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INVESTIGATION ON COHERENCIES BETWEEN RESIDUAL STRESSES AND TOOL GEOMETRY BY HARD TURNING

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A wide group of scientists are concerned by the studying of chip removal in hard turning even today. The reason for that is that the cutting conditions must be chosen accurately to exploit the benefits provided by hard turning. Among the parameters influencing the material removal, the edge geometry of the cutting tool also plays a decisive role since the effective chip removal is ensured by a special edge formation made from a hardened surface of about 60 HRC hardness. In this paper the effect of the tool rake angle on the chip removal process is investigated, examining a relatively wide interval of the rake angle value.

Keywords: hard turning, residual stresses, rake angle

Introduction

To choose the cutting tool with a proper edge geometry, the research experience gained so far through the examinations of the characteristics of workpieces and tools must be taken into account. When applying PCBN tools generally the negative rake angle is preferred often supplied with facets. The proper smoothness of the cutting edge is reached by honing after grinding and/or coating. The cutting edge geometry significantly affects the physical properties of the workpiece, the status of the tool wear and the residual stress in the surface of the workpiece. The change of the cutting edge has got the highest effect on the change of residual stress in the surface layer of the workpiece. However, there have been researches [1, 2, 3] on how the change of the rake angle concretely influences the stress condition, and that does not necessarily show linearity with the change of the rake angle. There were researchers who proved that a certain decrease of the value of the rake angle increased the compressive residual stresses, but with a further increase a lower compressive stress remained [1, 3].

Residual stresses in case of hard turning

Residual stresses play a very important role in the research of the surface quality. The surface structure characteristics are considered the most important part of the surface quality. The most important technical components of the surface quality can be seen in *Fig. 1*. Kloos and Kaiser [2] researched residual stresses by various ways of manufacturing.

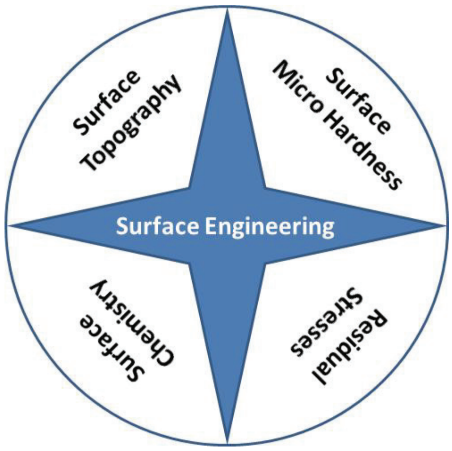


Figure 1: The most important areas of surface engineering [1]

However, they found residual stresses only in semi-finished and ready- machined parts. Residual stresses are in one respect static triaxial stresses, and stresses emerging from external mechanical effects (cutting force components and/or moments). They always develop in microscopic scale, in the direction of the cross- section of the multi- layered surface deformed plastically by external and internal forces [2]. The compressive residual stresses play the most important role in the surface layer. The most important consequence of the compressive residual stresses is their effect on the fatigue life [1, 3]. *Fig. 2* shows the possible causes of residual stresses.

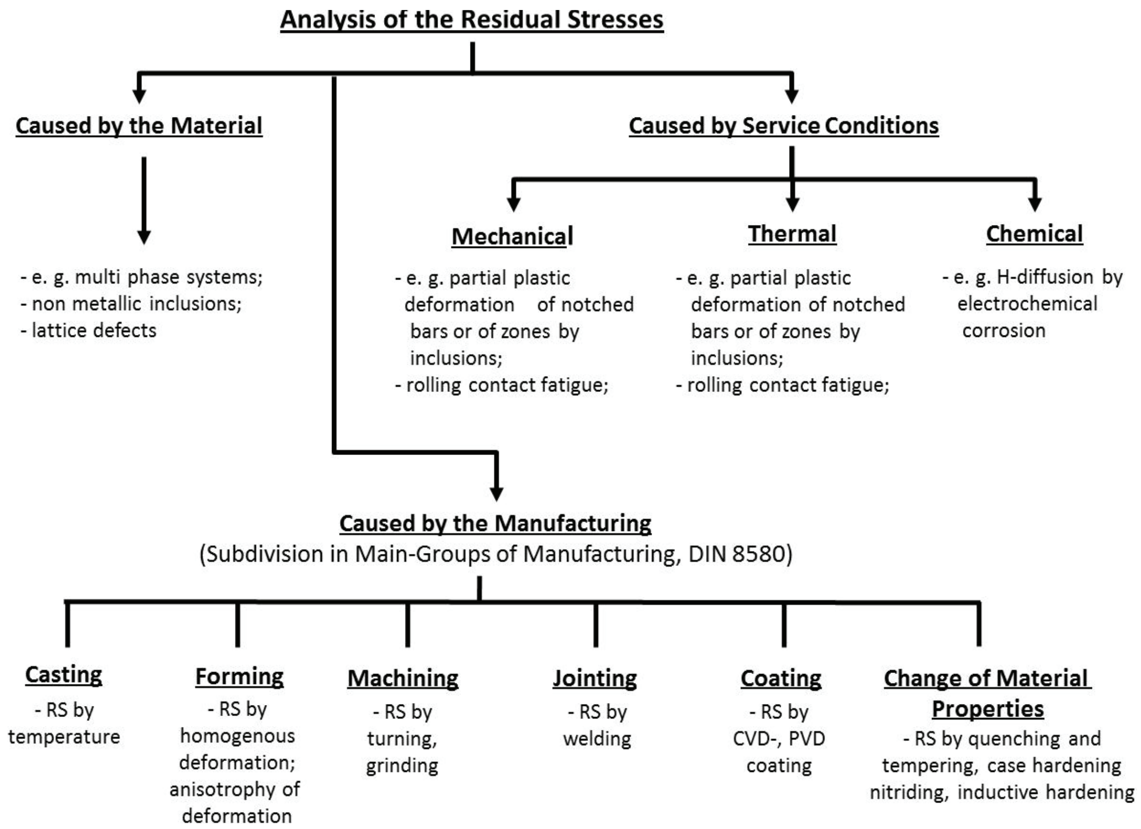


Figure 2: The causes of residual stresses [1]

Byrne et al. [1, 4] examined the behaviour of the residual stresses in case fine of finishing processes with geometrically defined cutting edges of hardened steels. Their opinion is that the values of the residual stresses are in dependence of the value of friction between the workpiece and the cutting tool [4]. Dahlman et al. [5] researched the influence of the rake angle and cutting parameters on the residual stress of the workpiece surface in case of hard turning. The used material was hardened steel (AISI 52100) with the hardness 62 HRC [1, 4]. They researched the influence of the rake angle from -6° to -61°. In case of application -61°, the maximum values of compressive residual stresses were approximately six times higher than in case of -6° [1, 4]. Rech and Moisan [6] researched the mechanical stresses in case of hardened steels (27MnCr5) with hardness 850 HV (65.7 HRC). They researched the external conical surfaces of gears in mass production. According to their research the residual stresses are determined by the tool material, the tool coatings, the edge geometry and the various machining parameters [1]. The changes of the physical properties of the surface layer are due to the cutting force and the cutting temperature [1, 6]. The typical residual stress profile in the tangential direction can be seen in *Fig. 3* (v_c=110 m/min, a_p=0.1mm, f=0.1 mm/rev).

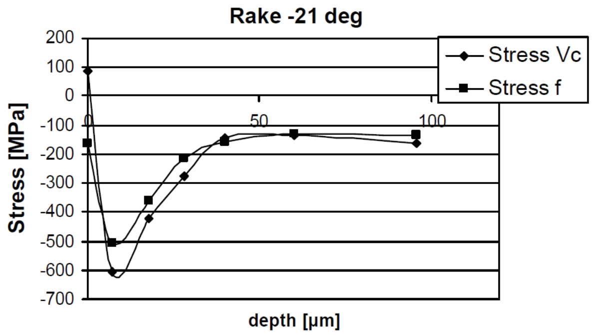


Figure 3: Residual stresses at rake angle of -21° [5]

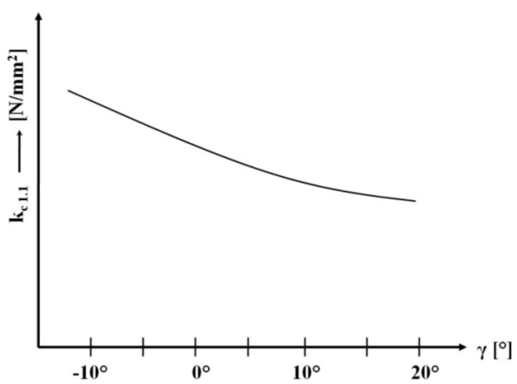


Figure 4: The unit cutting force in dependence of the rake angle [7]

Modelling of residual stresses with FEM-simulation in case orthogonal hard turning

The research of the residual stresses in case of orthogonal hard turning was executed with the application of Finite Element Method (FEM). The investigation of the rake angle change effect on the residual stresses in tangential direction was done by the 2D version of Third Wave AdvantEdge™ 5.5 program package, which is optimised for cutting process, therefore several researchers [8, 9, 10] use this software to simulate metal cutting. For the material quality 16MnCr5 (AISI 5115) used by us, we have to find the proper model of "deformation- stress" which has to meet two important requirements: high accuracy and a relative mathematical simplicity, because of quick computation. For the behaviour of the workpiece material used by us, a Johnson-Cook model was applied. This model is a strain-rate and temperature dependent, visco-plastic material model suitable for problems where strain rates vary over a large range (10^2–10^6 s^{-1}), and where the temperature changes due to plastic deformation caused by thermal softening [11]. We used the next form of the Johnson-Cook equation:

$$\sigma_{eq} = \underbrace{\left(A + B \cdot \bar{\varepsilon}^n\right)}_{Elasto-plastic\ term.} \cdot \underbrace{\left(1 + C \cdot \ln\left(\frac{\dot{\bar{\varepsilon}}}{\dot{\bar{\varepsilon}}_0}\right)\right)}_{Viscosity\ term.} \cdot \underbrace{\left(1 - \left(\frac{T - T_{room}}{T_{melt} - T_{room}}\right)\right)^m}_{Softening\ term.} \quad (1)$$

where σ_{eq} is the equivalent stress, $\bar{\varepsilon}$ is the plastic strain, $\dot{\bar{\varepsilon}}$ is the plastic strain rate, $\dot{\bar{\varepsilon}}_0$ is the reference plastic strain rate, T is the temperature of workpiece, T_{melt} is the melting temperature of workpiece material, T_{room} is the room temperature, coefficient A is the yield strength, B is the hardening modulus, and C is the strain rate sensitivity coefficient, n is the hardening coefficient, and m is the thermal softening coefficient. For the definitions of designations showed above, and their interpretation we cannot give more details because of lack of space, they can be found in the quoted literature [1, 2, 3, 4, 6, 8]. The values of the parameters of Johnson-Cook equation for material 16MnCr5 are: σ_{eq}=400 MPa; A=588 MPa; B=680 MPa; C=0.057; n=0.4; m=0.7 [11]. The process parameters of the experiment are listed in *Table 1*.

Table 1: FEM-software input parameters

Workpiece	
Workpiece length	5 mm
Workpiece height	3 mm
Workpiece material	Cubic Boron Nitrid
Tool	
Rake angle	+15°…-30°
Rake face length	3.0 mm
Relief angle	6°
Relief face length	3.0 mm
Cutting edge radius	0.01 mm
Material	20MnCr5
Simulation	
Max. number of nodes	24 000
Max. element size	0.1 mm
Min. element size	0.01 mm
Process	
Depth of cut (ap)	0.2 mm
Length of cut	3 mm
Feed	0.2 mm/rev
Cutting speed	180 m/min
Friction coefficient	0.35
Coolant	Not used

The effect of the rake angle on the residual stresses

In our investigations the effect of the rake angle was analysed in the interval of 0 – -26° in 5 degree steps. The results of FEM-analysis of the tangential residual stresses in the hard turned workpiece surface can be seen in *Fig. 5*. On the left side of the figures *(Fig.* 5, *6,* and *7)* the processed tangential residual stresses are shown at different values of depth (0–150 μm) of the machined surface layer. On the right side of the figures the colour FEM-results of the machining process can be seen. At the value of as γ_o=0° the effect compressive residual stresses emerge in the surface layer. It is characteristic that starting from a small value of tensile stresses in the surface layer even at a small depth high compressive residual stresses are present. Reducing the rake angle, the maximum value of the compressive stress increases. Reaching the γ_o=-25°rake angle the value of the compressive stress increases from 800 MPa to 1200 MPa that is to its half as big again at the examined depth of surface. The presence of the compressive stresses is beneficial since it means the hardening up of the surface layer, which is advantageous for the life of the components built in the structure (Fig. 5-6). The compressive stresses are highly important for the hardening of the material surface. Therefore it is worth applying a negative rake angle in the researched rake interval (γ_o = 0 – -25°) in case of hard turning, by all means. Having a tool with γ_o=-20°, the change of the stress condition of the workpiece was examined depending on the distance from tool tip. The change depending on the depth of the surface layer is shown in Fig. 5.

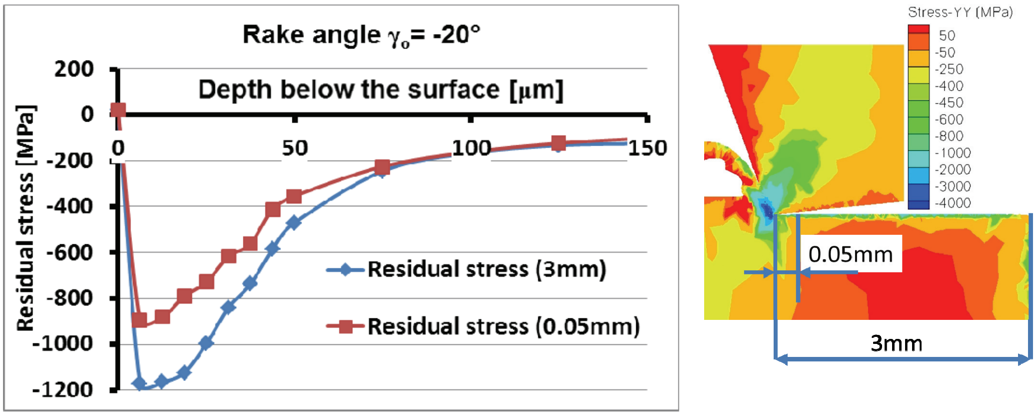
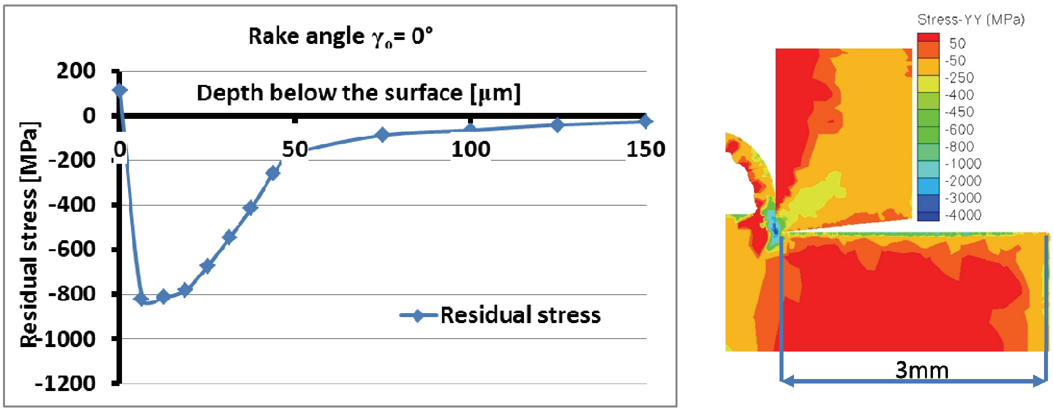
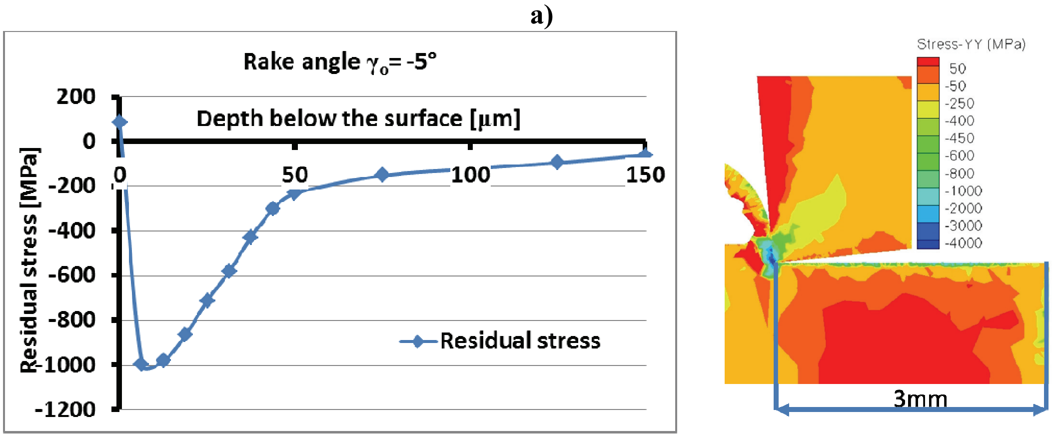


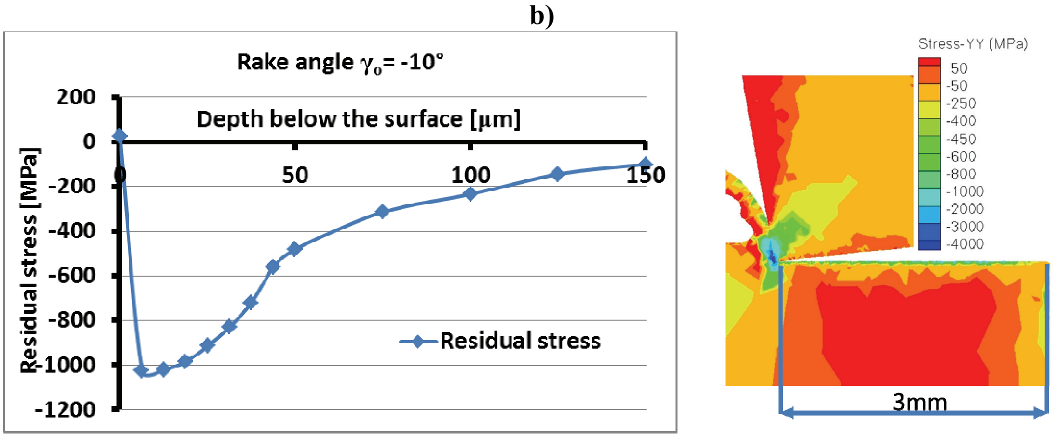
Figure 5: The change depending on the depth of the surface layer (γ_o=-20°)



a)

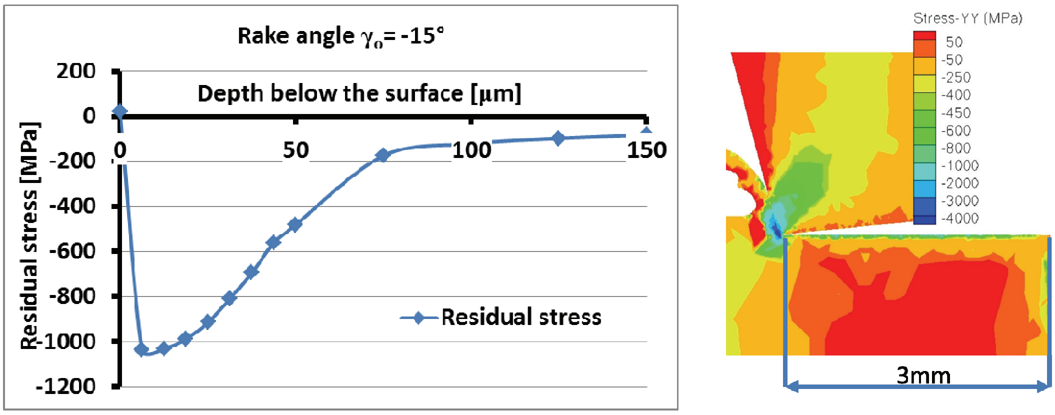


b)



c)

Figure 6: The change of the residual stress depending on the depth of the surface layer
(a: γ_o=0°; b: γ_o=-5°; c: γ_o=-10°)



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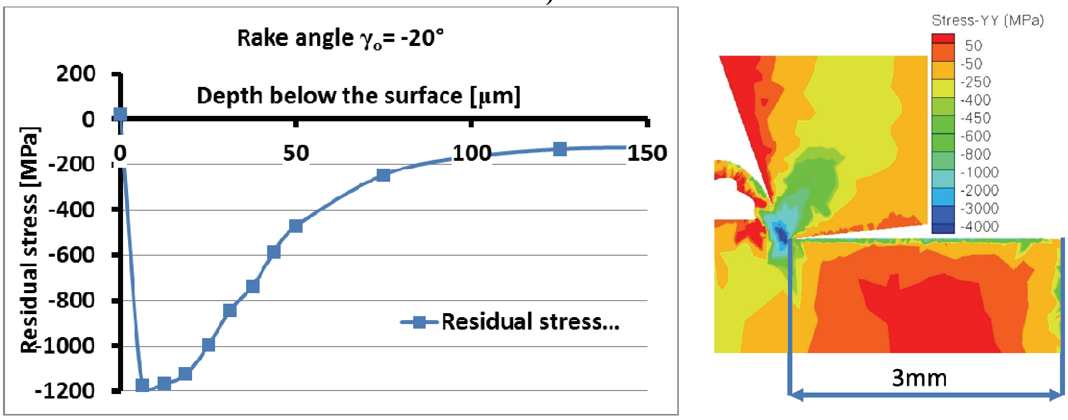

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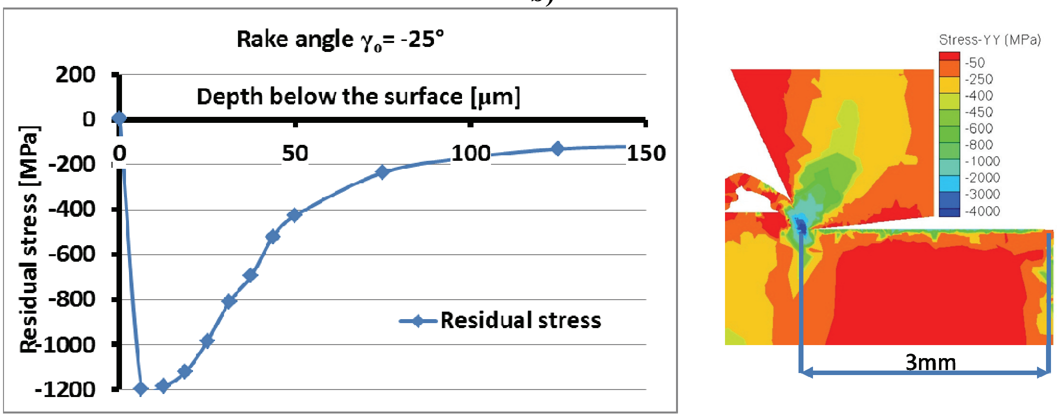

c)

Figure 7: The change of the residual stress depending on the depth of the surface layer (a: γ_o=-15°; b: γ_o=-20°; c: γ_o=-25°)

Conclusion

This paper presents the comparison of the residual stresses by means of FEM simulation, in hard turning, changing the values of rake angles. In cutting generally by all means we strive to choose a cutting technology which supposedly develops the some residual stress. The experiments show that having a value of γ_o negative rake angle, this expectation can be ensured. The research reveals how significantly the tool edge geometry affects the planned surface creation. In the researched rake interval it is worth applying the biggest negative rake angle, because here the compressive residual stresses are the highest.

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