SURFACE INTEGRITY EVALUATION OF TURNING WITH AUTO-ROTATING TOOL

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ABSTRACT

The technical practice requirements come to have increased demands on higher productivity, speed and quality of the machining process of various materials. Hard to machine materials, whose machining led to the development of turning with rotating cutting edge are not an exception. The machining process of auto-rotating tool is more complicated than the conventional process of turning, especially for the process of reshaping cutting layers into chips. There is a significant load in the system, that may affect the life of the cutting edge of the tool as well as the whole system and also in the final extent of the qualitative parameters of the workpiece (product/product). The article specifies the knowledge and findings of measurement in machining material 100Cr6 with an auto-rotating tool. The measurements were conducted to evaluate the integrity of the surface (roughness) of the workpiece to the impacts of cutting conditions, in particular the feed and the cutting edge inclination. It also analyzes the presence (size, character, action) of residual stresses concentrated in the surface layers of the workpiece by changing the cutting conditions.

Keywords: residual stress, turning, roughness, autorotation-tool, surface.

INTRODUCTION

In relation to the cause of rotary motion of the tool in the machining process, the authors divided these tools into two basic groups:

- forced rotation tools,
- auto-rotating tools [1, 2].

Tools with forced rotation has the motion enabled by a standalone drive. The tools of another group are forced to rotary motion by friction between contact surfaces of the tool and workpiece. Both of the tool motion principles can be used in:

- turning (as turning tools),
- planing (as planing tools),
- milling (as milling tools) [1, 3, 4].

MEASUREMENT OF RESIDUAL STRESS

From the theory of elasticity the relationship between residual stress (σ) and strain (ε) on the sample surface under plane stress is given by the Bragg equation, \( \lambda = 2d \sin \theta \), relating incident X-ray wavelength (λ), lattice inter-planar spacing (d) and diffraction angle (θ) (Fig. 1).

The direction of maximum residual stress that can be tensile or compressive, is assumed to occur in the cutting or grinding direction during most machining operations [5, 6, 7].
CONDITION OF THE EXPERIMENT

The experiment was performed on lathe SUI 40. Cutting parameters set was based on previous experiment, as constant revolutions and depth of cut: \( n = 600 \text{min}^{-1} \), \( a_p = 0.5 \text{mm} \), angle of cutting edge \( \lambda_s = (30^\circ, 45^\circ, 50^\circ) \), feed \( f = (0.3; 0.45; 0.7; 0.9) \text{mm} \). Workpiece diameter \( d = 50 \text{mm} \). Based on theoretical calculation of roughness [1, 8, 9], we continued on roughness parameters verification. Subsequently, after performed experiments we detected the residual stresses of machined surface by unconventional tool with a circular rotating disc. Roughness measurement was set in accordance with DIN EN ISO 4288: 1988. Position of the tool to the workpiece has a negative angle on the cutting edge as shown in Figure 2 [1, 10, 11, 12].

Next, the results were made using a Mitutoyo SJ 400, residual stresses in the surface layer was measured by X-ray diffractometer PROTO iXRD which is shown in Figure 3. The depth of the penetrating X-ray beam is 8-12 microns, depending on the voltage on the lamp. Machined material was bearing steel 100Cr6, [14, 15, 16], the microstructure is shown in Figure 4.

RESULTS OF EXPERIMENTS

Record of roughness measurement under cutting conditions \( \lambda_s = 30^\circ \) and feed \( f = 0.45 \text{mm} \) is shown in Figure 5a and cutting conditions \( \lambda_s = 50^\circ \) and feed \( f = 0.9 \text{mm} \) is shown in Figure 5b.

For selected parameters the three-dimensional roughness diagrams were constructed that are shown in Figure 6. The selected numerical values of these measurements are shown in Table 1. The surface roughness is calculated as the arithmetic mean of the three measurements. The advantage of these diagrams is that they show the overall progress of roughness depending on the inclination of the cutting edge \( \lambda_s \) and feed \( f \).

| Feed f [mm] | \( \lambda_s = 30^\circ \) | \( \lambda_s = 45^\circ \) | \( \lambda_s = 50^\circ \) |
|-------------|-----------------|-----------------|-----------------|
| f=0.45      | R_a=5.50        | R_a=4.06        | R_a=2.34        |
| f=0.9       | R_z=30.30       | R_z=20.87       | R_z=14.83       |
| f=0.45      | R_a=2.10        | R_a=2.31        | R_a=2.34        |
| f=0.9       | R_z=12.00       | R_z=13.27       | R_z=14.83       |
| f=0.45      | R_a=2.34        | R_a=2.34        | R_a=6.59        |
| f=0.9       | R_z=14.83       | R_z=20.40       | R_z=30.30       |

Table 1. Surface roughness parameters
Chosen parameters of the average values of residual stresses were processed into Table 2. The mean value of 36 measurements were carried out in 10° by rotating the sample as shown in Figure 7.

By residual stress measuring several parameters were monitored such as normal residual stress, shear stress and FWHM parameter. Tension $\sigma$ is the normal stress relative to sample surface. FWHM is fullwidth at half maximum and determines the width of Gaussian distribution.

For the selected cutting conditions the graph of residual stresses was made, depending on the cutting conditions and angular rotation. The graph of residual stresses is shown in Figure 8 and 9.

Table 2. Residual stress values in turning with rotary tool

| Depth of cut $a_0$ [mm] | Feed $f$ [mm] | Angle of the cutting edge [$^\circ$] | Residual stress $\sigma$ [MPa] | Shear stress $\tau$ [MPa] | FWHM [$^\circ$] |
|-------------------------|---------------|----------------------------------|-------------------------------|--------------------------|---------------|
| 0.5                     | 0.45          | 30                               | 127.14 ± 13.33               | -126.10 ± 6.67           | 2.79          |
|                         | 0.9           | 30                               | 125.25 ± 14.19               | -125.68 ± 14.19          | 2.81          |
|                         | 0.45          | 45                               | 189.73 ± 12.84               | -118.96 ± 6.71           | 2.80          |
|                         | 0.9           | 45                               | 247.98 ± 14.32               | 20.14 ± 7.16             | 2.83          |
|                         | 0.45          | 50                               | 228.26 ± 11.14               | 12.70 ± 5.59             | 2.76          |
|                         | 0.9           | 50                               | 564.35 ± 43.48               | -146.79 ± 21.76          | 2.73          |
CONCLUSIONS

From the experiment results, the lowest values of the roughness parameters $R_a$, $R_z$, are achieved with an angle of inclination $\lambda_s = 45^\circ$. Feed rate $F$ does not have such a significant impact, which in the feed $f = 0.45$ mm, the value of $R_a = 2.1\mu$m and $R_z = 12\mu$m. When feed $f = 0.9$ mm, the value of $R_a = 2.31\mu$m and $R_z = 13.27\mu$m. The worst results of surface quality were with $\lambda_s = 50^\circ$ and feed $f = 0.9$ mm where the $R_a$ parameter had the value $6.59\mu$m. $R_z$ for evaluation parameter was the worst quality achieved at $\lambda_s = 30^\circ$, and feed $f = 0.45$ mm, where the measured value was $30.3\mu$m.

In the evaluation of residual stress the best results were achieved when $\lambda_s = 30^\circ$. Feed rate at the cutting edge angle has no significant impact on the size of the introduced stress into the material. Stress magnitude was around $125\text{MPa}$. All measurements of residual stresses using auto-rotary
tools should have tensile character (determined by “+” sign), indicating the possible formation of cracks in the surface layers. Compared to the forged outer bearing ring, the compression stress in turning in component predispose a longer life [4]. With the increasing inclination of the cutting edge increases the impact of displacement on the size of residual stresses. Tested at maximum slope ʎs = 50°, the value stresses at the feed f = 0.45 mm 228MPa and at a feed f = 0.9 mm was worth more than 2 times higher σ = 564MPa.

The treatments of the material does not affect the FWHM parameter, because this parameter reflects the granular structure of the material.

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