

*microfinishing film, abrasive grain,
superfinishing, diamond, coated abrasives*

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BASICS OF THE SUPERFINISHING RESULTS PROGNOSTICATION BY THE DIAMOND LAPPING FILMS

Superfinishing with the use of diamond lapping films differs to a significant extent from other machining methods. This is finishing surface machining, one which is realized by a slow rewinding of a microfinishing film, putting it in an oscillating motion and pressing the tool to the surface being machined. The surface being machined moves with a speed which is substantially greater than that of the tool feed. A characteristic feature of the process is a one-time use of the tool, the result being a need of an optimal selection of the machining parameters. Investigations of the topography of the microfinishing film surface were conducted with the use of new parameters that describe the arrangement and the shape of the vertices of active grains. The following were used for the purpose of assessment: coefficients that had been developed that describe the features of the shape of the tool surface, such as the standardized coefficient of the flatness of vertices w_{ki}^N , the standardized number of vertices in relation to an area unit L_{wi}^N and the dissipation coefficient of the height of the location of vertices w_{rwi}^N . For the purpose of the assessment of the smoothening ability of diamond lapping films, the smoothening potential coefficient w_p was developed, which is defined as the geometric mean of the abovementioned indices.

1. INTRODUCTION

Superfinishing with the use of diamond lapping films differs to a significant extent from other machining methods. This is finishing surface machining, one which is realized by a slow rewinding of an microfinishing film, putting it in an oscillating motion and pressing the tool to the surface being machined. The surface being machined moves with a speed which is substantially greater than that of the belt feed. A characteristic feature of the process is a one-time use of the tool, the result being a need of an optimal selection of the machining parameters.

A one-time use of the active surface of the diamond film means that the active grains remain for a certain time which depends from the tool feed speed in the machining area, and they do not participate again in the forming process of the surface being machined [8]. One needs to pay attention to the fact that it is not all abrasive grains that are used

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in the forming of the object being machined; however, the participation of active grains is greater than in the case of machining with the use of tools with small workability [5],[6],[7].

A determination of the contact probability of the tool grain vertices and the surface being machined is important for the determination of the machining potential of the tool and the selection of its feed speed [1]. Those parameters that describe the volumes of the grains and the formation of the environment of the grains constitute further important properties of the tool, as they decide to a significant extent about the accumulation of the products of the smoothing process and their removal from the machining area [2].

2. EVALUATION OF THE SUPERFINISHING ABILITY OF MICROFINISHING FILM

The indices given below, which take into account the impact of the following properties, have been formulated for the purpose of an evaluation of the superfinishing abilities of specific microfinishing films:

- w_{ki}^N – flatness ratio of the vertices of abrasive grains that is standardized in interval $a < w_{ki} \leq b$,
- L_{wi}^N – number of vertices that is standardized in interval $a < L_{wi} \leq b$ that is related to an area unit,
- w_{rwi}^N – scattering ratio of the location height of vertices that is normalized in interval $a < w_{rwi} \leq b$,

that are expressed by means of the following formulae:

$w_{ki} = \frac{\sqrt{A_{zi}}}{h_{wi}}$	(1)	$w_{ki}^N = \frac{w_{ki} - a}{b - a}$	(2)
$L_{wi}^N = \frac{L_{wi} - a}{b - a}$	(3)	$w_{rwi}^N = \frac{\sigma_{w_{wi}}}{h_{wi}}$	(4)
$w_{rwi}^N = \frac{b - a}{w_{rwi} - a}$	(5)		

where:

A_{zi} – area of the base of the elevation above the plane that is distant from the highest vertex of the microfinishing film surface by the value of 35% of the St parameter,

h_{wi} – height of the highest vertex of the elevation over the plane that is distant from the highest vertex of the microfinishing surface by the value of 35% of the St parameter,

L_{wi} – number of vertices that are elevated above the plane that is distant from the highest vertex of the microfinishing film surface by the value of 35% of the St parameter, related to an area unit,

w_{rwi} – scattering ratio of the height of the elevation of vertices,

σ_{wwi} — standard deviation of the height of the highest vertices of elevations above the plane that is distant from the highest vertex of the diamond lapping film surface by the value of 35% of St .

Values a and b were determined on the level of 0,9 of the minimum value of the parameter standardized and 1.1 of the maximum value respectively.

The index of the smoothing potential of microfinishing films w_p (6) is determined as the geometric average of coefficients: $w_{ki}^N, L_{wi}^N, w_{rwi}^N$, that are determined for the established values of a and b .

$$w_p = \sqrt[3]{w_{ki}^N L_{wi}^N w_{rwi}^N} \tag{6}$$

The values of the features and indices for the accepted standardization limits are found in Table 1.

Table 1. Values of features and indices of the evaluation of the ability of the tools to smoothen machined surfaces

i	L_{wi} [mm ⁻²]	L_{wi}^N	A_{zi} [μm ²]	h_{wi} [μm]	w_{ki}	w_{ki}^N	σ_{wwi}	w_{rwi}	w_{rwi}^N	w_p	St [μm]	Sa [μm]
1	6880	0,95	6,82	0,23	11,4	0,92	0,22	0,95	0,26	0,61	2,9	0,3
3	1136	0,15	8,2	0,37	7,68	0,46	0,38	1,02	0,21	0,24	6,9	0,7
9	480	0,06	18,6	0,88	4,91	0,11	0,67	0,77	0,45	0,14	8,2	0,9
15	592	0,07	50,6	0,87	8,16	0,52	1,19	1,36	0,02	0,10	14,1	1,7
30	160	0,01	228	1,87	8,07	0,51	1,75	0,94	0,28	0,11	17,3	2,7

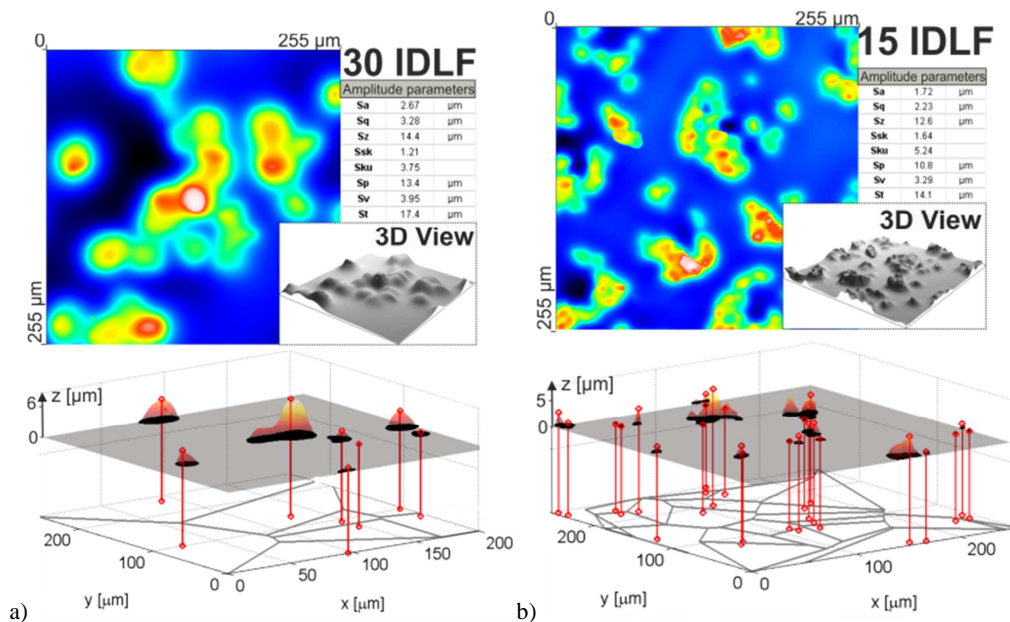


Fig. 1.1. Images of selected surfaces of diamond lapping films and the intersection area of the plane with the cut-off plane that is distant from the highest vertex by 35% of the value of St parameter including a projection on the O_{xy} plane of Voronoi cells with a nominal grain dimension of 30 (a), 15μm (b)

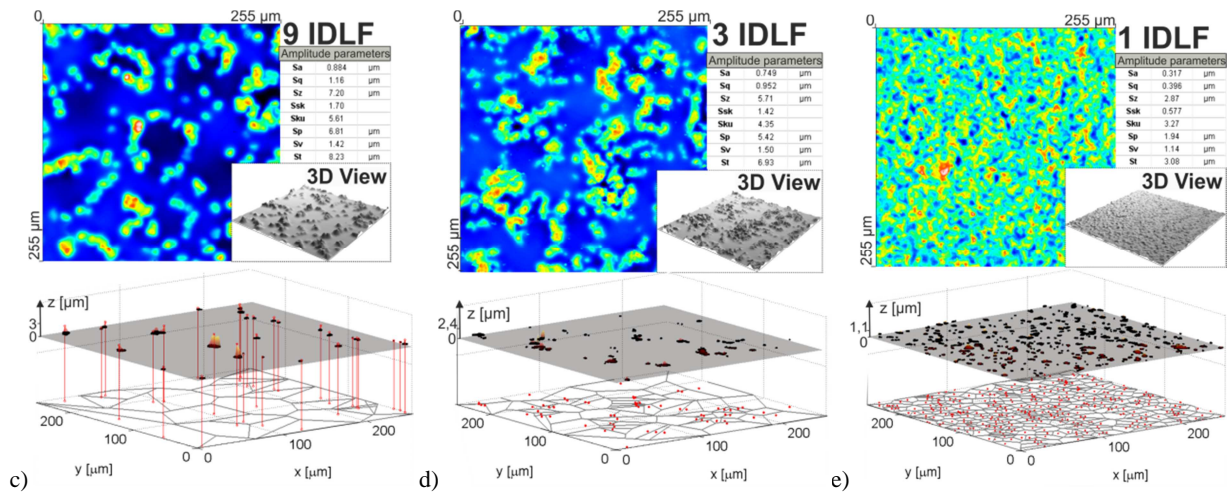
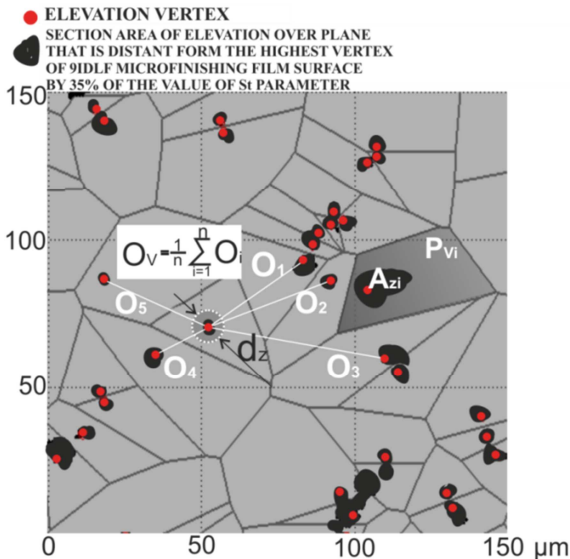


Fig. 1.2. Images of selected surfaces of diamond lapping films and the intersection area of the plane with the cut-off plane that is distant from the highest vertex by 35% of the value of St parameter including a projection on the O_{xy} plane of Voronoi cells with a nominal grain dimension of 9 μm (c), 3 μm (d), 1 μm (e)

Investigations of the topographies of diamond lapping films for superfinishing were conducted with the use of confocal laser scanning microscopy in the LEXT OLS4000 measuring system by Olympus company. Microfinishing films were tested with various nominal sizes of diamond grains (IDLF1, IDLF3, IDLF9, IDLF15 and IDLF30) (Fig. 1.1 and Fig.1.2). The section areas of abrasive aggregates A_z (Fig. 2) were determined that were elevated above the surface of the cut-off plane that was distant from the highest vertex by 35% of the value of St parameter from the highest vertex of the microfinishing film surface. The diagrams (cf. Fig. 1) present the areas of the sections of elevations, where the highest elevation point was marked and Voronoi cells were projected on the O_{xy} plane. The highest



vertices of elevations (Figs. 1-3) constitute the central element of Voronoi cells. Those sub-areas that are determined with the aid of Voronoi cells serve the purpose of finding the nearest neighbors. All of those cells that directly adhere to the cell in question constitute its closest neighborhood (Fig. 2). For each abrasive grain, distances O_i were calculated that were determined on the basis of an individual neighborhood. Distance O_v was determined as the average arithmetic of the single distances of abrasive grains from the nearest neighborhood, where n stands for the number of grains (Fig. 2-3).

Fig. 2. Representation of the decomposition of surface into Voronoi cells

For the purpose of an evaluation of the volumetric efficiency of machining that can be obtained, relations were determined between the area of Voronoi cells P_v that constitute an isolated neighborhood of vertices and the area of the base of the elevation above the cut-off plane on the level of $0,35St$ (St being proper for a given tool) (Figs. 1, 2, 4) and the area of the nominal section of the grain A_N (Fig.5). An evaluation of the capacity to store machining products in spaces between the grains is the result of the value of the P_v/A_N ratio. For the IDLF1 film ($377\mu\text{m}^2:085\mu\text{m}^2$), this ratio is 300-400, which means that the distances between grain vertices over the accepted level are significant and they are from 15 to 20 sizes of the grain.

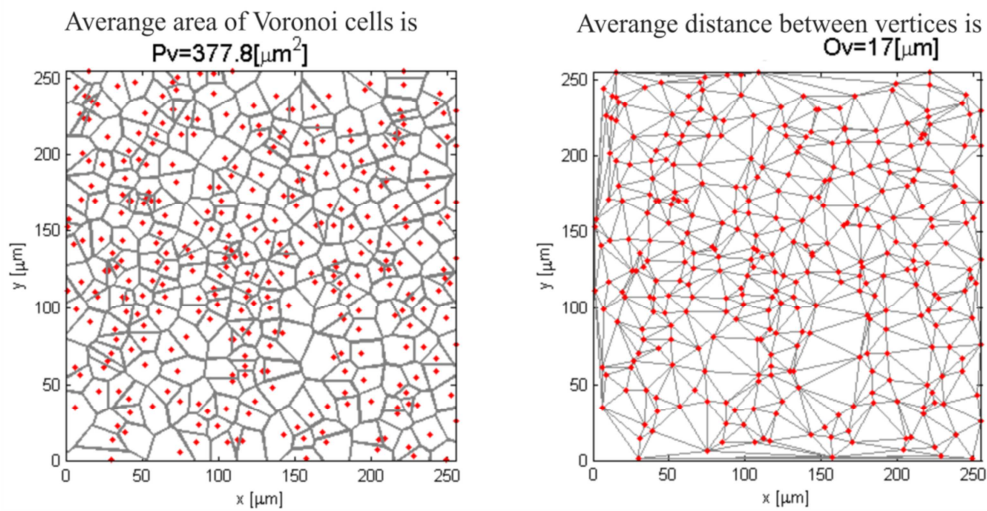


Fig. 3. Decomposition of the surface of IDLF 1 type diamond lapping film with the use of Voronoi cells, whose central points are constituted by the vertices of elevations over the plane (left side) and a projection on the Oxy plane of those sections that connect the vertices of elevations over the plane (right side) that is distant from the highest surface vertex by the value of 35% of the St parameter

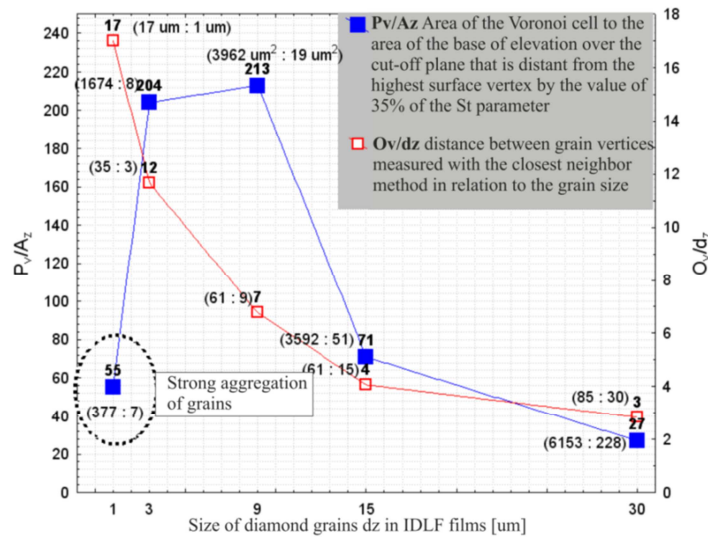


Fig. 4. Ratio of the area of Voronoi cells P_v , which constitute isolated neighborhood of vertices, to the area of the base of elevation above the cut-off plane on the level of $0.35St$ P_v/A_z and ratio of distances between vertices to the nominal grain size for microfinishing films O_v/d_z

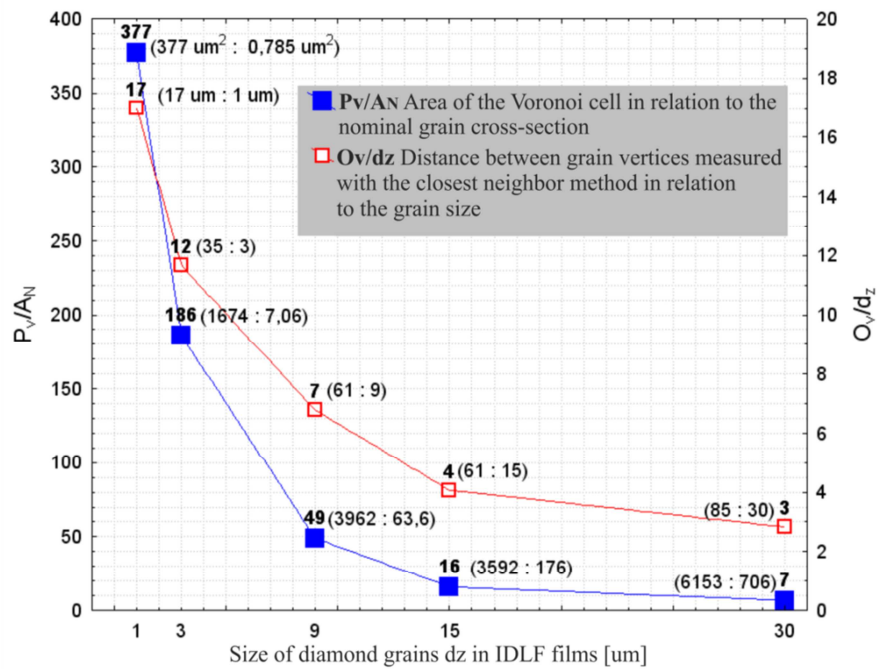


Fig. 5. Ratio of the area of Voronoi cells P_v , which constitute isolated neighborhood of vertices, to the area of the nominal grain cross-section P_v/A_N and ratio of distances between vertices to the nominal grain size for microfinishing films O_v/d_z

3. ASSESSMENT OF SURFACE SMOOTHNESS LEVEL AFTER MACHINING

A GW-1 super finish attachment (Fig. 8) was used in order to investigate the superfinishing process. A GW-1 type super finish attachment is suited for being mounted on an engine lathe in a cutter holder seat. It makes it possible to use interchangeably bands with the widths of 1/2", 1" or 2". The tool feed speed is $v_f = 0 \dots 90$ (max 500) mm/min, the oscillation frequency is $f = 0 \dots 500$ 1/min and the oscillation amplitude is $A = 2,5$ mm. The roll downforce range is $F_n = 10 \dots 90$ (max 200) N and it was realized with a pneumatic servo-motor that was fed from the system of the pressure of 0.6 MPa. Input voltage: 230V, installed power: 400 W, overall dimensions: 575×250×300mm, mass: ca. 25kg.

Fixed disc plates from an aluminum alloy and coated with a nickel layer constituted the objects machined. The machining was realized for 20 seconds with the displacement speed of the object's surface in the area 75 m/min, with a pressure roll of the hardness of 50°Sh. Smoothing was realized with an oscillation of the tool with the frequency of 80 Hz, the tool feed speed was 60 mm/min.

For the assessment of the geometric structure of the surface, the mean power spectral density function was used (Fig. 6-7). The frequency analysis of the surface was determined in a perpendicular direction towards the machining marks. It was observed that with the nominal grain size increasing, the power amplitude rose, for larger wave lengths in particular.

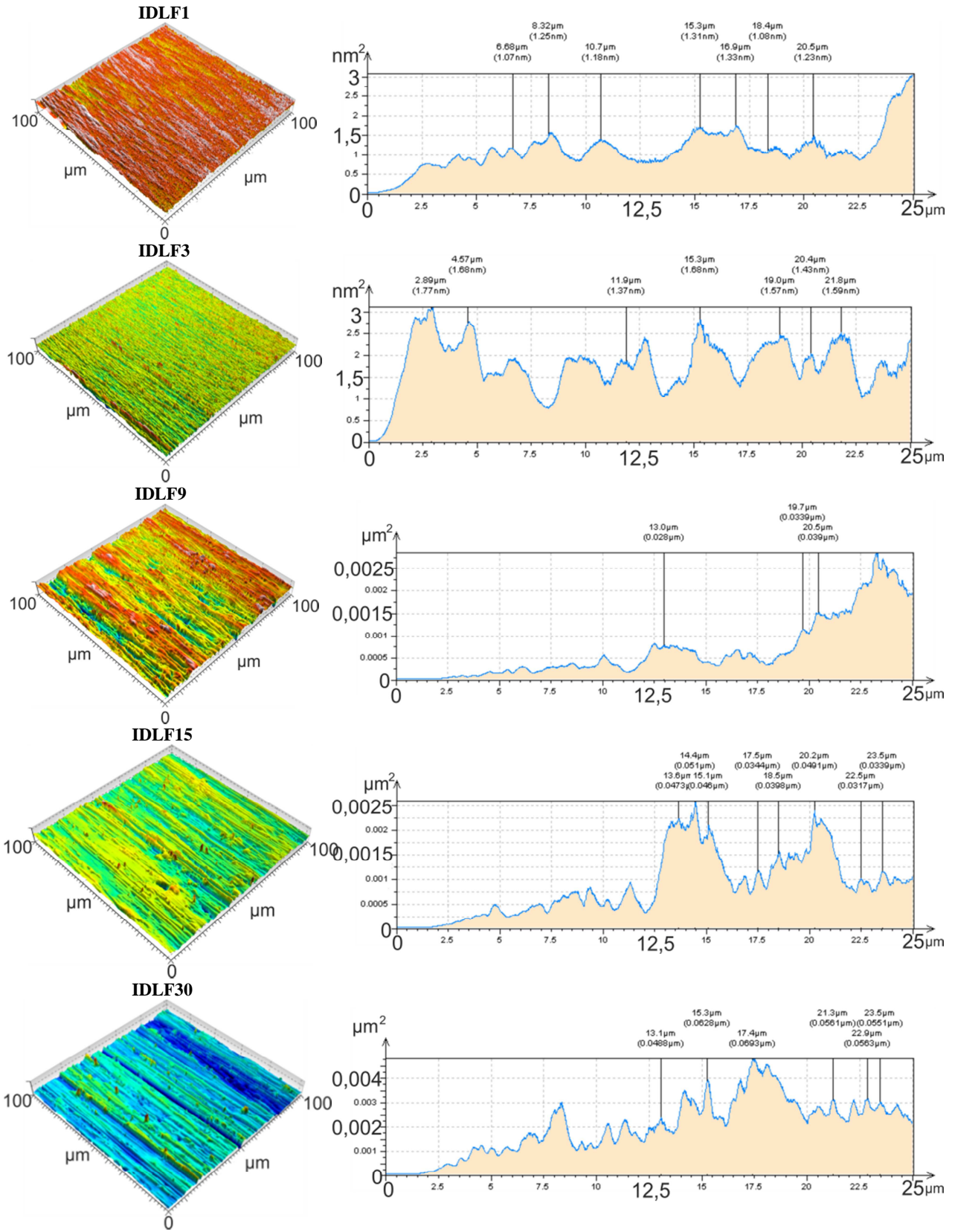


Fig. 6. Images of surfaces that are machined with successive IDLF type diamond lapping films including an analysis of the mean power spectral density in the wave length range 0-25 μm

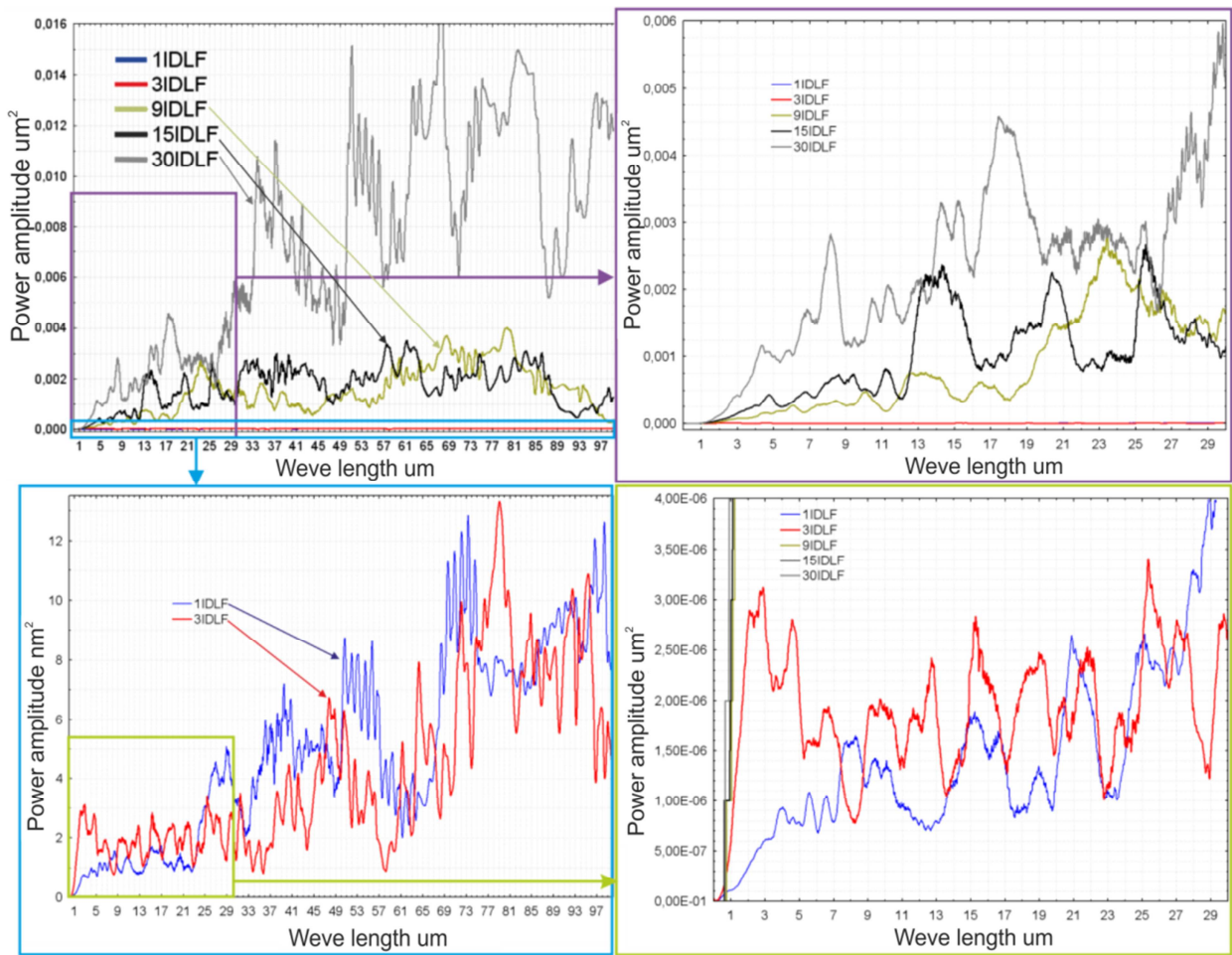


Fig. 7. Mean power spectral density in wave length range 0-100 μm of surfaces that have been machined with microfinishing films with a diamond grain of the following dimensions: 1 (IDLf1), 3 (IDLf3), 9 (IDLf9), 15 (IDLf15), 30 μm (IDLf30)

For the assessment of the efficiency of superfinishing with the use of IDLF films with grain sized 1, 3, 9, 15, 30 μm , the factors of the assessment of tool properties that had been developed were used, and they were compared with the results of machining (Fig. 12). The coefficient of the surface superfinishing level after machining $w_{pwi}(7)$ was made dependent of the location of the cut-off plane, for which there occurs a maximum number of elevations above this level (Fig. 9), and it was made dependent of the number of elevations $L_{wi_{MAX}}$ in relation to an area unit.

Please refer to Table 2 for the values of this coefficient.

$$w_{pwi} = \frac{\sqrt{L_{wi_{MAX}}}}{\left(\frac{h}{S_t}\right)_{L_{wi_{MAX}}}} \quad (7)$$

$$w_{pwi}^N = \frac{b-a}{w_{pwi} - a} \quad (8)$$

where:

$L_{w_{MAX}}$ – maximum number of islands on a given level of the location of the plane ($h_{L_{w_{MAX}}}$) that cuts off the surface after machining with a tool in relation to an area unit, mm^{-2} ,

$h_{L_{w_{MAX}}}$ – level of the location of the plane that cuts off the surface after machining with a microfinishing film, where the greatest number of islands was obtained,

S_t – maximum height of the surface that was obtained after machining with tool, μm ,

w_{pwi} – surface smoothening coefficient, mm^{-1} ,

w_{pwi}^N – standardized surface smoothening coefficient $a < w_{pwi} \leq b$.

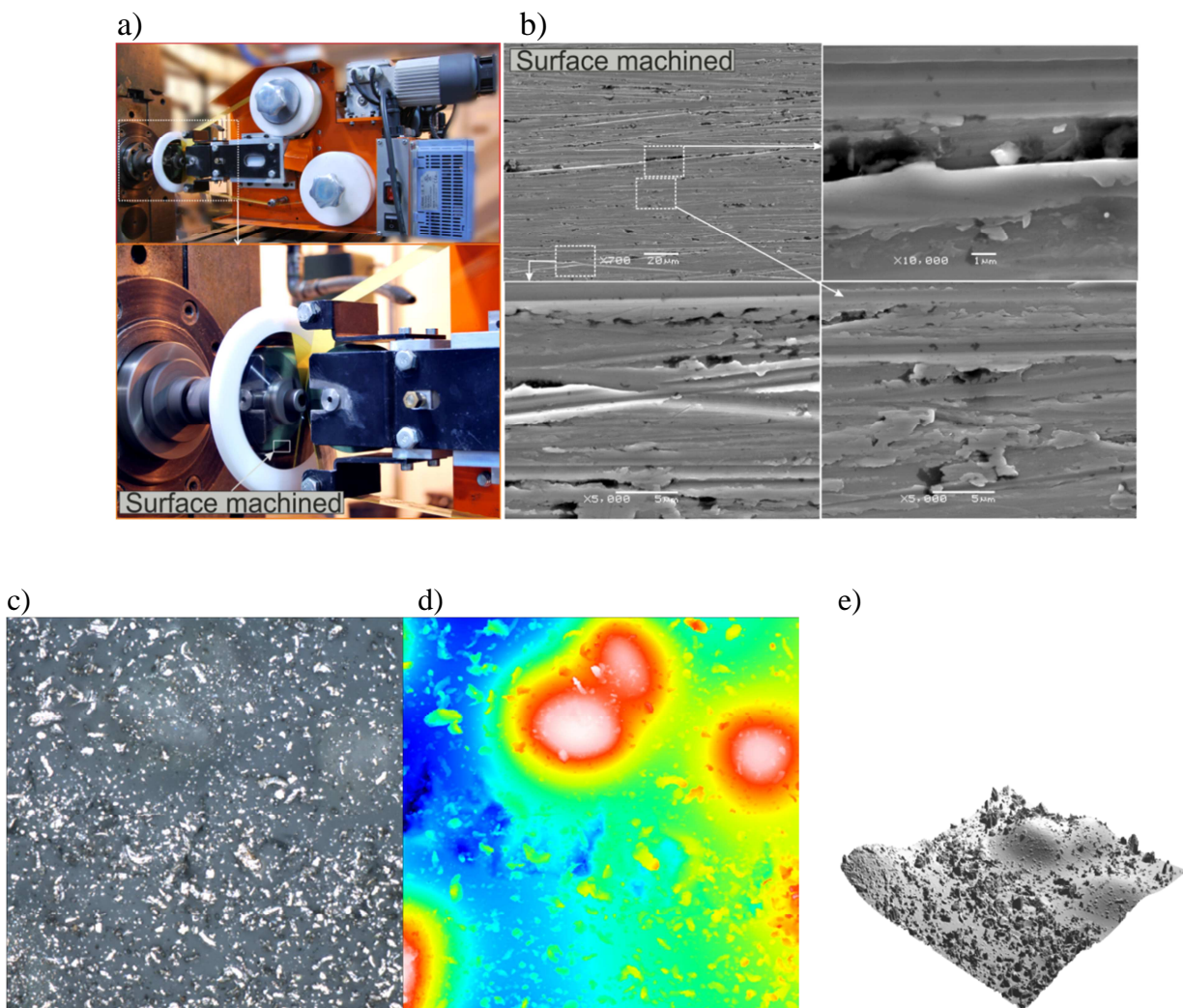


Fig. 8. Test stand with super finish attachment GW-1 (left side) (a), Images that were obtained with the use of a scanning microscope, nickel layer that was superfinished with a microfinishing film with a nominal grain size $30\mu\text{m}$ (b), Images of IDLF30 film surface after machining that were obtained with the use of LEXT OLS4000 measuring system: photo (c), height map (d), 3D image (e)

Table 2. Values of features and coefficients for the assessment of the smoothing level of the surface after machining

i	L_{wiMAX} [mm ⁻²]	$\left(\frac{h}{S_t}\right)_{L_{wiMAX}}$	W_{pwi} [mm ⁻¹]	W_{pwi}^N
1 IDLF	235520	0,5	974	0,99
3 IDLF	218000	0,5	934	0,95
9 IDLF	20650	0,35	410	0,37
15 IDLF	18320	0,45	301	0,25
30 IDLF	21000	0,55	263	0,20

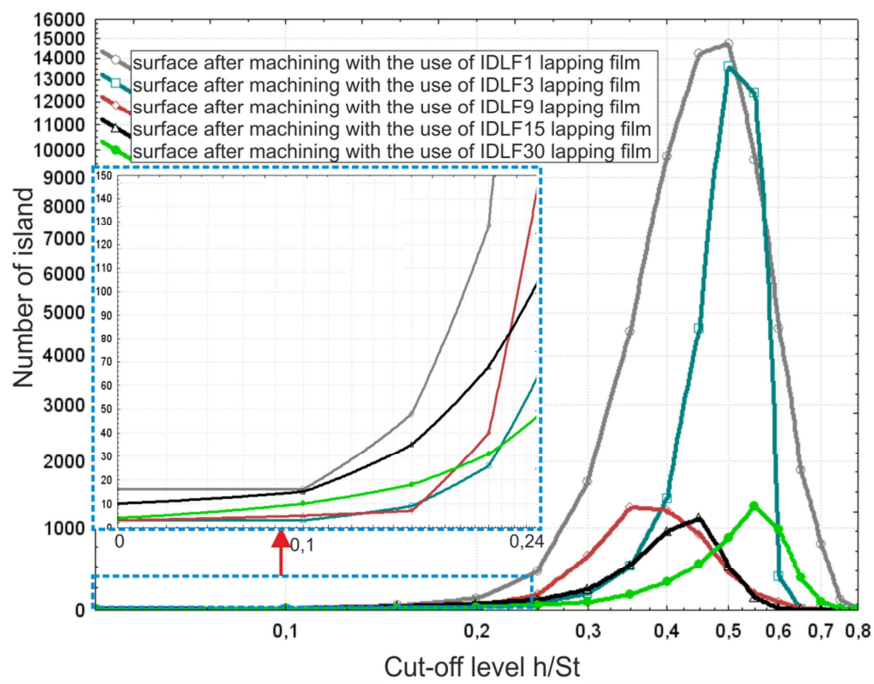
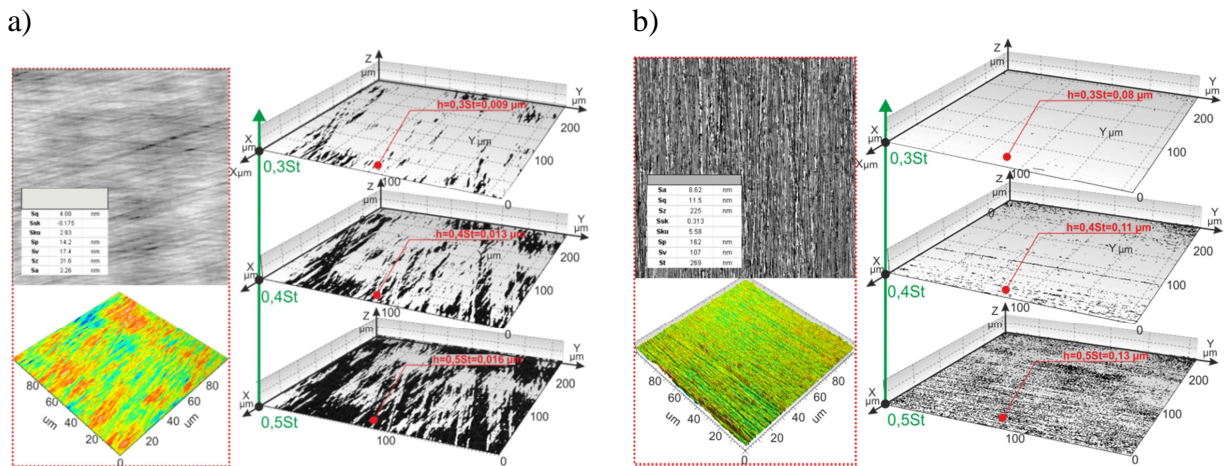


Fig. 9. Number of islands depending of the location of the cut-off plane calculated from the highest vertex of surfaces that were machined with IDLF type tools on a surface with dimensions 256×256 μm



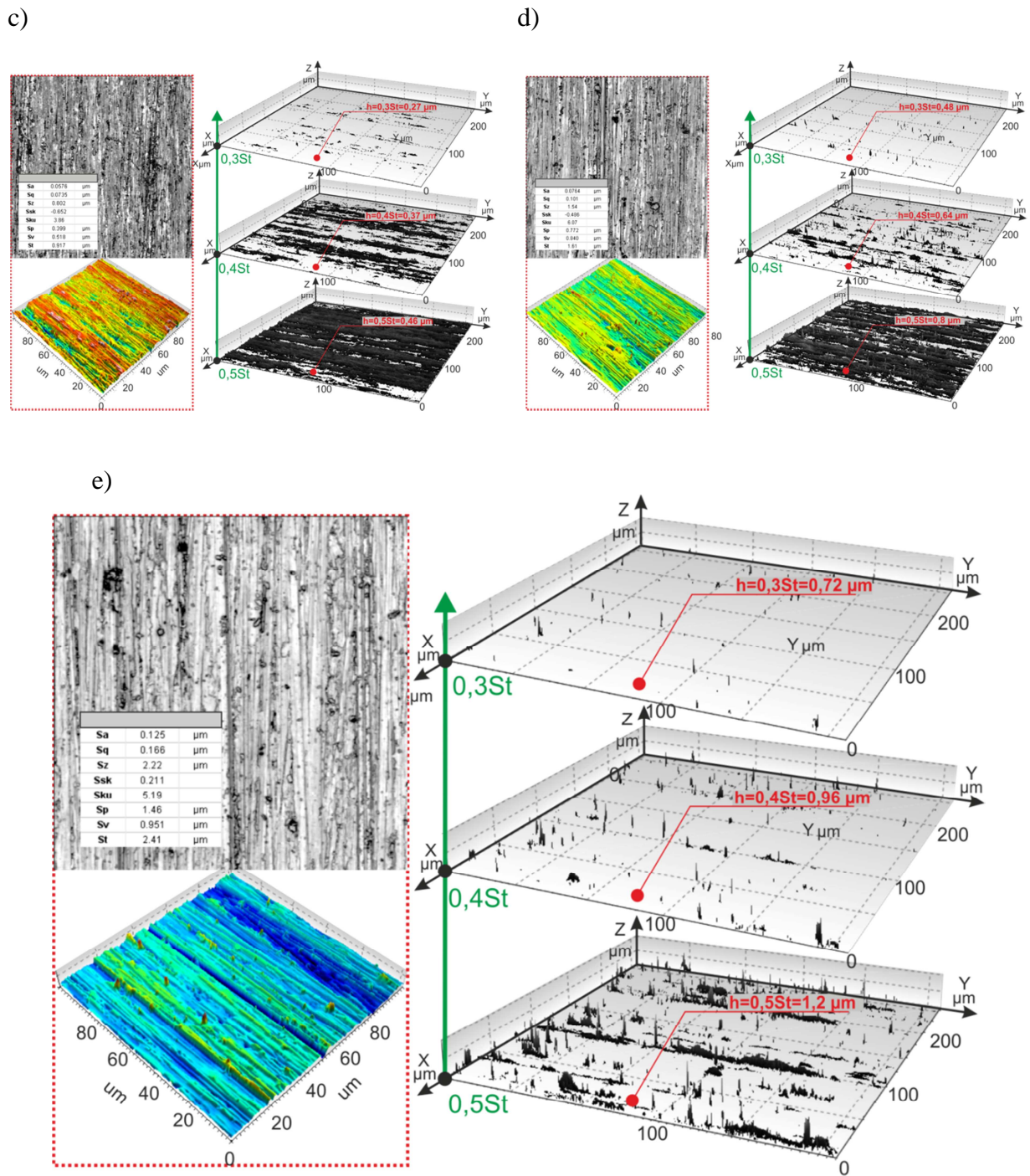


Fig. 10. Images of the surface including an illustration of elevations above the cut-off plane located on three heights ($0.3St$ $0.4St$ $0.5St$) from the highest vertex of the surface after machining with IDLF type tools with nominal grain sizes 1 (a), $3\mu\text{m}$ (b), $9\mu\text{m}$ (c), $15\mu\text{m}$ (d), $30\mu\text{m}$ (e)

The results related to the surfaces superfinished are presented in Fig. 8, while the values of coefficient w_{pwi}^N (8) (standardized coefficient of surface smoothening) for the individual films are presented in Fig. 11. Fig. 12 covers the dependences of parameters St

and S_a for the surfaces machined from coefficient w_p (coefficient of the smoothing potential of microfinishing films). Fig. 13 presents the influence of this coefficient on the effects of smoothing, which are described with parameter w_{pwi}^N .

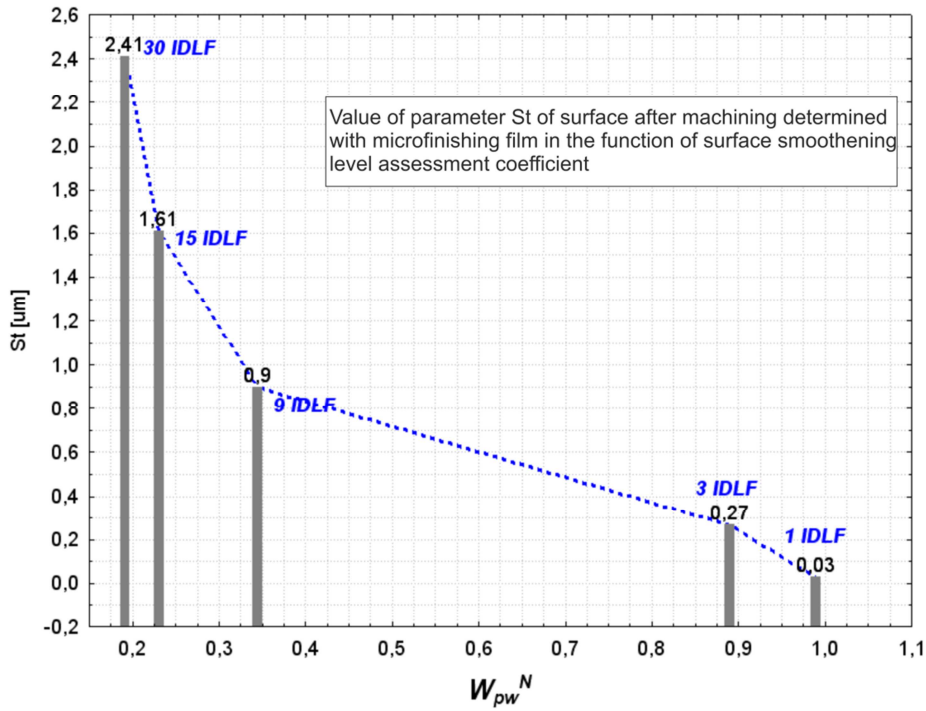


Fig. 11. St parameters of the surface after machining with individual diamond lapping films in relation to standardized surface smoothing coefficient W_{pwi}^N

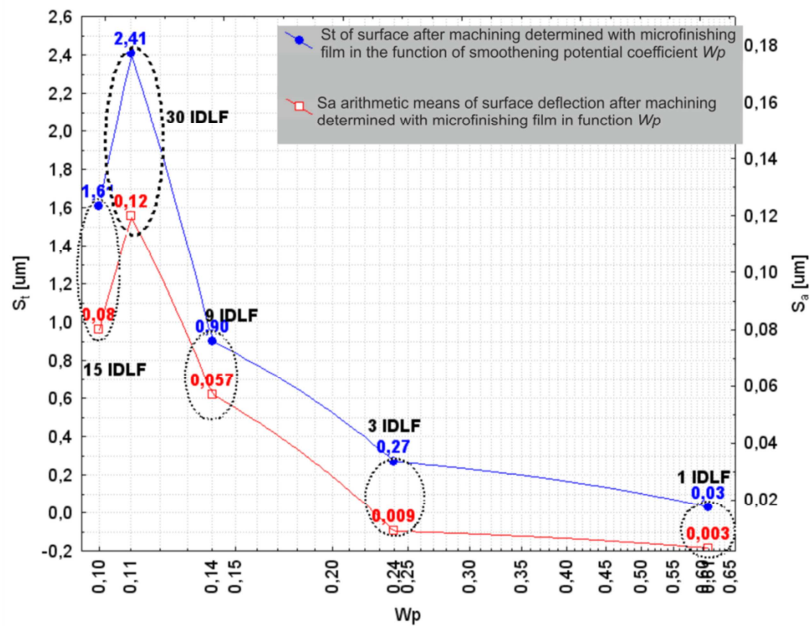


Fig. 12. St and S_a parameters of surfaces after machining with individual diamond lapping films in relation to the smoothing potential coefficient of respective IDLF type tools

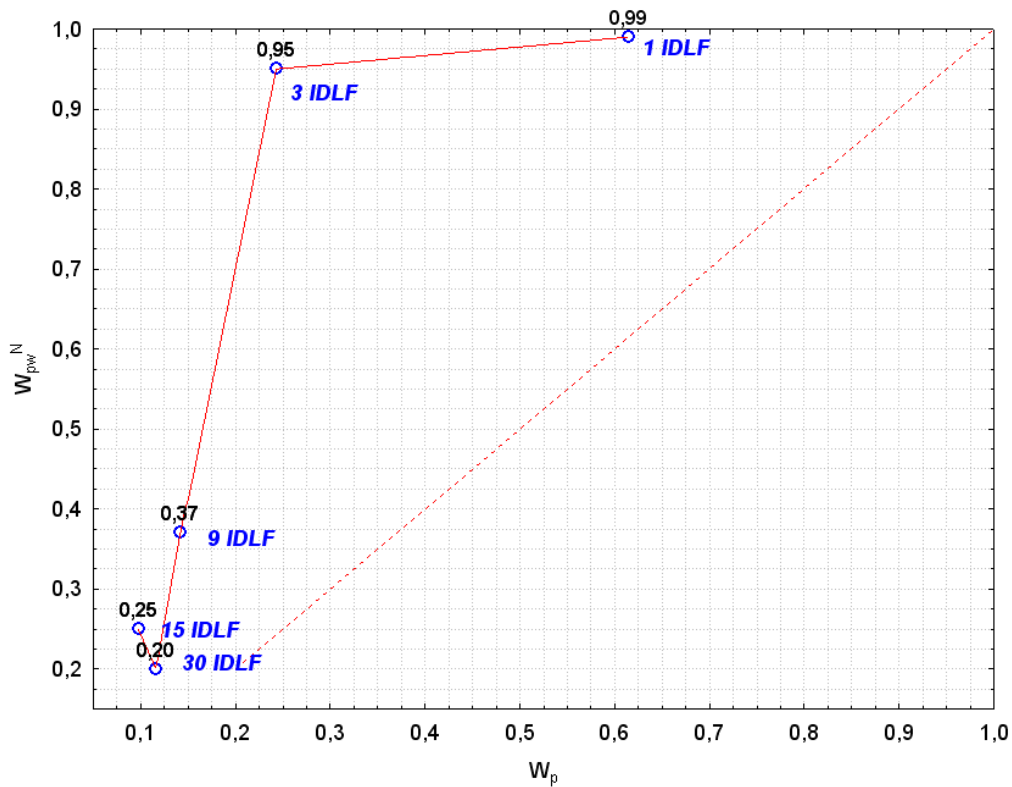


Fig. 13. Influence of the smoothing potential coefficient w_p of IDLF tools on standardized surface smoothing coefficient w_{pw}^N

4. SUMMARY

Investigations of the topography of the diamond lapping films surface were conducted with the use of new parameters that describe the arrangement and the shape of the vertices of active grains. The following were used for the purpose of assessment: coefficients that had been developed that describe the features of the shape of the tool surface, such as the standardized coefficient of the flatness of vertices w_{ki}^N , the standardized number of vertices in relation to an area unit L_{wi}^N and the dissipation coefficient of the height of the location of vertices w_{rwi}^N .

For the purpose of the assessment of the smoothing ability of microfinishing films, the smoothing potential coefficient w_p was developed, which is defined as the geometric mean of the abovementioned indices, according to which the smallest smoothing potential is demonstrated by the *IDLF15* tool, and the greatest one is exhibited by the *IDLF1* diamond lapping film.

The Voronoi cells method was used in the assessment of the arrangement and distances between vertices.

In order to assess the usefulness of the indices developed of the assessment of tool surface for the prognostication of machining results, experiments were conducted that

consisted in smoothening of flat and very even surfaces ($St=4nm$) with IDLF tools with a diamond abrasive mound with nominal grain sizes being 1,3,9,15,30 μ m. Next, the topography of the surface after machining was examined. The coefficient of the assessment of the smoothening level of machined surfaces w_{pwi}^N was developed (a standardized surface smoothening coefficient) that is dependent of the maximum number of islands in relation to an area unit and the level of the location of the cut-off plane where the maximum number of islands occurred (Fig. 9 and 10). Furthermore, the mean power spectral density function was used for the evaluation of the geometric structure of the surface.

The methodology accepted permits a determination of the influence of the features of the microfinishing film on the size and shape of individual contact fields of the surface machined with the cooperating surface. It also permits a prognostication of the results of superfinishing and planning the duration of the individual operations in sequential processes of superfinishing.

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