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Norbert KĘPCZAK
Radosław ROSIK
Witold PAWŁOWSKI
Małgorzata SIKORA
Błażej WITKOWSKI
Grzegorz BECHCIŃSKI
Wojciech STACHURSKI

THE DYNAMICS OF WEAR OF CUTTING INSERTS DURING TURNING OF NON-HOMOGENEOUS MATERIAL ON THE EXAMPLE OF POLYMER CONCRETE

DYNAMIKA ZUŻYCIA PŁYTEK SKRAWAJĄCYCH PODCZAS TOCZENIA NIEJEDNORODNEGO MATERIAŁU NA PRZYKŁADZIE POLIMEROBETONU*

The article presents the results of studies on the dynamics of wear of five different cutting inserts (for machining difficult-to-cut materials, for finishing cast iron machining, for roughing cast iron machining, for steel machining and for stainless steel machining) during turning a non-homogeneous material such as polymer concrete. Polymer concrete is a difficult-to-cut, anisotropic, composite material. During the tests, a record of the components of the cutting force in real time was made. After each machining pass, the Ra and Rz surface roughness values were measured in the direction perpendicular to the machining marks and photos were taken under the microscope of the inserts corners, on the basis of which the width of major flank wear land and the width of minor flank wear land were measured. The view of each insert after the tests was also presented. Finally, the conclusions about the dynamics of wear of inserts taking part in the study as well as their applicability during polymer concrete turning were formulated.

Keywords: *dynamic of wear, turning, polymer concrete, cast iron, surface roughness, cutting force.*

W niniejszym artykule zaprezentowano wyniki badań dynamiki zużycia pięciu różnych płytek skrawających (do obróbki materiałów trudnoobrabialnych, do wykończeniowej obróbki żeliwa, do zgrubnej obróbki żeliwa, do obróbki stali oraz do obróbki stali nierdzewnej) podczas toczenia niejednorodnego materiału, jakim jest polimerobeton. Polimerobeton jest trudnoobrabialnym, anizotropowym materiałem kompozytowym. Podczas wykonywania badań dokonywany był zapis składowych siły skrawania w czasie rzeczywistym. Po wykonaniu każdego przejścia obróbczego zostały zmierzone wartości parametrów chropowatości Ra oraz Rz obrobionej powierzchni w kierunku prostopadłym do śladów obróbki oraz zostały wykonane zdjęcia pod mikroskopem naroży płytek, na podstawie których zmierzono zużycie głównej powierzchni przyłożenia oraz pomocniczej powierzchni przyłożenia. Zaprezentowano również wygląd każdej z płytek po przeprowadzonych badaniach. Na koniec sformułowano wnioski na temat dynamiki zużycia płytek biorących udział w badaniu, a także stosowalności ich podczas toczenia polimerobetonu.

Słowa kluczowe: *dynamika zużycia, toczenie, polimerobeton, odlew mineralny, chropowatość powierzchni, siły skrawania.*

1. Introduction

Polymer concrete (PC, mineral cast) is a multi-component composite material in which the filler is mostly inorganic aggregate grains, whereas the binder is resins [1, 2, 4, 6, 7, 13]. PC is used for the production of various products, such as prefabricated sanitary devices, corrosion resistant constructions, acid tanks, wells, drains, highways, repair materials or machine parts, such as guides, tables or machine tool beds [11]. The increasingly common use of mineral cast forces the use of more precise molds for their implementation. Depending on the requirements for precision, dimensional tolerances, surface roughness, PC's can be made in wooden, plastic, metal, cast iron or combined molds [6]. For this reason, in order to obtain the appropriate parameters of the surface layer, elements made of mineral cast, after removing from the mold, should be machined. The heterogeneity of the material which is the polymer concrete makes the wear of the cutting tool very dynamic. The structure of a composite material such as PC includes very hard aggregates and a soft bonding material (polymer resin). In addition to the differences in the hardness of the materials that make up the composite, there is a significant difference in the method of material separation during processing (cracking, chip formation, etc.) and significant differences in the thermal energy flow during the cutting process between the various materials included in the polymer concrete. Such a structure of the machined material results in very complicated conditions in which the machining tool works. Hence it is need to define and investigate the mechanism of wear of cutting tools during the processing of polymer concrete.

In the cutting process, the working surfaces of the tool stay in contact with the chip and surfaces of the workpiece moving in relation to them. Phenomena occurring on these surfaces cause wear of the cutting tool, mainly consisting in changing the geometry of the tool in

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** its working part and consequently the loss of the cutting ability of the tool [3]. These phenomena include:

- mechanical abrasion,
- adhesion,
- diffusion,
- chemical phenomena (mainly oxidation).

The share of each phenomenon in the tool wear process is not the same and depends on the machining conditions, the greatest impact of which is the cutting speed [3]. Other forms of tool wear are:

- micro-crushing of tool material around the cutting edge,
- plastic deformation of the tool material,
- microcracks in the tool material.

The tool can also be damaged by breakage a large volume of material in the working part of the tool as a result of exceeding the immediate or fatigue strength of the material [3]. The above mentioned processes cause that the working part of the tool changes the geometry losing its cutting capacity.

In order to determine the wear dynamics of cutting tools, the indicators are used which are using a number of parameters, describing the flank wear and the face wear [3, 9, 10]. Figure 1 shows wear indicators for a turning tool [8].

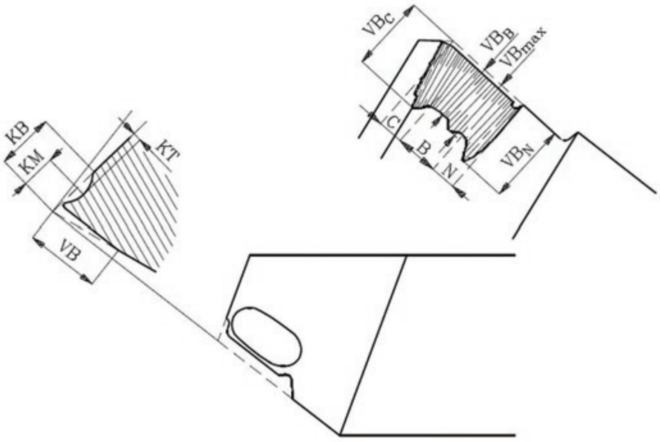

Fig. 1. Indicators of turning tool wear [8]

On the flank surface, wear occurs along the cutting edge in the form of a strip of variable width. Increased corner wear (VB_C) is mainly caused by concentration of stresses and higher temperature in this cutting zone, whereas groove (VB_N) is caused by the influence of the surface layer, most often by hardening after the previous operation (e.g. a casting shell) and chemical processes (e.g. oxidation process) [8].

On the tool face surface, wear occurs in the form of a crater located, in most cases, at a distance from the cutting edge (KM – distance between the center of the crater and the cutting edge or KB – width of the crater). This is the zone in which the highest temperature on the face occurs during cutting [8].

The wear on the flank surface occurs practically under all machining conditions, while significant wear on the tool face is characteristic of high cutting speeds. As a measure of wear on the flank surface, the width of the VB_B in the central active part of the main cutting edge is assumed, whereas the wear on the tool face is usually described by the depth of the crater KT [8].

The wear of the cutting tool is accompanied by such phenomena as:

- deterioration of the smoothness of the machined surface,
- change in the overall dimensions of the workpiece,
- increase in the level of vibrations and noise,
- increase in the cutting temperature.

Most of these phenomena are used to actively detect tool wear, e.g. in automated production.

The process of wear of the cutting tool is a process that takes place during the tool life period with different intensity. Typical wears versus time are shown in Figure 2 [8].

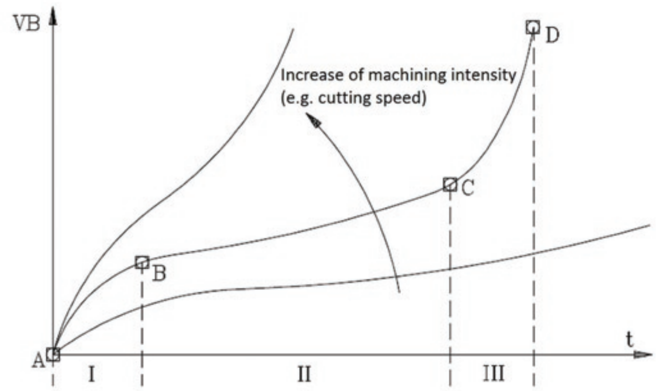

Fig. 2. Typical tool wear versus time [8]

In most cases, three characteristic phases of abrasive wear of the tool can be distinguished [8] as follows:

I – the initial, short-term phase (section AB) is mainly caused by the surface reaching the tool and the removal of surface unevenness resulting from the sharpening,

II – the second phase (BC section) is characterized by low consumption increase and is generally 90% of the total working time of the tool,

III – in the third phase (CD section) the VB increases rapidly, which is caused by the increase of forces and temperature during the machining with the worn tool. The entry of the tool into this period of wear means its bluntness.

The work of the tool in the third wear period is unprofitable because it gives small increases in cutting time at the expense of high tool wear and a significant increase in sharpening costs. In addition, there is a real threat of destruction of the tool and the workpiece in the case of catastrophic wear of the tool [8].

Such a wear mechanism of the cutting tool has been described in the literature and relates to the cutting of isotropic materials. The polymer concrete as an anisotropic material is the subject of this study. In order to determine the dynamics of wear of the cutting inserts during the turning process, the wear index of the cutting tool VB of the major flank (VBm_afwl) and the minor flank (VBm_ifwl) were determined. Surface roughness tests of the machined workpiece as well as measurements of the cutting force components were also carried out.

2. Nomenclature

v_c	cutting speed
f	feed
a_p	depth of cut
F_x	resistance force
F_y	feed force
F_z	peripheral force
F	cutting force
Ra	surface roughness
Rz	height of roughness
M_aF	major flank
M_iF	minor flank
VB	tool wear
VBm_afwl	width of major flank wear land
VBm_ifwl	width of minor flank wear land

3. Materials and methodology

3.1. Polymer concrete

The material used for the tests was a polymer concrete offered by the RAMPF company, available on the market under the name EPUCRET 140/5 [5]. It is a material used for casting small machine parts, i.e. guides, tables or beds, weighing less than 500 kg. It consists of aggregates with dimensions ranging from a few micrometers up to 5mm. In order to prepare the samples, the mass proportions of the hardener and epoxy resin were firstly mixed thoroughly until a homogeneous consistency was obtained. The appropriate mass fraction of the mineral filler was then added and the whole was mixed again until a uniform appearance of the composition was obtained. The mixture prepared in this way was covered with a mold, ensuring proper concentration of the batch in order to avoid air bubbles forming inside the samples. Then the sample solidified in the form for 24 h, taking at the same time 80-90% hardness, and after removing the sample from the mold, the whole was still aged for 14 days, taking full hardness. A series of cylindrical samples with dimensions: diameter Ø40 mm and height 60 mm were prepared for the tests. Figure 3 shows the view of a sample prepared for testing, placed in a three-jaw chuck of a CNC lathe.

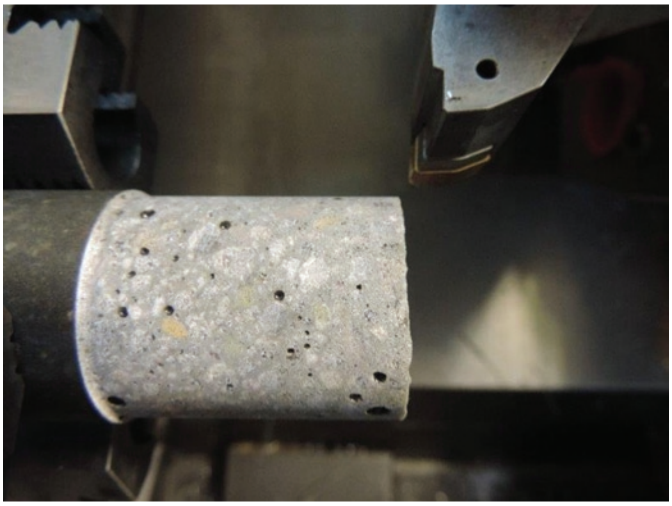

Fig. 3. The view of sample made of polymer concrete

3.2. Turning inserts

The research was carried out for 5 types of Sandvik cutting inserts:

- WNGA 060408 S01030A 7015 for machining difficult-to-cut materials,
- WNMG 060408 KF 3005 for finishing cast iron machining,
- WNMG 060408 KR 3205 for roughing cast iron machining,
- WNMG 060408 PM 4225 for steel machining,
- WNMG 060404 WF 2015 for stainless steel machining.

Table 1 presents a summary of the cutting parameters recommended by the manufacturer for individual inserts.

The WNGA 060408 S01030A 7015 insert is designed for machining difficult-to-cut materials. Cast iron turning inserts (WNGA 060408 KF 3005 and WNMG 060408 KR 3205) have been selected for testing due to their improved machining properties. Cast iron can be treated as a non-homogeneous material. In cast iron parts, such as machine tool bodies, there are various types of pores, inclusions, etc. that make machining of such an element a complicated process. In such a cast there may also be mineral inclusions just below the surface as a result of the casting process, e.g. from sand molds. Inserts WNMG 060408 PM 4225 and WNMG 060404 WF 2015 were selected for testing in order to compare the quality of machined polymer concrete using inserts intended for processing of traditional construction materials such as steels.

3.3. Methodology

The research was carried out on the HAAS lathe with the catalog number SL10 in the Institute of Machine Tools and Production Engineering at the Lodz University of Technology. Longitudinal turning processes were carried out with the following parameters, which were determined during preliminary tests:

- cutting speed v_c = 50 m/min,
- feed f = 0.2 mm/rev,
- depth of cut a_p = 0.25 mm.

During the cutting process, a cooling lubricant was fed into the cutting zone. Due to lubricating properties, the fluid caused a drop in processing temperature and lower dust content.

During the tests, a cutting force components were recorded to determine the total cutting force. The measurement path consisted of Kistler 9121 dynamometer, Kistler 5070A amplifier and recorder in the form of an AC transducer card for the 2855A4 type PCI bus mounted in a PC computer. After each machining pass, the roughness values Ra and Rz of the machined surface were measured in the direction perpendicular to the machining marks (according to the PN-EN ISO 4287:1999 [12]). A portable Mitutoyo SJ-210 roughness gauge was used for this purpose. Photographs were also taken under the microscope of the inserts corners (noses), on the basis of which the width of major flank wear land and the width of minor flank wear land were measured after each machining pass. In addition, the views of each insert after the tests was presented. Each experiment was carried out 3 times. Average values and their standard deviations presented in the graphs represent the obtained results of studies on the dynamics of wear of cutting inserts during turning of non-homogeneous material on the example of polymer concrete.

4. Results and discussion

During machining a mineral cast, there is mainly wear on the minor flank. However both width of the major flank wear land VBm_afwl (Fig. 4) and the width of minor flank wear land VBm_ifwl (Fig. 5) were taken into account for the wear value assessment. After each pass, the

Table 1. List of cutting parameters for individual inserts

Parameter	WNGA 060408 S01030A 7015	WNMG 060408 KF 3005	WNMG 060408 KR 3205	WNMG 060408 PM 4225	WNMG 060404 WF 2015
Depth of cut a_p [mm]	0.07 ÷ 0.80	0.20 ÷ 2.00	0.24 ÷ 4.50	0.50 ÷ 4.00	0.30 ÷ 2.00
Feed f [mm/rev]	0.05 ÷ 0.30	0.08 ÷ 0.25	0.17 ÷ 0.42	0.15 ÷ 0.50	0.05 ÷ 0.25
Cutting speed v_c [m/min]	150 ÷ 250	255 ÷ 280	305 ÷ 390	275 ÷ 425	260 ÷ 305

wear of the individual insert was measured. The results of these measurements are shown in the following figures, thanks to which it was possible to analyze the tool wear as a function of time.

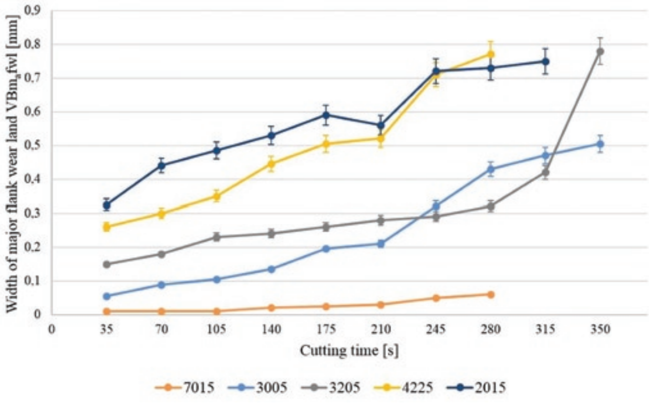

Fig. 4. The width of major flank wear land versus time

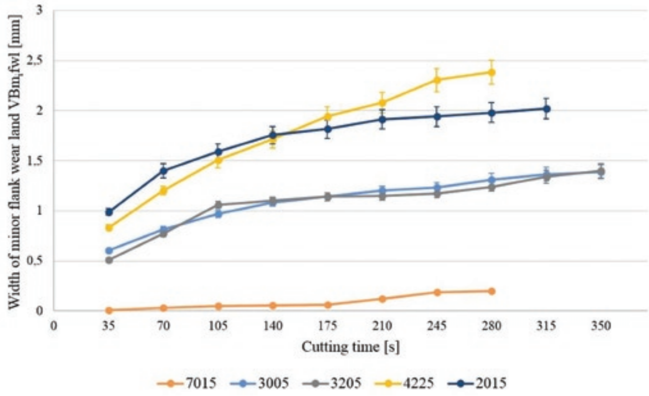

Fig. 5. The width of minor flank wear land versus time

The highest wear was observed for WNMG 060408 PM 4225 (intended for steel machining) and WNMG 060404 WF 2015 (intended for stainless steel machining). The major flank and minor flank worn out very quickly and after 280 seconds the operation of these tools was loud. Additionally, after this time, the corner (nose) recession was found, which resulted in a decrease in the actual depth of cut, which was only 50% of the set depth of cut. The maximum recommended criterion for tool wear should not exceed VB = 0.3 mm. It was considered that with this value of the wear parameter VB the experiment should be stopped. It can be observed that the coating of the tools was not durable and resistant to abrasion. The smallest width of the major flank wear land and the minor flank wear land were achieved during turning with the tool marked WNGA 060408 S01030A 7015. Small differences in wear VB were obtained with each pass (compared to other inserts). Unfortunately, the stresses on the tool face which were obtained during machining had the effect of destroying the tool (breakage off the corner), which eliminated the plate from further tests (Figure 9a).

During each machining test, the components of the cutting force F_x, F_y and F_z were measured in real time. On this basis, the value of the total cutting force was calculated and shown in Figure 6 as a plot of the average value of the cutting force obtained during the three-fold repetition of the experiment with the standard deviation as a function of time.

The values of the cutting force components significantly affect the accuracy and surface quality of the machined parts. The high turning forces of the mineral cast cause faster wear of the tools and the machine tool also. The lowest values of cutting force were obtained during cutting with the insert with the designation WNGA 060408 S01030A 7015. Unfortunately, during one of the experiments between 280 and 315s the insert was destroyed. For inserts marked as WNMG 060404 WF 2015 and WNMG 060408 PM 4225, after 300 seconds of machining the mineral cast, the forces were so high that during process the machine tool was excited to vibrations. On the basis of the forces courses, it can be seen the rate of wear of the tools. Due to the low wear of the WNGA 060408 S01030A 7015 insert, it retained good cutting properties for a long time, which resulted in much lower forces than in the case of other tools.

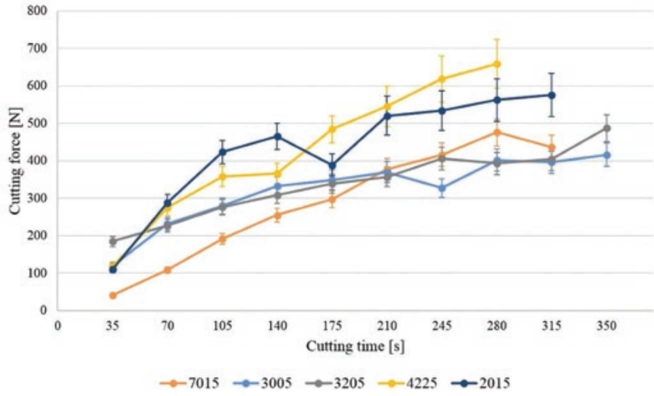

Fig. 6. The cutting force versus time

There are many factors affecting the roughness of the treated surface. Type of using tool, its geometry, machining parameters and type of workpiece. In this case the non-homogeneity of the material, which consists of aggregates grains of various sizes, makes obtaining a repeatable measurement of the machined surface complicated. It is illustrated by the large spread of the average value, presented by means

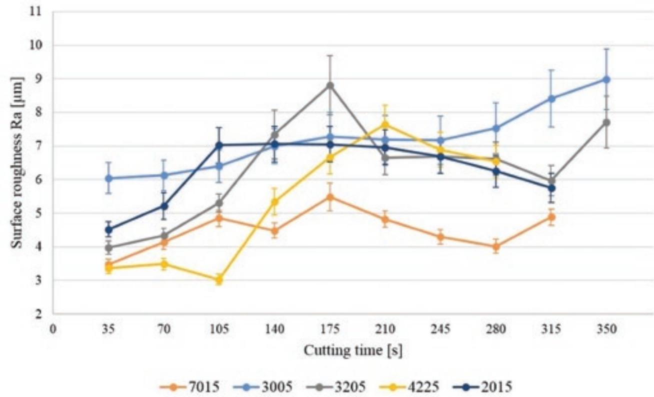

Fig. 7. The surface roughness Ra versus time

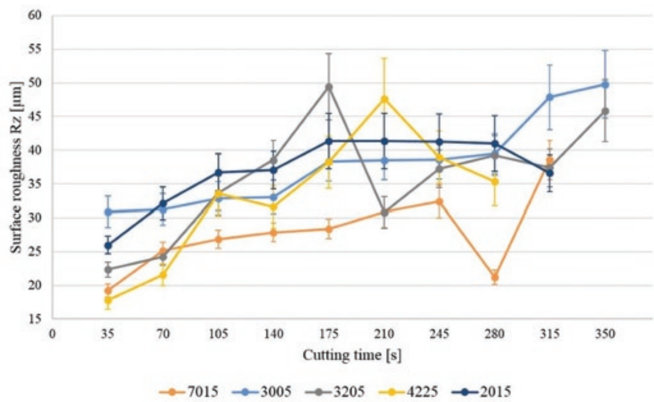

Fig. 8. The surface roughness Rz versus time

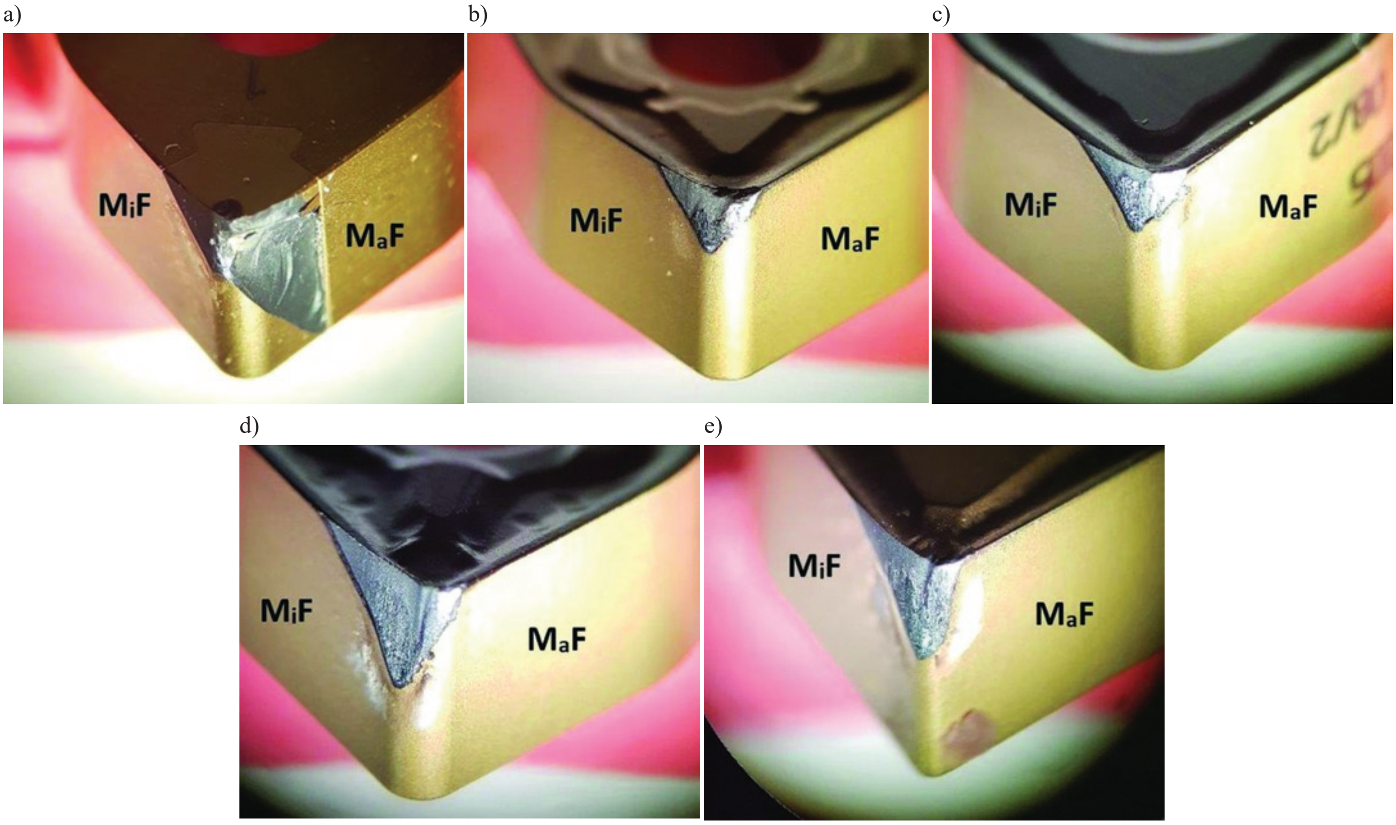

Fig. 9. Views of inserts after the machining a) WNGA 060408 S01030A 7015, b) WNMG 060408 KF 3005, c) WNMG 060408 KR 3205 d) WNMG 060408 PM 4225, e) WNMG 060404 WF 2015

of the standard deviation. The values of roughness parameters Ra and Rz are shown in Figures 7 and 8.

As predicted, the best quality of the machined surface was obtained using the WNGA 060408 S01030A 7015 insert. For this tool, the smallest values of the Ra and Rz roughness parameters were obtained, which were repeatable for each experiment. with the smallest value of standard deviation. It is worth noting that in this case, despite the tool wear, the roughness value Ra slightly increased by about 1.5 µm, and roughness Rz by about 10 µm compared to the initial values. For other inserts, along with the increase in tool wear, the surface roughness value increased about three times for the Ra parameter and approximately twice for Rz. This indicates a very fast abrasion of the major flank and minor flank surfaces. Therefore during measuring the roughness of the machined surface, a much larger spread of the measured values was obtained.

In addition, photos were taken under a microscope of each insert after the tests, which are presented in Figure 9.

On the basis of the conducted research, it is possible to describe the mechanism of tool wear in the case of machining of non-homogeneous materials such as polymer concrete in the scope of cutting conditions adopted during tests. Comparing graphs of the tool wear course as a function of time for isotropic materials (Fig. 2) and anisotropic materials (Fig. 4 and 5), it can be noticed that in the case of polymer concrete machining there is no clear division into 3 characteristic phases of abrasive tool wear. It can be presumed that phase I (tool run-in) proceeds from the beginning of the machining process and ends before the first measuring point (in the 35 second of the test), however, to confirm this fact, additional tests should be performed in this time interval. However, with time, the clear boundary between phase II and III is blurring, and the obtained graphs are characterized by relatively linear course. It can be interpreted as an uniform increase in tool wear during machining. Uneven, random distribution of different grain sizes (from micrometers to millimeters) in a mineral cast means that the machining of non-homogeneous material is a complex process and the conditions of this treatment are variable at any time during that process. Analyzes concerning the nature of the wear mechanism course are very difficult, and the conclusions in this respect depend on the type of material which was machined, type of cutting insert and cutting parameters. Generalizations in this field could be developed on the basis of a stochastic approach, but it would require much larger number of tests and measurements to be carried out. The research presented above outline the mechanism of wear of the cutting tool and the trends of changes in the cutting result parameters (roughness of the machined surface) of the anisotropic material which is the mineral casting.

5. Summary

Based on the results of the tests, it can be clearly stated that tools for steel (WNMG 060408 PM 4225) and stainless steel (WNMG 060404 WF 2015) machining should not be used for turning a polymer concrete. During the use of these inserts, a significant increase in cutting forces, an increase in the Ra and Rz roughness parameters as well as accelerated tool wear were observed.

In addition, the tests showed that the best results for the tool with the WNGA 060408 S01030A 7015 cutting insert were obtained. In this case, the smallest roughness values Ra, ranging from 4 to 5 µm, were obtained. When cutting with the other tools, the roughness values of the Ra parameter were obtained in the range from 4 to 8 µm. Analyzing also the values of the width of major flank wear land and width of minor flank wear land, the WNGA 060408 S01030A 7015 insert was characterized by the smallest wear values of these surfaces, which did not exceed VB = 0.3 mm. However, in the case of other inserts, these values exceeded the accepted limit of wear even several times.

The value of cutting forces is an important indicator of the dynamics of the turning process. In this case, the cutting force was initially the lowest for the WNGA 060408 S01030A 7015 insert. However, in the second part of the tests, the lowest cutting forces were obtained for WNMG 060408 KF 3005 and WNMG 060408 KR 3205 inserts, designed for cast iron machining.

A comparison of the mechanism of wear in the cutting zone for machining isotropic materials and polymer concrete was made. Differences in the wear process that have been tested have their origin in the specificity of the composite material and in the properties of the individual components of this composite material. Due to the fact that the machining of mineral cast material is becoming more and more common, the conducted research may become the basis for the process of selecting the right cutting inserts due to their durability during turning non-homogeneous materials.

The experimental tests have shown that in the case of turning a mineral cast, the durability of the tool is a critical parameter. This applies mainly to numerically controlled machine tools. Using inserts too long without replacement can cause large unwilling errors in the shape and dimensions of the workpiece. In contrast, frequent replacement of inserts causes time-consuming and costly machine tool downtimes.

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Norbert KĘPCZAK
Radosław ROSIK
Witold PAWŁOWSKI
Małgorzata SIKORA
Błażej WITKOWSKI
Grzegorz BECHCIŃSKI
Wojciech STACHURSKI
Institute of Machine Tools and Production Engineering
Faculty of Mechanical Engineering, Lodz University of Technology
ul. Stefanowskiego 1/15, 90-924 Lodz, Poland

E-mails: norbert.kepczak@p.lodz.pl, radoslaw.rosik@p.lodz.pl, witold.pawlowski@p.lodz.pl, malgorzata.sikora@p.lodz.pl, blazej.witkowski@p.lodz.pl, grzegorz.bechcinski@p.lodz.pl, wojciech.stachurski@p.lodz.pl