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grinding modelling,
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GRINDING PROCESS OPTIMIZATION WITH APPLICATION OF SIMULATION SYSTEM

The author of this paper undertook a study on developing algorithms and programs for complex simulation of precision grinding process. The developed models of grinding processes reveals features which enables designing a new models of grinding tools with optimal grains shape and size, and its orientation on the grinding tool surface. The optimization process is feasible due to possibility of the models to carry out the simulation within a vast range of process parameters variability and exact gathering data concerning individual contact of grains. The innovation solution of presented models is based on isolation of individual grains during the simulation process and analyzing the phenomena in the grinding zone in relation to single grain. The most significant analyzes concern: the grain activity and its load, the average cut layers, flotation of single grain depth of cut along the grinding zone, and the influence of grains shape, size and arrangement on aforementioned phenomena.

1. INTRODUCTION

The efficiency and quality of abrasive machining processes has a decisive influence on the costs and quality of elements produced as well as whole products. The machining potential of abrasive tools is used insufficiently. One of more important reasons for an insufficient use of the machining potential is a slow development of new abrasive tools – development work focuses more on the improvement of the known technologies and not so much on the creation of new abrasive tools. Also, due to high costs of research into tools from ultra-hard materials concerning new tools, such research has not made a sufficient progress. The use of the machining potential of tools depends of the optimization of the loading of abrasive grains, while typical empirical research allows solely for the designation of the global features of the process and not local ones, and temporary working conditions of active abrasive grains. The development of new modeling methods and the simulation of generation processes will facilitate a substantial progress in the creation of the basis of the system under development [1,2,3].

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It will enable to set assumptions for the creation of new abrasive tools with parameters to facilitate obtaining the expected results of machining, an increase of the productivity of the process and a much better use of the machining potential of grinding wheels.

2. FUNDAMENTALS OF MODELLING

Models of the process geometry where developed based on the experimental results of microcutting process carried out with a single grain. The aim of the experiments was to obtain the conditions for chip formation according to grain shape, depth of cut and value of cutting speed for different type of the grains and machined material. To achieve that objectives the experimental stand has been developed, based on plane grinding machine equipped with grinding tool with a grip for mounting a single grain (Fig. 1a), material sample mounted on dynamometer (Fig. 1b), what enables the measurement of grinding forces during cutting. The results of each experiment where gathered in databases for father analysis.

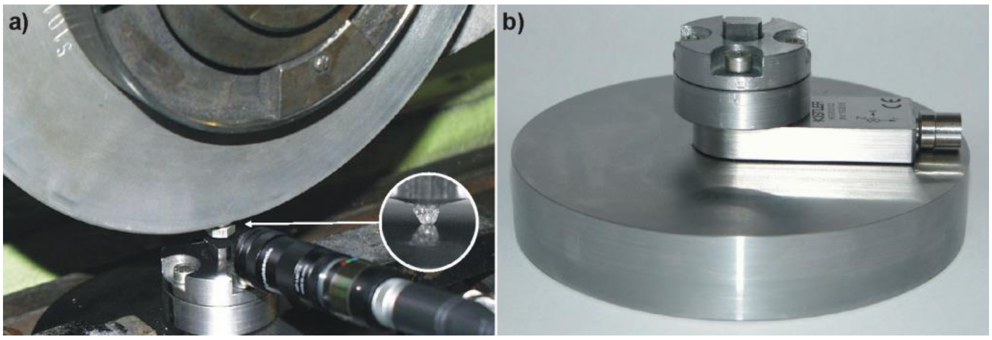

Fig. 1. Experimental stand for microcutting process: a) grinding tool with single grain, b) material specimen

Each material sample after cutting experiment was measured with profilometer in order to obtain the data on depth of cut, size of pile-ups and deviation of that on the length of the cut. A microscopic pictures of a grains and the scratches made by a cutting edges identified on the grains were also obtained with the use of scanning electron microscope (Fig. 2).

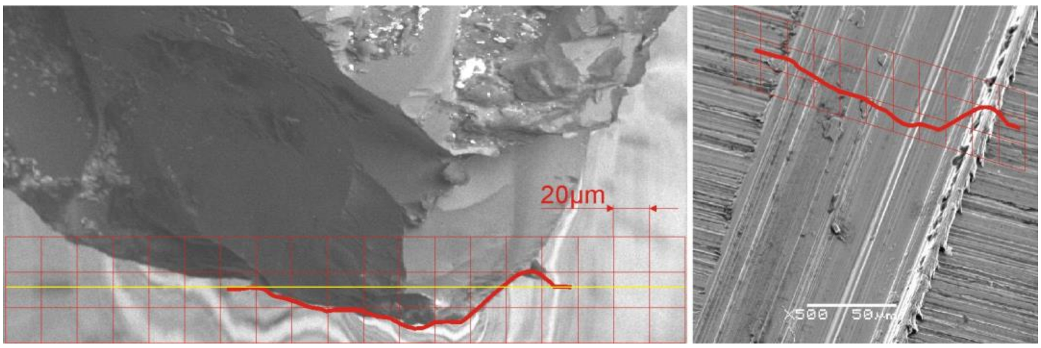

Fig. 2. SEM-pictures of the grain and scratches made by single grain during microcutting

2.1. THE GRAINS SURFACE MODELLING

Analyses of the stereometry of real grains on the basis of research formed the basis for the development of models of abrasive grains. Modeling of the surfaces of abrasive grains is provided with application of an elastic neural network. In the neuron model developed, the output parameters are the number of the grain vertices, the apex angle and the vertex radius. As a result of the work of the system, a random model of a grain with set parameters is obtained. In the network developed, the weights of individual neurons represent the coordinates of points on the surface of the grain generated. The work of this neuron network consists in the change of the values of neuron weights, as a result of which the coordinates of points describing the surface of the modeled grain are obtained [4]. The elastic neuron network consists of N neurons, where each one of them has a vector of weights w_n to determine its location in space R^N. The purpose of the network's adaptation is to obtain such a final form of the network, i.e. such vectors of the weights of neurons w_n and such vectors of connections N_N that it should map the abrasive grain's surface (Fig. 3).

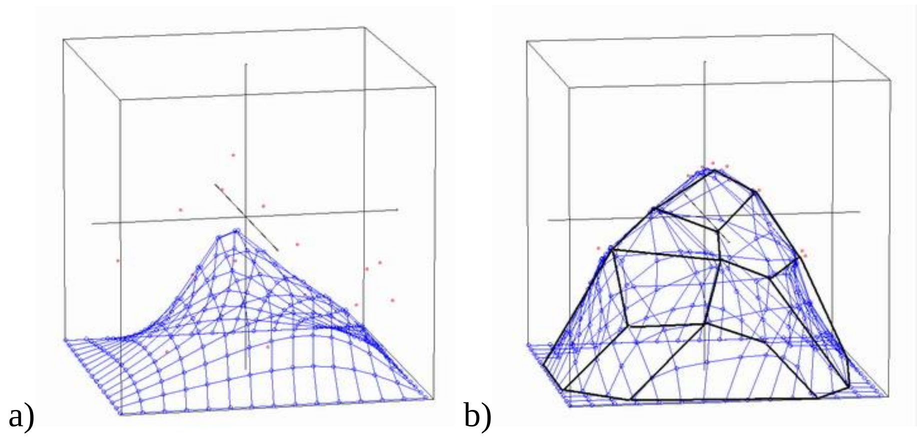

Fig. 3. a) Adaptation process of an elastic neuron network. b) Network's final form depicting the surface of the simulated abrasive grain

Each modeled grain is saved in the grains database of simulation system in the matrix form. During a grinding wheel modeling the grains are randomly selected from database and are located on the grinding wheel surface model.

2.2. THE GRINDING WHEEL SURFACE MODELLING

Structure of grinding tool is composed of grains located randomly on its surface. Both a grain size and its locations have a great influence on quality of machined surface. In the developed model of grinding tool surface, one of the most significant factor of optimization of grinding process is achieved with optimal location of grinding grains on the surface.

In the process of modeling a grinding tool surface, every single grain is randomly located on the surface with specified grain concentration C_{gr} (Fig. 4a).

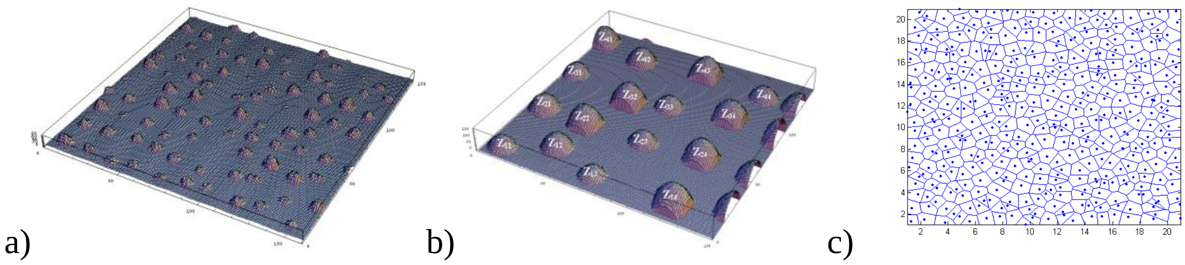

Fig. 4. Grinding wheel topography a) model; b) indexes of grains; c) evaluation of grain location with Voronoi diagrams

With every generated grain there is associated vector of grain parameters, describing temporal states of the grain during the whole process (e.g. number of contacts with workpiece material, volume of removed material, normal and tangential forces etc.). After grain generation, the working surface of the grinding wheel is generated by the aggregation of single grains into one surface, where each grain has a unique index (Fig. 4b). Thanks to that, the characteristic of behavior of contact during the process could be thoroughly discovered. On generated surface the model of the bond is placed on. As a completion to this task, models of grain displacement and removal and the dressing process are also elaborated.

2.3. MODEL OF THE GRINDING KINEMATICS

Developed model describes the relative displacement of the single grains in relation to material displacement in Cartesians co-ordinations in surface grinding. Fundamentals of grinding process model description are mathematical equations describing single grain trajectory displacement on the path of cutting in the grinding zone. Taking in to account superposition of grinding wheel rotational movement and reciprocating movement of workpiece relative movement a single grain in grinding zone is described by trochoidal path Equations for the cutting path in the functions of grinding wheel angular displacement relative to x-y coordination system with its origin fixed to the workpiece are defined for horizontal (1) and vertical (2) displacement of cutting point.

$$y = \frac{D_s}{2}\sin\psi \pm \frac{D_s}{2}\frac{v_{ft}}{v_s}\psi \tag{1}$$

$$z = \frac{D_s}{2}\left(1 - \cos\psi\right) \tag{2}$$

Developed model of grinding process takes into consideration reciprocal interpenetration of material and grinding wheel profiles in the grinding zone. Base on this kinematic-geometrical relation during the simulation process, a successive cross-sections, grinding forces and energy for a single grain can be calculated.

2.4. FORCES AND ENERGY MODELLING

During the grinding process only a small percent of the grain located on active grinding wheel surface and having contact with workpiece participate in the work of material separation in the form of chip. The other part of active grains performs a work of plastic deformation and friction. Total energy of grinding depends on elastic and plastic deformation of material, internal friction of chip formation, friction on the contact surface of active grains and workpiece. Depending on workpiece and grinding wheel topography, vibrations during grinding and stiffness of machine tool and grinding wheel, the work of cutting is variable on the length of cut made by single grain. For more precise estimation of grinding forces and energy the proposed model allows the calculation of normal and tangential forces and specific energy in relation to single grains as well as total forces and energy during the whole process of simulation.

In the modelling of dependences of forces on parameters and conditions of grinding, it is assumed that the normal F_{nk} and tangential F_{tk} component of force affected a single grain depends on elementary cutting resistance k_l and cross section area of cut A_k (Fig. 5).

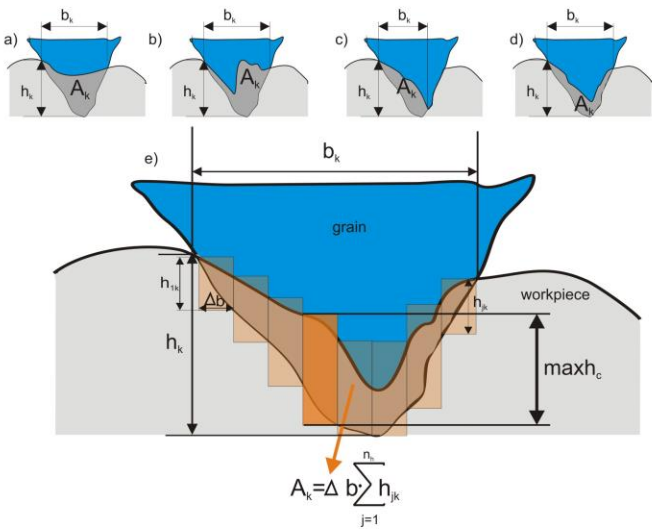

Fig. 5. Cross-section area of the cut

The elementary cutting resistance depends on cross section area of cut, radius of grain tip ρ, angle of grain tip 2ε, and mechanical properties of material expressed by constant C_p. Equations for calculating the grinding forces can be expressed by the formulas:

$$F_{nk} = k_1(A_k, \rho, \varepsilon, C_p) \cdot A_k \quad (3)$$

$$F_{tk} = k_\mu(v_s, \rho, \varepsilon) \cdot F_{nk} \quad (4)$$

where: k_μ proportionality coefficient of grinding forces. The cross-section area (Fig. 5) is defined as:

$$A_k = \Delta b \cdot \sum_{j=1}^{n_h} h_{jk} \tag{5}$$

The grinding energy related to single active grain is a function of tangential component of grinding forces acting on the discreet length of grain interaction with workpiece in the grinding zone:

$$E_k = F_{tk} \cdot \Delta l_k \tag{6}$$

Energy variability during the grinding process is conditioned mainly by cross section area shifting, caused by different depth of cut and randomness of grain shape.

3. OPTIMIZATION OF GRINDING PROCESS ENERGY

Developed models enable precise analysis of phenomena taking place in grinding zone during grinding. It is possible due to information registration of individual grain contacts with its time and location in the grinding zone. In order to present a potential of grinding models the results of a few results from simulation experiments are presented.

3.1. ENERGY OF GRINDING WITH GRINDING WHEELS WITH CONTINUOUS AND DISCONTINUOUS ACTIVE FLANK

The simulation results presented in this paper prove the fact that the grinding process, and work connected with this, occur still outside point p_o, that is beyond the plane which goes through the grinding wheel axis (Fig. 6). For the case presented and for the kinematic

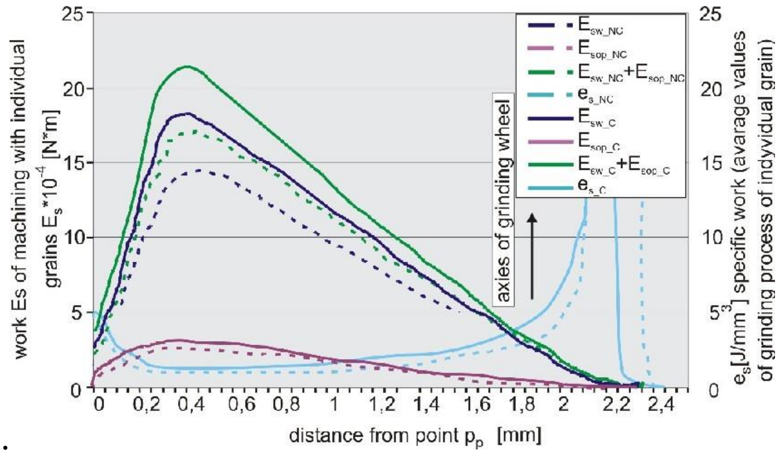

Fig. 6. Variability in the grinding zone: work Es of machining with individual grains, work Esw of scratch creation by individual grains, work Esop of creation of fashes, proper work es for grinding wheels with continuous (C) and discontinuous active flank (NC)

conditions assumed: v_{ft}=5m/min, v_s=120m/s, a_e=0,02mm, , this point (p_k) is 0,45mm away from p_o.

It is evident from the diagram presenting the distribution of grinding energy that during grinding with a grinding wheel with a discontinuous active flank the proper work per one abrasive grain is smaller than for a continuous surface of the grinding wheel, and the zone of active machining of grains is longer (Fig. 7).

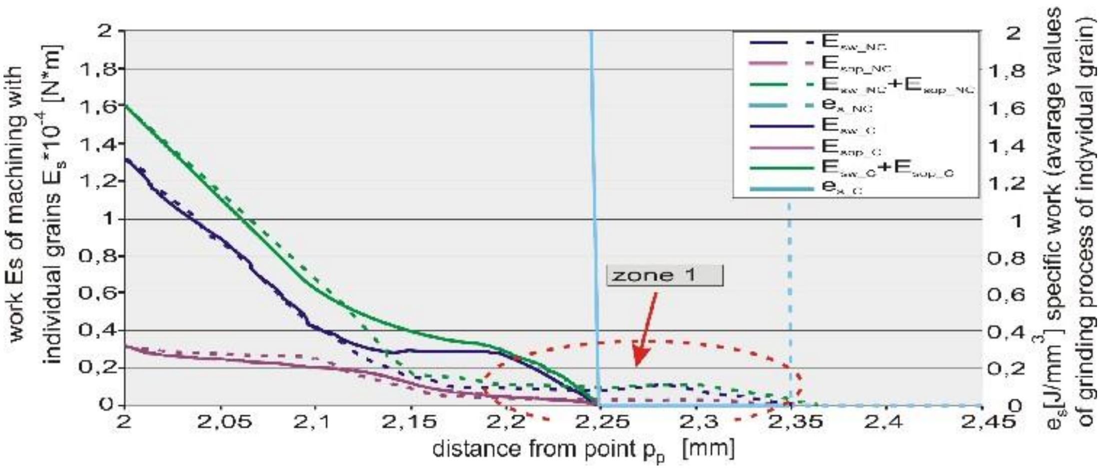

Fig. 7. Variability of energetic parameters, zone 1-output zone 2- final part of the grinding zone outside point p_0

The energy distribution in the initial range of lengths of the zone from 0 to 0.2 mm (Fig. 8), serves to prove the fact that the impact of grains upon the ground surface is different for continuous and discontinuous active flanks. In the final range of the grinding zone from 2 mm to 2.45 mm from initial point p_p=0, presented in enlargement in Fig. 8, it is unambiguously evident that the grinding wheel grains with a discontinuous active flank do a lot of more machining work than grains in a grinding wheel with a continuous active flank

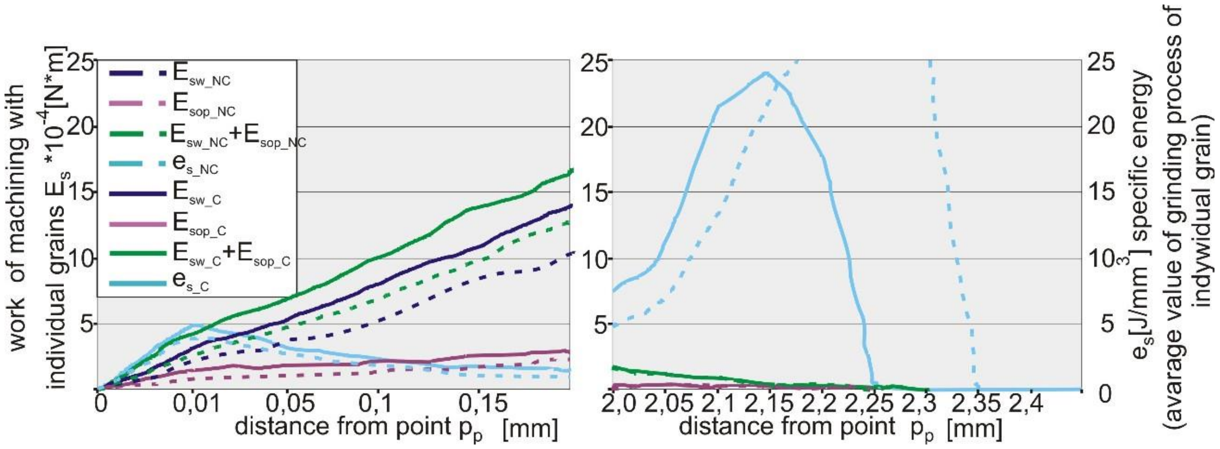

Fig. 8. Distribution of work in the grinding zone: a) start of machining zone, b) end of machining zone

Designations in the diagrams determine the following: E_s - work (energy) of grinding per one abrasive grain; (E_{sw_NC}, E_{sw_C}) - work of chip creation with grains in a grinding wheel with a discontinuous (NC) and continuous (C) active flank; (E_{sop_NC}, E_{sop_C}) -creation work of a pile-up and plastic strains of a material for grinding wheels with a discontinuous (NC) and continuous (C) active flank; (e_{s_NC}, e_{s_C}) - proper work of machining with one grain with a discontinuous (NC) and continuous (C) active flank.

The simulation of a machining process allows for the determination of variations in work carried out by grains located in a defined elementary strip of the active flank of the grinding wheel in the machining zone and in a defined duration of this process, i.e. t_i. This is presented in Fig. 9 (variations in machining work for time t_i=0,102 ms, with grains located in the zone of contact with the object machined). In this picture, one can also define the number of grains which are in contact at the same time as well as their loads connected with machining work carried out.

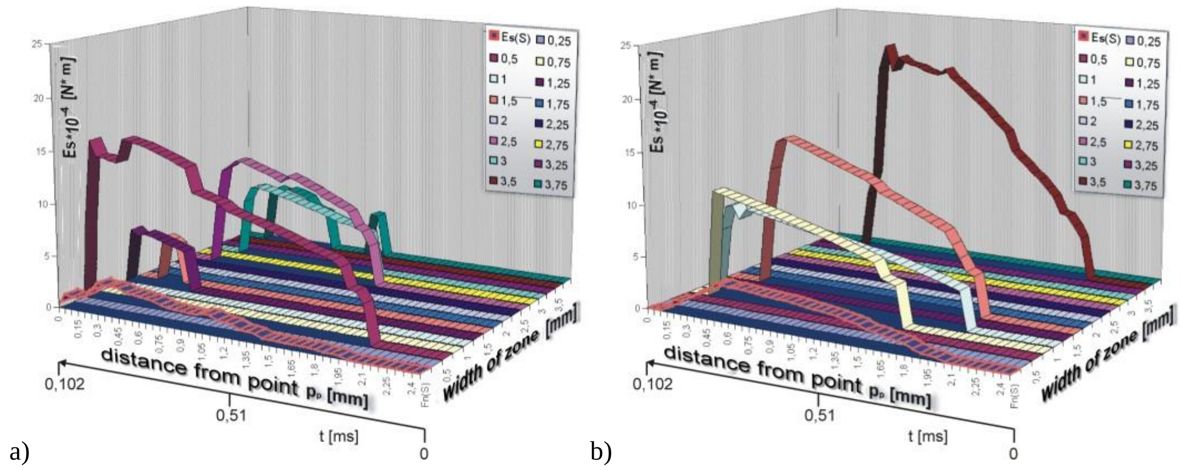

Fig. 9. Variation in local values of micro-machining work with grains in the grinding zone while machining with a grinding wheel with a: continuous active flank (C) b: discontinuous active flank (NC) for time t_i=0,102 ms

The Fig. 9 clearly reveal an influence of the macro-geometry of the active flank of the grinding wheel on the load of grains in the grinding zone, which is distinctly larger for grains of a grinding wheel with a discontinuous active flank (NC) (Fig. 9b). Active grains of a grain with a continuous active flank (C) in the machining zone are less loaded, they perform less machining work, while the number of grains which perform machining simultaneously is larger (Fig. 9a).

3.2. GRINDING ENERGY COMPARISON OF GRINDING WHEELS WITH DIFFERENT MACRO AND MICRO TOPOGRAPHIES OF SURFACE

The results of simulative examinations conducted make it possible to compare the nature of work of grinding wheels with different types of abrasive grains, which in turn have various geometrical parameters (i.e., regular boron nitride and aloxite). The grains of regular boron nitride with small radiuses and rounded vertices possess more favorable micro-geometrical properties which facilitate the creation of a chip in the grinding zone. This is documented by the diagrams presented in Fig. 10, which point to larger sections of the machined layers and to a smaller tendency of the creation of pile-ups (larger E_{sw} and smaller E_{sop}). Hence, the proper grinding work es with grinding wheels with grains from regular boron nitride is smaller, too. Fig. 10 presents a sample comparative list of distributions of grinding work values, its components and of proper grinding work for grinding wheels with varied active flank topographies: for an aloxite grinding wheel with a regular and random distribution of grains a) and b), a regular boron nitride grinding wheel c), and an aloxite grinding wheel with a discontinuous active flank.

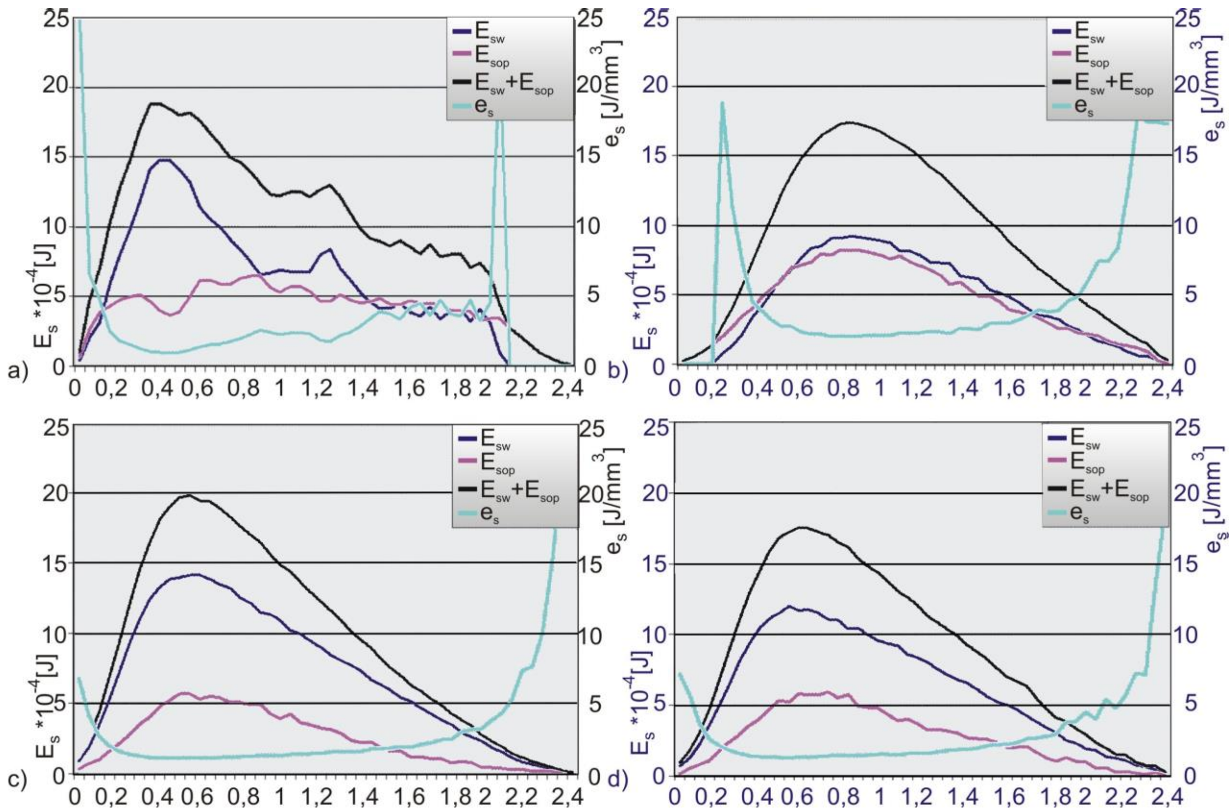

Fig. 10. Comparison of distributions of grinding work Esw Esop and of proper work es in the zone for a grinding wheel with a continuous flank a) a grinding wheel with a regular distribution of grains on the active flank; b) a grinding wheel with aloxite grains with randomly distributed grains; c) regular boron nitride with randomly distributed grains; d) aloxite with a discontinuous flank

The diagrams enable one to assess the working conditions of grains in the grinding zone. In the case of the aloxite grinding wheel with a random distribution of grains on its active flank, the local variability of work performed with individual grains is of a slightly different nature as compared with a grinding wheel with regularly distributed grains, for which proper work in the output zone is smaller, and work in the input zone is larger.

4. CONCLUSIONS

The research results presented and their analysis enable one to assess the influence of the macro- and micro-topography of the grinding wheel active flank upon energetic properties of the grinding process, as well as upon the quality of the surface layer.

A regular distribution of grains facilitates a smaller diversity (variation) of the sections of layers machined with individual grains, which is the reason for a certain growth of the proper machining energy, which in turn is one of the factors deteriorating the physical and chemical properties of the surface layer.

Macro-geometry of the grinding wheel active flank, determined with its dis-continuity, has a vital influence upon the nature of the load of abrasive grains in the machining zone. In the case of grinding wheels with a discontinuous active flank, grains machine larger sections of the material while their number is decreased due to this discontinuity, owing to which the work conditions of grains change, i.e. their energy decreases; so does the path of the grain work connected with deformations of material ridging for the initiation of the chip creation process, which facilitates a decrease of the proper grinding energy.

In generation grinding of planes, a discontinuity of the grinding wheel active flank in the form of grooves has an influence upon the roughness of the surface machined. Circumferential grooves, depending of the transverse feed, impair the topography of the surface machined and cause the occurrence of strips with a higher degree of roughness, or even the occurrence of non-machined strips. Skew grooves facilitate a creation of local protrusions on the object with a higher level of roughness, while transverse grooves constitute of form of discontinuity, which does not result in increased levels of local roughness on the object machined. A pictorial diagram of the influence of discontinuity in the form of transverse grooves on the roughness of the surface machined in the function of the share of groove in the total surface is presented in Fig. 11.

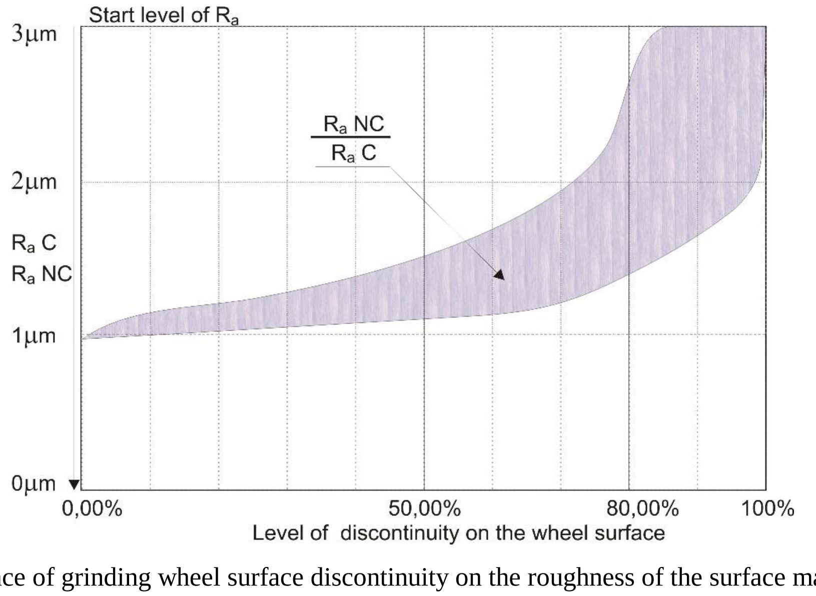

Fig. 11. Influence of grinding wheel surface discontinuity on the roughness of the surface machined, where: RaC- roughness of the surface machined with a grinding wheel with a continuous flank, R_aNC- roughness of the surface machined with a grinding wheel with a discontinuous flank

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