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microfinishing micro-chips,
discontinuity

Wojciech KACALAK[1]
Katarzyna TANDECKA[1*]
Lukasz RYPINA[1]

EVALUATION OF MICROMACHINING PROCESSES USING DATA IN THE FORMAT AND GEOMETRIC CHARACTERISTICS OF MICRO-CHIPS

Studies on micro-chips formed in the process of micromachining, including grinding and microfinishing using abrasive films, were conducted. Geometric characteristics of the micro-chips were analyzed and the presence of very long chips compared to their width was observed. One also reported the presence of very high temperatures in the treatment zone despite the applied cooling, which resulted in the formation of spherical chips. The occurrence of two characteristic spherical chip structures was observed followed by evaluation of their chemical composition. Based on the tabular structure of band chips, characteristic micro-discontinuities in the microcutting process were determined.

1. INTRODUCTION

Abrasive micromachining processes are commonly used in the production of precise elements of machines and systems in industries such as construction machinery, shipbuilding, automotive, aviation, aerospace, military, and also in construction, mining, medicine and many other industries [6].

Machined materials constitute a very diverse collection - these are steels and alloys, including light metals and their alloys, ceramics, cemented carbides, composite materials such as granite and basalt, glass, concrete, wood, plastics, and precious stone crystals such as diamond, ruby, sapphire, emerald and also silicon monocrystals as well as many other materials characterized by increased hardness and resistance to abrasion.

Among micromachining processes, one can distinguish grinding with small depths and high speeds, as well as the processes of microfinishing with abrasive films.

In microfinishing process with abrasive films which is different than grinding, compliant fixing of abrasive grains in the film pressed against the object with flexible roll causes the reduction of high of grains' vertices in the treatment zone which increases the

[1] Koszalin University of Technology, Faculty of Mechanical Engineering, Department of Precision Engineering, Koszalin, Poland
[*] E-mail: katarzyna.tandecka@tu.koszalin.pl

uniformity of mechanical and thermal loads [8,],[9],[10],[11],[21],[22]. The speed of the film displacement is several times reduced compared to the speed of the object, which in turn is much less than the speed of grinding, and therefore results in the formation of very long machining marks [12],[13].

Microfinishing process consists of several steps in which one uses tools with successively finer grains [20]. Machining is performed by scrolling the abrasive film from the feed gear into the winding gear. Between these gears, there is a gear pressing abrasive film to the workpiece [18],[19],[15]. The hardness of the pressure gear and its pressure force affect the surface area of the contact zone of the tool with the workpiece [16]. Significant feature of the process is that the speed of the abrasive film shifting is from 500 to 3000 times lesser than the shifting speed of the workpiece. Consequently, abrasive grains are found in the treatment zone for a long time and form machining marks of considerable length. Machining products formed in the smooth zone must fit in the spaces between grains.

2. GEOMETRIC FEATURES OF MICRO-CHIPS

To study the characteristics of the micro-chips in the process of micromachining, products formed during microfinishing with abrasive films and grinding using a small machining depth, were used.

The process of microfinishing with abrasive films was carried out using IMFF-type abrasive films, that is films for finishing, wherein the abrasive grains made of electrocorundum are deposited on the surface of the polyester carrier using electrostatic method, which results in such orientation of abrasive grains to maximize their machined ability. In the machining process, one used films with a nominal particle size of 15 μm, the workpiece was 40 H steel shaft thermally improved to a hardness of 60 HRC. The machining was performed for 160 seconds with a speed of the object estimated at 35 m/min with pressure gear used with elastomer hardness of 80^{o}Sh A. The speed of the film movement was 160 mm/min, and the pressure force was 60 N.

After finishing process, one collected micro-chips samples, which are products of micro-finishing from the abrasive film surface. In order to determine the geometric characteristics of micro-chips, data acquisition was performed using a Phenom table-top scanning electron microscope, which allowed to obtain magnification to 100.000×.

In order to compare the products of micro-machining, one conducted the process of grinding with small depths. One used 1-250×25×76.2-99A100K7VTE10-35 grinding wheel with ceramic binder grains' size of precious electrocorundum sized 125–150 μm. The following parameters of the process were used: circumferential speed of grinding wheel 35 m/s, conditioning traverse 0.1–0.15 mm, longitudinal feed 25 m/min. Samples were microfinished using of X153CrMoV12 (NC11LV) material, made of ledeburitic chromium tool steel for cold work, with a hardness of 63 HRC. The resulting image with 1600× magnification after examination under the microscope is shown in Fig. 1a.

It was observed that micro-chips are characterized by a high length to width ratio. To determine the geometric characteristics of machining products, one used image analysis using SPIP applications. The results of width and length of chips after the processes of micro-machining are shown in Fig. 2, where in red one indicated the relationship for micro-chips as products of the micro-finishing process with abrasive films, and in blue - for the products after grinding process.

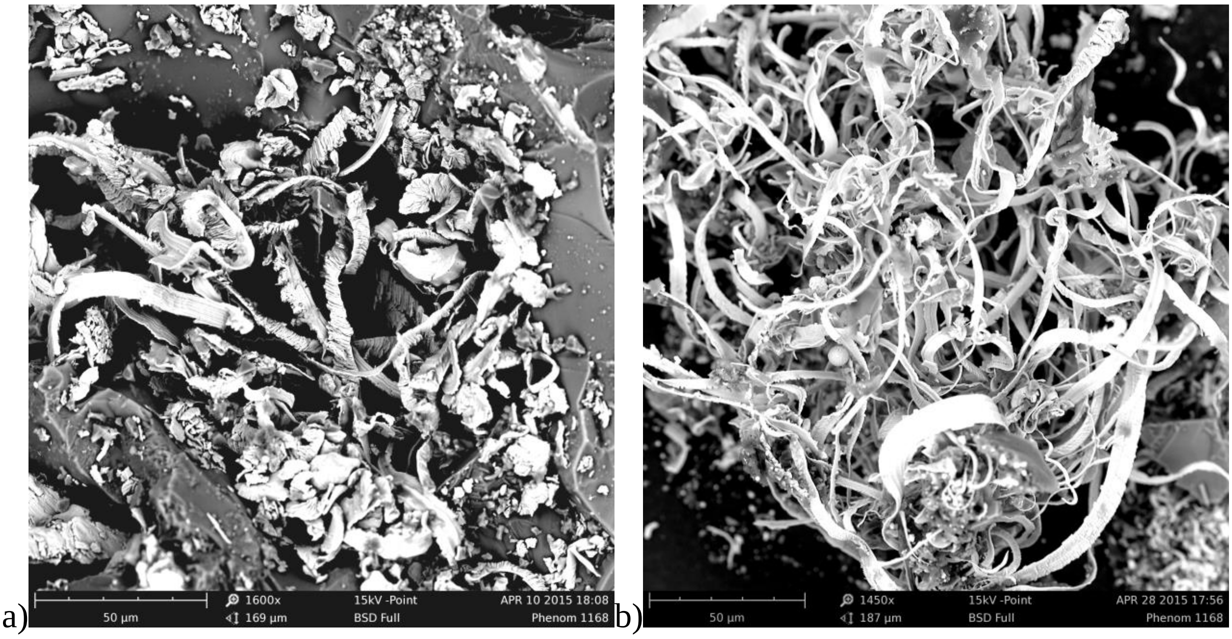


Fig. 1. SEM image of the micro-chips with chips separated individually with the use of image analysis a) after grinding process b) obtained as a result of polishing with abrasive films

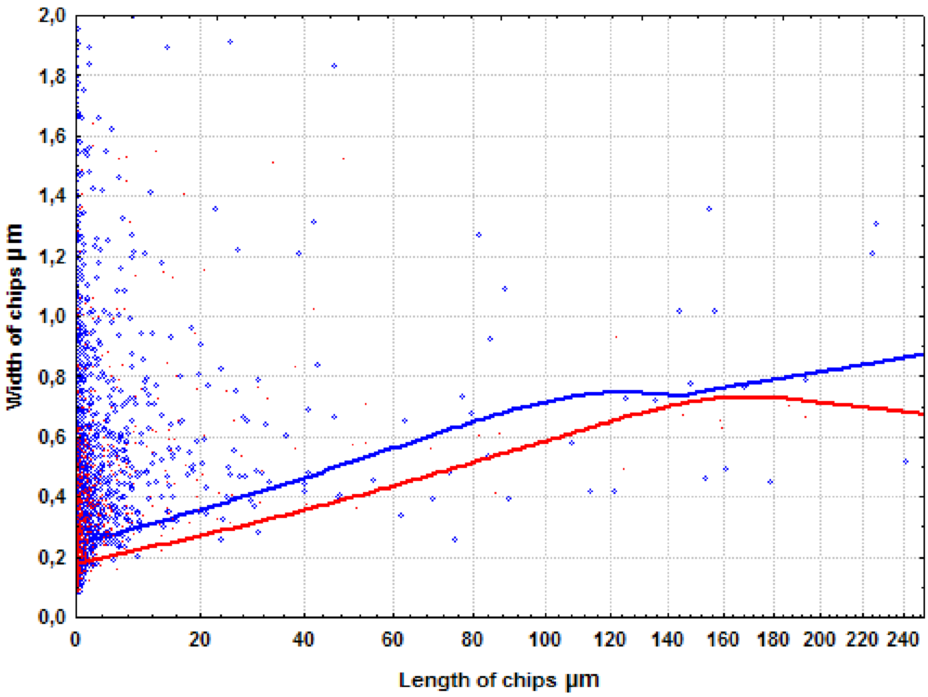


Fig. 2. Scatterplot representing width and length of chips

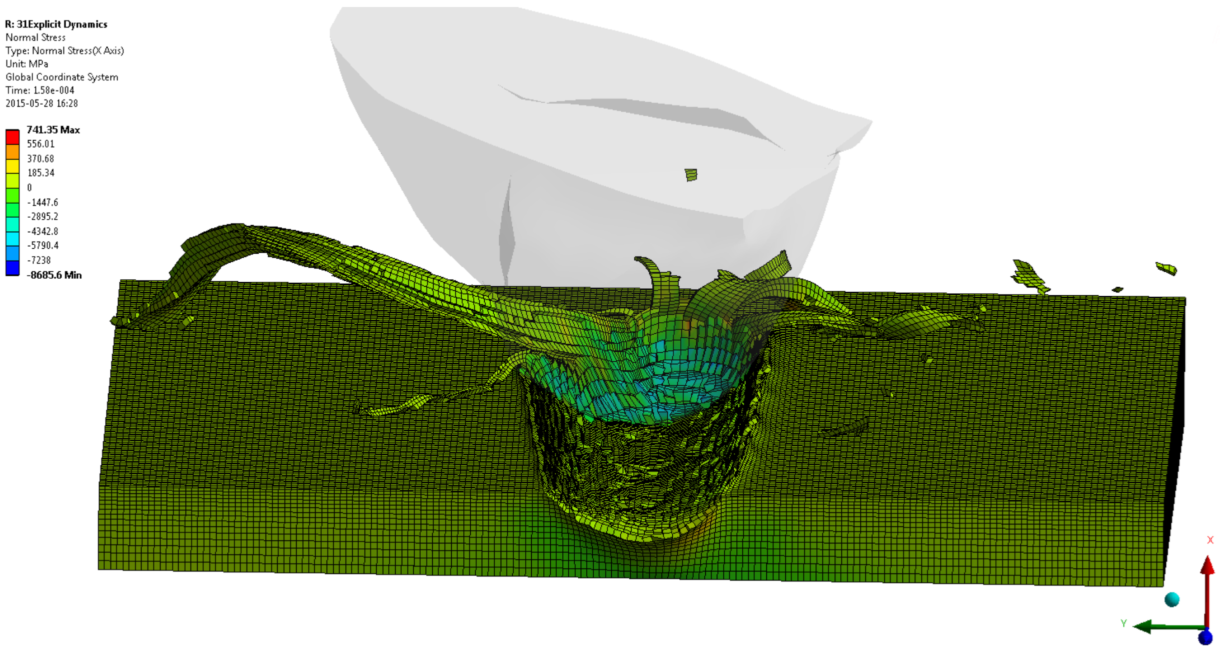
The occurrence of long and narrow chips in each of the micromachining processes tested was reported. Smaller width in relation to chip's length occurs when micro-polishing with abrasive films is used, which has a direct relationship with nominal size of grains and specificity of machining and results in a long surface contact of a single grain with the workpiece [4],[5].

3. DISCONTINUITY OF THE PROCESS OF MATERIAL DISPLACEMENT IN THE CONTACT ZONE OF GRAINS AND SUBJECT LAYER SHAPED

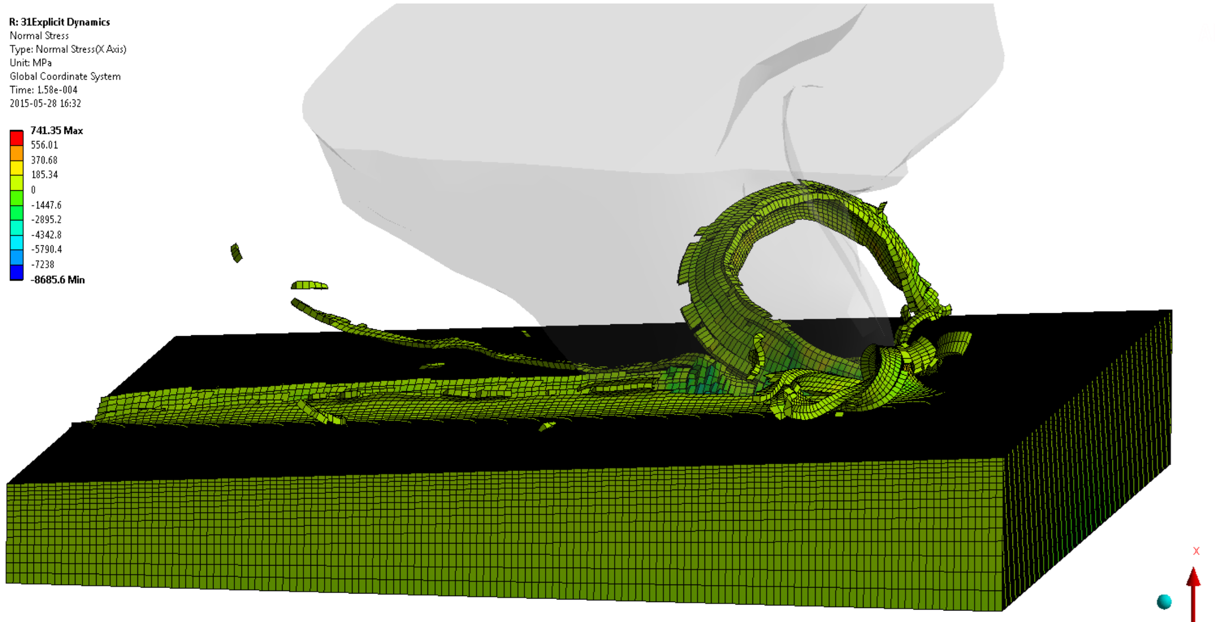
In the conducted microscopic studies of micro-chips, one observed large variation in shapes and forms of machining of products, as well as their characteristic stepped structure. To better understand the mechanism of formation of such different forms of micro-chips [1],[2],[3],[17] one performed modeling process of microcutting of a single grain in 3D, in an environment using finite element method.

The modeling was done using Ansys system for abrasive grains presented in Fig. 3 and for the workpiece – 4340 stain and microcutting speed v_s=25 m/s. To obtain more information about the particular process for different grains' depth, sample surface was inclined so that the depth of microcutting differed from 0 μm to 200 μm.

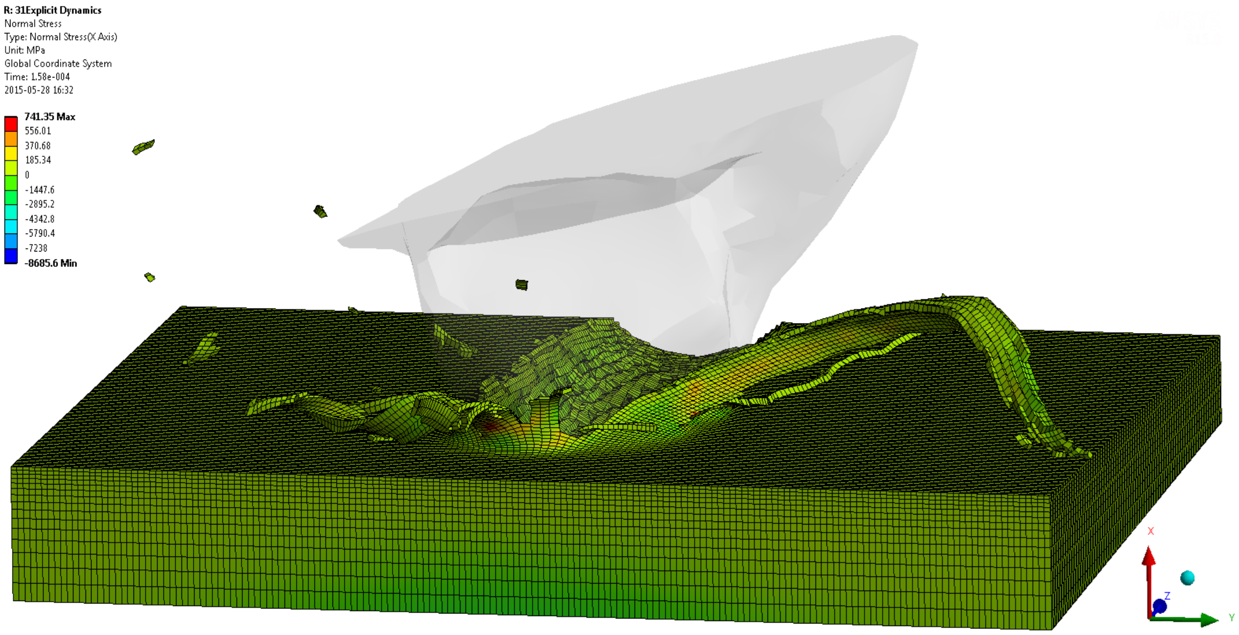
The objective of this study was to determine the effect of geometric characteristics of abrasive grain corner on lateral material flow, chip formation and separation of the material. It should be noted that in micro-machining, lateral (with respect to microcutting track) material flows are dominated, while typically, one examines only the geometric conditions of chips' formation in a perpendicular cross-section to the surface of the object and parallel to the direction of blade movement [7],[14]



a)



b)



c)

Fig. 3. Discontinuity images in the process of chip formation in micro-cutting with s single grain (a, b, c)

In the modeling study, one used real geometry of grain made of precious electrocorundum digitized with the use of highly precise GOM's ATOS Triple Scan optical scanner. It can be observed, that as a result of the action of a single abrasive grains towards the workpiece, as a result of the uplift of the material particles of the object, numerous chips of different widths and shapes (Fig. 3) are formed, which has a direct relationship with the existence of many rubbing planes of abrasive grain of a complex shape.

4. EVALUATION OF THE FREQUENCY OF MICRO-CHIP ELEMENT FORMATION OF TABULAR STRUCTURE

Micro-discontinuity of machining processes appears in the form of stepped shaped construction of micro-chips (Fig. 4). The study of tiles' thickness g_p which form chips taking into account swelling coefficient w_{sp} allowed determining the frequency of micro-discontinuity in the micromachining processes tested, that is in grinding and microfinishing with abrasive films.

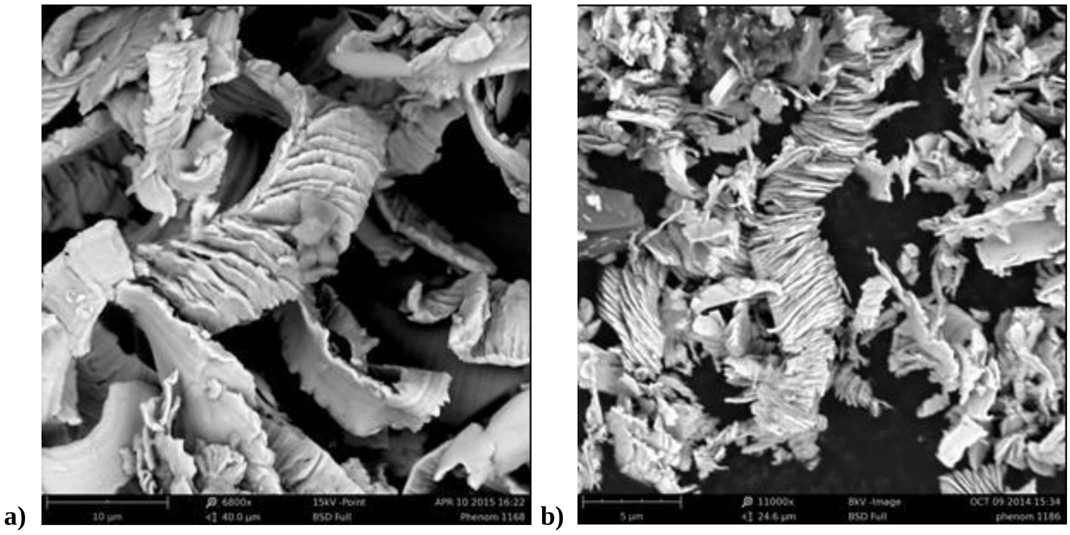


Fig. 4. The stepped construction of micro-chips as products of grinding process (a), microfinishing with abrasive films (b)

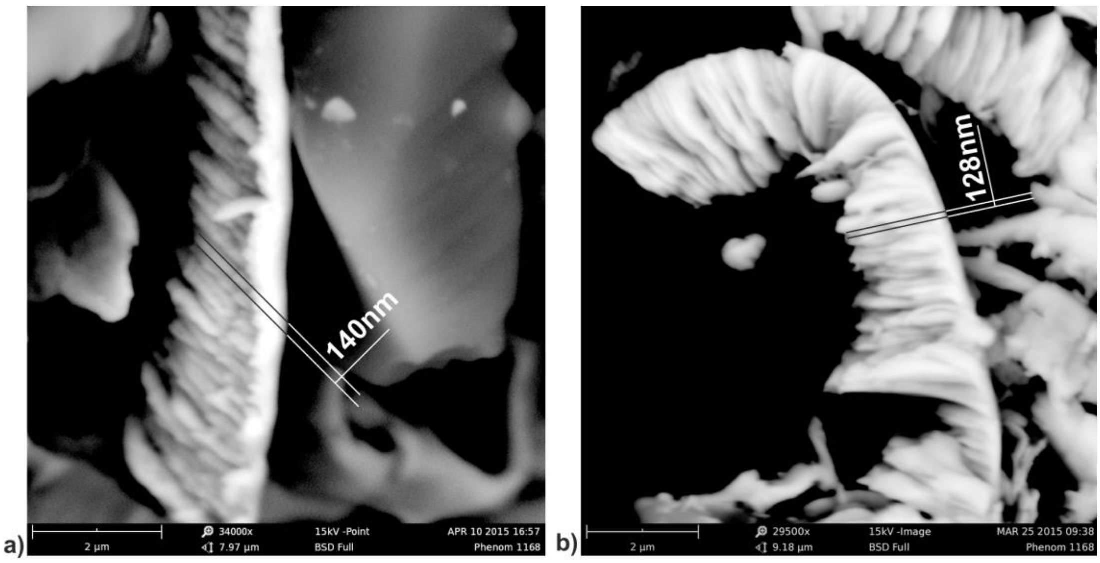


Fig. 5. Stepped construction of micro-chips products of grinding process: (a) microfinishing with abrasive films, (b) with determined thicknesses of tiles gp

The frequency of material separation in the process of micro-machining was determined according to the following formula (1):

$$f_w = \frac{v_p}{g_p w_{sp}} \tag{1}$$

where:
f_w – frequency of micro-discontinuity in the process of material separation determined by the evaluation of chip structure,
v_p – speed of the workpiece in the process of microfinishing with abrasive films or circumferential speed of grinding wheel in grinding process,
g_p – thickness of the chip tile of stepped structure (Fig. 5),
w_{sp} – swelling coefficient (resulting also from the displacement of tiles forming the stepped structure of the chip) which is estimated to be about 10.
The following results were obtained:

f_w (microfinishing) = 0,45 MHz f_w (grinding) = 25 MHz

Analyzing the results obtained, it can be observed that much higher frequencies of material separation are reported in the process of grinding, which is directly influenced by the speed of machining. In both processes, similar thickness of micro-chips' tiles are observed, which should be considered depending on the characteristics of the workpiece.

5. CHARACTERISTIC FEATURES OF MICRO-CHIPS OF SPHERICAL SHAPE

In the processes of micro-machining, one also observed chips which form was closely related to spherical shape. In the microfinishing process, one used coolant injected as a flow into the machining zone, however despite the cooling used, temperatures in the machining

a) b)

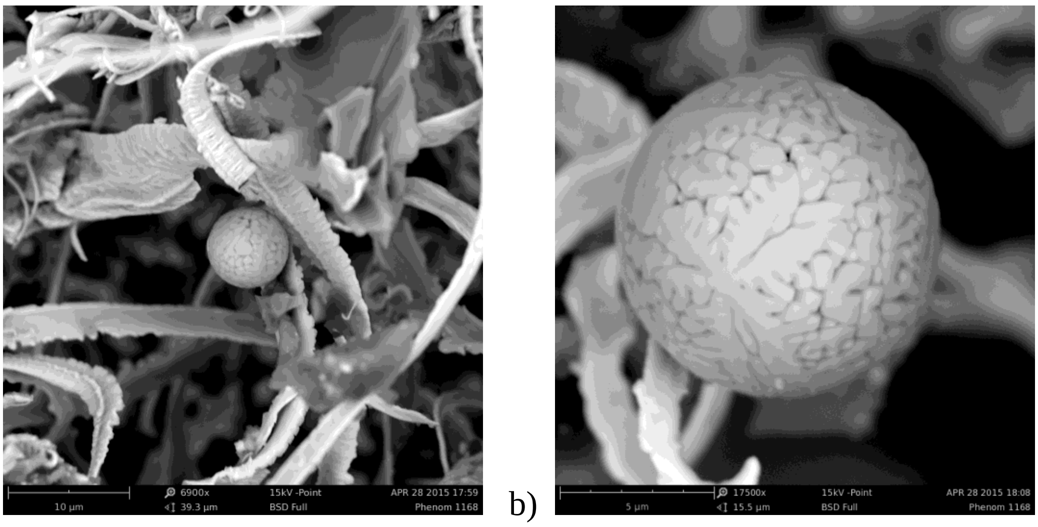


Fig. 6. Chips of spherical form generated in the process of grinding

a) b)

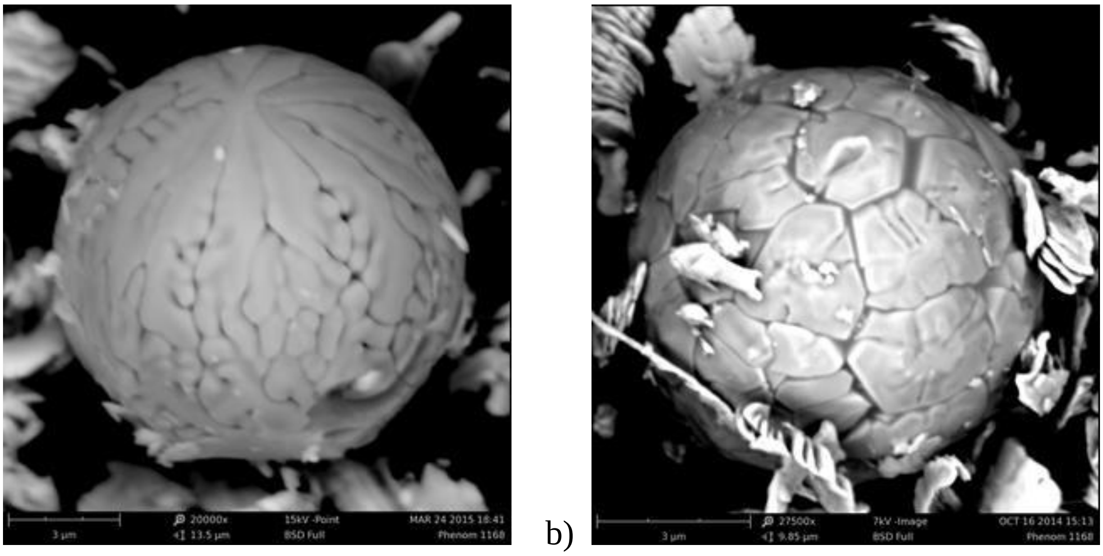


Fig. 7. Chips of spherical form generated in the process of polishing with abrasive films

zone were high and caused melting and rapid solidification of the small fragments of material, which results in formation of spherical chips with a very complex structure on the surface of the spheres. Different sizes of microspheres whose diameter ranged from a few to tens of micrometers, were observed.

After evaluation of chemical composition of spherical chips (Fig. 8, Table 1), one observed strong oxidation of the material in comparison to classic forms of chips. At the same time, one observed two types of chips' surface structures as a result of microfinishing with abrasive films shown in Fig. 7.

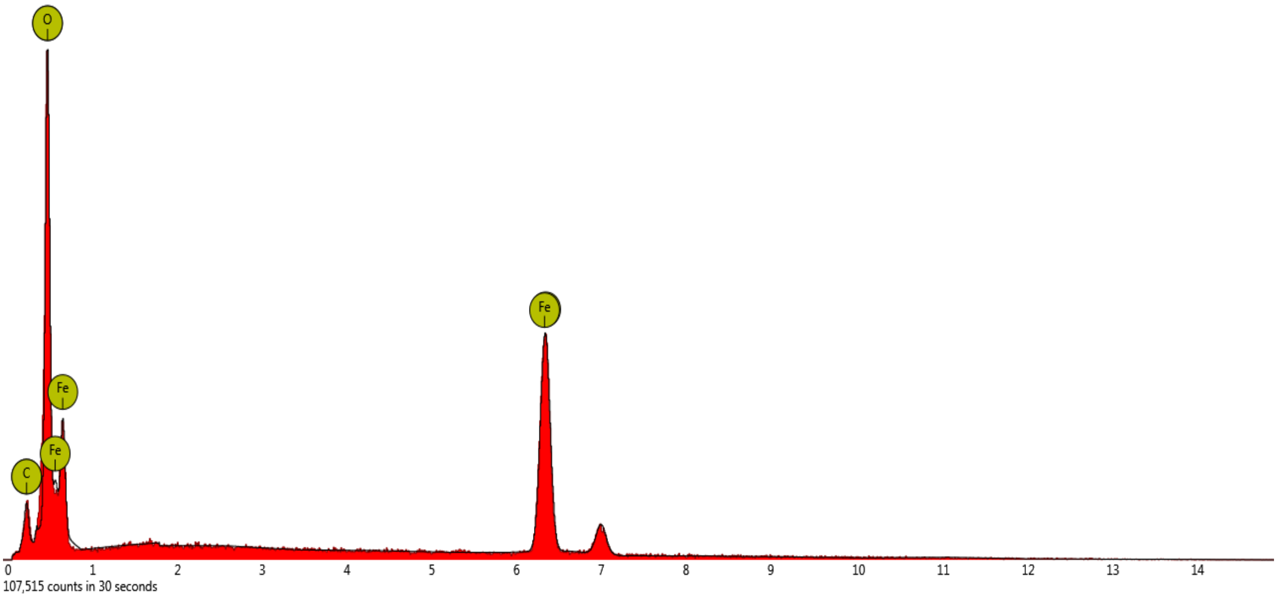


Fig. 8. Plot of scattered X-radiation energy from the micro-area of the chip tested in the form of Microsphere

Table 1. The volume content of individual elements in spherical micro-chip

Element symbol	**Element name**	**Volume content %**	**Error of the result**
O	Oxygen	72.2	0.0
Fe	Iron	25.8	0.0
C	Carbon	2.0	0.6

6. SUMMARY

The phenomenon of micro-discontinuities of chips' formation and its frequency may be determined based on their characteristic, stepped construction. It was found that thickness of steeped shaped plates forming the chip is approximately 150 nm, which allows to estimate the frequency of slips (displacement of chip elements) at f_w=0.4–25 MHz depending on the kinematic characteristics of the process.

The adopted methodology allows determining the micro-discontinuities and statistical parameters of chips and their construction characteristics. The results of the study allow making recommendations regarding increased efficiency of extremely precise machining, including the structure of films, characteristics of the pressure rolls and characteristics of the surface topography of grinding wheels.

ACKNOWLEDGMENTS

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