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High-accuracy surface topography measurements of abrasive tools using a 3D optical profiling system

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Abstract

This paper presents and discusses the proposed use of the Talysurf CLI 2000 system for performing high-accuracy measurements of the surface topography of abrasive tools. Specifically, the paper presents a brief description of the Talysurf CLI 2000 system (Fig. 1), as well as one of its modes of use, involving the chromatic aberration phenomenon. The selected results of the analysis of the measurement data obtained for the surface of a small-sized flat grinding wheel 1-20×20×10 SG 80 M 8 V (Fig. 2) and relevant visualizations pertaining to this analysis are given in the paper as well. All analyses of the measurement data were carried out using the TalyMap Silver software (Figs. 3-4). The obtained experiment results confirmed a high degree of usefulness of Talysurf CLI 2000 and the dedicated software (TalyMap Silver) for high-accuracy measurements of abrasive tools (grinding wheels). Therefore, the use of optical analysis methods may be an interesting alternative to the methods currently utilized in the assessment of abrasive tools.

Keywords: 3D optical profiling system, high-accuracy measurements, surface topography, abrasive tools, grinding wheel.

Precyzyjne pomiary topografii powierzchni narzędzi ściernych z wykorzystaniem optycznego systemu profilometrycznego

Streszczenie

We współczesnym przemyśle wytwórczym dąży się do uzyskania bardzo wysokiej jakości wykończenia powierzchni. Na uzyskanie zakładanej jakości ma wpływ szereg czynników związanych m.in. ze stanem makro- i mikrogeometrii powierzchni narzędzia ściernego. Ocena i odpowiednia analiza stanu powierzchni ściernic ma więc w tym kontekście znaczenie podstawowe. Może być ona prowadzona za pomocą różnego rodzaju systemów pomiarowych, wykorzystujących wybrane metody stykowe oraz metody optyczne. W odniesieniu do ściernic precyzyjne pomiary stykowe i ich analiza mogą okazać się niewystarczające lub trudne do przeprowadzenia. W takim przypadku muszą być one zastąpione lub uzupełnione pomiarami optycznymi. Stwarza to pewne komplikacje wynikające m.in. z każdorazowej kalibracji urządzeń, wprowadzania innych parametrów pomiaru dla każdej z metod, oddzielnej analizy uzyskanych danych za pomocą różnych typów oprogramowania komputerowego. Wymienione działania znacząco wpływają na czas, dokładność i koszt przeprowadzenia pomiarów. Jedną z propozycji rozwiązania ww. problemów może być zastosowanie nowej klasy zintegrowanych systemów pomiarowych, oferujących możliwość oceny badanego przedmiotu za pomocą różnych technik pomiarowych dostępnych na jednej platformie sprzętowej. W pracy zaproponowano wykorzystanie optycznego systemu profilometrycznego Talysurf CLI 2000 firmy Taylor-Hobson Ltd. do precyzyjnych pomiarów topografii powierzchni narzędzi ściernych. Dokonano krótkiej charakterystyki urządzenia oraz opisano jeden z trybów pomiarów wykorzystujący zjawisko abberacji chromatycznej. W części eksperymentalnej zaprezentowano wybrane wyniki analiz i wizualizacji danych pomiarowych uzyskanych dla powierzchni małogabarytowej ściernicy płaskiej o oznaczeniu technicznym 1-20×20×10 SG 80 M 8 V. Analizy przeprowadzono w oprogramowaniu TalyMap Silver. Uzyskane wyniki potwierdziły dużą użyteczność zastosowanego systemu Talysurf CLI 2000 oraz szerokie możliwości dedykowanego oprogramowania TalyMap Silver, co może stanowić ciekawą alternatywę dla wykorzystywanych już metod oceny stanu narzędzi ściernych (ściernic).

Słowa kluczowe: optyczny system profilometryczny, precyzyjne pomiary, topografia powierzchni, narzędzia ścierne, ściernica.

1. Introduction

The modern manufacturing industries often strive to obtain a high quality of surface finish. In so doing these industries use numerous types of material removal procedures, such as: modern variations on grinding (e.g. HSG (*High Speed Grinding*) [1], CPCG (*Continuous Path Controlled Grinding*) [2], HSP (*High Speed Peelgrinding*) [3], Quickpoint method [4], polishing [5] and microfinishing [6]. A variety of factors influence the condition of the surface obtained as a result of using the above-mentioned processes. They are related to, among other things, the inherent properties of the used material, the processing parameters and conditions, as well as the condition of the abrasive tool surface.

It is also of high practical value to deal with issues related to the recognition of surface characteristics and the determining of the surface condition of abrasive tools. Such an assessment may correspond to both the surface macro- and microgeometry. The former is related to determining the deviation of shape and the dimensions of the tool. The latter, more complex assessment, may be realized both in relation to the selection of proper assessment parameters, as well as the analysis of the abrasive tool and the condition of its surface microgeometry.

For assessment of the surface texture parameters of abrasive tools [7] a variety of measurement systems are used [8-10]. These systems use particular stylus methods [11] and numerous optical methods [12-15]. In the case of grinding wheels, the precise stylus measurements may turn out to be insufficient or hard to perform. Such measurements can be particularly difficult if we talk about grinding wheels with a very open structure or high porosity grinding wheels, which are characterized by relatively large intergranular spaces. The occurrence of intergranular spaces may cause measurement discontinuities, or even serious damage to the stylus in extreme cases. The above described situation is highly disadvantageous. When deciding upon stylus measurements, one must bear in mind how crucial it is to perform them carefully and with a high degree of precision [16]. If the realized stylus measurements do not yield the desired results, it is necessary to replace, or complement, them by using optical measurements [17]. This generates certain complications resulting in: the need to recalibrate systems each time they are used, the introduction of different parameters for each of the methods and the need for a separate analysis of the acquired data using various types of computer software, amongst other issues. The operations enumerated have a considerable influence upon the duration, the precision and the cost of the measurements.

One possible solution to the above-mentioned problems may be to use a new integrated measurement system, which offers the possibility to assess the examined object using a variety of measurement techniques (all of which would be available on a single hardware platform). An example of such a system is the Talysurf CLI 2000 optical profiling system, produced by Taylor-Hobson Ltd. A short description of the system, along with an example of measurement results carried out on selected surfaces of abrasive tools, are presented later in this work.

2. Characteristics of the 3D optical profiling system Talysurf CLI 2000 with CLA gauge

The integrated measurement systems CLI (*Chromatic, Laser, Inductive*) were developed at the beginning of the 21st century by a British company Taylor-Hobson Ltd. In 2003 the company introduced the CLI 2000 system onto the market [18] and in 2004 it presented further devices marked as CLI 1000 and CLI 500 [19]. Talysurf CLI 2000 is characterized by a modular construction. The foundation of the system is a granite base, with gantry, to which a gauge cover and a vertical slide (*z* axis) are mounted. The gauge is equipped with sockets for mounting further, optional, gauges. In the base there is a motorized stage enabling movement within the *x* and *y* axes. The CLI 2000 allows for the acquisition of surface topography measurements in 2D and 3D, by utilizing the following three methods, dependant on the complexity of the measurement task:

- stylus method – measurement with an inductive gauge,
- optical (confocal) method – based on the chromatic length aberration phenomenon,
- optical method – using a laser gauge.

The general characteristics of methods and selected metrological parameters of the gauges used in the 3D optical profiling system Talysurf CLI 2000 are compiled in Tab. 1.

Tab. 1. General characteristics of gauges and their selected metrological parameters used in the 3D optical profiling system Talysurf CLI 2000
Tab. 1. Ogólna charakterystyka czujników i ich wybranych parametrów metrologicznych stosowanych w systemie pomiarowym Talysurf CLI 2000

Gauge type	Range [mm]	Resolution	
		Vertical [μm]	Lateral [μm]
Laser triangulation* (2000 Hz scanning frequency)	10	1	30
	30	3	70
Chromatic Length Aberration** (2000 Hz scanning frequency)	3	0.1	5
Chromatic Length Aberration BE (2000 Hz scanning frequency)	0.3	0.01	3
Chromatic Length Aberration HE (2000 Hz scanning frequency)	0.3	0.01	1
Inductive*** (with 2 μm radius diamond stylus)	0.1-0.5-2.5	0.004-0.01--0.02	2

*Main benefits: laser gauge, wide range, inspection speed, cost effective
**Main benefits: non-contact, CLA gauge, high resolution and accuracy, fast scanning
***Main benefits: inductive gauge, high resolution and accuracy, internal features

A general view of the Talysurf CLI 2000 measurement system, alongside a diagram that shows the operating principles of the CLA gauge based upon the chromatic aberration phenomenon (as utilized during the experiment), is depicted in Fig. 1.

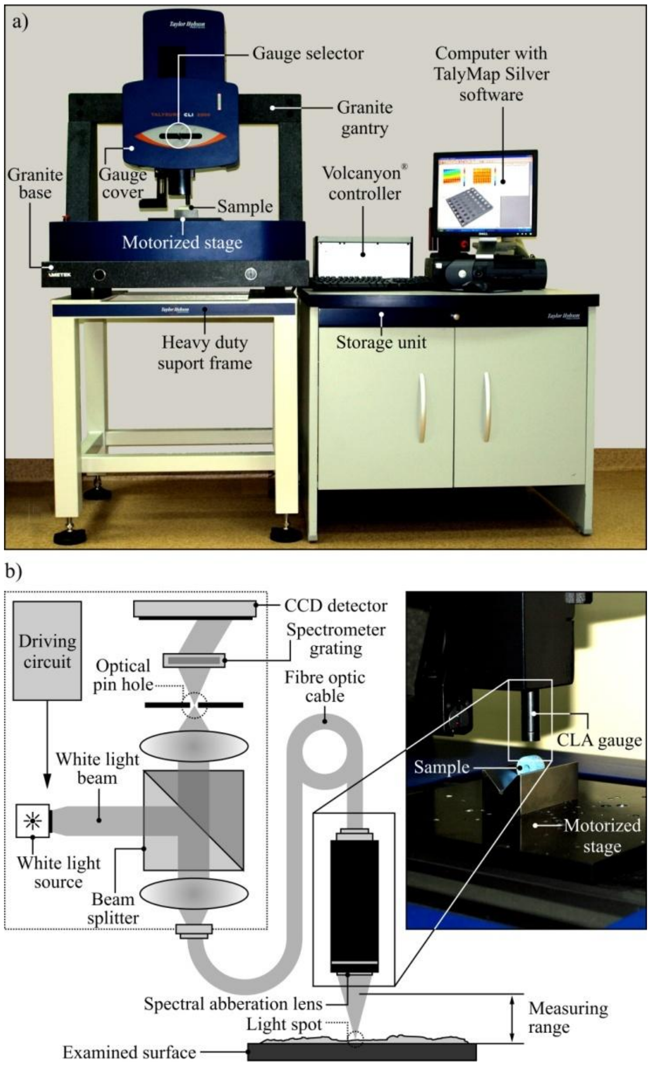

Fig. 1. 3D optical profiling system Talysurf CLI 2000 produced by Taylor Hobson Ltd.: a) general view of the system, b) diagram showing the operating principles of the CLA gauge based upon the chromatic aberration phenomenon
Rys. 1. System pomiarowy Talysurf CLI 2000 firmy Taylor Hobson Ltd.: a) widok ogólny systemu, b) schemat przedstawiający zasadę działania czujnika CLA, wykorzystującego zjawisko aberracji chromatycznej

The CLA gauge based on the chromatic length aberration phenomenon was used during the experiment that is described in detail in Section 3. White light was directed by a beam splitter through a spectral aberration lens onto the examined surface. The lens splits the light into a wide range of wavelengths and at any point on the surface only any one particular wavelength was focused. Light was then reflected from the surface to an optical pin hole. This element permits only the wavelength in focus to pass through it. Finally, a spectrometer grating deflected the light onto a CCD sensor to interpolate the spatial position of the data point.

The measurements, regardless of the selected method, were carried out using the Talyscan CLI 2000 ver.2.6.1 software provided by the system manufacturer. For analysis and visualization of the measurement data, TalyMap Silver ver. 4.1.2 software, using Mountains Technology™ produced by Digital Surf, was used. The same producer also provides the an operational controller for the system elements, entitled Volcanyon®.

The optical profiling system Talysurf CLI 2000 [18], is designed for high-accuracy measurements of surface elements made from various materials and processed with various techniques, in both 2D and 3D modes. Due to the universality of the system, it has become highly popular within numerous fields of modern science and technology, including:

- mechanical engineering (surface topography measurements of polishing pads manufactured in the Chemical Mechanical Planarization (CMP) process [20]),
- material engineering (surface topography measurements and analysis of clear polyester topcoats [21]),
- optoelectronics (surface topography assessment of ceramic materials used in commercial optoelectronic assemblies [22]),
- medicine (surface topography analysis of resin-based composite materials used in dentistry [23]).

3. The experiment

The main goal of the experiment was to analyse the possibility of measuring the surface topography of abrasive tools using the 3D optical profiling system Talysurf CLI 2000.

3.1. Characteristics of the sample

The measurements were carried on various types of grinding wheels, that differed from each other due to the material they were constructed from, their grain size and the application. This work focuses on the results obtained from one type of grinding wheel, with the technical designation 1-20×20×10 SG 80 M 8 V. It was a small-sized flat grinding wheel with sintered microcrystalline corundum grains SG, number 80. The tool was characterized by a hardness classification M and a structure classification 8 and it utilized a ceramic bond. Such grinding wheels are used in internal cylindrical grinding processes in the bearing industries (e.g. steel 100Cr6).

3.2. Pre-measurement procedures

The pre-measurement procedure was reduced ensuring the appropriate settings on the Talysurf CLI 2000 were selected and that the sample was properly prepared for measuring.

The conditions within which the measurements were realized are shown in Tab. 2, while Fig. 2 depicts the general view of the Talysurf CLI 2000 during the measuring process.

A CLA gauge (scanning frequency: 2000 Hz, measuring range: 3 mm) was installed in the measuring system. The sample was cleansed with compressed air and placed in the v-block. Ten areas, within which the surface topography was registered, were clearly demarcated on the sample surface. After manual calibration of the CLA gauge height in relation to the measured grinding wheel area, measurement conditions were set using the Talyscan CLI 2000 software.

Tab. 2. The conditions of surface topography measurements for 1-20×20×10 SG 80 M 8 V grinding wheel by 3D optical profiling system Talysurf CLI 2000

Tab. 2. Warunki pomiaru topografii powierzchni ściernicy 1-20×20×10 SG 80 M 8 V za pomocą systemu pomiarowego Talysurf CLI 2000

Parameter	Value
Measured surface area (axes *x*, *y*, *z*) [mm]	1.5 × 1.5 × 0.256
The number of profile points (axis *x*)	1501
Distance between profile points (axis *x*) [μm]	1
The number of profiles (axis *y*)	1501
Distance between the profiles (axis *y*) [μm]	1
Vertical resolution (axis *z*) [μm]	0.00847
Measuring speed [μm/s]	200
Measuring time [s]	79780

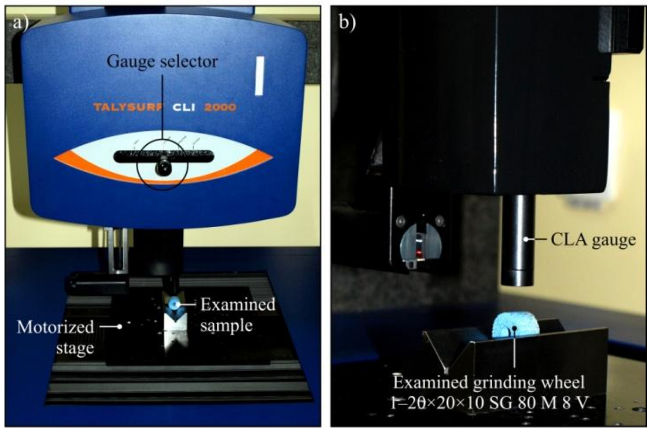

Fig. 2. 3D optical profiling system Talysurf CLI 2000 produced by Taylor Hobson Ltd., during the surface topography measurements of abrasive tools: a) general view of the system , b) close-up of examined 1-20×20×10 SG 80 M 8 V grinding wheel mounted in v-block

Rys. 2. System pomiarowy Talysurf CLI 2000 firmy Taylor Hobson Ltd., podczas pomiarów topografii powierzchni narzędzi ściernych: a) widok ogólny systemu, b) zbliżenie na ocenianą ściernicę 1-20×20×10 SG 80 M 8 V zamocowaną w pryzmie

3.3. Analysis of the surface topography

On completion of the measurements all data were transferred to a computer equipped with TalyMap Silver ver. 4.1.2.4307 software. The main purpose for using TalyMap Silver was to enable the proper processing of the measurement data, so that thorough statistical analysis (determining 2D/3D parameters and other select functions) and data visualization could occur.

Figures 3 and 4 present a collection of analyses and visualizations registered for Area No. 4 from the small-sized flat grinding wheel 1-20×20×10 SG 80 M 8 V.

After opening the input file with extension *.sur, a pseudo-color map was generated (Fig. 3a), which underwent leveling using the least squares method and then the cylindrical form was removed. Moreover, the surface map was checked to see whether there were some points for which no measurement values were registered (non-measured points).

The surface image (whose size was 1.5×1.5×0.256 mm),having been prepared in this way, was then subjected to further transformations. These included determining the so-called photo simulation image (Fig. 3b) and the contour diagram (Fig. 3c). Photo simulation facilitates generation of quasi-realistic surface images, whose heights are encoded using proper shades of gray. Automatic and manual setting of the surface lighting parameters is also possible. A proper angle of light incidence highlights the surface shaping features and allows for its visual evaluation. The contour diagram shows the plane that intersects the surface at different altitudes. Particular altitudes are encoded with colors (the lowest ones – blue, the highest ones - red).

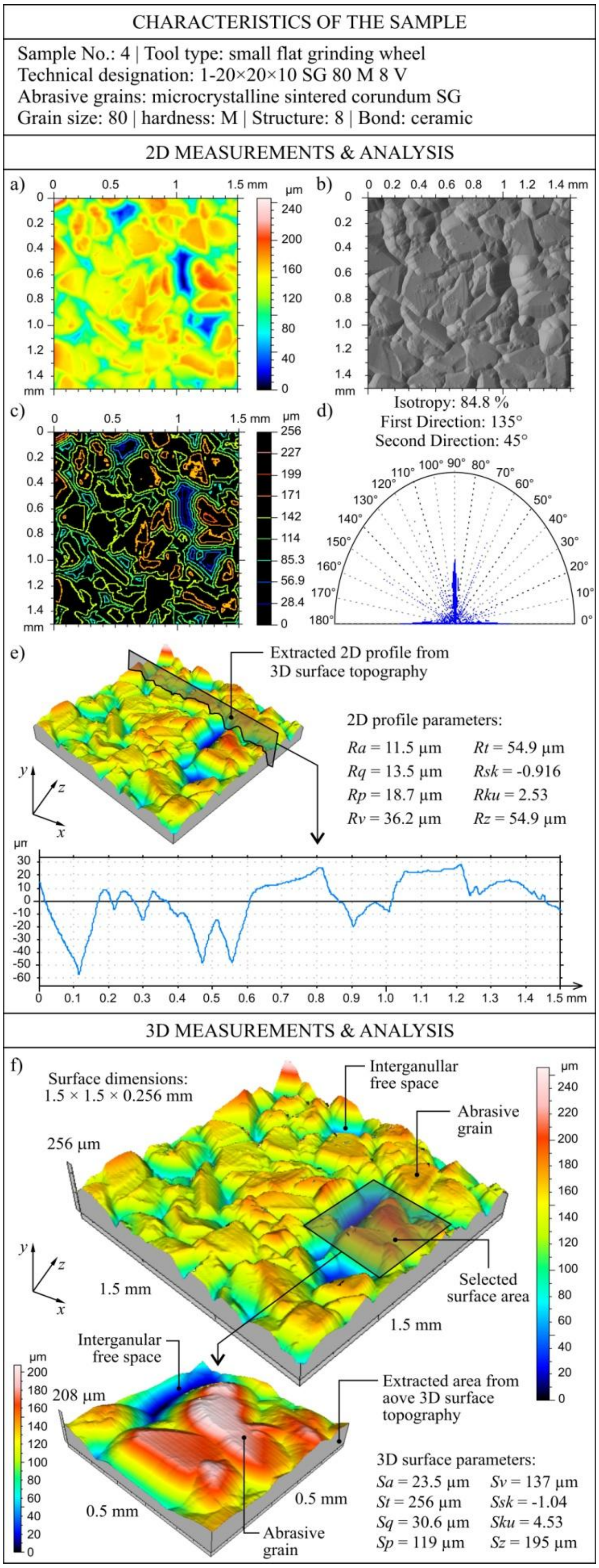

Fig. 3. Example analysis carried out in TalyMap Silver software for the surface of a small flat type grinding wheel 1-20×20×10 SG 80 M 8 V: a) pseudo-colour map, b) photo simulation, c) contour diagram, d) diagram of texture direction, e) 2D profile with parameters, f) 3D surface topography with parameters extracted and fragment of surface with visible abrasive grains

Rys. 3. Przykładowe analizy przeprowadzone w oprogramowaniu TalyMap Silver dla powierzchni małogabarytowej ściernicy płaskiej 1-20×20×10 SG 80 M 8 V: a) mapa powierzchni (kolory indeksowane), b) fotostymulacja, c) diagram konturu, d) diagram kierunkowości powierzchni, d) profil powierzchni wraz z parametrami, e) topografia powierzchni wraz z parametrami

Fig. 3d depicts the texture direction diagram. It is an interesting function which allows for the determination of the direction of chatter marks. In the example described in this paper it was used for information purposes only, as the grinding wheel surface texture does not have any precise direction. This is confirmed by the high isotropic value of the surface, which is 84.8%. The 2D surface profile was shown in Fig. 3e along with the selected parameters, while the continuous axonometric map, in the form of a surface topography, is presented in Fig. 3f. From the input surface topography (mode: photo, horizontal angle $\alpha = 50^\circ$, vertical angle $\beta = 50^\circ$, details resolution: highest), sized 1.5×1.5×0.256 mm, a smaller surface fragment, sized 0.5×0.5×0.208 mm, was extracted. It presented surface details, including single abrasive grains and intergranular spaces. One of the greatest advantages of the TalyMap Silver software is the possibility of selecting the place and size of the selected surface area, which can be visualized later in various 2D or 3D modes.

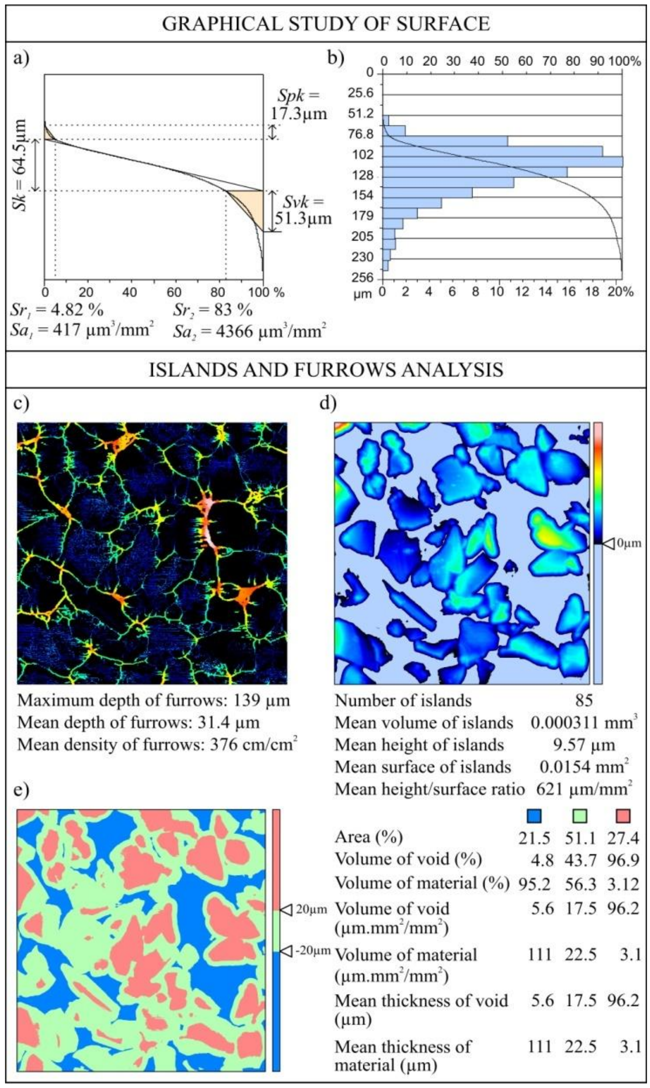

Fig. 4. Example analysis carried out in TalyMap Silver software for the surface of a small flat type grinding wheel 1-20×20×10 SG 80 M 8 V: a) graphical study of *Sk* parameters, b) Abbott-Firestone curve, c) vectorisation of the micro-valleys network, d) graphic analysis of islands with parameters, e) slices study – grinding wheel surface divided by two horizontal planes and representation of surface below, above and between two given altitudes with calculated parameters

Rys. 4. Przykładowe analizy przeprowadzone w oprogramowaniu TalyMap Silver dla powierzchni małogabarytowej ściernicy płaskiej 1-20×20×10 SG 80 M 8 V: a) graficzna analiza parametrów objętości, b) krzywa udziału materiałowego (krzywa Abbotta-Firestone'a) c) wektoryzacja sieci mikrowgłebień powierzchni, d) graficzna analiza wysp wraz z parametrami, e) przecięcie powierzchni ściernicy dwiema poziomymi płaszczyznami oraz reprezentacja powierzchni powyżej, poniżej i pomiędzy zdefiniowanymi poziomami wraz z wyznaczonymi wartościami parametrów

Another example collection of analyses for Area No. 4 of the small-sized flat grinding wheel 1-20×20×10 SG 80 M 8 V is shown in Fig. 4.The graphical study of the volume parameters, Abbott-Firestone curve [24, 25] and the amplitude distribution are shown in Fig. 4a and Fig. 4b. All of the above mentioned analyses were realized in accordance with the EN ISO 25178-2 [26] and EN ISO 13565-2 standards [27].

Analyses of islands and furrows were shown in Figs. 4c-4e. Fig. 4c presents vectorization of the micro-valleys network across the surface. This method enables the detection of all furrows on the examined surface, allowing the determination of their average and maximum depth, as well as the average density per surface unit. The furrows can be represented in the image on basis of colorful depth encoding, or by extracting the primary and the secondary furrows, taking their depth into consideration.

Fig. 4d presents the graphical analysis of islands with the determined values of volume parameter. They were determined for the 0 μm threshold, which corresponded to measuring an average surface. A similar set of volume parameters was also determined for the analysis presented in Figure 4e. It enabled the assessment of the material volume and the empty intergranular space in the area of the grinding wheel that is cut at a certain height by two planes. The analysis was carried out respectively for threshold values of 20 and -20 μm, from the average area. On the basis of the cross-section obtained, such parameters as the percentage volume and average thickness of the material and void space were determined.

During the experiment a problem related to the operation of an algorithm used for detecting subareas which characterize the abrasive grains was highlighted. This is especially visible in the analyses presented in Figs 4d-e. It demonstrates that the procedure for extracting the subareas is still inadequate, as the distinction may regard both the grain and the bond. During subsequent analyses it is crucial to familiarize oneself with the algorithm and carry out a more detailed analysis of the grinding wheel surface topography, in order to extract the subareas that describe active abrasive grains.

4. Conclusions

The considerable limitations of the stylus method for assessment of abrasive tools, necessitates a search for alternative solutions. The use of optical methods may be one of interesting alternatives. These methods are dynamically developed and implemented in a number of modern measurement systems. One of them is the 3D optical profiling system Talysurf CLI 2000, produced by Taylor Hobson Ltd and described in this work. CLI 2000 represents a new class of integrated systems, offering the opportunity to assess the examined object using a variety of measurement techniques available on a single hardware platform.

The measurements of abrasive tools presented in this work are an example of the effectiveness of the Talysurf CLI 2000 and prove that it has numerous advantages. It simultaneously offers a methodology which can be used in the assessment of the active surfaces of abrasive tools, including grinding wheels. This methodology can be extended to other analyses available in the dedicated TalyMap Silver software, depending on the goal of the measurements carried out.

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