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Research Article

SURFACE INTEGRITY EVALUATION OF TURNING WITH AUTO-ROTATING TOOL

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ABSTRACT

The technical practice requirements comes 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].

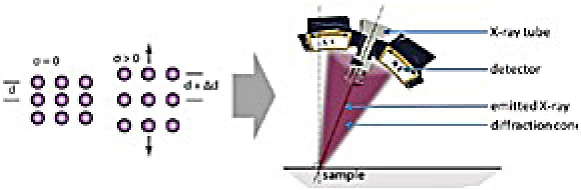

Fig. 1. Principle of measuring of residual stress by X-ray diffractometry based on Brag's Law [5]

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 = 600min^{-1}, a_p = 0.5mm, angle of cutting edge λ_s = (30°,45°,50°), feed f = (0.3; 0.45; 0.7; 0.9)mm. Workpiece diameter d = 50 mm. Based on theoretical calculation of roughnes [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].

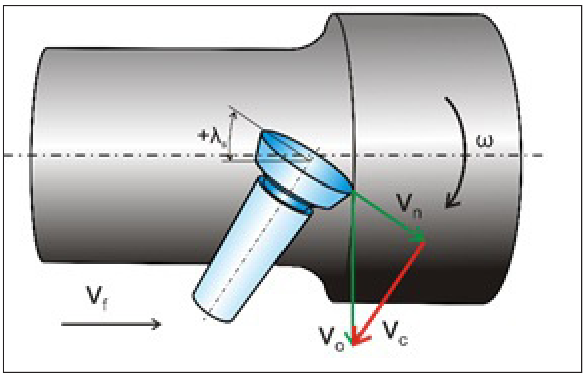

Fig. 2. Tool position relative to workpiece, negative angle λ_s [13]

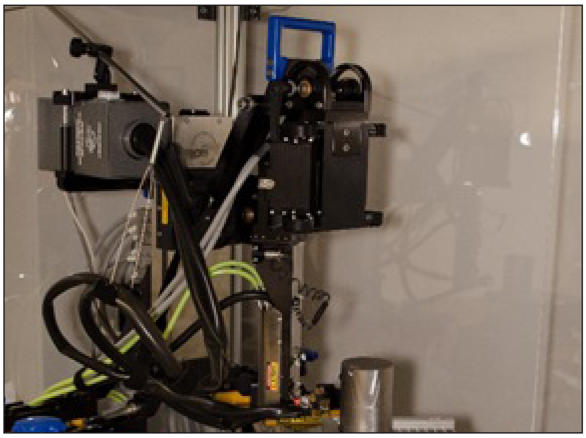

Fig. 3. Process of residual stress measurement with XRD diffractionmeter

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.

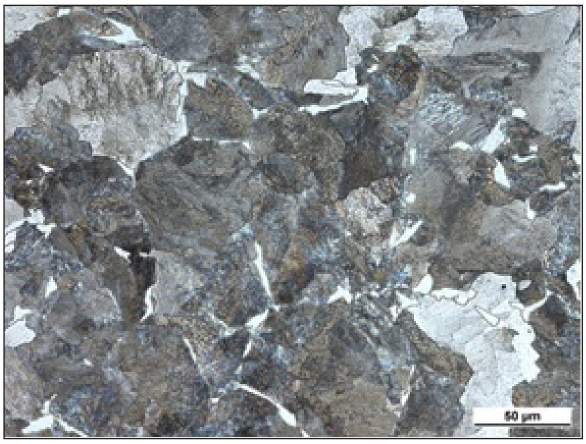

Fig. 4. Microstructure of bearing steel 100Cr6

RESULTS OF EXPERIMENTS

Record of roughness measurement under cutting conditions λ_s = 30° and feed f =0.45 mm is shown in Figure 5a and cutting conditions λ_s = 50°and feed f =0.9 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 λ_s and feed f.

Table 1. Surface roughness parameters

Feed f [mm]	λ_s=30°		λ_s=45°		λ_s=50°	
	f=0.45	f=0.9	f=0.45	f=0.9	f=0.45	f=0.9
Ra [µm]	5.50	4.06	2.10	2.31	2.34	6.59
Rz [µm]	30.30	20.87	12.00	13.27	14.83	20.40

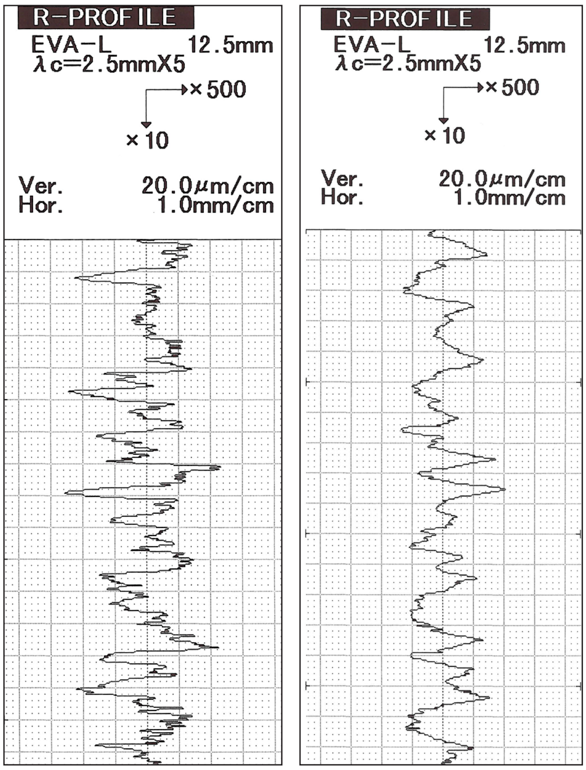

Fig. 5. Roughness graphs of surface machined with rotary tool: $\kappa_s = 30°$, f = 0.45 mm (left) and $\kappa_s = 50°$, f = 0.9 mm (right)

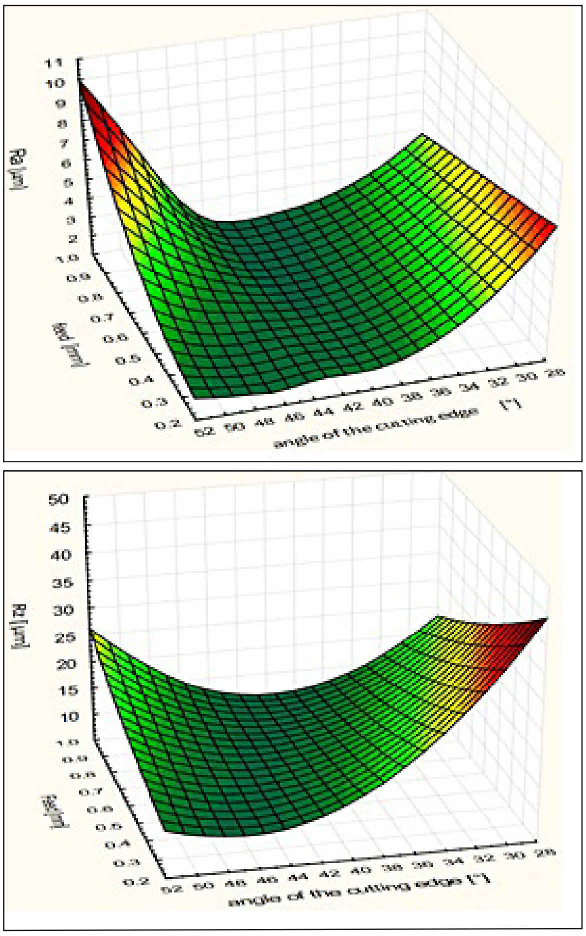

Fig. 6. Roughness parameter Ra in turning with auto-rotary tool (above) and roughness parameter Rz in turning with auto-rotary tool (below)

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 σ 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.

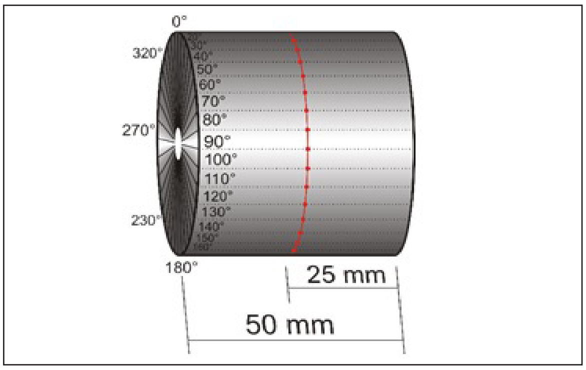

Fig. 7. Position of measured points for X-ray diffraction

Table 2. Residual stress values in turning with rotary tool

Depth of cutt a_p [mm]	Feed f [mm]	Angle of the cutting edge [°]	Residual stress σ [MPa]			Shear stress τ [MPa]			FWHM [°]
0.5	0.45	30	127.14	±	13.33	-126.10	±	6.67	2.79
	0.9		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		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		564.35	±	43.48	-146.79	±	21.76	2.73

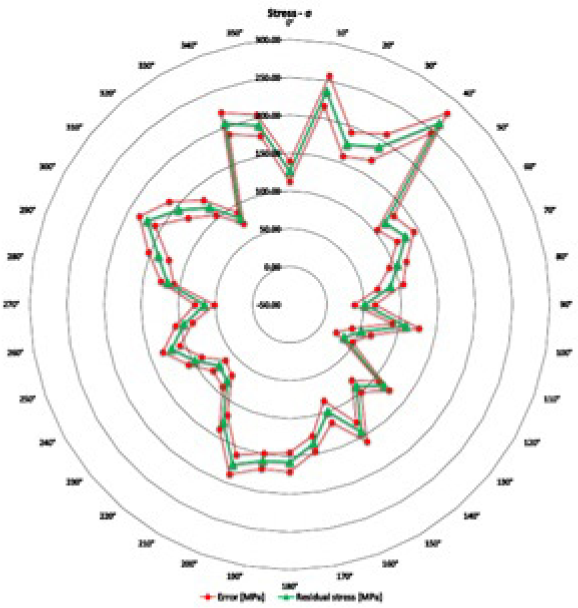

Fig. 8. Residual stress graph with cutting parameters λ_s = 30°, f=0,45 mm

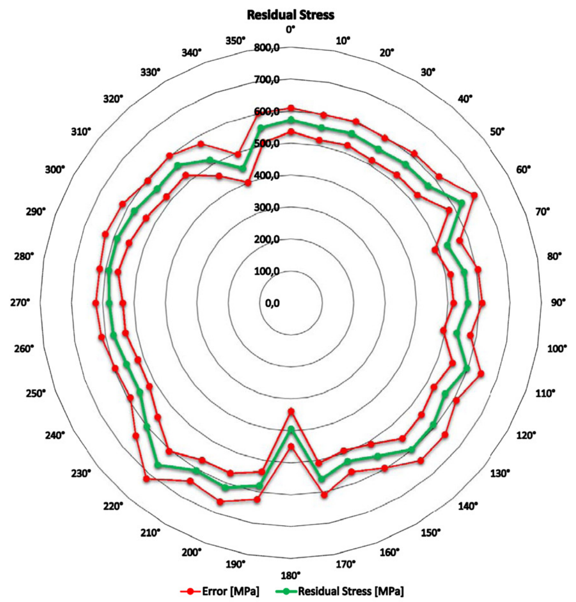

Fig. 10. Residual stress graph with cutting parameters λ_s = 50°, f=0,9 mm

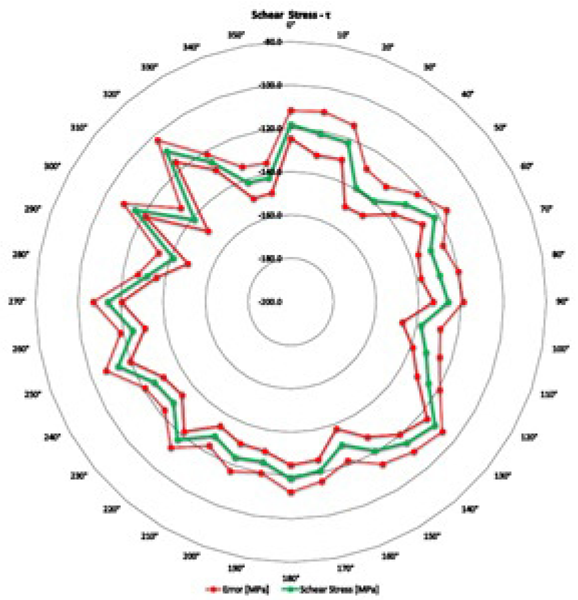

Fig. 9. Shear stress graph with cutting parameters λ_s = 30°, f=0,45 mm

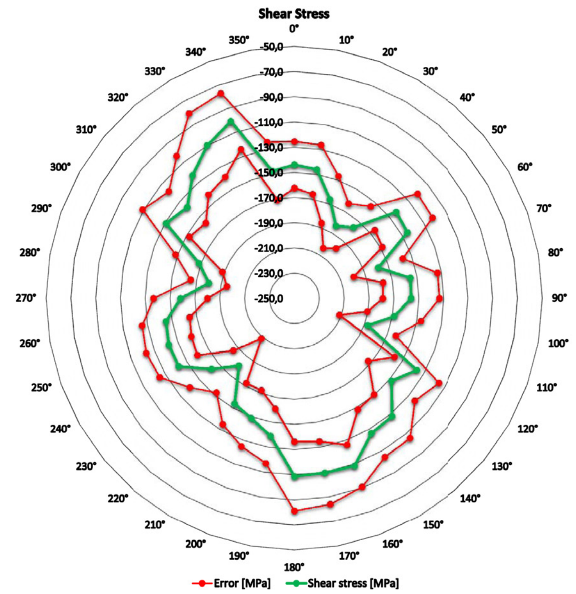

Fig. 11 Shear stress graph with cutting parameters λs = 50°, f=0,9mm

CONCLUSIONS

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

In the evaluation of residual stress the best results were achieved when λs = 30 °. Feed rate at the cutting edge ange has no significant impact on the size of the introduced stress into the material. Stress magnitude was around 125MPa. 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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