

# MEASUREMENT TECHNIQUES USED FOR ANALYSIS OF THE GEOMETRIC STRUCTURE OF MACHINED SURFACES

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## ABSTRACT

The quality of machined surfaces, resulting from the manufacturing process and conditioning their functionality, is determined by the surface geometric structure (SGS). There is a close relationship between surface properties, shape, qualitative imagining of the surface topography, technique and technology employed for machining purposes [1, 2]. If a given surface is to have practical applications in engineering, the correct technological process needs to be chosen.

In the paper, various techniques used for measuring the surface geometric structure were described. The results of the study, which were obtained from different measuring devices like Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM) and Optical Interferometer (WLI), were presented. Optical Microscopy (OM) was shown as a helpful device to analyse some aspects of surface topography. Each measuring technique provided different, yet complementary data on the topography of the machined surfaces. Owing to this, a full characterization of the geometric surface structure of the machined surfaces was enabled, including surface properties resulting from the applied technological process.

Based on the measurements made, the characteristics of chosen devices (measurement techniques) were defined with an indication of how they can be applied to the analysis of the surface geometric structure (SGS). The devices which are considered to give the best view of examined surfaces and allow a thorough analysis of their irregularities were then indicated.

## KEYWORDS

surface metrology, measurement techniques, SGS analysis.

## Introduction

The surface geometric structure (SGS) is the outcome of the machining (manufacturing) process of products [3]. Therefore, the quality of machined surfaces can be judged by the surface geometric structure.

The analysis of the *SGS* is necessary and essential for assessing the surface features.

The analysis of the *SGP* consists of three parts: describing measurement methods (techniques), pre-

senting a surface, and conducting a parametric assessment of the surface.

The basis for the analysis of the topography of a given surface is the selection of appropriate measurement techniques that will enable proper description of this surface and subsequent evaluation of its shape based on obtained images and geometric parameters.

There are many techniques for measuring the surface geometric structure – Fig. 1.

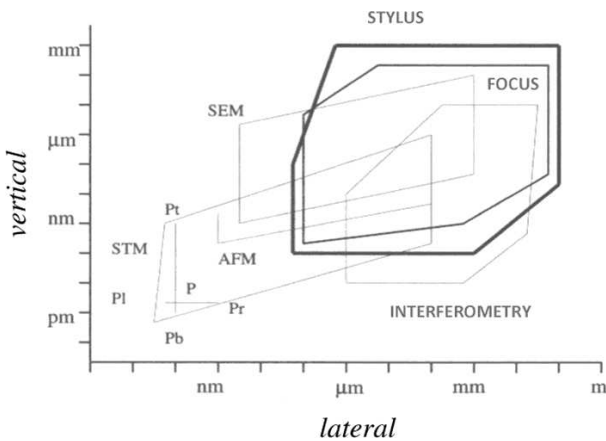


Fig. 1. Scope and resolution of the 3D surface measuring methods [4, 5].

None of them, however, if used alone, can give complete description of the examined surfaces. It is advisable to employ a variety of techniques to obtain complementary information on the surface topography, which will facilitate interpretation of obtained results [6, 7].

The presentation of a machined surface involves connecting the measured/scanned points so that the obtained image represents the tested surface [8]. There are two ways to present a measured surface: it can be shown with the use of a contour map as well as using an isometric view created with an axonometric projection.

The assessment of a machined surface can be quantitative as well as qualitative. A quantitative assessment requires the determination of the parameters describing the measured surface. This is possible due to the developed hallmarks of the surface geometric structure (3D), which, similarly to the 2-dimensional profile (2D), were divided into functions and parameters; the details were discussed, inter alia, in the following references [2, 9, 10].

A quality assessment is based on the analysis of images which are obtained from surface measurements taken with the use of a variety of devices (measurement techniques).

## Materials and methods

### Characteristic of research materials

The surfaces of elements made of tool steel (material *Type A*) and oxide ceramic (material *Type B*) were studied.

The surfaces of the elements made of tool steel were subject to electric discharge machining (further referred to as EDM). The EDM process was performed using copper electrodes; cosmetic kerosene

was used as a dielectric liquid. Pulses were delivered by a generator based on transistor control which allowed to control the energy of single discharges.

The surfaces of the elements made of oxide ceramic were subject to an abrasive process (lapping). The diamond micropowder lapping paste was used as an abrasive. During the machining process, the granulation of diamond micropowder was being changed until the desired surface had been achieved.

### Methodology of research

The geometric structure of machined surfaces obtained from the machining process (erosive and abrasive one), were tested with the use of the following four research devices: atomic force microscopy (AFM), scanning electron microscopy (SEM), white light interferometer (WLI), and optical microscopy (OM). The tests were done in the Institute for Sustainable Technologies – National Research Institute (Department of Tribology) and the Institute of Metallurgy and Materials Science – Polish Academy of Sciences.

The atomic force microscopy (AFM) – Fig. 2, allows to capture images of surfaces with the resolving power of the nm order, thanks to the use of the interatomic van der Waals forces. The surface is scanned by a sharp tip which is attached to the end of a flexible lever (the cantilever). In this method, the laser beam is reflected off the back of the cantilever and collected by the photodiode detector [8, 11, 12]. AFM works in two modes: contact and non-contact.

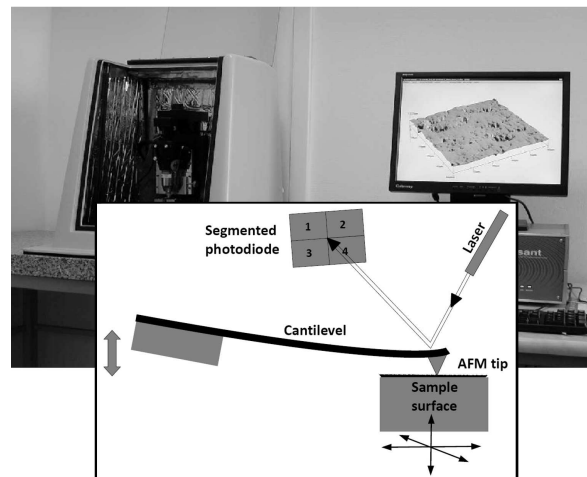


Fig. 2. The measurement principle of AFM.

The operating principle of the AFM is based on the measurement of impact forces the cantilever has upon the tested surface while it is being scanned.

The advantage of the AFM is a very good resolution in the *z*-axis and the high quality of images;

whereas its drawback is the small measurement range – the scanning area is no larger than  $100 \times 100 \mu\text{m}$ .

The parameters during research: non-contact mode, the scanning area  $30 \times 30 \mu\text{m}$ .

The scanning electron microscopy (SEM) – Fig. 3, allows, among others, the qualitative analysis of the surface irregularities.

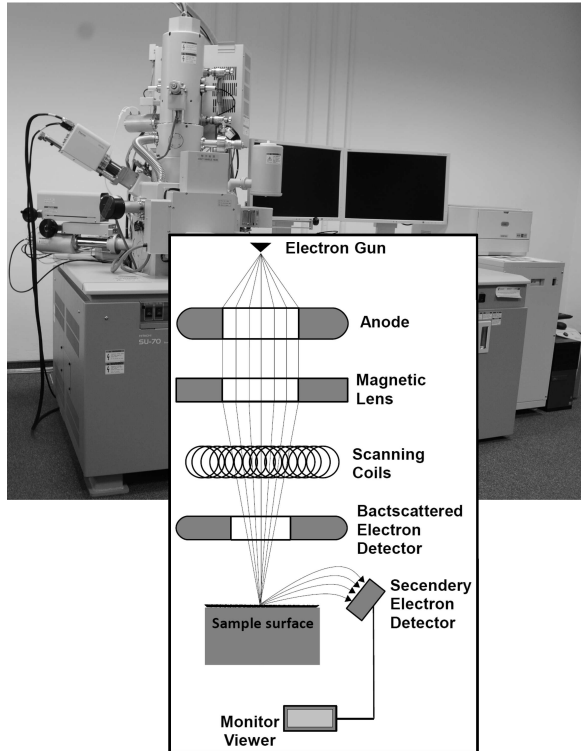


Fig. 3. The measurement principle of SEM.

The working principle of the SEM is the emission of secondary electrons from a sample, which is excited by the incident electron beam directed onto the tested area. The secondary electrons are formed by collisions of the incident electrons with the sample atoms which release electrons with lower energy [11, 12].

A large depth of field, high resolution [12] and the quality of obtained images are the advantages of SEM. The drawbacks are the necessity of using a vacuum and a small range in the Z-axis.

The parameters during research: non-contact mode, magnification  $\times 200$  for material *Type A* and  $\times 2000$  for material *Type B*.

The optical interferometer allows to capture the surface geometric structure of an ultra-high vertical resolution, up to 10pm (regardless of the applied magnification) [8, 12]. Its operating principle is based on the use of one of the varieties of white light interferometry (WLI) – Fig. 4, so-called scanning broadband interferometry (SBI).

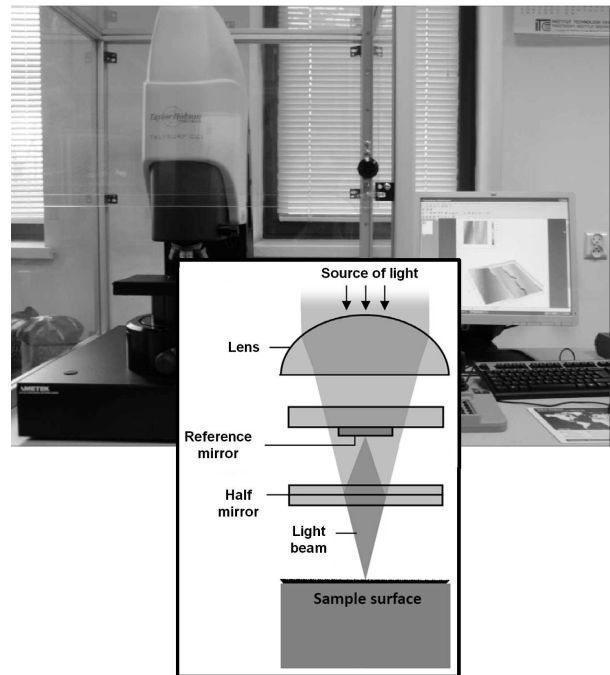


Fig. 4. The measurement principle of WLI.

The advantage of the WLI is a large measuring range as compared with the aforementioned devices, great accuracy of scanning, and a good resolution. The disadvantage, however, is a relatively small measurement area.

The parameters during research: the sensitivity in the Z-axis is 0.01 nm, the scanning area  $1.65 \times 1.65 \text{ mm}$ , the objective lens (Mirau [13])  $\times 10$ .

The optical microscopy (OM) with digital video recording allows to capture images of sample surfaces at different magnifications and directly record consecutive fields of view.

The advantage of the OM is that, compared with other techniques, it allows observation of the large areas of a surface. On the other hand, it fails to show the features of surfaces described by low roughness parameters, or machined surfaces characterized by high technological quality, which may be considered as the disadvantage of the device.

The parameters during research: the lens  $\times 20$  (magnification  $\times 200$ ).

The use of different measurement devices (techniques) allowed to collect additional information on the surface characteristics (including irregularities) formed in the machining process as well as enabling the analysis and interpretation of the results.

For the purpose of a quantitative assessment of the machined surface, the sophisticated metrology software was used (*TalyMap v.6.1* and *Motic Images Plus v.2.0* program).

Results and discussion

The machined surfaces obtained from the manufacturing process were analyzed qualitatively and quantitatively. Selected results were shown on four figures (Figs. 5–8) and in table (Table 1).

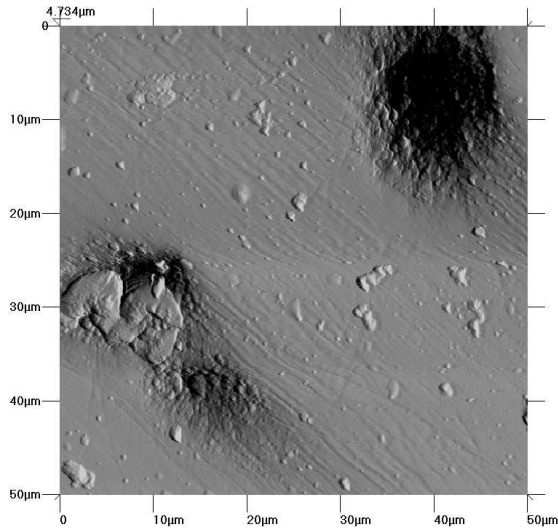


Fig. 5. Measurement result (material *Type B*) – AFM.

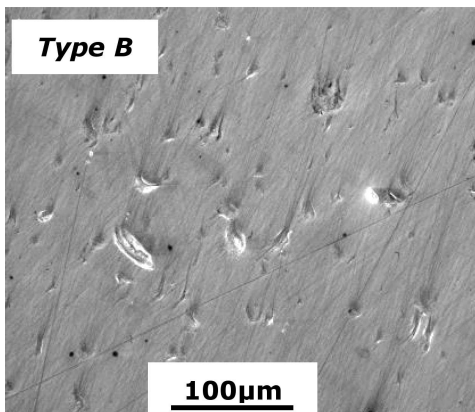
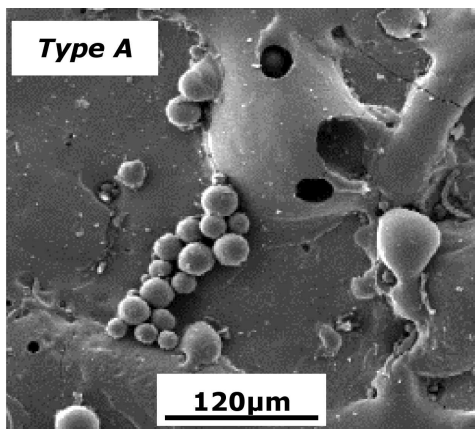


Fig. 6. Measurement results – SEM.

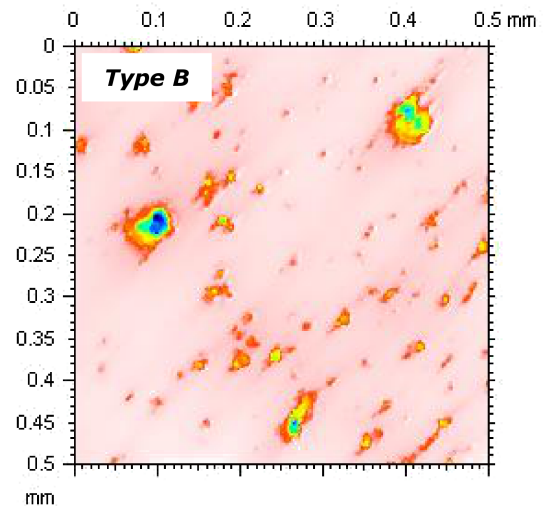
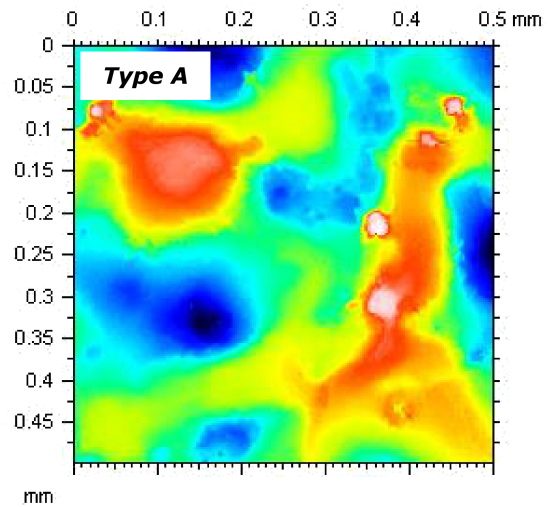


Fig. 7. Measurement results – WLI.

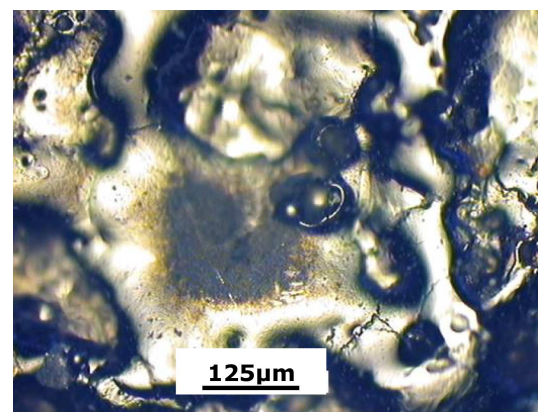


Fig. 8. Measurement result (material *Type A*) – OM.

Figures from Fig. 5 to Fig. 8 contain the images obtained with the use of four research devices. The results allow to evaluate the quality of the machined surfaces.

Table 1 presents the parameters describing the condition of the machined surfaces, which allows a quantitative assessment of the machined surfaces.

Table 1  
Measurement results – metrology software.

Material Type A		Material Type B
Roughness parameters		
TalyScan	$S_a=10,30 \mu\text{m}$	$S_a=0,181 \mu\text{m}$
	$S_q= 12,50 \mu\text{m}$	$S_q= 0.380 \mu\text{m}$
	$S_t= 66,10 \mu\text{m}$	$S_t= 5.50 \mu\text{m}$
	$S_{sk}= 0.197$	$S_{sk}= -5.77$
	$S_{ku}= 2.37$	$S_{ku}= 46.90$
	$S_{tr}= 0.811$	$S_{tr}= 0.662$
	$S_{ds}= 31183 \text{ 1/mm}^2$	$S_{ds}= 3463 \text{ 1/mm}^2$
Average dimensions of the surface features [ $\mu\text{m}$ ]:		
Motic	(radius)	<ul style="list-style-type: none"> <li>• Crumbles (diameter): <math>2.7\div 4.8</math></li> <li>• Traces of the grinding (length): <math>50\div 150</math> (width): <math>16\div 32</math></li> </ul>
	<ul style="list-style-type: none"> <li>• Craters: 26.5</li> <li>• Cavities: 16</li> <li>• Spheroids: 21</li> </ul>	

In the images displayed on figures the differences between the machined surfaces, which result from the different treatment methods, are shown.

On the surfaces obtained from the electric discharge machining (*Type A*), the various types of surface irregularities can be seen. They take on the form of craters (cupped concave), cavities (empty or filled with the treatment products), remelted areas, burrs (the material elements resembling droplets), a few cracks (surface discontinuities) and spheroids (balls of material).

The surface geometric structure formed in the EDM process is the result of mutually overlapping craters (resembling the spherical bowls) and the other earlier mentioned irregularities.

On the surfaces subject to lapping (*Type B*), characteristic scratches left by the abrasive, hard diamond micrograins, can be seen. There are some traces of the previous processing (grinding), resulting from the short time of lapping of the samples. In addition, many crumbled bits were reported on the machined surface, which results from the material properties (high hardness, and thus increased brittleness).

During the research, it turned out that not every type of a machined surface could be measured with the use of any device. To some extent, it has to do with the topography of the machined surfaces (too rough or too smooth) and the limitations of the measuring devices. For this very reason, no measurement results have been obtained from AFM for the surface of *Type A* (too high surface roughness) and from OM

for the surface of *Type B* (too smooth surface, barely visible surface defects).

In order to gather information and conduct a quantitative assessment of the machined surfaces, two types of sophisticated metrology software were used. From the data presented in Table 1 and the images shown on figures (Figs.5–8), it can be inferred that the surfaces have a different geometric structure.

The roughness parameters of the machined surface measured with the use of the WLI were obtained with the *TalyMap v.6.1* program.

On the surface measured using the WLI, we cannot see the surface irregularities which emerged on the surface when it was measured with the scanning electron microscopy SEM. Taking measurements of these irregularities (features) was possible due to the *Motic Images Plus v.2.0* program.

Both white light interferometry WLI and scanning electron microscopy SEM, providing complementary information on the samples, allowed to make a comprehensive analysis of the machined surface

SEM gives a real image of the measured surface with all its irregularities, which allows a qualitative assessment of the machined surfaces; whereas a quantitative assessment of these surfaces is enabled by the use of WLI and the sophisticated metrology software.

## Conclusions

This paper offers a short overview of selected measurement devices (techniques) useful in the analysis of machined surfaces. Some capabilities of metrology software facilitating the analysis and assessment of SGS were shown as well. It should be noted that:

- Atomic Force Microscopy (AFM): it allows to show small surface areas, providing high-quality images; it enables viewing details of a machined surface within the measured areas (see the another works of the authors [14, 15]).
- Scanning Electron Microscopy (SEM): allows measuring and imaging of the surface microstructure; if sophisticated metrology software is used for the analysis purposes, surface irregularities can be measured easily – small defects which failed to be captured with the use of AFM and WLI (see the another work of the authors [14]).
- Optical Interferometer (WLI): allows to measure all types of surfaces; enables an accurate quantitative assessment of the measured surfaces using specialized software; defects taking the form of cavities, hills or wear products deposited on ma-

chined surfaces are possible to be measured with a high accuracy (see the another works of the authors [14, 15]).

- Optical Microscopy (OM): allows a measurement of the surfaces characterized by large roughness; furthermore, it shows huge surface areas, thus exposing more defects, including wear products deposited on these surfaces (see the another work of the authors [16]).

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