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A METHOD AND NEW PARAMETERS FOR ASSESSING THE ACTIVE SURFACE TOPOGRAPHY OF DIAMOND ABRASIVE FILMS

This paper describes the methodology and results of research on the tribological characteristics of the surfaces of diamond abrasive films using a stereometric analysis. Abrasive films are used in various finishing processes of surfaces with very high smoothness and accuracy. A morphological analysis of surface vertexes in the plane that is parallel to the film surface and the perpendicular direction allowed an assessment of the distances between particles by means of a decomposition of the surface into Voronoi cells. When studying the formation of the aggregates of diamond particles and the spaces between them, one may infer about the machining potential of the abrasive film and determine the recommended kinematic conditions of the film that ensures the maximum use of this potential. Owing to the investigations related to the morphology of diamond abrasive films, one can observe relevant characteristic abrasive aggregates that vary in term of size and shape depending on particle sizes. Units with elongated shapes have a superior machining ability in relation to spherical-shaped units. One of significant parameters proposed that describe the technological potential of abrasive films is the edge length to width ratio of diamond units. Different operating modes are discussed. A statistical analysis of the dynamics observed of abrasive interfaces allowed a pertinent description of the abrasive process taking into consideration nominal and apparent as well as abrasively efficient morphologies.

1. INTRODUCTION

Micro-lapping with abrasive films differs from the other methods of abrasive machining. This is a surface treatment where the abrasive film is pressed against the surface of the workpiece with a roll with a specific susceptibility (Fig. 1). The velocity of the workpiece surface towards the film is great and is usually 10-170 m/min. The film velocity is small and is 10-150 mm/min. The single use of the abrasive film surface is a characteristic feature of the process.

Over a certain time, which depends on the film velocity, active particles remain in the machining area, and they do not participate again in forming the machined surface [6]. Not all of abrasive particles participate in shaping the workpiece machined, yet the participation

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of active particles is greater than in case of machining with the use of tools of high stiffness [7],[9],[10],[11].

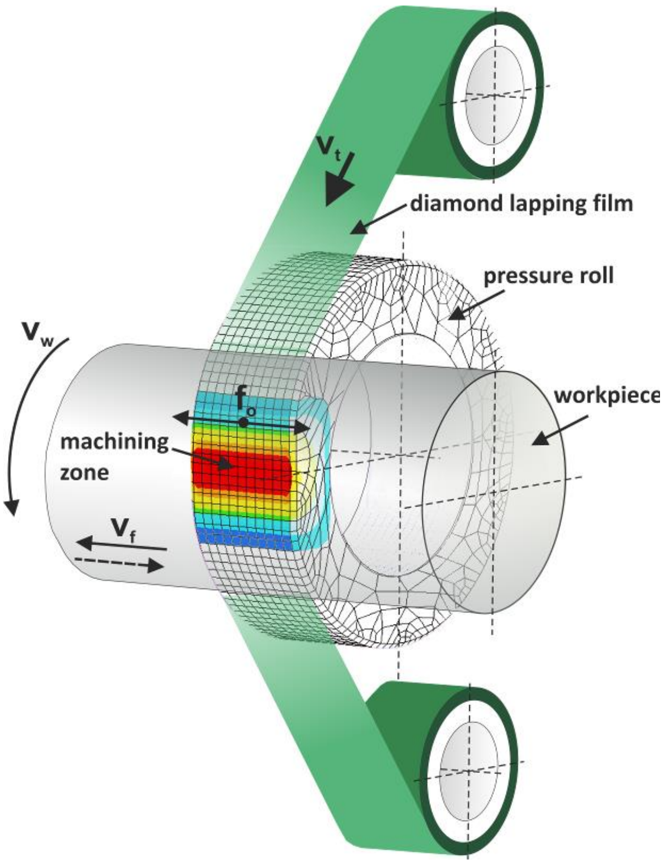


Fig. 1. Processing system for surface superfinishing, where: f_o- oscillatory movement of the tool, v_w- direction of the rotary movement of the workpiece, v_f - feed motion direction, v_t - film travel direction (experimental device)

The purpose of the present study is to establish possibilities to increase the activeness of abrasive particles through the modifications of the features of abrasive films and the properties of the systems of the film pressure to the surface machined. Finding out of the probability of the contact of the film abrasive particle vertices with the surface machined is important for the determination of the machining potential and the selection of its velocity [2],[12]. Those parameters which characterize the capacity and the formation of the environment of particles constitute the important features of the tool. To a great extent, they decide about the possibility to collect the finishing process products and to remove these from the processing area.

IDLF (Imperial Diamond Lapping Films) films for micro-finishing consist of diamond particles packed in units. They are characterized by a long life cycle, and they ensure very good effects of surface finishing. The main application areas of diamond abrasive films include machining of optical fiber connectors, superfinishing of flat surfaces and finishing of cylindrical surfaces. IDLF lapping films are used in the machining of hard-machinable materials such as glass, sintered carbides, ceramics, hardened steel, Inconel type alloys and composites. In the production the of film, particles are made of synthetic diamond that range in size from 0.1 to 60 μm, and which are embedded in resin that is deposited on a polyester tape. An assessment of the properties of IDLF abrasive films is a complex problem because of the diversified geometry of abrasive particles and their aggregation on the film surface. When studying the surface formation of abrasive units, one may conclude about the machining potential of diamond abrasive films and ensure the conditions of its complete use [1].

2. ASSESSMENT OF THE TOPOGRAPHY OF THE ABRASIVE FILM SURFACE

In this study, the results of an examination of the topography of IDLF type abrasive films (Imperial Diamond Lapping Films) manufactured by 3M firm with the nominal abrasive grain sizes: 0.5 (0.5IDLF) (Fig. 2) 1 (1IDLF) (Fig. 3) and 3 (3IDLF) (Fig. 4) micrometers were presented. The characteristic feature of such tools is that diamond particles and their aggregation are completely embedded in the thin layer of the binder [5]. Due to diamond particles being “embedded” in the glue, the measurements of the tool surface topography are considerably more difficult, particularly with the use of optical methods [8].

A confocal microscope is used for the examination of tools with very small particles.

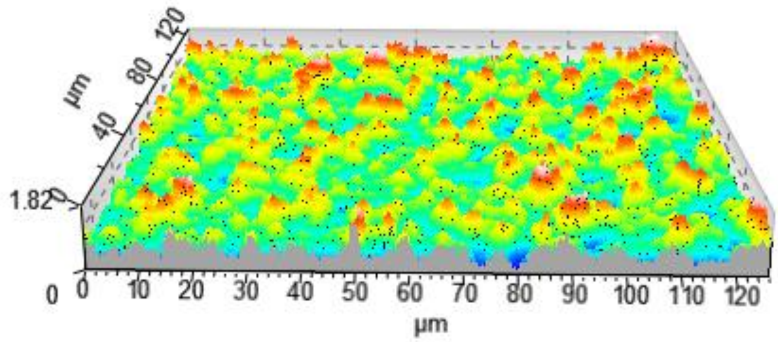


Fig. 2. Topography of the abrasive film surface with diamond abrasive particles with the nominal size of 0.5 μm (0.5IDLF)

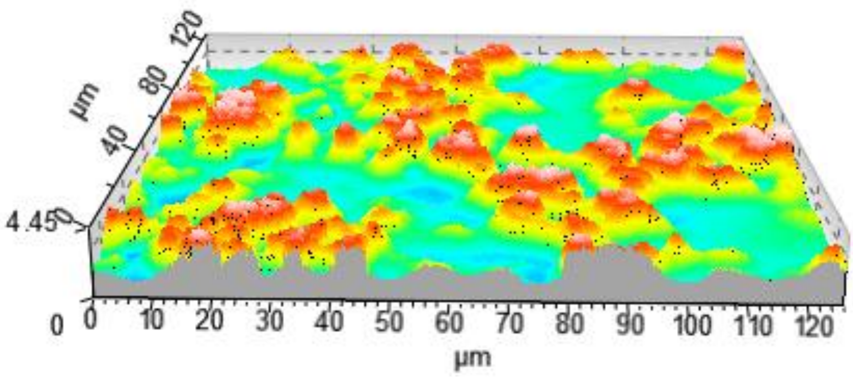


Fig. 3. Topography of the abrasive film surface with diamond abrasive particles with the nominal size of 1 μm (1IDLF)

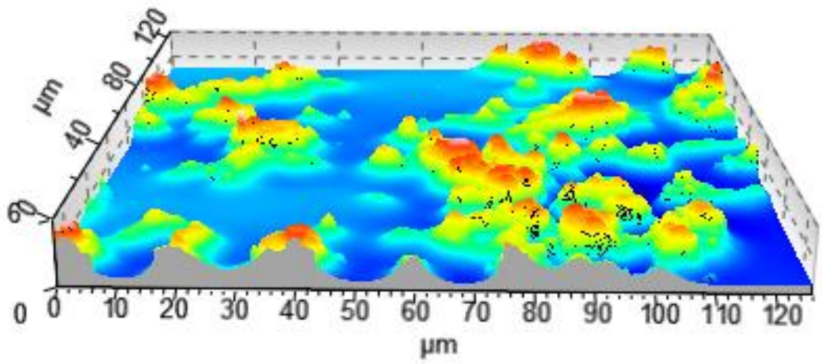


Fig. 4. Topography of the abrasive film surface with the diamond abrasive particles with the nominal size of 3 µm (3IDLF)

An important problem is to establish which of the particle apexes form the set of neighbouring apexes. In order to solve this problem, abrasive film surfaces underwent a disintegration of the area into Voronoi cells, where the central point of each sub-area constitutes the particle vertex [3,4]. The sub-areas serve the purpose of finding the closest neighbours, and all those Voronoi cells that are directly adjacent to the cell under consideration constitute its the closest neighbourhood (Fig. 5).

The surface areas of the Voronoi cells for various films and levels *h* (Table 1) were determined as a decomposition of the area into sub-areas with the central vertex *z(x,y)* as a point.

The average area of Voronoi cells diminishes with an increase *h*, i.e. the distance of the plane of elevations from the highest surface vertex, because the number of elevations over level h increases. The distances were calculated between the elevation vertexes of the closest neighbours. An application was developed for an analysis of the geometric features of the elevations over the established level: from 20% to 40% of the St (total height of the surface) parameter value from the highest surface vertex (Fig. 5). Diagrams (Fig. 6-10) present the surfaces of elevations for which the highest point of elevation was drawn and Voronoi cells were projected on the *Oxy* plane. The highest vertexes of elevations are the central element of Voronoi cells. The operation of the investigation of the elevations was carried out for various levels *h* from the highest vertex (Fig. 6, 7, 8, 9, 10).

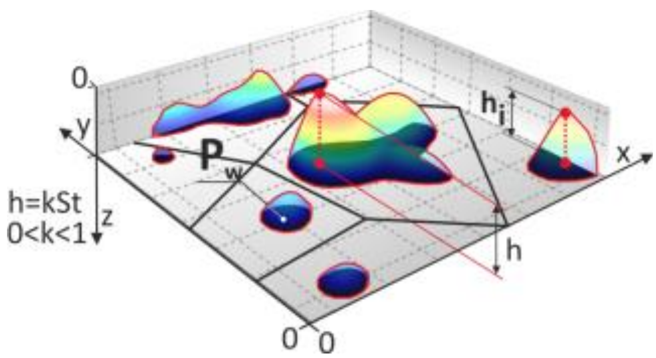


Fig. 5. Heights and fields of elevations over the plane which is distant from the highest top by the *kSt* value

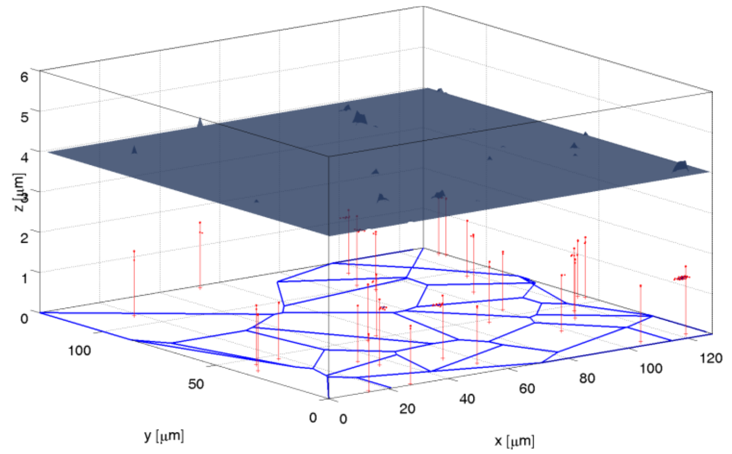


Fig. 6. Intersection fields of the 0.5 IDLF type abrasive film surface and projection onto the plane of Voronoi *Oxy* cells whose central points are the vertexes of elevations over the plane which is distant from the highest vertex by the distance value of *h =0.2St*

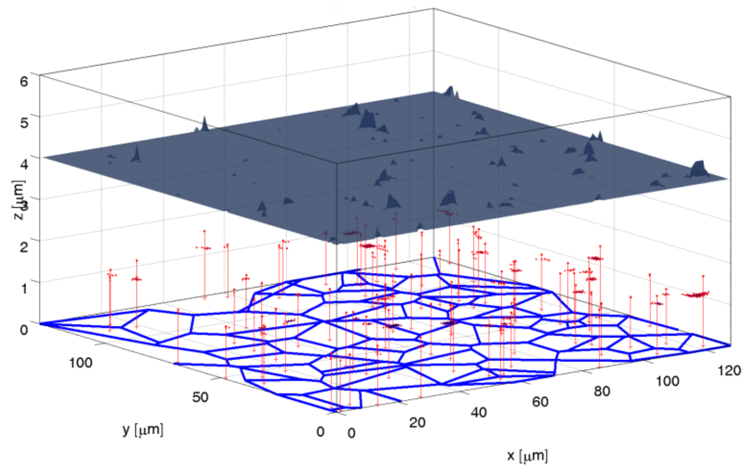


Fig. 7. Intersection fields of the 0.5 IDLF type abrasive film surface and projection onto the plane of Voronoi *Oxy* cells whose central points are the vertexes of elevations over the plane which is distant from the highest vertex by the distance value of *h = 0.3St*

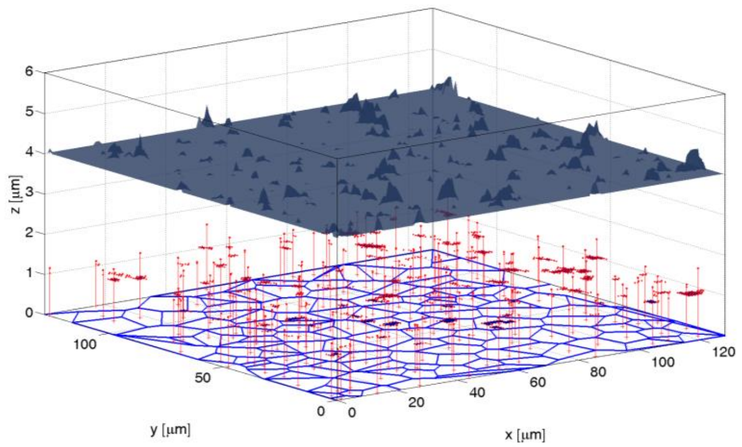


Fig. 8. Intersection fields of the 0.5 IDLF type abrasive film surface and projection onto the plane of Voronoi *Oxy* cells whose central points are the vertexes of elevations over the plane which is distant from the highest vertex by the distance value of *h =0.4St*

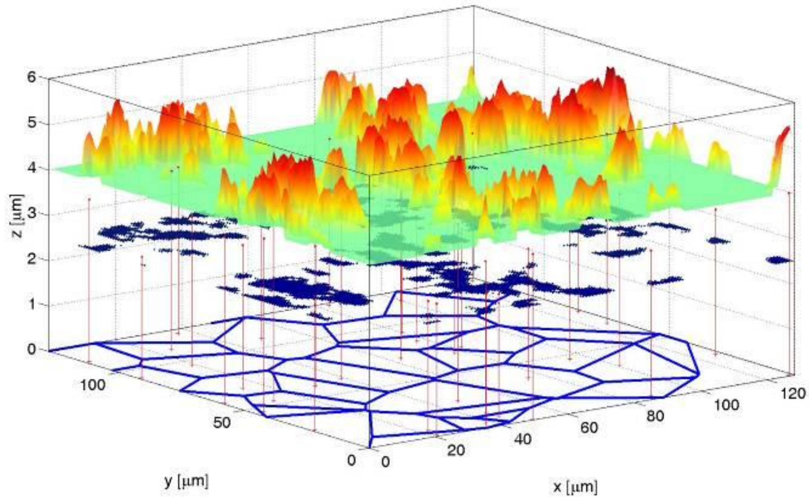


Fig. 9. Intersection fields of the 1 IDLF type abrasive film surface and projection onto the plane of Voronoi *Oxy* cells whose central points are the vertexes of elevations over the plane which is distant from the highest vertex by the distance value of *h =0.4St*

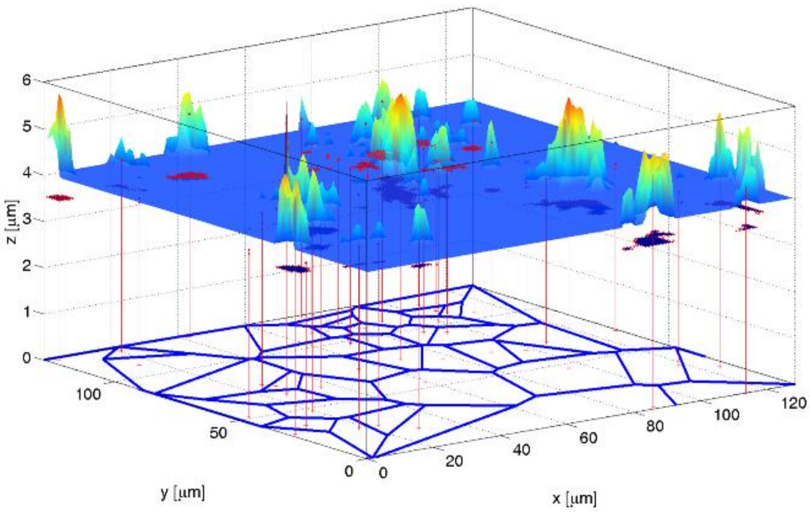


Fig. 10. Intersection fields of the 3 IDLF type abrasive film surface and projection onto the plane of Voronoi *Oxy* cells whose central points are the vertexes of elevations over the plane which is distant from the highest vertex by the distance value of *h =0.4St*

Table 1. Value set of indexes for the assessment of the surfaces of diamond abrasive film

Film	k	St µm	h µm	P_V µm^2	O_{VG} µm	a_g µm	O_{VG}/a_g	N_a 1/mm^2
0.5IDLF	0.2	1.83	0.366	565	12.68	0.5	25.36	1856
0.5IDLF	0.3	1.83	0.549	207	6.96	0.5	19.92	5056
0.5IDLF	0.4	1.83	0.732	110	5.18	0.5	10.36	9536
1IDLF	0.2	4.47	0.894	260	7.53	1	7.53	4032
1IDLF	0.3	4.47	1.341	264	7.9	1	7.9	3968
1IDLF	0.4	4.47	1.788	443	10.8	1	10.8	2368
3IDLF	0.2	6.01	1.202	820	14.55	3	4.85	1280
3IDLF	0.3	6.01	1.803	585	11.9	3	3.96	1792
3IDLF	0.4	6.01	2.404	372	8.68	3	2.89	2816

where:

P_V – average field of Voronoi cell surfaces,

O_{VG} – distance from the closest neighbours determined with the use of Voronoi cells,

a_g – nominal size of abrasive grain,

N_a – number of elevations over the plane which distant by distance h starting from the highest vertex.

A consolidated film profile $z_s=f(x_s)$ (Fig. 11) in the form of an envelope of the sum of the projections of elevations over level h onto plane z_sx_s allows one to assess the expected lapping effectiveness.

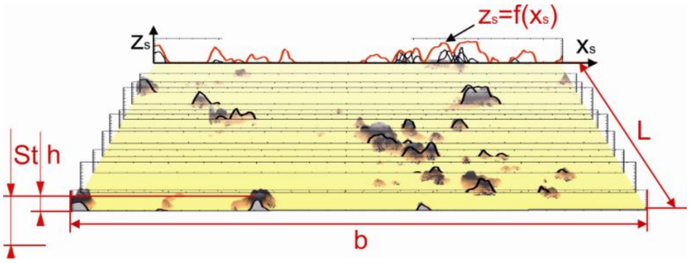


Fig. 11. Consolidated film profile $z_s=f(x_s)$ in the form of an envelope of the sums of the projections of elevations over level h onto plane z_sx_s

Lapping effectiveness – index w_{ep}, it is the relation of the field under the consolidated profile the value $A_f=bh$.

$$w_{ep} = \frac{1}{bh} \int_{x_s=0}^{x_s=b} z_s\big(z_s > (St - h)\big) dx_s \tag{1}$$

or

$$w_{ep} = \frac{1}{nh} \sum_{i=1}^{n} z_{si}\big(z_{si} > (St - h)\big) \tag{2}$$

Index w_{ep} depends from the length of the film surface examined (Fig. 12, 13, 14).

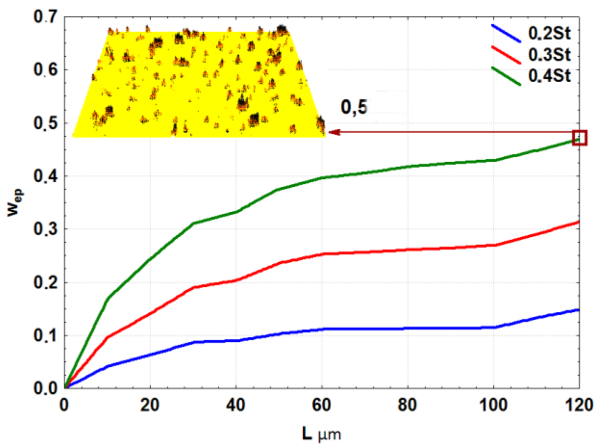


Fig. 12. Index w_{ep} depending on the length of 0.5 IDLF film

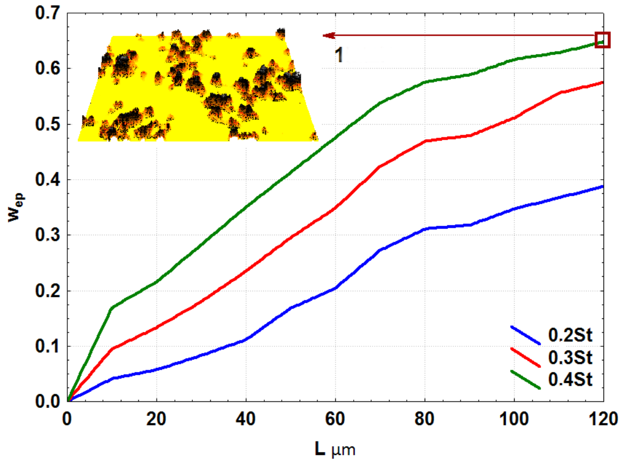


Fig. 13. Index w_{ep} depending on the length of 1 IDLF film

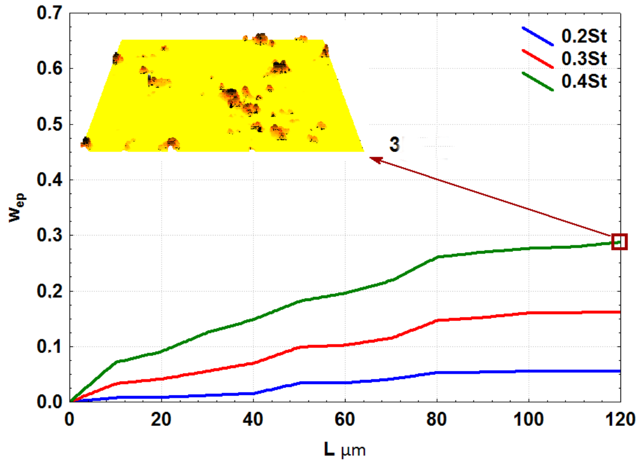


Fig. 14. Index w_{ep} depending on the length of 3 IDLF film

This can be used to determine the film surface required for the realization of a specific lapping operation. The examinations of the topography of abrasive films were carried out with the use of confocal laser scanning microscopy. The LEXT OLS4000 microscope works in two modes: microscopic and confocal. The microscopic mode permits an observation of diamond particles under the surface of translucent resin, while the confocal mode permits an analysis of the surface topography (Fig. 15, 16).

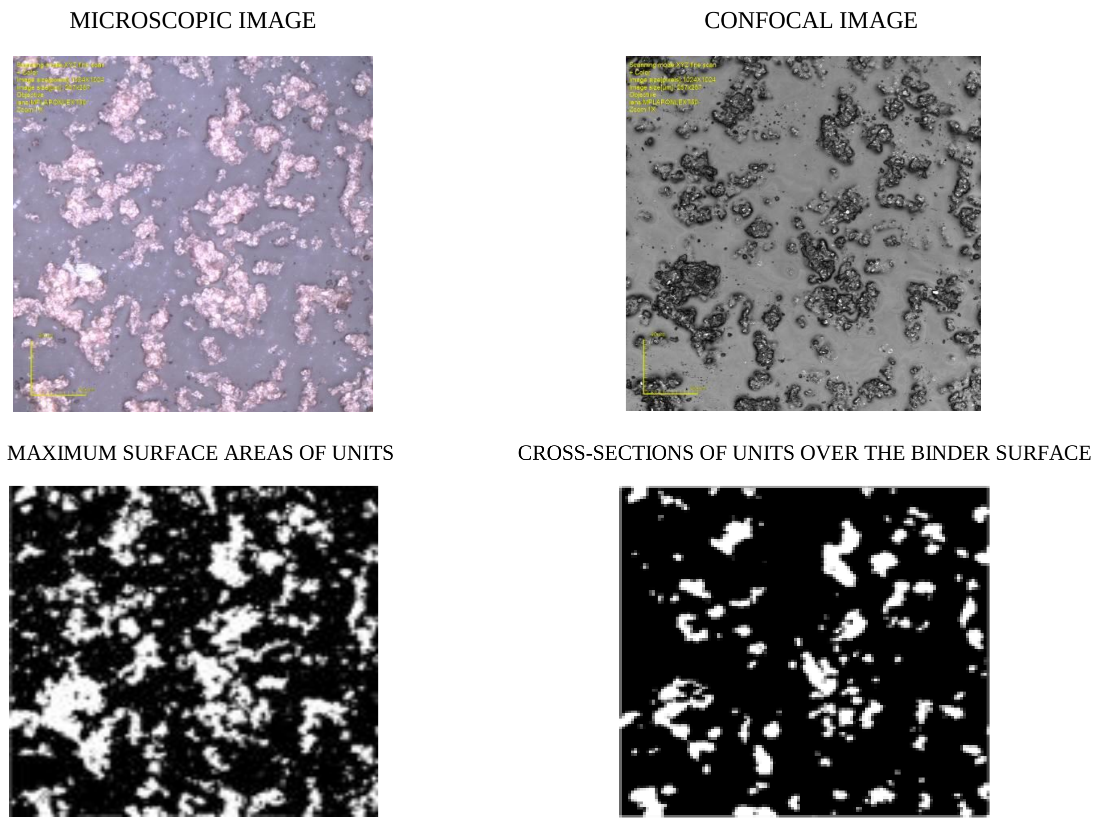


Fig. 15. Images: microscopic and confocal of the IDLF film surface with the nominal diamond particle size of 3 micrometers with the marked fields of the surfaces of abrasive units

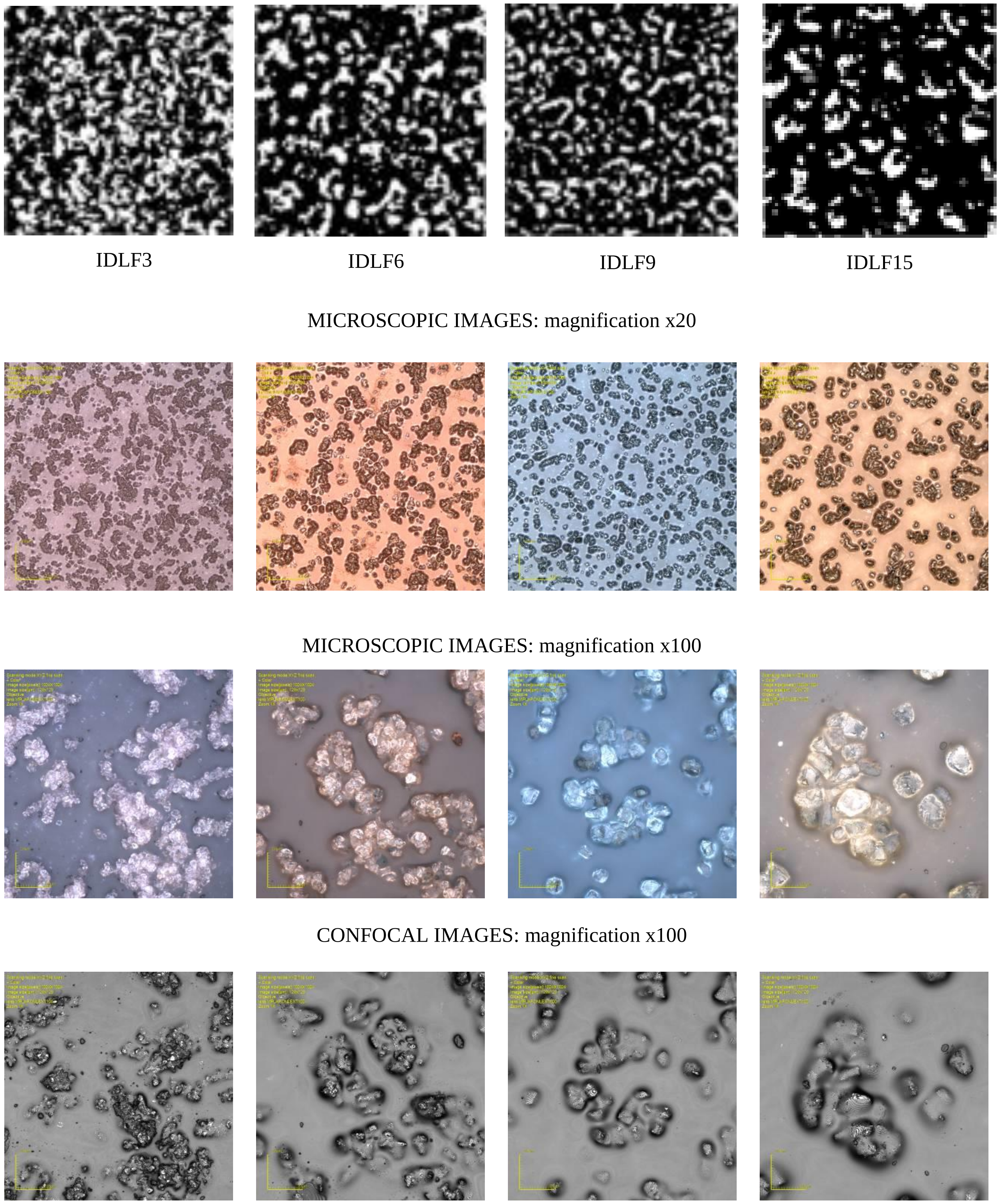


Fig. 16. Images of the surfaces of IDLF type abrasive films from the LEXT OLS4000 confocal laser scanning microscope manufactured by Olympus company

The distributions of the surface areas of the abrasive units A_m and A_p (Fig. 17) the cross-sections of the units with the binder surface for the film with the nominal abrasive grain size of 3 (3IDLF) micrometres are presented in Fig. 15. After an analysis of the probability distributions of the maximum surface areas of the abrasive and the surface areas of the cross-sections of the units over the binder plane (Fig. 18), it was found that a significant part of the abrasive material will not be used in the machining process. For the determined distances of the units from the closest neighbours (Fig. 19), in the set of units elevated over the binder surface, a symmetric distribution of distances was obtained. The distribution of distances between the particles is similar to the symmetric one.

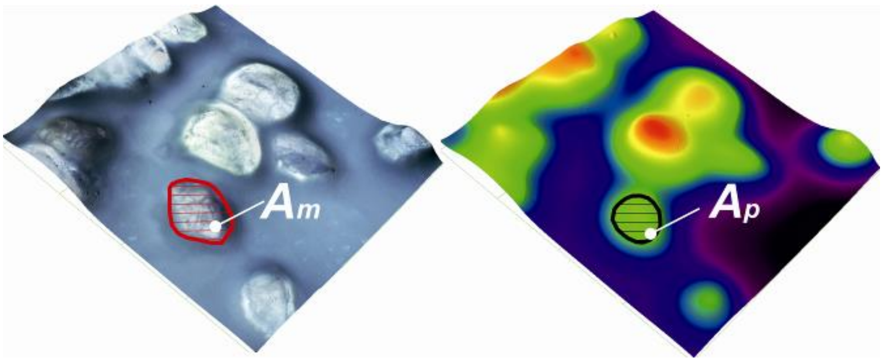


Fig. 17. Images of the surface of the IDLF type abrasive film with the marked surface area of abrasive particle A_m and the cross-section area of the particle that protrudes over binder level A_p

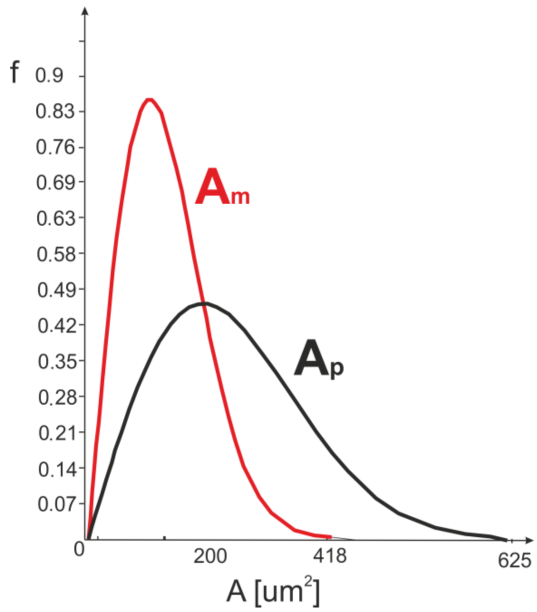


Fig. 18. Distributions of the surface areas of the cross-section of units elevated over the binder plane and maximum surface areas of the cross-section of 3 IDLF abrasive film units

It was demonstrated that an important parameter in the description of the features of the units is the ratio of the length of the unit to its width (Fig. 20) (Fig. 22), defined as the length and width of the rectangle described on the surface area of the unit. This parameter describes the shape of the cross-section. For the circle and square it is always 1, while for more complex shapes, it is higher than 1.

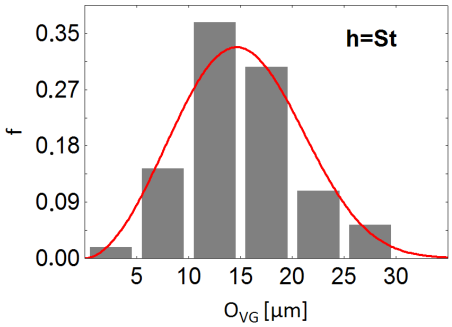


Fig. 19. Distances O_{VG} of neighbouring elevations of units over the binder surface of 3 IDLF abrasive film

The occurrence both of single particles and those units that include from 2 to a dozen or so particles was observed (Fig. 23). Another parameter that describes the shape of the cross-section of the units over the binder surface is the diameter of a circle with the surface area that is equal to the surface area of the cross-section of the unit and the Feret's diameter (the greatest distance between two points situated on the unit's perimeter) (Fig. 21). With an increase of the surface area of the of the unit's cross-section, the complexity of its shape is growing (Fig. 24). This increases the ability to store and remove the products of machining. Roundness *R* (Fig. 25) (3) with its value being closer to 1 for those shapes that are similar to the circle, is another next coefficient that describes the shape of the unit.

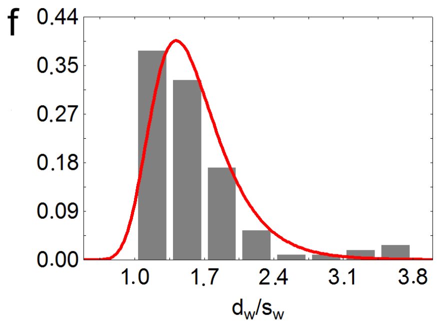


Fig. 20. Distribution of the value of the relation of the elevation length d_w to its width s_w for 3 IDLF film

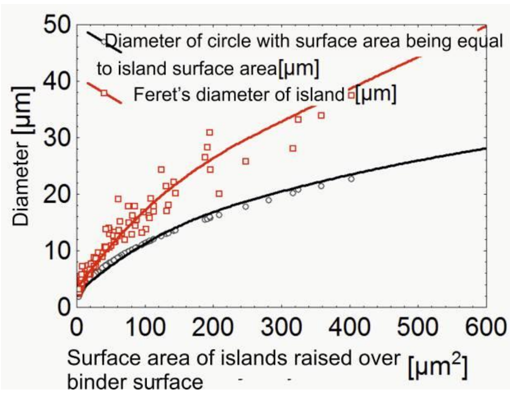


Fig. 21. Diameter of circle with surface area being equal to island surface area and Feret's diameter of island depending on the surface area of islands raised over binder surface for 3IDLF film

After an analysis of the determined densities of the values of the ratios between length to the width of the edge of the units, it was found that IDLF 9 and IDLF15 films demonstrate a smaller ability to aggregate the abrasive and to form less complex shapes of the units. For bigger particle dimensions (9 and 15 μm), units with large surface areas have almost exclusively elongated shapes (a large value of the edge length to width ratio of 30…50). This means favourable useful properties.

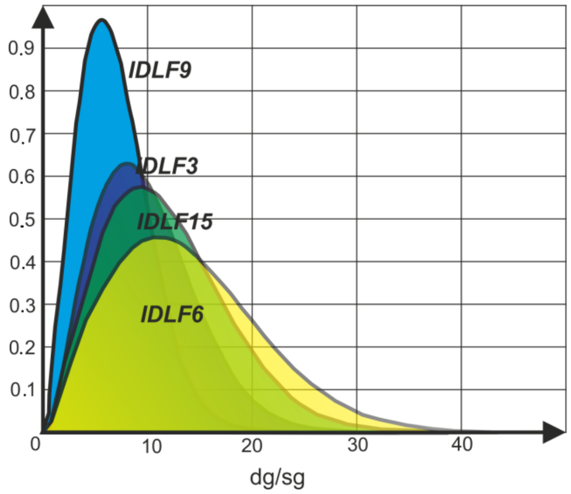


Fig. 22. Distributions of the quotient of the length to the width of the cross-section edge of units raised over binder surface for IDLF3, IDLF6, IDLF9, IDLF15 abrasive films

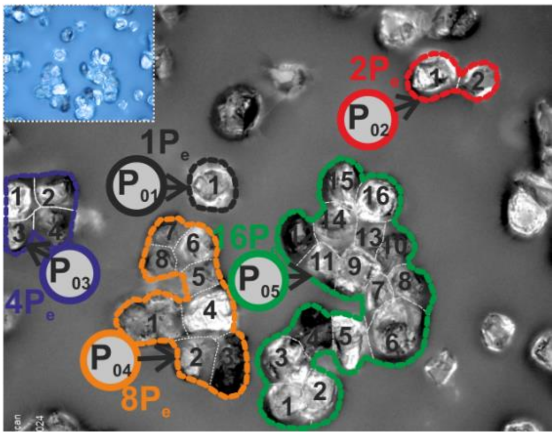


Fig. 23. Microscopic image (x100 magnification) obtained with the use of LEXT OLS4000 confocal laser scanning microscope manufactured by Olympus of the surface of IDLF type abrasive film with units marked with specific surface areas, P_e – surface area of single particle, P_{oi} – abrasive unit consisting of i particles

Parameters used for an assessment of the formation of abrasive units included:

$$R = \frac{4P_w}{\pi {d_w}^2} \tag{3}$$

R – coefficient of roundness
P_w – surface area of the cross-section of the unit raised over the binder surface

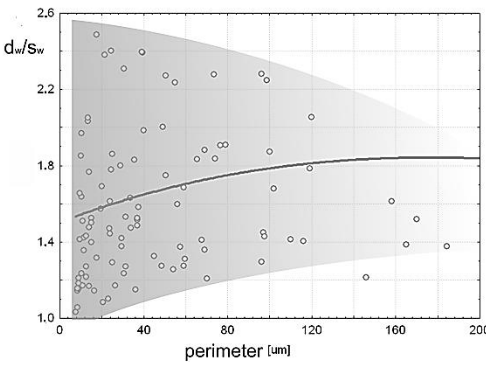


Fig. 24. Relation of the length d_w to the width s_w of elevations over the binder surface for the different lengths of their perimeter Ow for 3IDLF film

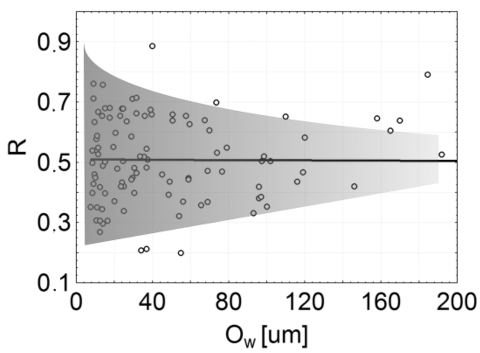
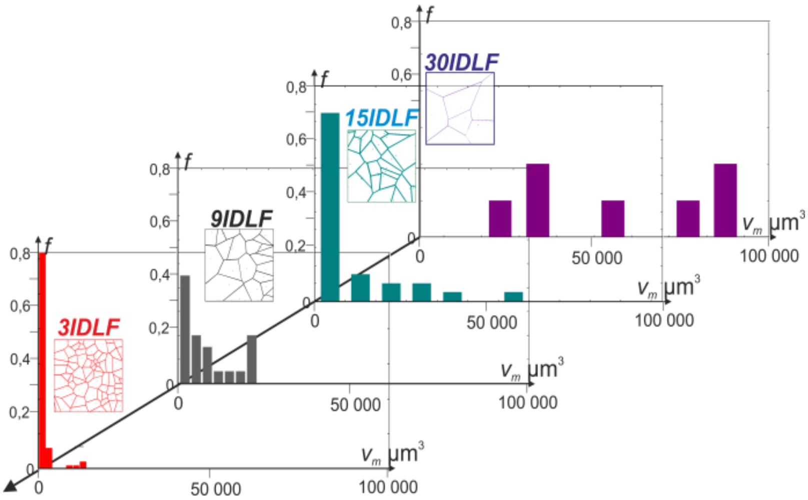


Fig. 25. Coefficients of roundness R (3) of elevations over binder surface

The assessment of the maximum volume of the material v_m which can be removed with the use of a film with a specified surface A_F takes into account a limitation in the form of the available volume of the surface between the vertexes where machining products can be collected. For this purpose, the relations between the surface area of Voronoi cells P_v (that constitute an isolated environment of the vertexes) and the surface area of the base of elevation P_w (Fig. 5) over the cut-off plane on the *kSt* level (*St* being proper for a given film) was define.



Fig, 26. Distribution of the value of volume for storing machining products for abrasive films under examination

An assessment of the abilities to store the machining products in spaces between particles follows from the value of the P_v/P_W ratio. The maximum volume of the material removed v_m can approximately be defined with relationship 4, where *Pv* is the surface area of Voronoi cells that constitute the environment of the particle, *h* is the situation of the cut-off plane being equal to the average value of particles plunging into the material machined, $k_f<1$ is the filling factor of the space with machining products, n is the number of the vertexes of particles raised over the cut-off plane, v_{zh} is the particle volume over level *h*. The volume distribution v_{mi} for 3IDLF, 9IDLF, 15IDLF, 30IDLF films is presented in Fig. 26.

$$v_m = k_f \sum_{i=1}^{n} v_{mi} \tag{4}$$

$$v_{mi} = (P_{vi} h \_ v_{zh}) k_f \tag{5}$$

3. CONCLUSIONS

The superfinishing process of surfaces with the use of diamond finishing films for precision lapping differs substantially for other machining methods. The machined surface is transported much faster than the abrasive film. The abrasive film which is slowly transported and pressed against the machined surface with the aid of a pressure roll is used once only. A single use of the tool means that abrasive particles are used only over a certain period of time that is determined by the film travel speed. Once they have left the machining area, they no longer participate in the process.

Owing to the research of the topography of diamond abrasive films with the use of confocal laser scanning microscopy, characteristic aggregation of the abrasive was observed. The size of the units and their shapes are diversified depending on nominal abrasive grain sizes. Units with an oblong shape demonstrate the better machining abilities compared with units with spherical shapes. The ratio of the edge length to the edge width of the diamond unit is a good parameter that describes the technological potential of the tool. The greater this coefficient, the more compound the cross-section surface of the unit raised over the binder surface is. This causes an increase of the machining ability and a higher effectiveness in the removal of machining products outside of the micro-lapping area.

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