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Wojciech KACALAK[1]
Katarzyna TANDECKA[1*]
Thomas G. MATHIA[2]

PREDICTION OF MICROFINISHING EFFECTS WITH THE USE OF ABRASIVE FILMS UTILIZING DATA CHARACTERIZING THEIR SURFACE TOPOGRAPHY

The publication describes the methodology and results of the studies on stereometric characteristics of the diamond surface of microfinishing films. This methodology is used in different treatments of precise finishing of very high smoothness and accuracy. One presented the results of analysis of vertices' size in parallel plane to the film surface and towards perpendicular plane to it. Moreover, one performed an assessment of the distance between the grains using surface decomposition on Voronoi cell surface. In order to determine the film surface necessary to perform a particular microfinishing operation, one developed an index which is dependent on the overall profile of the film in the form of an envelope of the sum of vertices' projections above a certain level. Studying the formation of diamond aggregates of abrasive grains and the spaces between them, one can conclude about the machining potential of microfinishing film and determine a recommended speed of the film displacement ensuring maximum utilization of this potential.

1. INTRODUCTION

Microfinishing with abrasive films differs from other processing methods of abrasive machining. This is surface machining wherein the abrasive film is pressed to object's surface with the use of roll of certain proneness (Fig. 1) [5],[6]. The speed of displacement of the object's surface relative to the film is large and is typically estimated at 10-170 m/min. The speed of film's displacement is small and accounts for 10-150 mm/min [15],[16],[20]. A characteristic feature of the process is the single use of the film surface [8],[9].

Grains active for some time which depends on the speed of the film displacement remain in the treatment zone and no longer take part in the process of construction of the workpiece surface. Not all abrasive grains are involved in the construction of the workpiece surface; however, the proportion of active grains is greater in comparison to machining with the use of tools of high stiffness [11],[12].

[1] Koszalin University of Technology, Faculty of Mechanical Engineering, Department of Precision Mechanics, Koszalin, Poland
[2] Centre National de la Recherche Scientifique, (CNRS) Laboratoire de Tribologie et Dynamique des Systemes, Lyon, France
[*] E-mail: katarzyna.tandecka@tu.koszalin.pl

The objective of the study is to evaluate the possibility of increasing the activity of abrasive grains via modification of the characteristics of abrasive films and properties of pressure form systems to the workpiece [2].[3],[10]. Determination of the probability of contact between grain vertices of film and the machined surface is important to determine machining potential and establishing the speed of its displacement [13]. The important features of the tool are the parameters characterizing volumes and construction of the grains' environment [17]. They decide mainly on the possibility of accumulation of the products of polishing process and their elimination from the treatment zone [7].[18],[19],[21].

Films for microfinishing of IDLF (Imperial Diamond Lapping Films) type consist of diamond grains packed as aggregates. They are characterized by long life and provide very good results of surface finishing. The main applications of diamond abrasive film are machining of the fiber optic connectors, additional polishing of flat surfaces, polishing of cylindrical surfaces. IDLF-type films are used for machining of difficult-to-machine cylindrical materials such as glass, cemented carbides, ceramics, hardened steel, Inconel-type alloys and composites. For the production of films, one uses grains made of synthetic diamond of sizes ranging from 0.1 μm to 60 μm, which are embedded in the resin deposited on a polyester tape (Fig. 2). Evaluating of the properties of IDLF-type abrasive films is a complex problem due to the diverse geometry of the abrasive grains and their aggregation on the surface of the film. Examining the construction of abrasive aggregates' surface, one can conclude on machining potential of diamond abrasive films and provide the conditions of their full utility.

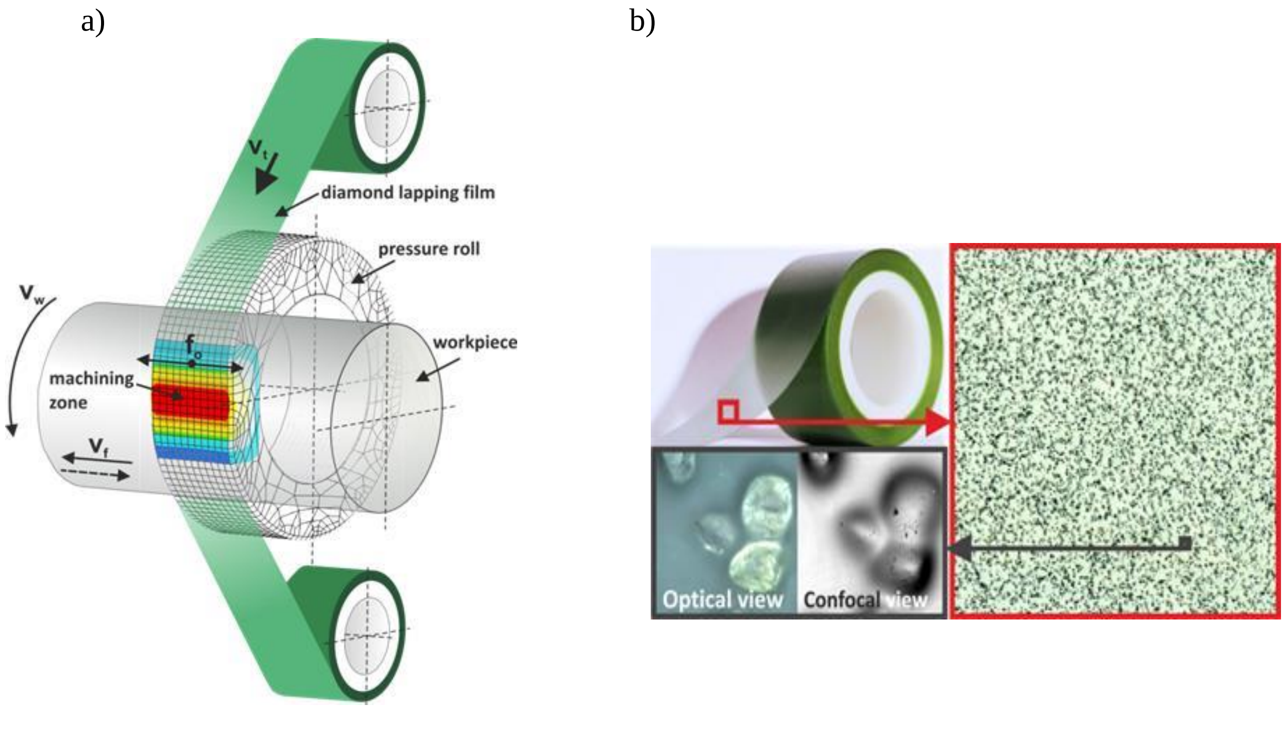

Fig. 1. Machining system for additional finishing of surface (a), where: f_o – oscillating motion of the tool, v_w – direction of circular motion of the object, v_f–direction of feed motion, v_t – direction of displacement of abrasive grain and (b) roll of abrasive film with visible abrasive grains embedded in glue

2. METHODOLOGY OF ANALYSIS AND EVALUATION OF ACTIVE SURFACE TOPOGRAPHY OF ABRASIVE FILM

In this study, we presented the results of the topography of IDLF-type (Imperial Diamond Lapping Film) abrasive films produced by 3M Company, of a nominal particle size of 1, 3 and 9 micrometers. A characteristic feature of such tools is complete embedment of diamond grains in a thin layer of binder and their aggregation (Fig. 2). By “embedment” of diamond grains in binder, measurements of tool’s surface topography are much more difficult, especially with the use of optical methods due to the low reflection coefficient. [14].

To study the tools with very fine grain, one used confocal microscope which enables the measurement of transparent surfaces.

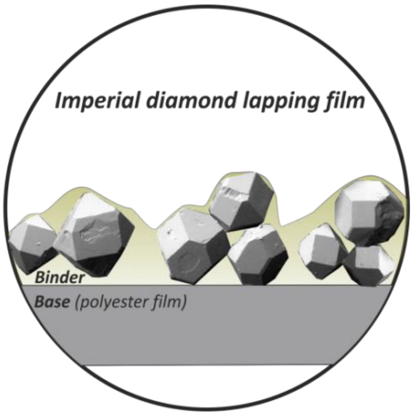

Fig. 2. Structure of diamond abrasive films

a) b)

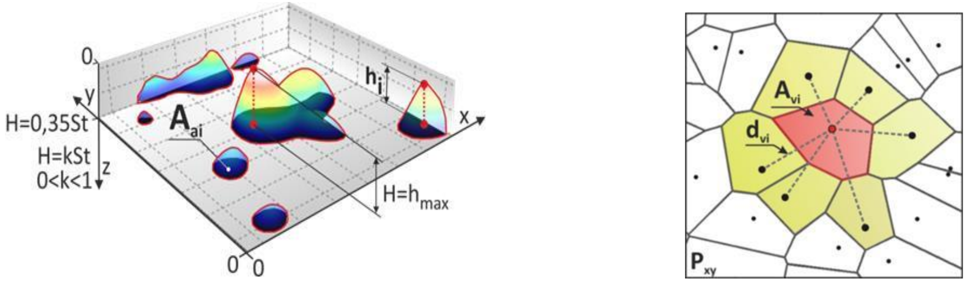

Fig. 3. Heights and field gradients above the plane away from the highest vertex of *kSt* value (A) representation of decomposition of the surface on Voronoi cells (b)

An important problem is to determine which of the grain vertices form a set of neighboring vertices [4]. To solve this problem, the abrasive film surfaces were subjected to area decomposition on Voronoi cells, where the center point of each sub-area is the vertex of the grain. Sub-areas are used to find the nearest neighbors, all Voronoi cells directly adherent to the cell of interest consist its nearest neighborhood (Fig. 3).

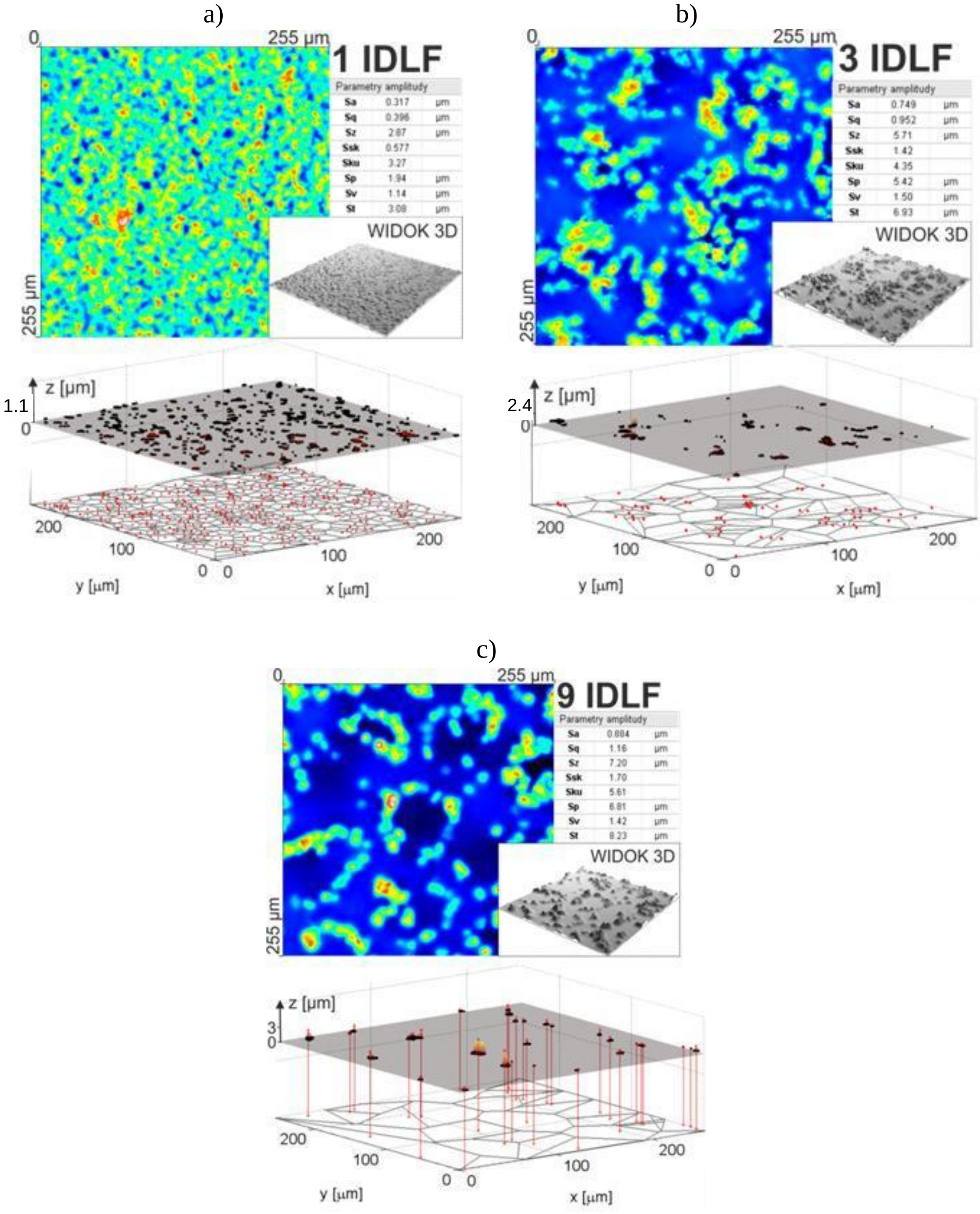

Fig. 4. Heights and surface gradients above the plane distant from the highest vertex by $H=kSt$ value and representation of surface decomposition on Voronoi cells on the surface of diamond abrasive films of nominal grain size a_g 1 µm (a), 3 µm (b) and 9 µm (c)

Voronoi cells' areas for different films and H levels (Table 1), (Fig. 3), were determined as decomposition surface on sub-areas with central peak of z(x, y) as the central point. The mean area of Voronoi cells decreases with $H=kSt$ increase, $0 < k < 1$, that is the distance of the surface gradient from the highest surface vertex as the number of gradients N_a increases above the H level. One calculated the distances between the vertices of gradients of the nearest neighbors d_{vi} and surface of Voronoi cells A_{vi}.

We design an application for the analysis of geometric features of gradients above an established level, from 20% to 40% of St parameter value, from the highest surface vertex. In Figures 4-6, one presented surface gradients, for which one established the highest point of the gradient and Voronoi cells projected onto the Oxy plane. The central element of Voronoi cells constitutes the highest vertices of gradients. The procedure of gradient evaluation was performed for different H levels, starting from the highest vertex.

Table 1. Set of indicators' values for the assessment of diamond abrasive films' surfaces

Folia	k	St µm	H µm	A_V µm^2	d_{vi} µm	a_g µm	d_{vi}/a_g	N_a 1/mm^2
1IDLF	0.2	3.08	0.616	264	7.9	1	7.53	1350
1IDLF	0.3	3.08	0.924	260	7.5	1	7.5	3990
1IDLF	0.4	3.08	1.232	180	4.1	1	4.1	7245
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
9IDLF	0.2	6.61	1.32	1820	15.6	9	1.73	549
9IDLF	0.3	6.61	1.98	1578	14.7	9	1.63	793
9IDLF	0.4	6.61	2.64	1011	12.42	9	1.38	1586

Symbols of indicators presented in Table 1 are as follows:
A_V – average surface area of Voronoi cells;
d_{vi} – distance from nearest neighbors determined using Voronoi cells;
a_g – nominal size of grain;
N_a – number of gradients above the plane distant by h calculated from the highest vertex.

With an increase in the distance of plane orientation distant by H from the highest vertex on the abrasive film surface, in terms of films of nominal particle sizes (3 µm and 9 µm), distance between grains d_{vi} determined by the nearest neighbors method decreases which is directly related to the increasing number of active gradients above this N_a plane.

3. SELECTION OF MICROFINISHING PARAMETERS WITH THE USE OF DATA ON ACTIVE SURFACE TOPOGRAPHY

Utilization of machining potential of the abrasive film depends on selection of machining parameters: speed of movement of the workpiece v_p, speed of the film movement v_f and average value of unit pressures q in the contact zone of workpiece and film surface.

For some time, products of machining process remain in the spaces between grains of abrasive film. The slower the film moves, the more filled these spaces are. Too rapid movement of the film, particularly when the traverse of the film is small, prevents from utilization of machining possibilities of the grains. Therefore, for specific parameters and machining conditions, it is possible to determine such speed of film displacement v_f, to fill spaces between grains at optimum level.

Too slow film displacement makes the spaces between the grains overfull which prevents from accumulation of machining products. Polishing efficacy is then drastically reduced. It should be noted that not all abrasive grains are used in the formation of machined surface, which depends on their position on film surface, surface topography of the film (Fig. 5), proneness of the pressure roll and unit pressures.

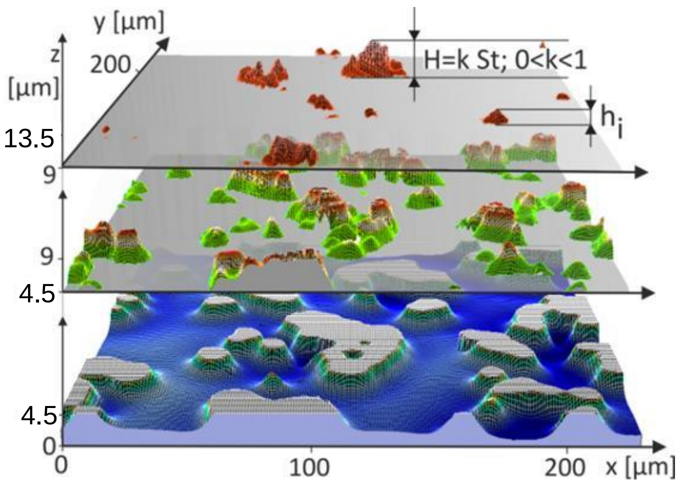

Fig. 5. Scheme for the evaluation of distribution of grains' vertices on the surface of abrasive film exemplified by 9IDLF abrasive grain surface

In order to determine the expected efficiency of polishing, one developed an index which is dependent on the summary profile of the film $z_s=f(x_s)$ (Fig. 6) in the form of an envelope of the sum of projection gradients above H level on z_sx_s plane. One can use w_{ep} index which describes the ratio between area under the overall profile and bH value to determine the length of the abrasive film necessary to obtain a specific surface roughness of the workpiece.

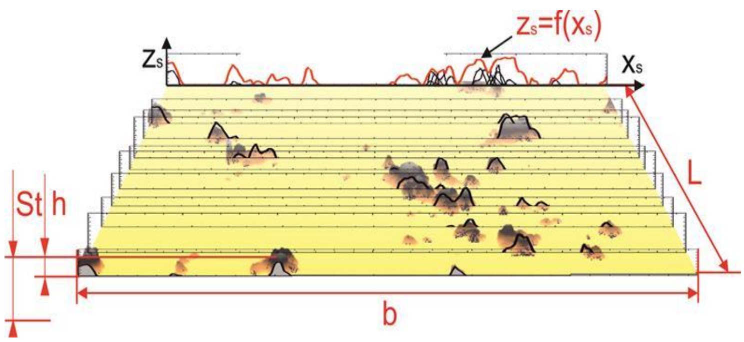

Fig. 6. The overall profile of the film $z_s=f(x_s)$ in the form of an envelope of sum of projection gradients above H level, on z_sx_s plane

w_{ep} index (1) depends on the length of film surface tested. It can be used to determine the film surface necessary to achieve a certain polishing operation.

$$w_{ep} = \frac{1}{bH}\sum_{i=1}^{b} \max\big(z(x,y)\big)\,, where\ H = kSt_{film} \tag{1}$$

Changes of w_{ep} index value depending on the length of the film for different k ($H=kSt_{film}$) values are shown in Figures 7, 8, 9.

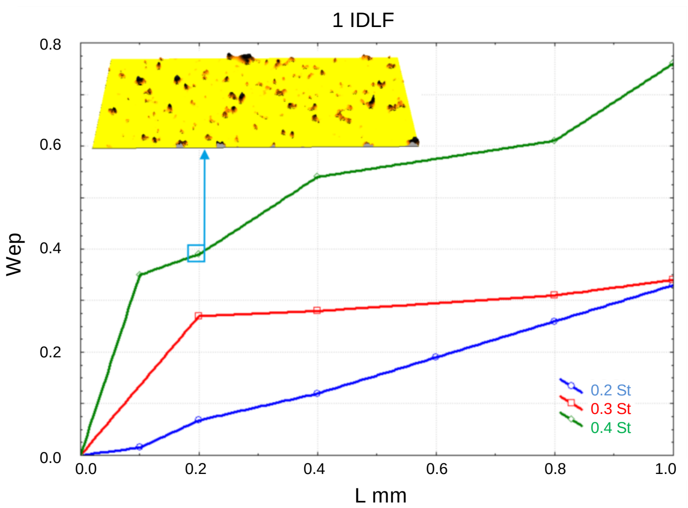

Fig. 7. w_{ep} index depending on the length of 1IDLF film

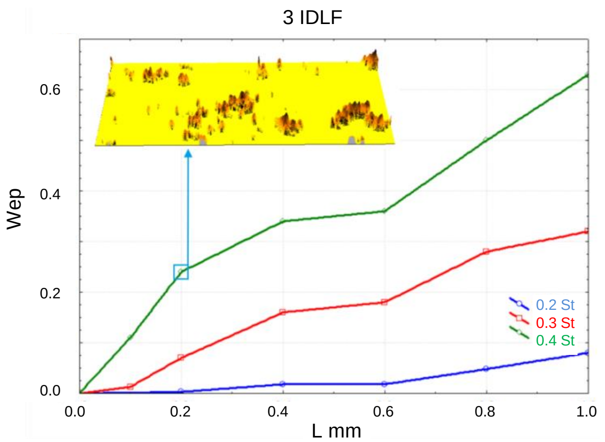

Fig. 8. w_{ep} index depending on the length of 3IDLF film

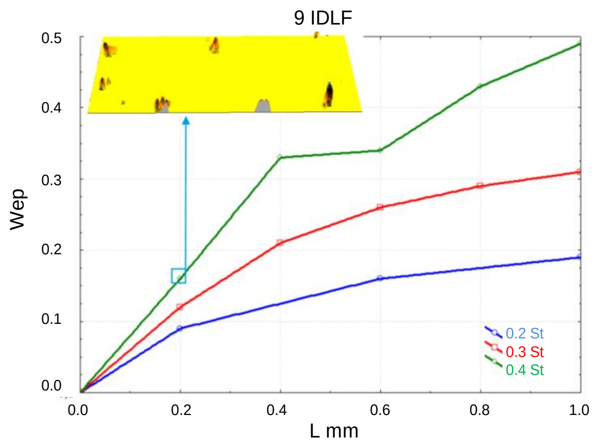

Fig. 9. w_{ep} index depending on the length of 9IDLF film

In order to verify the index developed, microfinishing studies were conducted. As workpieces, plates of fixed disks were selected due to the accuracy of results' comparison based on short machining cycles.

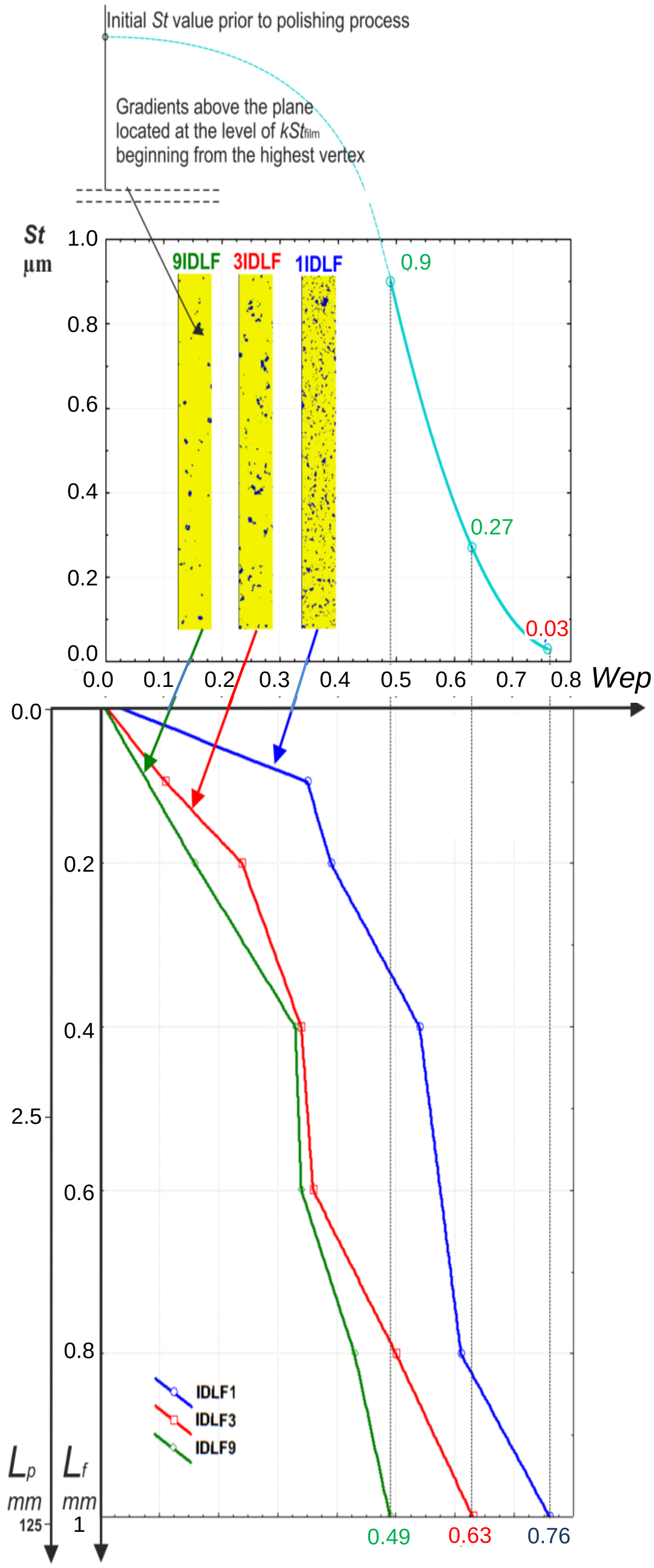

Fig. 10. The relationship between *St* parameter of the microfinished surface and the value of w_{ep} index determined for the plane position *H*=0.4*St*, for the film length L_f = 1mm and the contact length the workpiece L_p=125 mm

The machining was carried out at a displacement speed of the workpiece surface v_w=75 m/min, with the applied nip roll characterized by hardness equal to 50^oSh.

Microfinishing was conducted with frequency of film oscillation f_o = 80 Hz, the speed of the film displacement v_t was 60 mm/min. In order to determine *St* parameters of machined surfaces, that is the distance from the uppermost point of surface to the largest depth, studies using finished surfaces were performed with the use of profilographometer CCI6000 (Taylor Hobson). Figure 10 shows the relationship between *St* parameter of machined surface and w_{ep} index value. The data presented in Figure 10 shows that the index developed is simple and effective measure useful to forecast the results of finishing. It can also be used to determine the length of film necessary to obtain the determined surface features during certain microfinishing operation.

4. CONCLUSION

The process of additional polishing of surfaces with the use of diamond films for the precise polishing is significantly different from other machining methods. The machined surface moves at a higher speed than abrasive film. Gradually rewound abrasive film pressed against the surface of the workpiece using pressure roll is used only once. Single use of the tool denotes that abrasive grains are used only for certain time determined by the speed of film displacement, and after leaving the treatment zone they do not take part in the process again.

In order to make optimum use of the abrasive film and forecasting the conditions of the polishing process, w_{ep} indicator has been developed which describes the ratio between the area under the overall profile and bH value and may be used to determine the length of the abrasive film necessary to obtain a specific surface roughness of the workpiece.

The highest expected efficiency of polishing is observed for the abrasive film with a nominal abrasive grain sizes equal to 1 micron, which is directly related to the surface topography configuration and the observed strong aggregation of abrasive. The value of w_{ep} index for 1IDLF film is about twice the w_{ep} index for 9IDLF film.

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