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STUDY OF THE ROUND CUTTING INSERT WEAR IN MACHINING WITH SIMULTANEOUSLY ROTATING TOOL AND WORKPIECE

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Abstract: *The dynamics of mechanical engineering industry development requires manufacture of products from hard and difficult-to-machine materials. This requires engineers to be flexible and to use non-standard solutions such as the application of unconventional cutting schemes for such materials.*

When machining difficult-to-machine materials, cutting tools are subjected to intense mechanical and thermal loads, which lead to progressive wear and reduced tool life. The paper presents a wear study of a round cutting insert when processing hard material with a simultaneously rotating tool and workpiece. An analysis of wear type occurring during processing of difficult-to-machine materials when applying unconventional cutting scheme is made and the obtained results from measuring the magnitude of wear and the mechanism of wear are presented and analyzed.

Key words: *cutting tool insert wear, difficult-to-machine materials, non-traditional cutting schemes*

1. INTRODUCTION

The growing competition in the field of machine-building production related to increasing productivity, quality of the manufactured product and extending the life of tools to minimize costs for production lead to significant development of the industry through automation of production processes, implementation of digital measurement systems and intelligent process control. Despite the progress and development achieved, the processing of materials that are difficult to process by machining remain a challenge due to the specifics of their physical and mechanical properties [1].

Unconventional cutting schemes can offer a solution for the problem of machining materials which are hard to cut, while providing productivity and extending tool life by optimizing the dynamics of the cutting process and controlling the contact between the workpiece and the cutting tool [2–4]. The unconventional tangential cutting scheme with both rotating tool and workpiece of a CNC milling machine can improve cutting processes with and cutting tool life with reducing tool wear. This cutting scheme can improve the chip formation process, and it can reduce cutting forces, and increase tool life by uniform distribution wear along the cutting edge [5–8] of a round cutting insert.

Although many parameters affect the machining of hard to cut materials, the wear of the cutting tool insert is essential. It has a direct influence on the quality of the machined surface, dimensional accuracy and overall process stability [8–12]. Therefore, understanding and controlling cutting tool wear is key to improving the machining process.

There are studies on various aspects of cutting tool wear under a variety of cutting conditions, with studies focused on tangential patterns showing promising results in reducing wear and increasing productivity [13–15]. However, research dedicated special to the behavior of round cutting inserts in such configurations is still limited and not enough [16–22].

This paper describes an experimental investigation of the wear mechanisms of a round cutting insert when processing hard and difficult-to-machine material with rotation of the workpiece and cutting tool. The conducted

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research includes measuring the amount of wear on the cutting tool and evaluating the wear mechanism, obtained through the use of a measuring and stereomicroscope.

2. MATERIALS AND METHODS FOR CONDUCTING THE EXPERIMENTAL RESEARCH

For the experimental studies, a difficult-to-machine material SAF 2507 (super-duplex stainless steel) with a diameter of Ø40.0 mm was chosen. The austenitic–ferritic super-duplex stainless steel is widely used where high strength and superior corrosion resistance are required, particularly under chloride exposure. Common applications include gas and oil exploration, desalination, seawater cooling, and chemical processing [23] and is characterized by the following properties:

- High resistance to chloride-induced stress corrosion cracking;
- Superior resistance to both pitting and crevice corrosion, with pitting characterized by localized penetration of the metal surface and crevice corrosion defined as localized attack in occluded zones caused by loss of oxide passivity in stagnant media;
- Excellent resistance to corrosion;
- Very high mechanical strength [24-25];

In Table 1 the chemical material composition is shown.

Table 1

Nominal chemical material composition

Super-duplex (austenitic-ferritic) stainless steel SAF2507									
Number: 1.4410; Degisnation EN: X2CrNiMoN25-7-4									
C	Ni	Mn	P	N	Si	S	Cu	Cr	Mo
≤0.030%	7%	≤1.2%	≤0.035%	0.3%	≤0.08%	≤1.2%	≤0.5%	25%	4%

In processing of hard to machine steels is accompanied by high cutting forces, the formation of layers, due to which a higher cutting temperature develops, which leads to greater wear of the cutting tool insert. When applying non-traditional cutting schemes in rotary parts machining, with simultaneously rotating tools and workpieces, it is possible to reduce temperatures during machining, which occurs as a result of the temperature dissipation along the outer edge of the circular cutting tool insert. To ensure the above-mentioned kinematics and to conduct the experiment, a rotary tool with a circular cutting insert is used which is shown in Fig. 1 and Fig. 2. The parameters of the cutting tool insert are presented in Table 2 [26–27].

The technological equipment used to carry out the experiment are Bulgarian brand CNC vertical machining center RAIS M550 and an additional spindle needed for obtain rotating motion and for clamping the workpiece. They are selected to be able to implement the unconventional cutting scheme with simultaneously rotating of the tool and workpiece shown in Fig. 3.

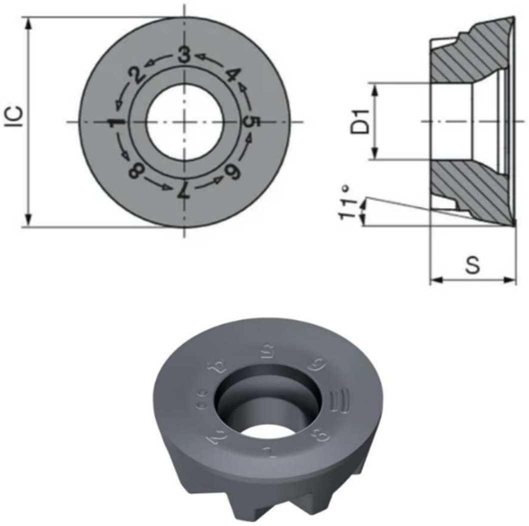

Fig.1. Round cutting tool insert for implement the unconventional cutting scheme

Fig.2. Rotary tool with round cutting insert for implement the unconventional cutting scheme

Table 2

Technical data of cutting tool insert

PARAMETERS	Cutting tool insert type
	RPHX 1605M8EN-M30 CTPM240
Designation	1605M8EN
Inscribed circle diameter / IC	16 [mm]
Fixing hole diameter / D1	5.5 [mm]
Insert thickness / S	5.56 [mm]
Clearance angle major / AN	11 [°]
Coating name	CTPM240
Material suitability	Stainless steel (main application); Steel (secondary application)

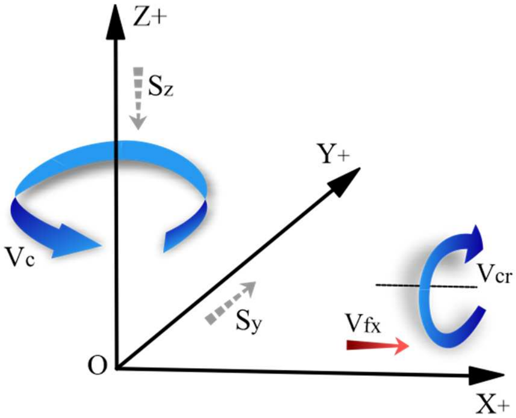

Fig 3. Unconventional tangential cutting scheme realized on CNC vertical machining center RAIS M550

In the kinematic scheme shown in Fig. 3:

- Vc is the main rotational cutting tool movement;
- Vcr – rotational workpiece movement (with the workpiece rotation axis location -parallel to the X-axis);
- Vfx – rectilinear feeding motion of the workpiece (obtained when the working table of the mains moves along the X-axis);
- Sy – rectilinear positional motion of the part. This motion serves to position the workpiece at the set cutting depth in a perpendicular direction to the axis of the workpiece rotation;
- Sz - rectilinear positional of the tool motion along the Z axis.

A real diagram of the experimental setup is shown in Fig. 4. The rotary tool is clamped into the spindle of the machine, and the workpiece made of material SAF2507 is clamped into an additional spindle providing rotational motion.

Fig. 4. Machining of a rotation symmetric workpiece with simultaneous rotating tool and workpiece

The mode parameters under which the experimental study was carried out are shown in Table 3.

Table 3

Cutting modes for machining with a simultaneously tool and part rotating

Rotation speed of the cutting tool	Rotation speed of the workpiece	Feed of the workpiece	Cutting depth
S=1800 rpm	S=1000 rpm	F=150 mm/min	a=1.5mm

Standard methods are used for cutting tool inserts wear determination. The wear of the cutting edge of the cutting tool insert is determined by the size of the h_w (Fig. 5). The wear of the cutting edge of the cutting tool insert, measured in the radial direction, is reflected in the change in the diametrical dimensions of the machined workpiece surface, which represents the dimensional wear of the cutting tools, marked by:

- h_d – cutting tool insert wear;
- h_w – wear of the cutting edge;
- h_0 – wear of the front surface.

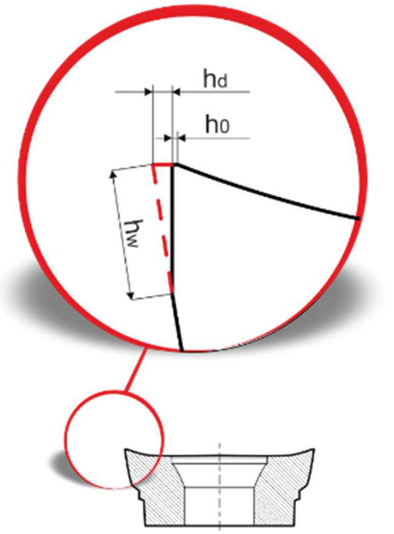

Fig. 5. Measurement scheme of cutting tool insert wear

Wear is determined by a linear method using a digital monocular microscope (Monocular Optical Zoom Lcd Screen Measuring Video Electronic Digital Microscope). The technical characteristics of the microscope are presented in Table 4.

Table 4

Digital microscope - technical characteristics

Monocular Optical Zoom Lcd Screen Measuring Video Electronic Digital Microscope	
Dimension	380*260*300mm
Illumination	6V4.5, LED, Ring Lamp
Theory	Video Microscope
Drawtube	Monocular
Camera resolution	2k, 1920*1080
Monitor/Screen	13.3 inch HD monitor screen (full HD)
Zoom Lens	0.7 - 4.5x
Digital Magnification	24 - 154x
Resolution	1920 * 1080P, 2MP ; 1/2" sensor, @60fps

Fig. 6 shows a electronic digital microscope used to measure the dimensional wear of a round shape cutting tool insert. It allows for accurate observation and quantification of wear model, such as diameter decreasing and cutting edge wear.

Fig. 6. Digital microscope for wear measurement of round cutting insert

In order to obtain detailed information on the wear of the round cutting insert, macrostructural studies were also carried out, using EUROMEX Binocular Stereo Microscope [28], shown on Fig. 7. The technical characteristics of the stereo microscope for the macrostructural study is presented in Table 5.

Fig. 7. Binocular stereo microscope for macrostructural studies

Table 5

Technical characteristics of Stereo Microscope

NexiusZoom Binocular Stereo Microscope	
1.	Binocular head
2.	HWF 10x/22mm eyepieces
3.	6.7 to 45x Magnification
4.	3W LED incident and transmitted illumination

Figure 8 shows the actual measurement scheme, in which the diameter of the cutting insert is measured and its wear change in time is monitored.

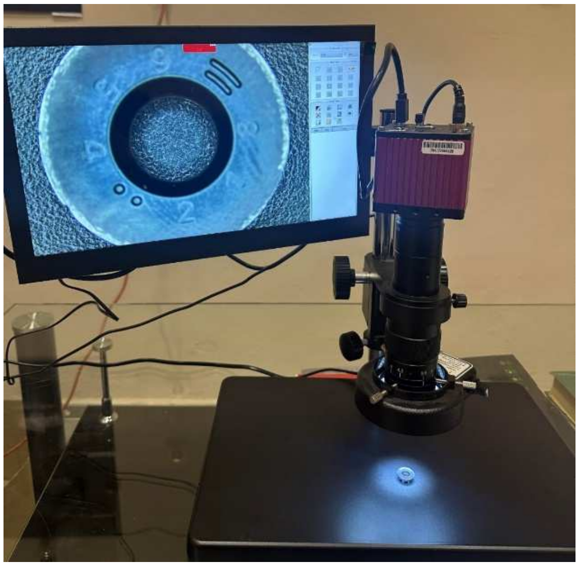

Fig. 8. Actual cutting insert wear measurement scheme

3. RESULTS

3.1. Dimensional method of measuring round shape cutting tool insert wear

The measurements were taken at regular intervals within a two-hour cutting process, allowing for an accurate assessment of the tool's wear dynamics. This approach provides an understanding of wear progression under real machining conditions.

The measured diameters of the cutting tool insert are shown in Table 6.

Table 6

Measuring results for dimensional cutting tool wear

№	Measured diameter, [mm]
1.	16,0000
2.	15,9973
3.	15,9948
4.	15,9931
5.	15,9912
6.	15,9895
7.	15,9879
8.	15,9863
9.	15,9847
10.	15,9827
11.	15,9813
12.	15,9798
13.	15,9783

Measurements were taken every 10 minutes of the machining process. The first value in Table 6 is of the measured diameter of a new insert before the start of the experimental studies (a view of the new insert can be seen in Fig. 9).

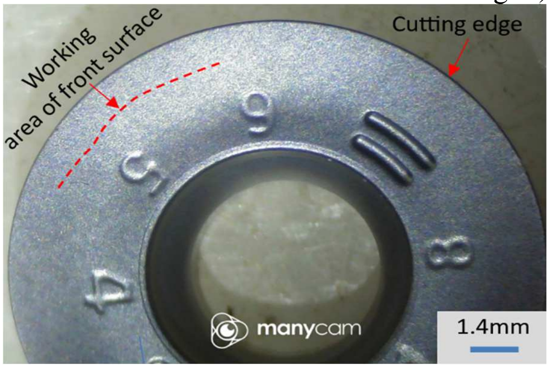

Fig.9 View of a new round cutting insert before conducting experimental studies

3.2 Macrostructural studies of measuring cutting tool insert wear

The conducted macrostructural studies on the wear of the round cutting tool insert are presented in Fig.10 and Fig.11.

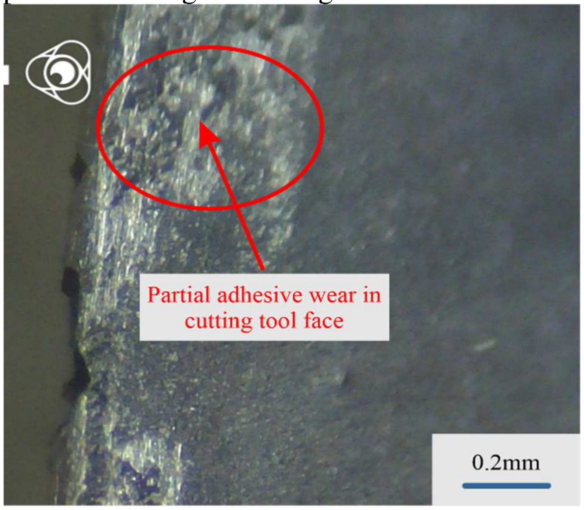

Fig.10. Macro study of the face of a round cutting tool insert (after loading under operating conditions) with observed adhesive wear

The contact areas of the tool with the workpiece are of interest in this experimental study. The cutting tool life depends on its production quality, the correct choice of tool material, consistent with the mechanical characteristics of the processed material. In addition to the properties of the cutting tool-workpiece friction pair, the cutting mode parameters that determine the temperature in the cutting zone are also very important.

The bond between the bonded material and the cutting tool is adhesive and is based on Van der Waals forces in the contact cutting zone.

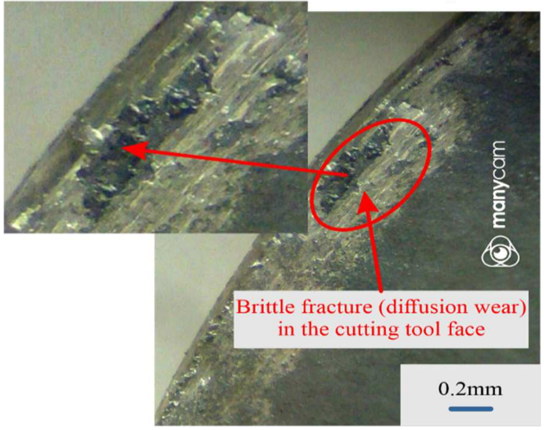

Fig.11. Macro study of the face of a round cutting tool insert (after loading under operating conditions) with observed diffusion wear

With increasing temperature and operating time, diffusion processes occur in the areas of adhesion, which lead to a diffusion bond in the contact zone between the separated adhesion material and the tool material. This bond is of high strength and peeling of the bonded material together with the material from the cutting tool occurs. As a result of these phenomena, zones of brittle failure are observed.

Both considered zones (adhesion and diffusion) are observed in Fig. 12. Brittle fracture concerns both the working surface and the cutting edge of the cutting tool insert.

Fig. 12. Adhesion and diffusion zone on the face and cutting edge of a round cutting tool insert

4. CONCLUSIONS

After the conducted experimental studies and the analysis of the results obtained from the assessment of the wear type and the mechanism of wear, the following conclusions can be drawn:

- the dimensional wear of the cutting insert is minimal, and occurs according to the established dependencies in conventional machining processes;
- in the most general case, complex wear, adhesive and diffusion of the cutting insert is observed;
- with increasing the contact zone temperature during operation of the tool at the initial stage, an adhesive zone of material adhesion from the workpiece is observed;
- with an increasing the temperature and operating time in the areas of adhesion, diffusion processes occur, which lead to a diffusion connection in the contact zone between the separated adhered material and the tool material.

The tasks for future research are related to conducting experimental studies at different mode parameters during machining, aimed at reducing adhesive and diffusion wear of the cutting tool.

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Studiul uzurii plăcuței așchietoare rotunde la prelucrarea cu sculă și piesă de prelucrat în rotare simultană

Rezumat: Dinamica dezvoltării industriei inginerești mecanice necesită fabricarea de produse din materiale dure și dificil de prelucrat. Acest lucru impune inginerilor să fie flexibili și să utilizeze soluții nestandardizate, cum ar fi aplicarea unor scheme neconvenționale de așchiere pentru astfel de materiale. La prelucrarea materialelor dificil de prelucrat, sculele așchietoare sunt supuse unor sarcini mecanice și termice intense, ceea ce duc la uzură progresivă și la reducerea duratei de viață a sculei. Lucrarea prezintă un studiu de uzură al unei plăcuțe așchietoare rotunde la prelucrarea unui material dur cu o sculă și o piesă de prelucrat care se rotesc simultan. Se realizează o analiză a tipului de uzură care apare în timpul prelucrării materialelor dificil de prelucrat atunci când se aplică o schemă neconvențională de așchiere, iar rezultatele obținute din măsurarea magnitudinii uzurii și a mecanismului de uzură sunt prezentate și analizate.

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