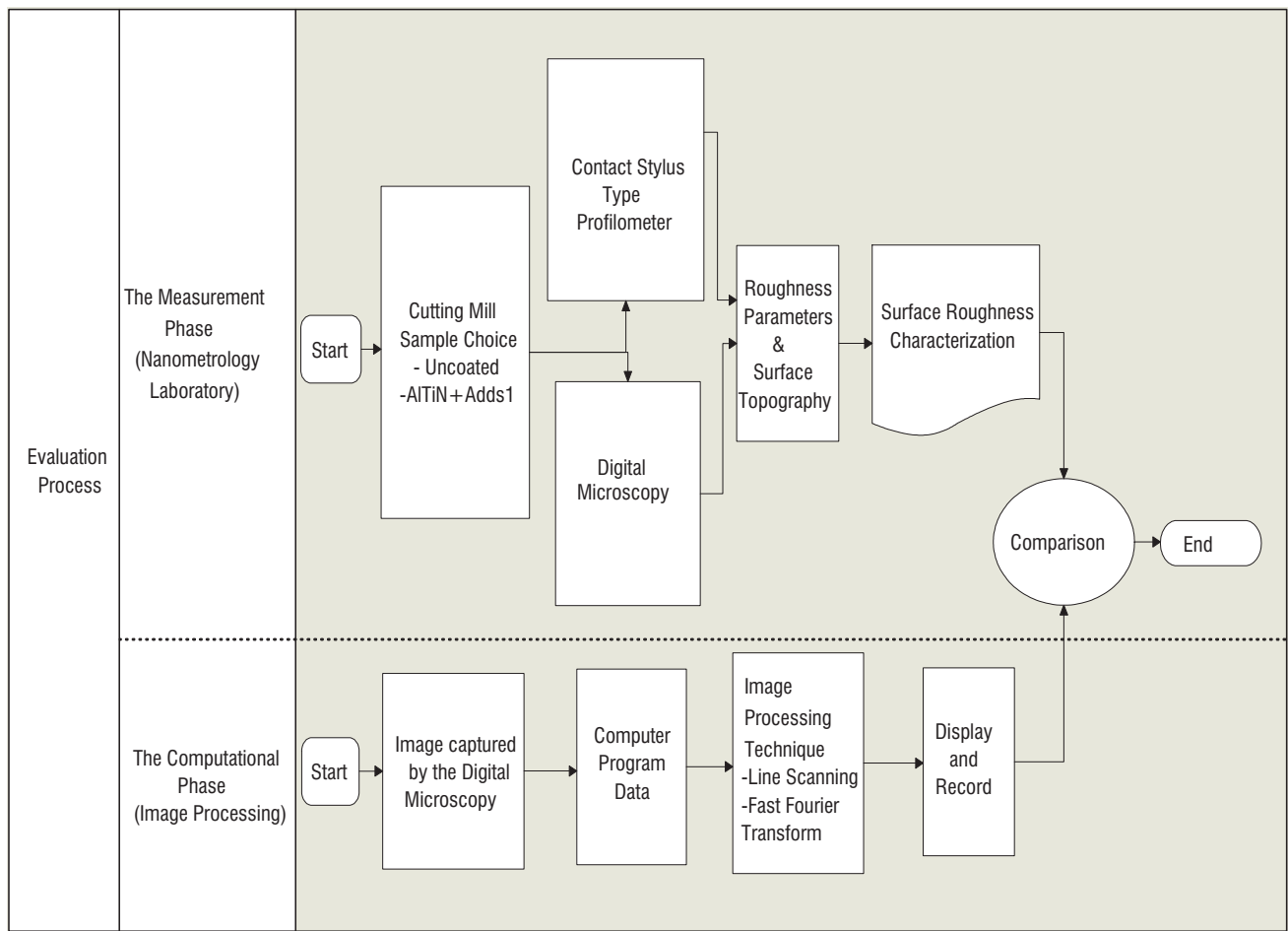


Fig. 1. The evaluation process flow for characterization of surface roughness

in the colour of Anthracite. However the precise measurements to obtain surface roughness parameters have indicated that the coating process caused the same surface of the cutting mill a higher density of material with an irregular geometry. The irregularities caused by the coating process were observed using nanometrology methods to serve the already stated two basic problems in manufacturing tools; operational surface abuse and life time.

In this study, two samples from the machined cutting mills with the same geometrical characteristics were analyzed in order to assess surface roughness of both the uncoated and coated mills shown in Fig. 2.

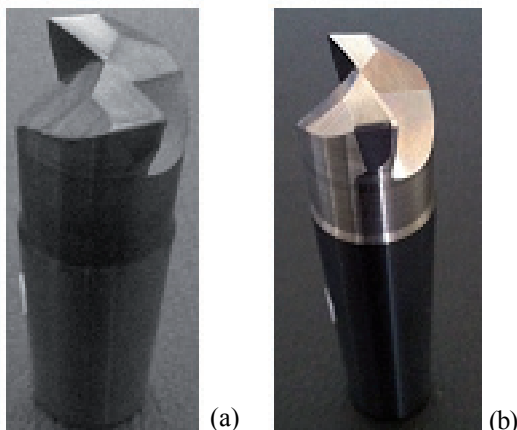


Fig. 2. The coated (a) and uncoated (b) cutting end mill samples

3. The Experimental Measurement Phase

Two high-precision cutting tools having cylindrical handlings of different textures, with and without coating were investigated by means of the evaluation of the roughness measurements as well as the analysis of the images captured from high-resolution digital microscope with the help of image processing techniques called Line Scanning and Fast Fourier Transform (FFT). The analyses of the surfaces of the cutting tools with different geometry, material as well as the surfaces of uncoated cutting tool with the same geometry and material and its coated counterpart were examined.

3.1. Contact Stylus Type Profilometer

The contact roughness measurement of the machined metal surfaces was performed by the Form Talysurf Intra 50 profilograph [2] with ultra software (FTS I μ) illustrated in Fig. 3 according to the ISO 4287 [3] by mapping the readings taken in a direction perpendicular to the direction of lay by calculating of the parameters Ra and Rz from a standard spectrum of roughness. Table 1 represents the specifications of the contact stylus profilometer.

Table 1. The specifications of contact stylus type profilometer

Measurement Method	Spatial resolution	Z Resolution	Range Z
Stylus Profilometer (SP)	1-2 μ m	3 -16 nm	0.2 - 1 mm

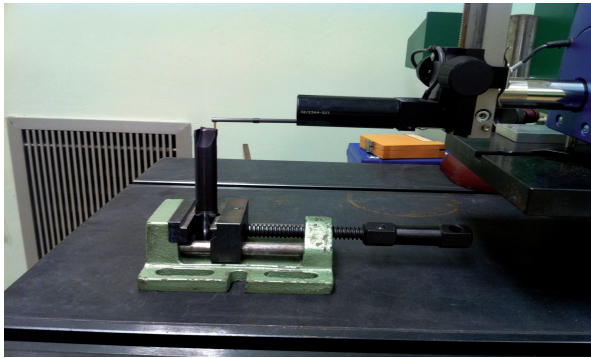


Fig. 3. Schematic diagram illustrating Form Talysurf Intra 50 profilograph during the contact measurement of end mill sample used in this study

3.2. The Digital Microscopy

The Keyence VHX-1000 digital microscope illustrated in Fig. 4 is a high resolution CCD camera based system with a high intensity halogen lamp and image processing capabilities that integrates observation, recording, and measurement functions [4]. Table 2 indicates the specifications of this digital microscope in detail.



Fig. 4. Schematic diagram illustrating the Keyence VHX-1000 Digital Microscopy

Table 2. The specifications of the digital microscopy [4]

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	

4. The Computational Phase

The captured images were processed and analysed using Matlab image processing toolbox. The techniques carried out in this study were Line scanning and Fast Fourier Transform (FFT).

4.1. Line Scanning

In this study, the true color images were binarised. The size of images was 1000 by 552. DN (Digital Number) values of binarised images were collected from the selected lines using line scanning technique used in Fig. 5 [5]. These selected lines were taken from the points at 300, 600 and 900 composed of 552 pixels on y axis.

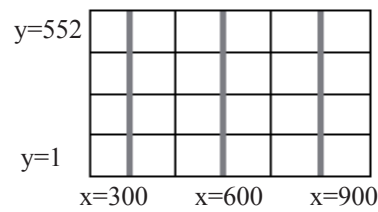


Fig. 5. Line Scanning Representation [5]

4.2. Fast Fourier Transform (FFT)

The true color images were reduced to 8 bit grey level images and grey images were sharpened by 20 pixels of radius and Gaussian blurry. Processed images were converted from spatial domain to frequency domain using Matlab Image Processing Toolbox (2D FFT).

5. Results

5.1. Measurement Results

The roughness measurements were carried out with Taylor Hobson Form Talysurf Intra 50 profilograph. The roughness data taken from the stylus profilometer were processed in TalySurf Intra software. In the measurements of the stylus profilometer, 60 mm stylus arm length, 2 μm radius conisphere diamond stylus tip size and 1 mN force (speed=1 mm/s) were selected [6,7,8,3]. The complicated digital based systems provide great image resolution as indicated in Table 2. The evaluation processes have been carried out in a 0.2μm interval by a software (Keyence VHX1000) 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. This property enables the instrument to get different views of surface structure. For the coated and uncoated end mills, a standard high-pass Gaussian filter with a long-wavelength cutoff of 0.8 mm was used and sampling length as 1.6 mm according to the ISO standards were chosen [3]. The analyses were then performed for all specimens for several roughness parameters but Ra parameter gave us much of the idea on the surface topography.

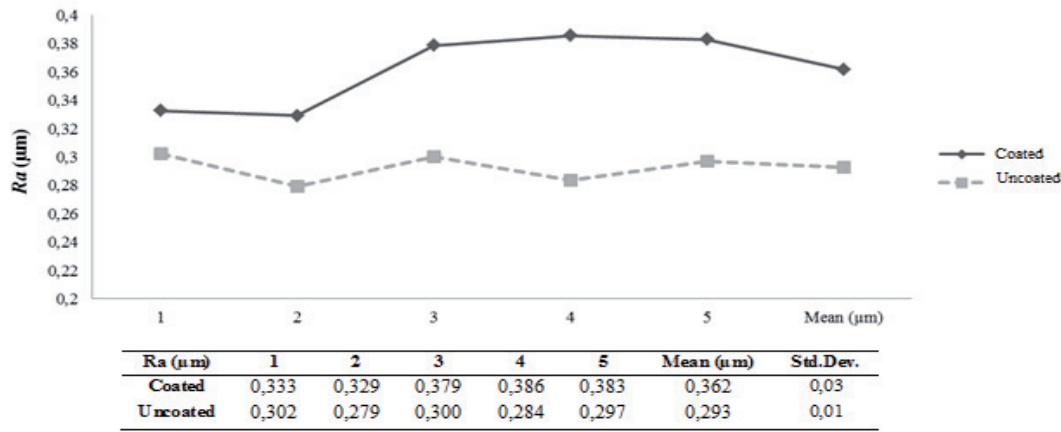


Fig. 6. R_a values belonging to the coated and uncoated end mill cutting tool

As observed in Fig. 6, 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. The aim of the study was to investigate the surfaces in terms of coating characteristics by measuring their roughness after their manufacturing processes.

5.2. Image Processing Results

In this study, the images taken from uncoated (Fig.7a) and coated (Fig.7b) endmills were analysed using line scanning and 2D FFT image processing techniques. The measurement results from the stylus profilometer were compared with those from the image processing techniques.

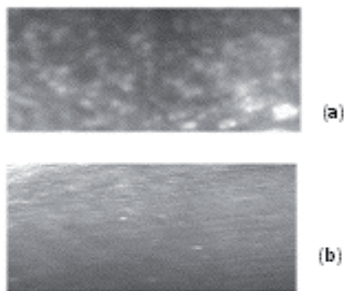


Fig. 7. The images taken from a) uncoated and b) coated end milling cutting tools

5.2.1. Line Scanning

The application of line scanning image processing method were carried out with the points at 300,600 and

Samples	End Mill with Coated	End Mill without Coated
Number of Pulses	x=300	147
	x=600	156
	x=900	138
Mean Values	147	160
Std. Dev.	9	8

900 composed of 552 pixels on y axis. The results of line scanning as an image processing technique from Figs. 9 and 10 indicate that pulse numbers and pulse widths are different for each surface. The number of pulses is shown in Fig. 8 respectively for coated and uncoated surfaces of the end mill samples taken from different regions.

The standard deviations of the analysed lines are 9 and 8 respectively for the coated and uncoated cutting end mill samples. The features of pulses taken from all regions represented consistency.

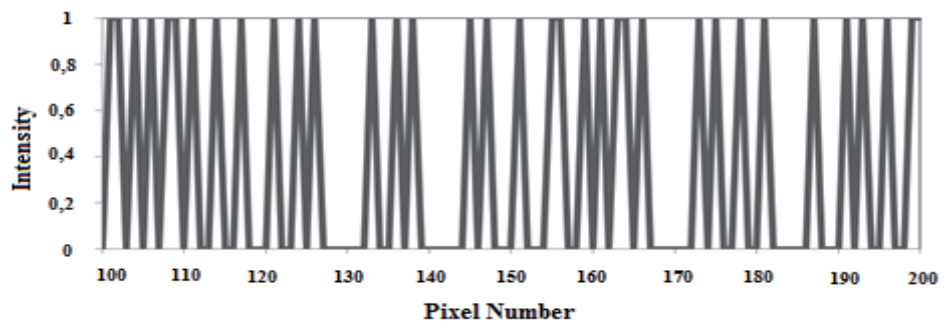


Fig. 9. The signal taken from the image of uncoated end milling cutting tool

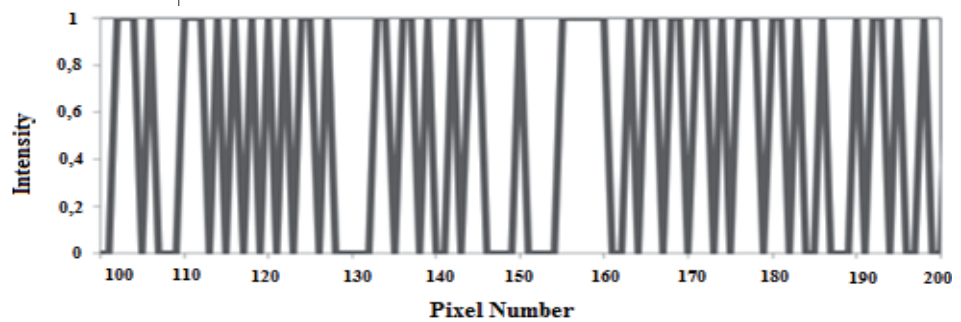


Fig. 10. The signal taken from the image of coated end milling cutting tool

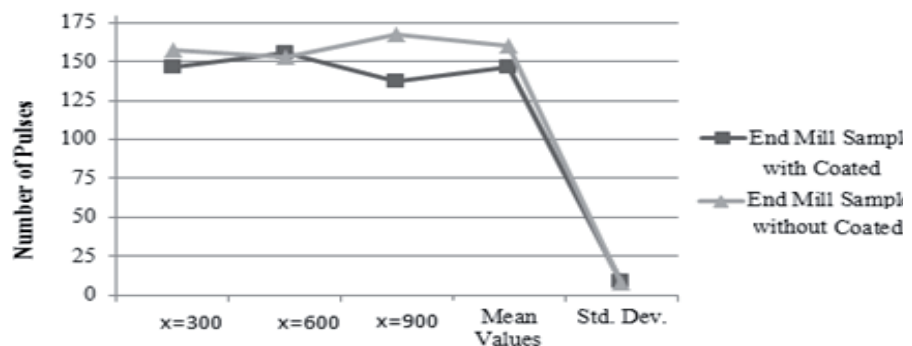


Fig. 8. The number of pulses taken from the end mill samples with and without coated

As observed in signal valleys, the width of pulse increases with surface roughness. The number of black pixels is higher in rough surfaces. This confirms that pulse width at valleys increase with increase in surface roughness.

5.2.2. Fast Fourier Transform (FFT)

FFT analyses results are shown in Fig. 11 for uncoated and coated tools.

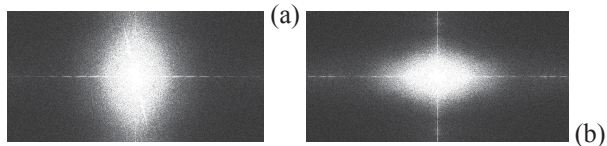


Fig. 11. The FFT images taken from a) uncoated and b) coated end milling cutting tool

Although R_a values from stylus profilometer for uncoated and coated cutting tools are not so distinguishable ($R_a = 0,293$ and $R_a = 0,362$, respectively), FFT images shows the difference. The diameter of white blob in the uncoated FFT image was found higher than that of coated FFT image.

6. Conclusions and Future Work

This study was performed by the researchers of different academic organizations through a process management toolbox delivering process improvement and communication enhancement. The methodology to define the surface roughness characterization of the end milling surface parameters using both the stylus readings and an image processing technique exhibited an advantage for more precise and accurate results.

The computer vision algorithm developed in the methodology presented a considerable potential in the determination of the surface roughness parameters that performed as a noncontact measurement technique in nanometrology. The evaluation process of the surface roughness parameters was carried out by using the image processing technique called Line Scanning and 2D Fast Fourier indicated results supporting detailed results.

The continuation of this study is to be the surface investigation of the cutting tools after a series of process and their coating performances and issues such as the optimization of the surfaces of the tools. The results will be evaluated for comparison of the surface roughness characterization, coating material effect and instrument life time as indicated in the process flow.

The future work of image processing is comprised of developing high quality image processing techniques to evaluate the surface roughness parameters of different imaging systems and techniques of high resolution, high digitization, and high CCD sensitivity.

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