PARTICULARITIES OF SURFACE FORMATION BY UNCONVENTIONAL MACHINING OF ROTATING TURNING TOOLS

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Abstract

Self-propelled rotary turning tools and actively driven rotary tools are characterized by different chip formation and different conditions of surface layer. Chips creating after conventional machining is influenced by specific patterns and can be affected by the machining scheme as well as the tool durability. This is a possible replacement for the coating effect of tool functional surfaces. The paper is focused on the issue of the state of surface layers after the application of the unconventional turning scheme. The state of the surface layers is evaluated by X-ray diffraction.

Keywords: Coating effect, functional surfaces of tool, self-propelled turning tool, turning

1. INTRODUCTION

The increasing working parameters of the machines, the development of various fields of technology lead to an increasing use hard-to-machine materials. These are materials with high strength, hardness and materials with specific physical properties. The machinability of such materials is the motive for the development of new cutting tool materials or their modifications. These provide for a favourable mutual interaction of the tool with the workpiece resulting in the required quality of the machined surface of the part. This process is linked to the requirement of machine economy, which increases when prolonging the cutting edge durability while shortening the times of major and minor activities. The main task is by the cutting tool, the material of its cutting part or its possible modification. Just the production and application of cutting tools means a qualitative leap in the development of cutting material materials. The application of coatings (TiN, TiC, TiAlN ...) and their multilayer combinations brings higher cutting edge durability. Such an adjustment, the effect of which is highly efficient, brings an extra cost to these modern new tools. The machining of tools rotating around their own axis is one of the perspective methods for turning, milling and shaping hard-to-machine materials. [1-3]

The principle of rotating tools

Today we know two basic ways of acting the rotary tools. Tools whose rotation is secured by the friction forces between the workpiece and tool surfaces (friction of the tool's head and the back of the machined surface). Such tools are known as self-cutting tools or tools that have an active motion from a special drive. The tooling diagrams for the individual machining modes are shown in **Figure 1**.

Machining of hard-to-machine materials is associated with high cutting forces and a significant thermal load on the cutting edge. The high strength of the cutting edge of such geometry tools is also an important feature of the tool that supports such an application. [2,4]

To ensure continuous rotation, the circular tool is adjusted with respect to the main motion vector under a sufficiently large angle of inclination of the cutting edge λ_s (**Figures 1** and **2**). The circular cutting edge, which has one degree of freedom after setting, causes the chip-forming process to be much more complicated than with conventional turning. From a kinematic machining scheme, see a significant difference in chip formation. This method achieves the effect of reducing the friction between the chip and the tool. This effect will substantially increase the durability of the cutting edge. The use of the method is to a certain extent influenced by the desired shape of the machined surface as well as the design of a suitable tool construction. [5-7]

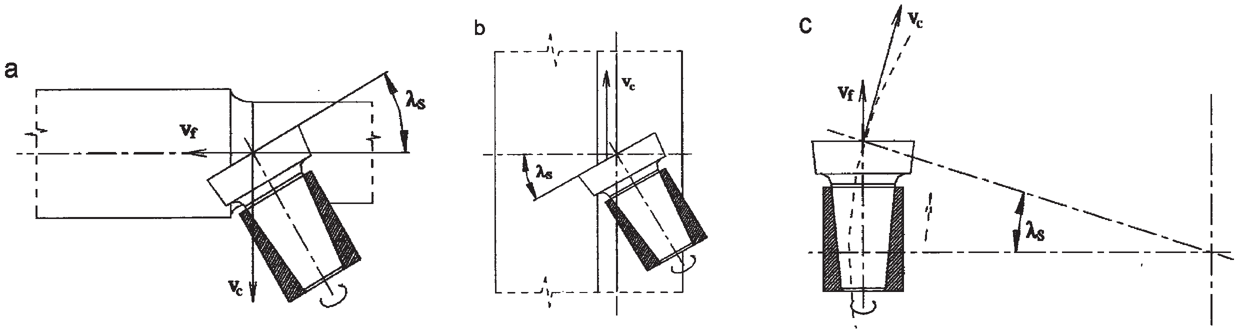


Figure 1 Scheme of rotating tools for: a) Turning, b) Planing, c) Milling

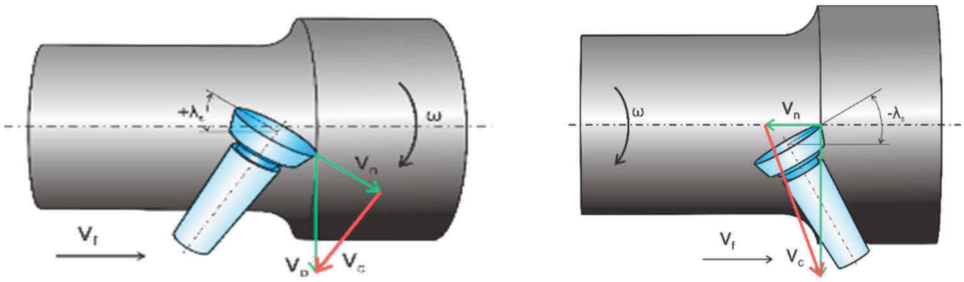


Figure 2 Model of the tool setting at different angles of the cutting edge

An important advantage of this machining method is the reduction of friction on the active surfaces of the tool. This affects favorably the durability, the formation of chips, the resulting cutting speed, which affects the temperature in the cutting zone, the force ratios, from which it can be deduced and the experiment confirming that a surface layer is produced, the roughness of which is beneficial and the properties of the subsurface layer are favorable. [5,8]

The rotation-affected final cutting speed "*w*" can be determined by calculating:

$$w = \frac{v \,.\, cos\lambda_s}{cos\lambda_{se}} \quad \text{when} \quad \lambda_{se} = \lambda_s - \lambda_t \tag{1}$$

$$\lambda_t = \frac{v_n \,.\, cos\lambda_s}{v - v_n \,.\, sin\lambda_s} \tag{2}$$

$$w = v\,(1 - 2.\xi.sin\lambda_s + \xi^2)^{\frac{1}{2}} \quad \text{when} \quad \xi = \frac{v_n}{n} \tag{3}$$

where:

W - vector of the resulting cutting motion (m·min^{-1})

λ_s - the angle of the main cutting edge (°)

v_n - circumferential rotational speed of the tool (m·min^{-1})

v - cutting speed (m·min^{-1})

ξ - coefficient of proportionality

Experiments have been performed to indicate the rotation speed of the "v_n" tool. This depends primarily on the angle of inclination of the cutting edge λ_s. This angle greatly affects the size of the deformation of the chips. The problem of chip formation is the combined state of the surface layer of the machined surface. In this context, the most important issues are deformation and friction. Work of deformation and friction changes in heat in the cutting process, the temperature of the machined material and the tool increases, thereby changing their properties. Turning the rotating tool from the point of view of chip formation is significantly different from turning with a conventional tool. Due to the special kinematic machining scheme, it can be expected that turning the knife will reduce the deformation of the chips. [5,6,9]

2. SETUP OF EXPERIMENTS

Turning: *Lathe: SN 55*

Tool: self-propelled turning tool a static turning tool - steel 19 855.5

tool radius - R_n = 17.5 mm, α_n = 12°

workpiece: 12 050.1

geometry and turning parameters:

the angle of the main cutting edge - λ_s (30°; 40°; 45°; 50°),

the normal angle of the tool face - γ_n (0°; 5°; 10°; 15°),

cutting speed - v_c (27; 58.2; 85.2; 121.2) m·min^{-1}

tool feed - *f (0.12; 0.24; 0.48; 0.56; 0.8; 1.0) mm*

depth of cut - a_p = 0.3 mm

Chamfers were studied during turning. The chip shapes trapped in the static and rotary tool are shown in **Figure 3.**

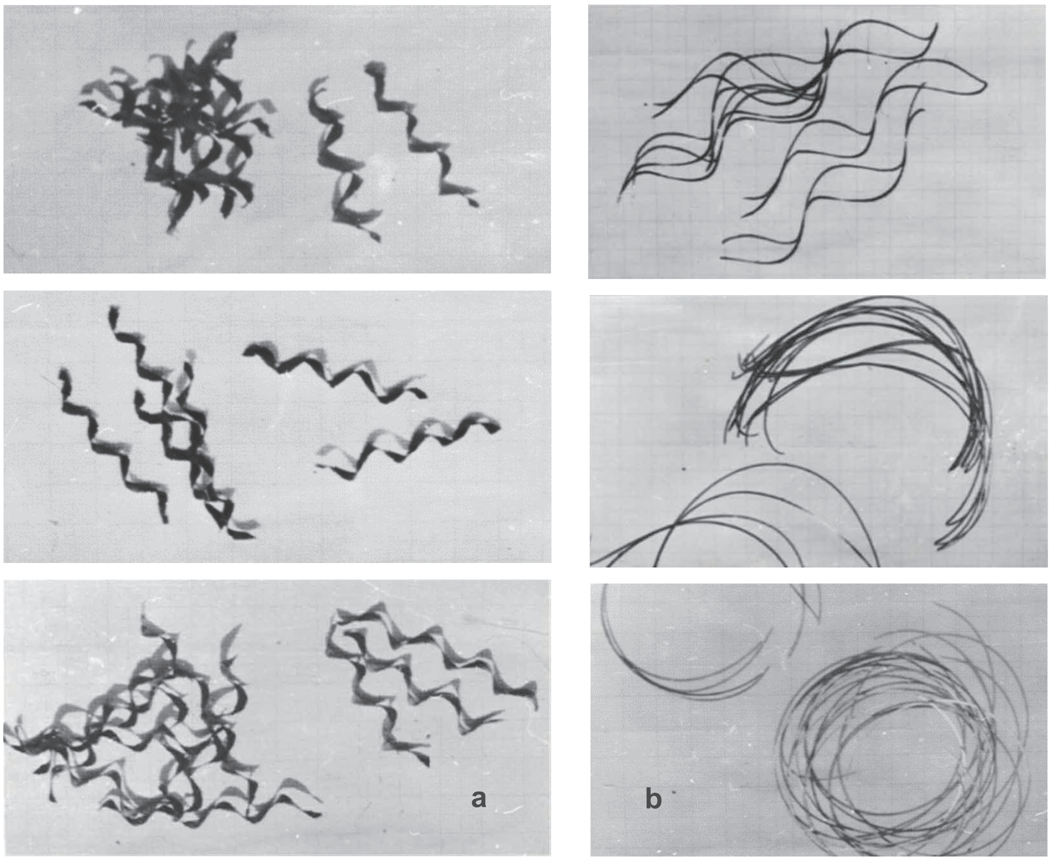
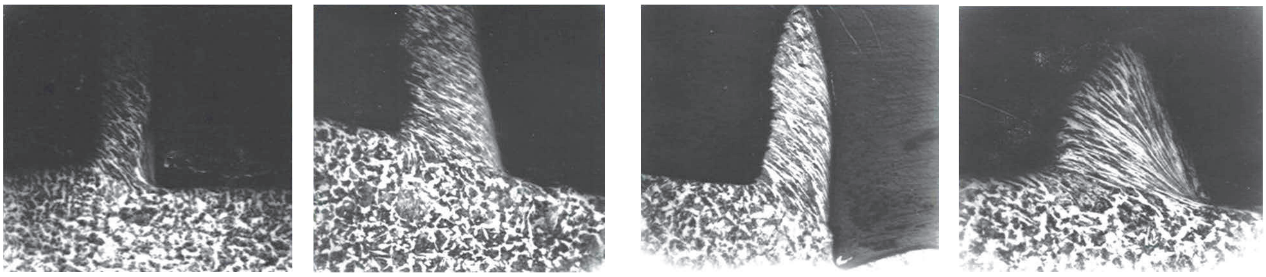


Figure 3 Shapes of chips a) static turning tool, b) self-propelled turning tool. (v_c = 44.4 m·min^{-1}; f = 0.48 mm; a_p= 0.3; λ_s = 30°; 40°; 50°; γ_n= 5°)

Chip formation was studied by capturing roots of chips under free cutting conditions using a special preparation. The micrographs of the roots are shown in **Figure 4.**



a b

Figure 4 Roots of chips a) *static turning tool*, b) *self-propelled turning tool* zoom 50x, (λ_s = 30°, 40°)

Micrographs capturing the metallographic cuts of the chip chamfer formation with self-propelled turning tool at angles λ_s = 30° and λ_s = 40° are not visible traces of increase. With the increasing angle λ_s, the plastic deformation of the material decreases, as evidenced by the β_1 angles. On the photomicrographs of the roots of the chips obtained during the work of the static turning tool, the braced layer of the material can be clearly distinguished, while the increase is more intense for λ_s = 30°.

- A comparison of the characteristics for the self-propelled turning tool and static turning tool can be seen in a substantial reduction of the chip compression "*k*" at the rotary tool. This may be explained by a different kinematic cutting scheme. Tool rotation has a significant effect on reducing the friction coefficient between the chip and the face of the tool.
- It can generally be noted that, as with conventional turning, even with the rotating tool, chip compression is changed by change the cutting conditions and geometry of the tool. With increasing cutting speed, feed rate, front angle, and cutting edge angle, the chip compression decreases.

Residual stress study:

Residual stresses were evaluated using an X-Ray diffractometer. The measurement was made by means of a positioning table perimeter at 36 points, after 10° as shown in **Figure 6**. The non-destructive measuring device X-Ray diffractometer is shown in **Figure 5**

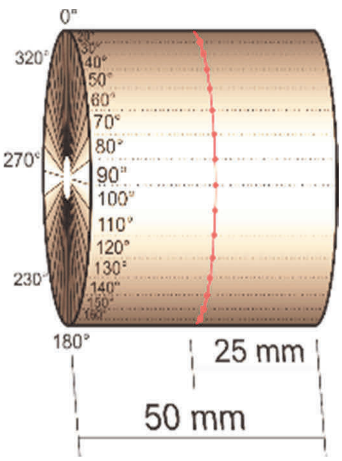


Figure 5 Scheme of measurement residual stress

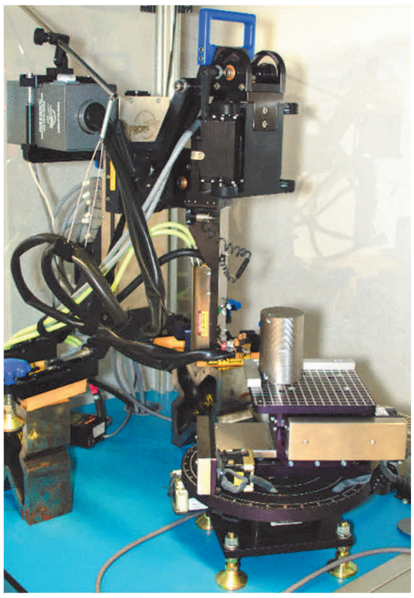


Figure 6 Non-destructive measuring device X-ray diffractometer

The average value of the 36 measurements on the workpiece by the said unconventional machining scheme is given in **Table 1**. **Table 2** shows the values after machining with a conventional knife (WNMG 0604 12).

Table 1 Results of residual stress with self-propelled turning

Depth of cut a_p (mm)	Feed f (mm)	Angle of cutting edge λ_s (°)	Residual normal stress (MPa)	Residual shear stress (MPa)	FWHM
0.5	0.45	30	127.14 ± 13.33	-126.10 ± 6.67	2.79
	0.90		125.25 ± 14.19	-125.68 ± 14.19	2.81
	0.45	45	189.73 ± 12.84	-118.96 ± 6.71	2.80
	0.90		247.98 ± 14.32	20.14 ± 7.16	2.83
	0.45	50	228.26 ± 11.14	12.70 ± 5.59	2.76
	0.90		564.35 ± 43.48	-146.79 ± 21.76	2.73

Table 2 Results of residual stress with conventional turning

Depth of cut a_p (mm)	Feed f (mm)	Residual normal stress (MPa)	Residual shear stress (MPa)	FWHM
0.5	0.45	435.47 ± 56.48	-102.11 ± 28.25	3.35
	0.90	613.95 ± 25.49	-35.09 ± 12.76	3.04

3. EVALUATION OF RESIDUAL STRESSES

Experimental residual stress measurement under all conditions has a tensil character. Such orientation of residual stresses in the material can lead to cracks. For the comparison of the stresses, experimental measurements were made under the same conditions as a conventional turning tool. The smallest internal stresses were achieved by setting the tool at an angle λ_s = 30° and feed f = 0.9 mm, where the residual stresses introduced into the material were 125.25 ± 14.19 MPa.

4. CONCLUSION

The highest residual stress was achieved using a conventional tool at feed rate f = 0.9 mm. The residual stress was 613.95 ± 25.49 MPa. Acceptable residual stress values were achieved under all tested unconventional tool conditions up to λ_s = 50° and feed f = 0.9 mm, where the residual stress was 2 - 3 times higher than the other measurements. The size of residual stress under the conditions mentioned was 564.35 ± 43.48 MPa. For the optimal cutting conditions in terms of residual stresses introduced into the material, a larger experiment would have to be carried out at different cutting speeds and cutting edge. Also, the size of the secondary cutting motion (feed f) has a significant effect on residual stresses. **Table 1** and **Table 2** also evaluates the FWHM parameter for which the chip machining does not have a significant effect. This parameter reflects the particle size of the material structure, and therefore the machining method does not affect it.

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