Investigation of cutting temperature and chip formation during rotational turning by multifaceted cutters

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Abstract. The influences of conditions of rotational turning by multifaceted cutters (RTMC) on the cutting point temperature under the intermittent cutting operation are examined. By employing a different geometry of the tool and selecting an appropriate tool peripheral speed so as to reduce the tool-workpiece contact time and frictions, tool temperatures and failures are suppressed. The morphology of the different types of chips generated during RTMC confirms the theoretical position of the intense fragmentation and removal of chips from the cutting zone.

1. Introduction

Edge cutting machining of the difficult-to-cut materials is treated as a considerable problem because of low operational durability of the cutting part of the tool and production. The new methods of processing of material based on high-speed methods of shaping, oriented to the use of modern multi-purpose machines with CNC in tool nodes, and automated production requires the use of the tool with the increased level of properties. It is known that operational durability of the cutting tool in many respects is determined by the temperature factors accompanying the process of edge cutting machining of metals [1-3], depending on intensity of diffusive and adhesive depreciation at the increased temperatures.

Therefore, studying thermal processes in area of cutting has a considerable practical value from the point of view of understanding of intensity of deformation processes in the area of cutting, the nature of distribution of temperatures on the surface of the cutting part, wear of the cutting tool and quality of the processed surface [4-6].

An effective method of process management of heat exchange and a decrease in temperature on edges is a transition from schemes of continuous turning to discrete periodic cutting of the material layer, including application of various methods of rotational turning [7-9]. In relation to the method of rotational turning by multifaceted cutters, the most important distinctive benefit from the known ones is the decrease in time of contact of each separate cutting edge of the tool with the processed material [10].

The objective of this research is to investigate the cutting characteristics of RTMC from thermal aspects and modeling the processes of chip formation.
2. Results and Discussion

For prospectively assessment of the new method of RTMC, there were conducted researches on distribution of heat between cuttings, the tool and the detail by a contactless method with use of the thermal imager, model Testo 875-1. The range of measurement of temperature with the device is from -20°C to 200°C. The limit of the admissible error of measurements: absolute $\leq 100$ °C ±2%; relative $>100$ °C ±2%. Experimental studies were carried out on the screw-cutting lathe of high accuracy “IZH250ITVM.F1” by using the tool module for rotary turning.

![Diagram](image)

**Figure 1.** The scheme of machining with a multifaceted rotational cutter: a) a kinematic scheme of installation on the lathe: 1 – rotational cutter; 2 – tool head; 3 – electro spindle E-18 / 0.63; 4 – bracket; b) a tool head; c) a general view of the experimental setup.

In order to establish a link between the parameters of the cutting and the change in temperature on the surface of the flank face and the chips one-factor experiments were conducted.

The following parameters of cutting conditions have been accepted: $f_w$ - line feed of the processed shaft revolution, 0.25 ... 1.2 mm/turn; circular workpiece feed; the number of revolutions of the workpiece 50 ... 630 turn / min; the number of revolutions of the tool, 6000 ... 18,000 turn / min; $a_p$ – cutting depth of 0.3 ... 1.5 mm. The number of facets of the tool module plate - 6. The tool temperature at the flank face is measured using apparatus Testo 875-1. In the condition of dry turning of steel, the tool temperature increases from approximately 50.6 °C to 96.4 °C, as the tool rotation speed increases from 200 m/min to 900 m/min.
Figure 2. Variation of temperature on the tool flank depending on: a) tool rotational speed; b) depth of cutting.

Experimental results indicate that the temperature increases depending on the cutting speed and depth (Figure 2 a,b). With an increase in constructive and longitudinal feed, the temperature remains practically constant. Analysis of the heat map indicates that by increasing the cutting speed, the amount of heat transfer into the chips increases, in the workpiece and the tool - decreases.

In addition, the temperature distribution of the flank face along the cutting edge of the insert during cutting is also measured.

Figure 3. The distribution of temperature along the length of the cutting (the blade by turning through angle 180°)

Computer processing of the heat map indicates that the chip surface temperature ranges from 60 to 110 °C; the temperature of the cutting blade entering the tool cutting zone is 30- 40 °C, the output is 40 - 60 °C. (Figure 3). This fact is certainly positive in terms of improving durability of the cutting elements of the rotary cutter. During long time tests of the cutting edges in the contact zone “tool - workpiece - chip”, the integral temperature is stabilized (Figure 4). In the optimal range of cutting conditions, the temperature does not exceed 120 °C. The small and almost uniform temperature without chipping is observed in both rake and flank faces along the cutting edge. Rotary cutting reduces tool temperatures and the amount of tool wear owing to interrupted incoming heat, thermal diffusion into the chip, and thermal dissipation into the air. Therefore, the tool-workpiece contact time, the length of the cutting edge, and heat capacity of the tool have a great influence on thermal behavior, however, there has been few studies concerning these influences.
Figure 4. The circuit changes of the chip thickness at RTMC and overall dimensions of the chip

These extremely low values of temperature on the surface of the instrument explain, in our opinion, discrete processes and the specifics of forming a new element type chip at RTMC. In accordance with the kinematics of the process, the contact between the chip and the front surface is not constant. An elementary chip size can be characterized by three parameters: the width, thickness and length (Figure 4).

The width of the chip determined by formula

\[ B = 2f_{nbr}, \]

where \( f_{nbr} \) is line feed to the face of the cutter, mm/turn.

The length of chip is

\[ L = 2f_{az_{t}} + l_{t}; \]

where: \( l_{t} \) – the length which depends on the depth of cutting, mm; \( f_{az_{t}} \) is the azimuthal supply of the blank on the brink the cutter, mm.

The thickness of chip:

\[ a_{p} = a_{mt} - \Delta h = a_{mt} - \sqrt{\rho^2 \cdot \sin^2 \kappa^2 + R_{\min}^2} + R_{\min}; \]

where: \( a_{p} \) – depth cutting in each situation of cutting edge, mm; \( a_{mt} \) – depth cutting in the plane of axis center, mm; \( \Delta h \) – height of possible residual of irregularities, mm; \( R_{\min} \) – the radius of machined workpiece, mm; \( \rho \) is the radius vector of the cutting edge contour, mm; \( k \) – the angle between the center axis and the contact point of the cutting edge and the machined surface.

The angle between the center axis and the contact point of the cutting edge and the machined surface is found by formula

\[ \cos k_{\max} = \frac{\rho_{\max} - B}{\rho_{\max}}; \]

where \( \rho_{\max} \) is the maximum radius vector of the cutting edge contour, mm.

In order to avoid the kinematic of undulation, it is necessary to appoint azimuthal supply by formula

\[ l_{t_{\max}} = \sqrt{R_{w}^2 - (R_{w} - a_{mt})^2}; \]

\[ l_{t_{\max}} \geq f_{az_{t}} + l_{t}. \]
where \( l_{\text{max}} \) – exit height of the cutting blade from the cutting area with respect to the plane of the centers, mm; \( R_w \) – the radius workpiece, mm.

The length, which depends on the depth of cutting, is determined by formula

\[
l_t = \sqrt{t_{\text{max}}^2 - (t_{\text{max}} - 2f_{\text{max}})^2} - f_{\text{size max}};
\]

(7)

From the scheme shown above (Figure 4), it is clear that the chip thickness is a variable and ranges from 0 to a value equal to the depth of cutting. In fact, numerical ratio \( \alpha_{\text{p}} / \alpha_{\text{mt}} \) determines the difference in variable shrinkage. Shrinkage varying cutting conditions can be adjusted over a wide range.

Several facets of the rotary cutter with special configuration, which constantly succeed one another in the contact area with the workpiece, ensure reliability of the chip. The shape and size of the chip depend on the workpiece material and the mode of cutting, but in all cases, the tool temperature (Figure 5) does not exceed 100 °C. This can significantly improve the conditions of the machining of plastic and viscous materials - such as aluminum, titanium and magnesium alloys. Efficiency and obvious advantages of RTMC illustrate the images of the morphology and the size of chips produced in conventional aluminum RTMC and turning in the same conditions (Figure 5).

![Figure 5](image1.png)

(a) (b)

Figure 5. Types of chips formed during processing of aluminum alloy (D16): a) 1- longitudinal turning, 2 - oblique turning, 3 - RTMC b) after the chip of RTMC type

The morphology of the chips of aluminum alloys obtained under different cutting conditions are presented in Figure 5. The microstructure of the cross-sectional dimension and shrinkage indirectly confirms the increased level of specific load and intensity of deformation processes per unit time at RTMC in comparison with conventional (Figure 6).

There are the traces of the individual layers of material with the thicknesses from 1-6 \( \mu \text{m} \) (Figure 6). The presence of the discontinuity surface also reflects the discrete nature of the deformation processes in RTMC.

![Figure 6](image2.png)

Figure 6. Morphology of elemental chips generated by RTMC from the aluminum based alloy.
It is known that long chips are heated and oxidized at the turning, increased contact time with the surface of the tool leads to its increased wear. Thus, the formation of crushed chips of a size of 0.05 to 1.5 mm, which is provided by RTMC, is of exclusive importance for the processing of viscous aluminum and especially titanium and magnesium alloys, to prevent combustion of the chip and intensive oxidation of the workpiece surface.

Results of studying the morphology of chips obtained in the various modes of RTMC are of special interest. Depending on distinctions of cutting conditions, different types of chips are created, which also reflects the high intensity of deformation processes in the area of cutting and a local warming up of chips elements to extremely high temperatures. The combined action of all extreme on intensity in a unit of time of power and temperature factors leads to formation of absolutely new structures of chips in the form of hollow spheres with sizes of 100 to 300µm and the wall thickness of about 1-2 µm (Figure 7). It opens the new prospects from the point of view of more effective use of waste in the form of cuttings by transformation into a marketable product. The purposeful change of the conditions of processing is possible to adjust the sizes and a shape of hollow spherical chips for their subsequent use in technologies of powder metallurgy and composite materials.

Figure 7. Structures of the steel chip in the form of hollow spheres

3. Conclusion
The obtained experimental data about the nature of temperatures distribution show that the main heat goes to cuttings. The area of directly working local sites of the cutting edge is constantly updated, and in the condition of high speed of rotation, it can be effectively cooled without additional liquid. The morphology of various types of the cuttings, which is formed at RTMC, confirms theoretical regulations on intensive crushing and removal of chips from the cutting area. Favorable conditions on the cutting part of the tool provide the decrease in intensity of thermal wear and the required quality of processing of a surface.

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