Flexible Tools with Diamond Blades for Polishing Granite Surfaces

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Abstract. Polishing is an operation of treating the surface of the stone that gives it final useful features, giving the surface shine, which in the final stage of stone surface treatment give it important usable features, which include: aesthetics, i.e. surface property of the stone, characterized by the glassiness of the surface in some case has a mirror effect, which is characterized by a high degree of reflection of light, allowing it to observe the structure of the stone well in the aspect of its decorative elements placed on its surface. The physical features of polished surfaces are, above all, a shorter time to maintain moisture on its surface, which is the basic factor of material destruction. The quality of the polished surface of natural stone determines the degree of its longevity, this principle is particularly important for polished marble and concrete surfaces. An important value of the quality of polished products is the assessment of this parameter in a commercial assessment. The property of achieving a high degree of polishing can only be achieved with the help of highly effective diamond tools for polishing operations, where the quality of their work is evaluated by instrumental methods using tools measuring the amount of reflected light from the polished surface (gloss meter). Flexible diamond tools for dry and wet polishing operations are a set of 8 discs with a diameter of 100 mm mounted on a fast link formed in the friction surface on a synthetic binder of diamond abrasive with a grain size of 50 ÷ 300 #. In order to increase the efficiency of surface treatment technology in polishing operations, it is necessary for granite processing for a given polishing operation with grain size 800 #, to select the appropriate hardness resulting from the synthetic binder formulation.

1. Introduction
The treatment of stone surfaces, which are used as a cladding element in construction, distinguishes between the many surface treatment operations the polishing operation, which is of two types of technology: wet or dry: Wet surface treatment, this type of machining increases the work input but rationally uses the tool's working area and creates a safe way of interacting with the material, causing minimal abrasion and eliminating surface overheating of the structure being processed, eliminating surface defects [1-4]. In this case, flexible discs with a central hole through which coolant is supplied in the form of water in the disc's working zone are used. Another method is a method of working in dry technology, which does not require creating special working conditions of the machining disk. In this method, the abrasive wear of the machining discs is higher than in the wet technology and the work of such a tool requires the grinder operator a lot of experience, because the probability of
occurrence of defects in this method is higher. Polishing to give the gloss surface is carried out with diamond powder grits from 400 ÷ 3000 #, with the use of the final disc, so-called Buff. Glue and waxes can be used in the process of gloss fixing, which fix the treated surface. The use of blades with different geometry and hardness of the binder and diamond powder grains which are selected depending on the type of stone being worked, for example, the final polishing of some types of marble can be finished with a grinding wheel, the grain size of which is 800 #, hard binder, small diameter geometry of diamond segments. Recommended rotation of the disc (n [rpm]) should be for finishing grinding 360 ÷ 960 rpm, while for polishing 660 ÷ 1200 rpm and even 1660 rpm for selected types of granite as recommended by literature [5-9]. Practical experience shows that grains with a higher grain size can be used for soft stones polishing. It is important not to pass through the next numbers of the grain granules, for a given and subsequent operation because such a procedure can lead to the lack of creation of a mirrored machined surface. In the process of polishing natural stone, a lot of dust and vapors generated as a result of abrasion of flexible discs on synthetic binders are produced, which are made of various chemical compounds, therefore the equipment of the grinder operator should include a protective mask and safety glasses. The use of flexible discs for the treatment of stone surfaces and the analysis of abrasive phenomena [9, 10] have shown that: a polishing operation due to friction can wipe off not a small part of the treated surface, approximately abrasive material consumption is 2 mm. The accuracy of the dimensional tolerance of the workpiece should be taken into account in the polishing operation. At present, an important and current research task in the field of material engineering is to refine the construction and material solutions of flexible discs on synthetic binders with increased effectiveness of their interaction for a given group of granules guaranteeing high quality of treated surface evaluated by new measuring methods using a gloss meter [11].

2. Diamond flexible blades for polishing granite surfaces

Flexible diamond discs called pads or turtles are products in the form of round flexible discs formed from synthetic resin binders with a diameter of 80 ÷ 300 mm with the surface structure of abrasive elements of various geometry called diamond working segments in the matrix which are used as abrasive synthetic diamond powder with a set for a given granular transitional operation, as in Figure 1.

![Figure 1. Flexible granite polishing wheels](image)

The pad attachment is made on a transitional base disk, which allows quick connection of various designs of the operating disk with the carrier adapter. Flexible discs for polishing marble and granite surfaces are characterized by high efficiency and high abrasive wear. The flexible disc design allows
for machining in hard-to-reach places and for machining slightly angled surfaces, angles. Flexible discs are working elements for surface treatment irreplaceable in finishing operations for polishing the surface of granite and marble. One of the characteristic features of the flexible disc is to provide its mounting surface with a fabric - Velcro, which allows you to quickly change the disc from higher to lower grain on the adapter.

Another important element that characterizes the dial is the surface of the work nipples with various geometric fillings, the surface of which resembles the turtle's shell. The working surface of the disc determines the effectiveness of its impact, which depends on the geometry, kinematic parameters and trajectory of the movement of the disc on the material being processed. Theory of the process of impact of the disc working segments on the material processed, presented in the literature [12-15], comprehensively determines the ways of shaping the geometry of kinematic parameters and the hardness of the binder segments depending on the type of material treated, assessed by its hardness. The set geometry profile allows effective use of the tool, reducing the thermal stresses created in the tool's contact with the material being processed and allowing the resulting spoil to be removed in the polishing process, which enables the granite surface to be gloss-treated.

Processing of hard pad materials is possible due to the use in the structure of the processing segment of synthetic diamond powders contained in a modified binder whose hardness is modified by the hardness of mineral powders added to the binder. The elasticity of the disc is made possible by the use of special polyurethane resins with high thermal resistance and a complex abrasive wear [9] with added additives conducive to the maintenance of diamond grain in the structure of the segment. The processing of granite materials in the polishing operation is possible thanks to the use of variable grit diamond powders, for each of the 8 stages of the machining operation, where for each one uses discs of different granularity and a precise variable hardness of the binder. The first stage uses discs with coarser diamond grain, which minimizes surface roughness. Next, the treated surface is treated with grains with a smaller granularity and the final stage uses a disc with segments of low granularity. As a result, a mirror surface is obtained that imparts physical and decorative properties to the treated surface.

The number grading for a given target with the marked diamond powder fraction starts with the number 30, which means coarse diamond grains, intended for the first coarse processing, and ends with the number of grain 3000, i.e. the disc for the so-called polishing of the finish. In addition, diamond disks are also produced in which the grain size of a diamond is classified as BUFF. With their help, the treated granite surface receives a perfectly mirrored surface. At the initial machining operation, which uses coarse grain to eliminate unevenness, creating scratches. Deep scratches are reduced by using discs with a higher grain number. Another swapping of the discs from the smaller to the higher grain numbers allows to achieve the expected degree of polished surface assessed by the amount of reflected light. In working with discs of variable granularity it is necessary to take into account the rotational speed of the disc. Shields with numbers 30 ÷ 100 are recommended to be used at revolutions n = 660 ÷ 960 rpm. Targets with the number above 1000 are recommended to be used at reduced speeds up to 660 rpm. Wet discs with a fluid coolant do not differ from dry discs. In the structure of abrasive segments, the discs for both methods have the same granularity fractions of diamond powders, while in the dry method the discs are used for treating moist surfaces. This condition extends the service life and time and does not allow the material to be overheated on its surface structure. Overheating of the treated surface can lead to the formation of a so-called surface sinter. The difference between wet and dry discs is found in the design of the diamond segments themselves. The discs for dry polishing have relatively large segments with larger widths of the output ducts between them. This structure of the working surface aims to eliminate clogging between the segmented space with sludge and dust. For the wet polishing technology, discs with an increased number of channels for extracting spoils with small segments, with segments with rounded edges, with
their radial arrangement allow using centrifugal force, effectively remove spoil resulting from abrasion of machined material and particles of the machining tool. The diamond segment matrix binder constituting the working surface of the disc made of modified polymeric materials differ in their hardness and thermal resistance. Blades with a soft diamond segment binder matrix that melt slightly can apply visible marks to the treated surface, which is why they are used in the wet method. In dry processing methods, structurally dense materials with increased strength and increased thermal resistance are used.

3. Modeling of the working surface of granite polishing discs
Working tool for modeling the geometry of the friction surface with the help of the computer program described in [15], where the exit surface is a full circle as in Figure 2a. In the case of an annular work tool (Figure 2b), it is more convenient to assume as the first formulation a friction surface in the form of a solid disk from which the concentric circle of the island with a smaller diameter is subtracted.

![Figure 2](image)

**Figure 2.** Some variants of geometrical form and arrangement of working elements on the mother-mother surface: a) full disc, b) annular work element (working tool), c) circular working elements, d) annular working elements, e) and f) rectangular working elements, g) and h) arched working elements; 1 - friction elements of the shield, 2 - islands [15]

Working elements, inscribed in the circle of the target, can be given various geometrical forms, their size and distribution on the circular surface of the output island. When all dimensional parameters and forms are determined, the last wording in the calculation program is assigned to them. In the case of the characteristic of circular working elements (Figure 2c), it will be important to enter the coordinates of their centers in the xy coordinate system, the radius of the circle R and the number of elementary friction surfaces n (x1, y1 ... xn, yn). If ring-shaped working elements are used instead of circular ones (Figure 2d), then the first circular islands with radius equal to the inner radius of the R1 ring should be subtracted and the last wording should be assigned to the calculation program. In the characteristics of these islands, the same coordinates of the location of their centers should be given x1, y1 ... xn, yn and the radius R1.

In the case of the size and position characteristics of rectangular work elements, it is sufficient to give the coordinates of the position of the three vertices of each of them, regardless of their...
arrangement in the plane of the target (Figure 2e and f). In the case of polygons, the positions of more vertices are taken into account. Characteristics of arcuate working elements (Figure 2g and h) includes the size of the external and internal radius of the arch, the size of the central angle and the coordinates of the center of the arc.

The calculation program allows for the definition of any geometric form and size of the working element, as well as its placement anywhere on the mother-mother surface using rotation and offset operations, as well as the simultaneous application of work elements of various geometrical form. In order to carry out an effective surface treatment of the disc working tool, rotating at the speed \( \omega_0 \), they are usually introduced into the translational movement with the speed \( V_p \). As noted in the description of disc machines, for the treatment of concrete surfaces (Chapter 1), in addition to the translational movement with the speed \( V_p \), the following can also be used: reciprocating movement of the blade rotation axis across the machining direction at \( V_{pz} \) or circular motion of the blade rotation axis with velocity \( \omega_0r \) using the adjustable (lever) radius of rotation \( r \). The computer modeling program allows for taking into account all types of motion, because it is formulated a route of displacement of the target, consisting of formulations of individual movement paths. The characteristics of the wheel's trajectory include determining the position of the center of the target and its kinematic parameters (speed of translation and rotation) at the beginning and the end of the next stage of motion. The stationary elementary field \( \Delta S \) of the machined surface is subjected to the action of various points of the disc working elements, in which there occur different in terms of magnitude and direction of the resultant velocity of component movements of the target. The change of this interaction for a simple case of surface treatment with the use of a full disk, performing a rotary and progressive movement, is an illustration of the resultant impact velocities of selected elementary disc surfaces on various elementary points of the work surface (Figure 3). The size and direction of the translational speed of all points of the working surface of the \( V_p \) disc are the same. The numerical value of the circular velocity \( V_{0R} = \omega_0R \) decreases with the changes \( r \) to \( r = 0 \) and on the perimeter of the disc is \( V_{0R} = \omega_0R \), while in the center of the disc falls to zero. Since the vectors of this velocity are perpendicular to the radius \( r \) and have a direction consistent with the direction of rotation of the disc, the resultant velocities \( \overline{W} = \overline{V}_p + \overline{V}_{0R} \) also change direction. As the next points of the disc working surface through the fixed elementary field \( \Delta S_0 \) change, the magnitude of the resultant velocity \( W_r \) of the impact \( W_r = \sqrt{V_p^2 + (\omega_0R)^2} \) from \( W_o = W_p \) takes place, and its direction deviates towards \( \overline{V}_p \) the points from \( r = R \) to \( r = 0 \) in the first phase of the translational motion, with the opposite deviations for the second phase of this movement.

The extreme elementary fields of the surface to be machined, lying in the distance \( + R \) \((+ \Delta S_R)\) and \( - R \) \((- \Delta S_R)\) from the center of motion of the target, will be under the action of the directional accidents \( \overline{W}_R = \overline{V}_p + \overline{V}_{0R} \), which for \( \Delta S_R \) are \( W_R = V_{0R} - V_p \), and for \( - \Delta S_R \) they have the value \( W_R = V_{0R} - V_p \). Elementary fields of the surface to be machined, lying between the line of the trajectory of the center of the target and its circumference of radius \( R \) see (Figure 3).

Elementary fields \( + \Delta S_d \) and \( - \Delta S_d \), spaced at \( + d \) and \( -d \) from the path of the target) will be under action the resultant velocities of \( W_{0R} = \sqrt{V_p^2 + (\omega_0R)^2} \), velocity from through decreasing resultant \( W_{0R} = \sqrt{V_p^2 + V_{0R}^2 - 2V_pV_{0R}\cos\varphi_0} \), to the value of \( W_d = V_p \pm V_{0d} \) in the first phase, and then increasing in the second phase of the movement to the value corresponding to the point on the circumference of the target. Summing up the resultant velocities of interaction of all points of the disc working surface with their simultaneous multiplication by the distance (quantum) of contact on a stationary surface of the work surface, we obtain the length of the working tool's impact line on a given point of the surface of the concrete structure.
Figure 3. Changes of the resultant velocities ($r_i = 0 ... R$) at the locations of surface points of the solid target with radius $R$, affecting the elementary fields of the machined surface located on the center line of the center of the target ($\Delta S_0$), remote from this line at a distance $d$ ($+ \Delta S_d$ and $- \Delta S_d$) and at a distance equal to the radius $R$ ($+ \Delta S_R$ and $\Delta S_R$) of the disk rotating at the speed $\omega_0$ and making the translational movement at the speed $[15]$

The presented interpretation of the kinematics of the impact of the disc working surface points reflects the principles of building a computer program for the calculation of the effectiveness indicators of the impact of the working tool on the surface to be machined. In this program a quantum time $dt$ is stored for which the sensors $L_i = (V_p + V_{0it}) dt$ are stored, and at the end of which the system parameter values $\overline{V}_p$, $\overline{V}_{0it}$, are determined, i.e. the position of the center of the target for the next sensor. The design of the computer program takes into account the impact on the machined elementary field (point of the machined surface) only the points of the working elements of the target, which allows the selection of the desired sum of working elements. The result of the calculations are graphs of the effectiveness of the working tool's impact including the lines of impact of all points of the working surface of the target, as well as the numerical values $S_g = \sum_{i=1}^{n} L_i [m]$, of the average, maximum and minimum effectiveness of impact as well as standard deviation and relative deviation indicators.

Optimization of sizes, quantities and distribution on the surface of the mother blade - working elements of a given geometric form - is carried out in the next steps towards the minimum standard deviation of the effectiveness of the impact. The proposed computer program also allows to optimize the effectiveness of the impact of disc working tools on a flat surface by selecting the path of the center of the disc, the use of partial covering of the disc's transitions and the use of additional reciprocating movement or circular motion of the disc rotation axis. Units of kinematic parameters
adopted for the developed computer program for modeling the surface structure of discs for surface treatment ($V_p$ [m/s] and $\omega_0$ [rpm]) do not constitute an obstacle for taking into account other units, provided that the appropriate conversion is made. In solving issues concerning the analysis of the effectiveness of the impact of disc working tools, optimization of the structure of existing geometric forms of disc working elements and construction of new ones, the output includes: disc diameters [m], disc progress speed [m/s] and rotational speed of disc [rpm]. For a given diameter of the dial the time quantum $dt$ is selected (in seconds, for example: $1.25 \times 10^{-3}$ s for a dial with a diameter $D = 0.2$ m, $2.5 \times 10^{-3}$ s for a dial with a diameter $D = 0.7$ m and $5 \times 10^{-3}$ s for a dial with a diameter $D = 1.2$ m), which determines the accuracy of the calculation. Taking into account the diameter of the disc or the width of the surface band to be worked ($L \leq D$) with the tool's working movement, the distance between the sensors on the reading line $x$ is determined (for the given diameters of the dial and the number of sensors $n = 60$ the distance between them is 0.003; 0.01 and 0.02 m).

The built-in computer program includes subroutines for specific, currently used disk work tool structures. They are used in the analysis of the influence of the output parameters ($D$, $V_p$, $\omega_0$) on the average efficiency of the given surface structure of the disc and the uniformity of the $S_{gi}$ distribution on the surface treatment bandwidth. The average $\overline{S_g}$ effectiveness of the working tool will be:

$$\overline{S_g} = \frac{1}{n} \sum_{i=1}^{n} S_{gi}$$  \hspace{1cm} (1)

where: $S_{gi}$ - value of interaction efficiency according to sensors [m].

The objective function in the process of optimizing the surface structure and kinematic parameters of the disc-shaped working tool is an indicator of the standard deviation of the effectiveness of its impact on the treated surface. The standard deviation indicator $\sigma$ is determined from the ratio of the standard deviation and the average effectiveness of the working tool:

$$\sigma = \frac{1}{\overline{S_g}} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (S_{gi} - \overline{S_g})^2}$$  \hspace{1cm} (2)

The value of the standard deviation index is equal to the effectiveness of the justified criterion of comparison of quality characteristics of individual work surface structures of disc working tools for surface treatment, and first of all the criterion of optimization in the process of modeling the disc surface structure, selection of kinematic parameters of the working tool, determining the coverage size of subsequent passes, and also the selection of additional movements both on the axis of rotation of the disc itself, as well as its working elements. In addition to the average $\overline{S_g}$, efficiency value of the standard deviation of the maximum and minimum effectiveness ($S_{g_{max}}$ and $S_{g_{min}}$), The calculation results include the value of the relative deviation index, determined from the formula:

$$\epsilon = \frac{S_{g_{max}} - S_{g_{min}}}{\overline{S_g}}$$  \hspace{1cm} (3)

The relative deviation index $\epsilon$ gives information about the uniformity of the $S_g$ distribution only on the basis of two sensors, nevertheless it can be a criterion for assessing the impact of working tools on the treated concrete surface. Extremely transparent for such an assessment are graphs of the efficiency.
distribution of the working tool on the width of its impact, which are to a large extent helpful in the optimization processes, because the effects of each project can be observed on the monitor screen.

As a result of differences in the values and directions of resultant velocities of impact of the working tool surface points on the elementary fields of the machined surface on both sides of the shield transition (Figure 3), the graphs of the distribution of its effectiveness on the machining widths have asymmetry. To justify the asymmetry of the $S_g$ distribution graphs along the sensor line $x$, a simulation was carried out allowing for graphical recognition of successive points of the working surface of the disc, acting on a given elemental surface treated, i.e. plotting the surface of the disc surface influence on one point of the machined element surface. For the sake of clarity, a dial with a diameter of $D = 0.5$ m and a translational speed $V_p = 0.1$ m/s was chosen.

In order to obtain a line of influence of the surface points of the target on any point of the surface to be machined, it must be passed through its entire circumference through the sensor reading line. For adopted parameters, it takes 5 seconds. If we want to receive a line of impact points as a result of one rotation of the target, then its rotation speed will be $\omega_o = 12$ rpm. This condition was assumed as the starting one and according to it the lines of impact points of the full target on the central (C) and intermediate (A and B) points of the machined surface were obtained at disc rotation speeds $\omega_o = 36$ and $\omega_o = 72$ rpm, i.e. for three and six spins for the time of moving the entire dial through the sensor line $x$ (at higher speeds of rotation of the dial the line drawing becomes unreadable). The results of this experiment are shown in Figure 4 for all variants, the direction of clockwise motion is assumed, and the direction of the progressive movement of the dial is perpendicular to the sensor line.

In the case of one rotation of the dial, an Archimedes spiral is obtained that turns towards the center of the target and then unscrews with one point of intersection. The point on the left side of the target acts on point C of the processed surface. Curling and developing the spiral line of impact of the target points on the fixed point C of the machined surface at its 3 and 6 turns becomes increasingly slower and the curves have respectively 3 or 6 points of intersection. As the spiral approaches the center of the target, the resultant velocities decrease (to zero in the middle of the target), and then increase (Figure 4). These differences in the spiral lines for the point C of the machined surface at changes in the rotations of the disc determine the length of the impact line at this point. For points A and B, located on the left and right of point C, the lines of influence on these points of the target are completely different. It should be noted that the point of the circumference of the disk in which it begins to affect the fixed points of the machined surface A and B, can only accidentally be found at the intersection of vertical lines to the sensor line $x$ at points A and B. According to Figure 4, they are shifted accordingly rotation angles of the disc, but the axis of symmetry of the line of the shield's impact points on the points A and B of the machined surface coincides with the diameter of the disc and the minimum distances to the center of the disc are AC and CB. For the points on the left from the center of the sensor line, the length of the line of impact points of the disc working surface on the left point A is larger than the line of influence on the right point B and the differences are greater for one rotation of the target than for three or six revolutions. Thus, as the velocity of the rotary motion of the target decreases, the asymmetry of the distribution of the effectiveness of its impact on the treated surface will increase, and the deviation coefficients from the average efficiency value will increase. Visualization of the disk point lines affecting a given point of the surface to be worked can provide a clear illustration of the impact of the structure of the working surface of the disc working tool on the length of the impact line. For this purpose, it is enough to apply a drawing of a given structure on the course of the proper lines of influence (Figure 4) and remove sections corresponding to the islands on the surface of the target.
Figure 4. The points of the surface of the complete target with diameter $D = 0.5$ m, affecting the points A, B and C of the machined surface at the translational speed $V_p = 0.1$ m/s and rotation speeds $\omega_o$, at 12, 36 and 72 rpm [15].
4. Conclusions

Flexible diamond discs formed on synthetic binders are nowadays the current direction of research in order to search for new efficient solutions of geometric and material structures with the application of the latest generation of synthetic diamond powders and synthetic polymer binders.

In the construction of new target discs is the selection of diamond grains for the purpose of developing an optimal material recipe for making segments for discs intended for a dedicated polishing operation.

The analyses of known and new constructions and studies show that tortoise-like constructions with round elements are characterized by increased interaction properties and ensure uniformity of the quality distribution of the reflected light.

The presented method of evaluating the abrasive effect of polishing discs allows the development and analysis of the simulation of the work of newly designed geometries of the grinding work surfaces of flexible discs.

References

[1] I. P. Scherbbakov, V. I. Vettegren, A. Y. Bashkarev and R. I. Mamalimov, “Transformation of the Surface Structure of Marble under the Action of a Shock wave,” Technical Physics, 2018.

[2] V. I. Vettegren, A. V. Panomariiev, G. A. Sobbolev, I. P. Scherakov and A. Y. Bashkarev, “Changers in the surface structure of the heterogeneous body (diorite) under friction,” Physics of the Solid State, 2018.

[3] L. Jaworska, “DIAMENT, otrzymywanie i zastosowanie w obróbce skrawaniem,” Wydawnictwo WNT, Warszawa, 2017.

[4] A. Bakoń and A. Barylski, “Ziarna i Mikroziarna Diamentowe,” Wydawnictwo Politechniki Gdańskiej, Gdańsk, 2017.

[5] J. Rajczyk, “Modelling the geometric structure of concrete work item processing,” Applied Mechanics and Materials, 2013.

[6] J. Rajczyk J, “Modelling the dynamic load process in the building technology process,” Applied Mechanics and Materials, 2013.

[7] M. Knapinski and P. Rajczyk, “Innowacyjne metody w prototypowaniu diamentowych narzędzi obróbczych do szlifowania powierzchni kamienia okładzinowego,” XXI Konferencja Innowacje w Zarządzaniu i Inżynierii Produkcji, Opole, 2018.

[8] J. Rajczyk and M. Kosin, “Methodology of analyzing a new geometry design of a friction plate effect on the engineered surfaces,” IET Conference Pubblications, 2011.

[9] P. Rajczyk and M. Knapinski, “Teoretyczno-doświadczalna analiza procesu wytwarzania tarcz sierińskich przeznaczo-nych do szlifowania wykończeniowego powierzchni granitowych, artykuł przekazany do druku Inżynieria zarządzania,” Cyfryzacja produkcji. Aktualności badawcze 1. PWE, 2015.

[10] P. Rajczyk, “Analiza nowych konstrukcji segmentowych tarcz sierińskich przeznaczonych do szlifowania granit, artykuł przekazany do druku Zarządzanie Przedsiębiorstwem,” Enterprise Management, 2018.

[11] S. A. Merazet, “Materiały informacyjno-techniczne firmy Merazet”, 2018.

[12] P. Rajczyk and M. Knapinski, “Examination of Diamond Grains in Segments on Metallic Binders for Granite Surface Treatment,” 27th International Conference on Metallurgy and Materials, TANGER Ltd., pp: 1693-1698, 2018.

[13] P. Rajczyk, “Analiza mechanizmu zużycia segmentu sieriowego narzędzia do obróbki powierzchni mineralnych, 42,” Studencka Konferencja Naukowa Potencjał Innowacyjny w Inżynierii Produkcji i Technologii Materialów, Wydawnictwo Wydziału
Inżynierii Produkcji i Technologii Materialów Politechniki Częstochowskiej, Częstochowa, pp: 493-495, 2018.

[14] V. O. Konovalov, O. U. Petasyuk and V. V. Chatechin, “Vyznachennya Mitsnosti Zakriplennya Almaznoho Zerna U Zayaztsi Pry Tsyklchnomu Navantazhenni, Tekhnichni nauky,” Visnyk ZHDTU № 3 (38), Ukraina, 2006.

[15] J. Rajczyk, “Podstawy naukowe doboru struktury geometrycznej i parametrów kinematycznych tarczowych narzędzi do obróbki powierzchni betonowych,” Wydawnictwo Politechniki Częstochowskiej, Częstochowa, 2004.