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Turning Tool with Helical Cutting Edge for Optimizing the Machining Time Performance

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Authors' contributions

This work was carried out in collaboration between both authors. Author KV formulated research issues and hypothesis of presented problem and designed the research and conducted experiments directly on machine tools. Author ZM methodically managed experiments, made protocols and evaluated results. Both authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

The paper presents turning with helical cutting edge employing the edge of twist drill and develops the special method of turning and its impact on the quality of machined surface. Finding the approach how to improve the surface quality and optimizing the machining time performance, the theoretical relation among the average maximum height of the machined surface profile Rz, the feed f and the radius of the tool tip r_ε is known. Increasing the feed f, the surface roughness Rz increases quadratically. On the other side, increasing r_ε, the surface roughness Rz decreasing hyperbolically. The limiting case is $r_\varepsilon = \infty$. The specification of such tool function is the cutting edge inclination angle λ_s. Another option is to use helical cutting edge. In such case, r_ε is curvature angle of helical edge. The experiments applied on different materials (dural and titanium alloys, brass) were performed to confirm the thesis of surface roughness quality improvement by use of helical cutting edge and moreover the significant increase in the productivity of turning were achieved regarding possibility to use several times larger feed rates.

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1. INTRODUCTION

The surface roughness and mechanism of its formation are analyzed and examined by the various methodologies and strategies that are adopted by manufacturers and researchers in order to predict surface roughness. The manufacturing process nature of the surface roughness formation mechanism along with the numerous uncontrollable factors that influence pertinent phenomena, make almost impossible a straightforward solution. [1] Moreover, the fishbone diagram with the parameters that affect surface roughness is elaborated in [1]. The concept of machining by helical cutting edge is used for example in turn-milling machining with end milling cutter [2]; furthermore, some producers of cutting inserts have developed inserts with helical cutting edges geometry that provide high productivity enabling cost savings and longer tool life comparing with conventional edge inserts.

The searching for non-traditional geometries of cutting tools (more in [3,4]) can lead to considerable increase of the quality of machined surface or reducing the machining time and at the same to obtain the high quality of machined surface.

The known theoretical relation among the average maximum height of the machined surface profile Rz, the feed f and the radius of the tool tip r_ε according to [5-11] is:

$$Rz = f^2 \frac{1}{8\, r_\varepsilon} = 0.125 \frac{f^2}{r_\varepsilon} \tag{1}$$

In 1972 Ladany [12] has already published the results of production finishing turning with a tool with helical cutting edge. He used a twist drill that was positioned regarding the workpiece according to Fig. 1.

The basis of method is the use of unutilized side edge of the twist drill for slide turning of continual cylindrical surfaces. The utilization of undamaged side edge of damaged twist drills is secondary benefit of presented method. The experimental tests have shown that the optimal inclination angle of the drill axis λ regarding the workpiece axis is about 50°[3,12].

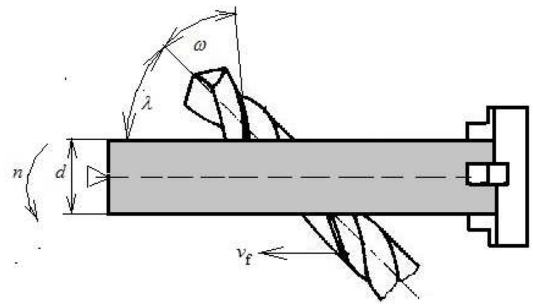

Fig. 1. Twist drill setting for turning with side cutting edge

Sztankovics and Kundrák [9,13] applied a similar helical tool which rotates against the direction of workpiece rotation. Further, Ladany derived a relationship for average maximum height of the machined surface profile in the following form:

$$Rz = \frac{f^2}{8r_\varepsilon} + tg^2(\lambda + \omega)\left[\frac{f^2}{4d} + \frac{f^2}{8r_\varepsilon}\right] \tag{2}$$

where d is the workpiece diameter, mm, λ is inclination angle of drill axis regarding workpiece axis, ω is helix angle, r_ε is curvature angle of helical edge.

Considering the fact that considerably large portion of cutting edge is engaged, the mentioned method is suitable for finishing turning by a large feed and small cut depth. The worn cutting edge can be replaced by moving into a new position in a clamping fixture. It can be supposed that this method of turning is suitable mainly for turning light metals, wood, titanium alloys which require small cutting forces.

The paper presents the results of experimental tests of turning of selected materials.

2. EXPERIMENTAL DETAILS

In Fig. 2 a helical drill made of high-speed steel with helix angle $\omega = 20°$ attached to a clamping fixture under the angle λ=45° with the possibility to change position in case of worn cutting edge is shown. The actual cutting edge inclination angle is: $\lambda_s = \lambda - \omega = 25°$.

Placing the cutting edge to workpiece axis level the tool has optimal geometry. Displacing above the workpiece axis, the working face angle increases and under the workpiece axis it decreases. Therefore, the turning is possible to be performed from the right to the left and vice versa. This change of working angles can be used for turning materials of various material properties. For every workpiece material, the different suitable cutting speed was determined, for aluminium alloy 141 m/min, for titanium alloy 44 m/min and for brass 31 m/min. The experiment goal was to find out how the helical tool behaves when turning the various materials as aluminium, titanium alloys and brass.

Fig. 2. Experimental tool clamped in a holder

3. RESULTS AND DISCUSSION

3.1 Machining of Aluminium

The often used aluminium alloy – dural (AlCu4Mg1) was selected for experiments. The samples were turned at the same cutting conditions. The problem of machining aluminium alloys lies mainly in considerable adhesion between machined and cutting tool materials resulting in „sticking“ of material on the cutting wedge that leads to worsening of machined surface micro-geometry. Therefore, the conditions of free cut are needful to be created. Fig. 3 provides the photo of tool (twist drill) position regarding the workpiece.

An experimental dependence Rz = f(f) obtained at turning by classical tool and a tool with helical cutting edge is shown in Fig. 4. As can be seen when the classical tool of r_ε=0.4 mm is used, the Rz values increase rapidly with the feed rate of 0.1 mm, which is consistent with the equation (1). The graph curve of helical tool with λ=45° rises very slightly. For example, to achieve Rz = 12 μm, we need f = 0.1 mm using classical tool. When using helical tool, the same Rz value can be achieved by f = 0.9 mm. This is a significant reduction in machining time.

Fig. 3. Position of tool cutting edge regarding the workpiece

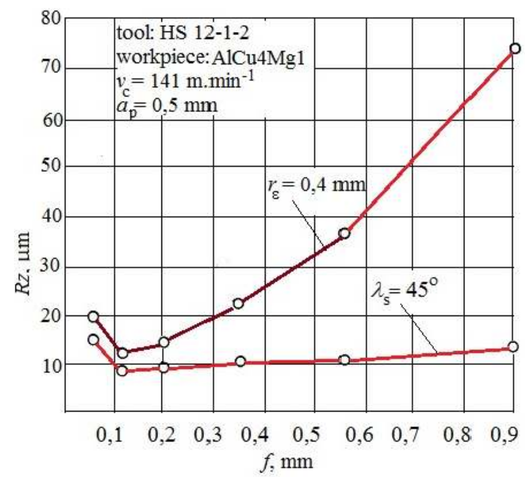

Fig. 4. Experimental dependences *R*z = f(*f*) for both tools

A visible difference of machined surface quality can be seen in Fig. 5. It illustrates an example of machined surface micro-geometry records after turning by both tools under the same cutting conditions with the feed of 0.69 mm. While turning by classical tool, Rz sharply increases with the feed except for the feeds smaller than 0.1 mm. The curve for helical tool rises very mildly. Rz does not reach the value of 15 μm even at the feed of 0.9 mm. For turning with a classical cutting tool, the record shows a visible size of a feed. It is not possible to identify the feed on the record on upper record. Only micro-irregularity of cutting edge transformed into machined surface can be visible.

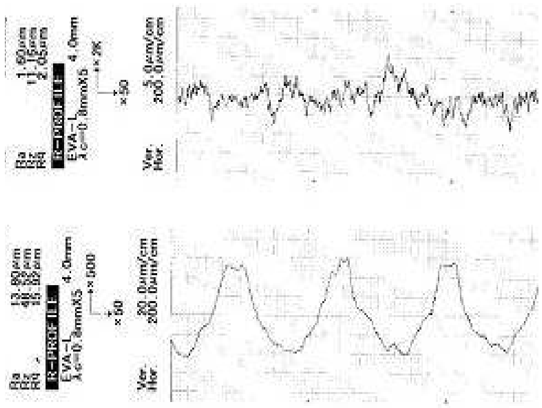

Fig. 5. Record of the profile of machined surface by helical cutting edge tool (up) and by classical tool with tip radius (down)

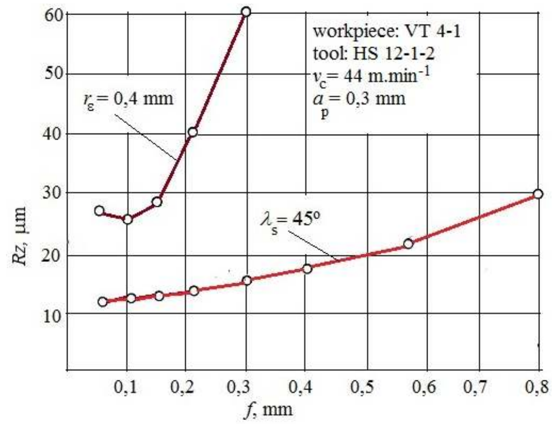

Fig. 6. Experimental dependences *R*z = f(*f*) for both tools

3.2 Machining of Titanium

Titanium (VT 4-1) is the material with high stiffness and toughness, low heat conductivity, high friction coefficient with other metals as well as with machined material [14].

Tests of turning with a classical tool made of high-speed steel (HS-12-1-2) with tool tip radius r_ε=0.4 mm and a tool with helical cutting edge with helix angle ω=20° were performed. The results, as well as the dependence of *Rz* - *f* are shown in Fig. 6.

The upper curve presents a classical dependence corresponding to equation (1). However, it does not reach zero. The influence of cutting edge radius is visible if the feed *f* is smaller than 0.1 mm and then *Rz* slightly rises. The other part of the curve has parabolic course, i.e. *Rz* rises rapidly with the increase of the feed. The turning by a helical tool provides considerably higher quality of surface in whole range of used feeds. The slope of the curve is controlled by the relationship (2) and is almost linear. If we want to obtain, for instance *Rz* = 30 µm, a feed rate cca 0.15 mm is necessary for turning by classical tool. Identical *Rz* value can be obtained by a helical tool at the feed of 0.8 mm, i.e. 5-times larger feed. It means there is a massive reducing of machining time.

Fig. 7 presents machining process by used broken twist drill welded to the holder. The difference in the quality of machined surface can be seen in Fig. 7.

Fig. 7. View of machining process of turning titanium alloy

The left section of the workpiece has been turned with a classical tool of tool tip radius 0.4 mm. The tool marks of different feed rates are visible. The right section represents turning by helical tool. The surface has mirror-like shine. The chips shape corresponds with typical free cut. In Fig. 8 there is a view of formed chips. Chips are of considerable width that corresponds with the length of engaged cutting edge and the thickness corresponds with used feed.

Fig. 8. Shape of chips obtained at turning titanium alloy by a helical tool

3.3 Machining of Brass

The brass is characterised by a good heat conductivity, medium stiffness and elementary chip. It can be supposed that turning with tested tool can improve the quality of machined surface. An experimental workpiece with two visible sections is shown in Fig. 9. The section machined with a helical tool (left) is smoother; the size of the feed rate cannot be visibly identified by tool marks (grooves) as in case of right section made by classical cutting tool.

Experimental dependences are shown in Fig. 10.

Fig. 9. Machined sample - turning by helical tool (left) and by tool of tip radius 0.4 mm

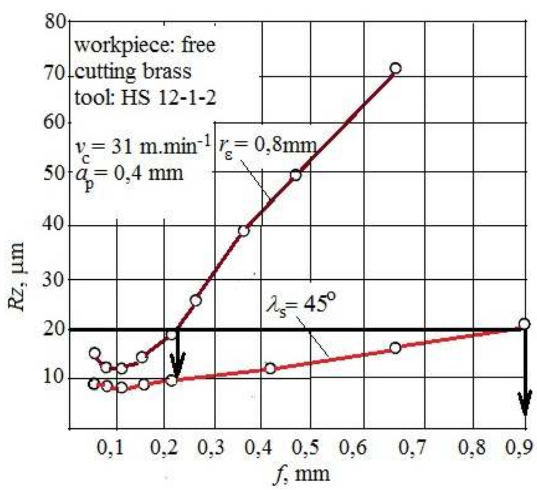

Fig. 10. Experimental dependences *R*z = f(*f*) for both tools

Similarly to previous materials, a helical tool helps to reach higher quality of machined surface. The difference in values of *Rz* rises with the increase of the feed. For example, at the feed of 0.65 mm, for the classical tool, *Rz* is 65 µm, for the helical one it is only 16 µm. Therefore this method of turning is suitable for large feeds.

4. CONCLUSIONS

The experimental verification of turning by helical cutting edge tools of selected workpiece materials showed the real possibility of a significant increase in the productivity of machining. For example, turning the brass (Fig. 10), the average maximum height of the machined surface profile *Rz* =20 µm is possible to achieve at feed rate of 0.2 mm using the classical turning tool with tool tip radius. A same *Rz* is achieved in turning by helical edge cutting tool at feed rate 0.9 mm what is 4.5 times larger feed rate and then the 4.5 times reduce of machining time. In fact, the helical cutting edge tool dependence curve *R*z = f(*f*) only slightly rises, comparing with that of tool tip cutting tool. It is due to the fact that the conditions of so called free cut are created. Moreover, the outgoing chip shape is different. It could reasonably be expected that even more significant results will be achieved using the tools of cemented carbide.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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