EVALUATION OF RESIDUAL STRESS IN CONDITIONS OF IRREGULAR INTERRUPTED CUT

ROBERT CEP[1], SARKA MALOTOVA[1], KAREL KOURIL[2], LENKA CEPOVA[1], LADISLAV KYNCL[1], MICHAL SAJGALIK[3], TATIANA CZANOVA[3]

[1]Technical University of Ostrava, Faculty of Mechanical Engineering, Ostrava, Czech Republic

[2] Brno University of Technology, Faculty of Mechanical Engineering, Brno, Czech Republic

[3] University of Zilina, Faculty of Mechanical Engineering, Zilina, Slovak Republic

DOI : 10.17973/MMSJ.2018_10_201804

e-mail: robert.cep@vsb.cz

Residual stress occurs in many machined components and parts and they cause the corrosion or destruction of components. The paper deals with evaluating residual stresses during an irregular interrupted cut with the use a ceramic cutting tool. Tests were performed on the conventional lathe with using a simulator of interrupted cut called “slats test”. The regular or irregular interrupted cutting process was simulated with a different number of clamped slats in the simulator. Machined slats were made from two kind of material, steel C45 and 14MoV6-3. For evaluation of residual stress there was selected the non-destructive method based on the principle of X-ray diffraction. The results were measured by the device Proto iXRD Manufacturing. The experiment was done in cooperation with the University of Zilina in Zilina, Slovakia.

KEYWORDS

interrupted cut, ceramic cutting tool, residual stress, x-ray diffraction, machining

1 INTRODUCTION

Currently, strong emphasis is being placed on the service life, dimensional stability, corrosion, etc. of the each component. Everything is influenced by changes deals in the residual stress of the material. Its analysis is very important and it could help improve the whole process, and manufacturing processes such as machining, welding, forming etc. [Petru 2017]

The basic mechanism of occurrence of residual stress are uneven plastic deformations, thermal expansivity during uneven heating or cooling down, structural changes and chemical processes. Residual stress could be classified as stress that is macroscopic, microscopic and submicroscopic. It is important for us is to determinate if the stress is compressive (-) or tensile (+). The best way is to get “zero” values of residual stress. So in the area of machining it is the best, that stress is compressive (-), because tensile stress (+) speeds up the corrosion in material, cracks, defects, pores and so on. Not only the suitable choice of the process conditions, but the mechanical properties of material too could cause a long service life and have a big influence on the type, size and distribution of the residual stress on a material.

For evaluating residual stress there exists lots of methods, such as destructive – mechanical or non destructive – physical. The best way is the selected non destructive method. The X – ray method is based on X-ray diffraction. In comparison with other methods e.g. neutron, ultrasonic, the main advantages of the X-ray method is the simplicity of the evaluation and the variability of the measured material and area. [James 1996]

The development of ceramics is still going forward thanks to its improved hardness, toughness and resistance against the mechanical and thermal shocks of an interrupted cut. Due to these properties we could use ceramics for continuous turning and for the interrupted cutting process. For the experiment there was used ceramics cutting inserts. [Cep 2017]

2 EXPERIMENTAL PART

2.1 *Specification of Experimental Part*

The test was focused on machining with the use of the interrupted cutting process with a constant cutting depth and cutting speed. For the test there was chosen the method of longitudinal turning called a “slats test”. The experiment was done with the use of special preparation, which was constructed at the Department of Machining, Assembly and Engineering Metrology, VSB-TU Ostrava (Fig. 1) - simulator of interrupted cut.

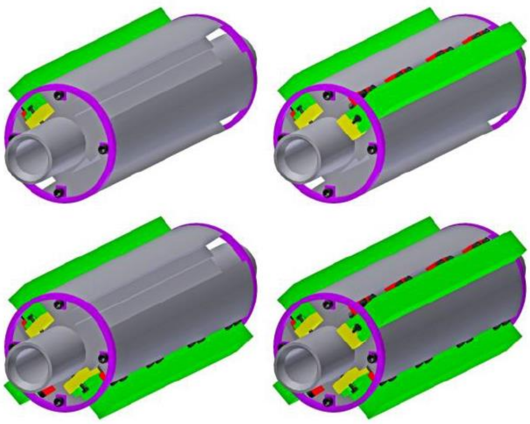


Figure 1. Simulator of interrupted cutting process [Cep 2017]

The slats were clamped into grooves by a chucking wedge. The slats, made from two kind of materials were clamped, into the preparation. For the simulation of the regular interrupted cutting process four slats were clamped into device. The irregular interrupted cut occurs when one of the slats was removed from the simulator. So the irregular interrupted cut came from 3, 2 or 1 slat in simulator. A frontal view is shown in Fig. 2.

The slats were machined with the use of a ceramic cutting insert which were tested on two kind of materials. Steel C45, which is one of the most used material for quenching and hardening. Steel is very well machined with good dimensional stability and it is suitable for stressed components where there are demands on the maximum utilization of the mechanical properties and it is used as an etalon. Steel 14MoV6-3 is alloyed with Mo-V steel resistant to high temperatures and creep, which excels in its high toughness resistance at a temperature of about 580°C. The microstructure is greatly affected by heat treatment. Tab. 1 shows the mechanical properties of the both materials. This material is very often used for the production of many components. [Cep 2013, Karpuschewski 2013]

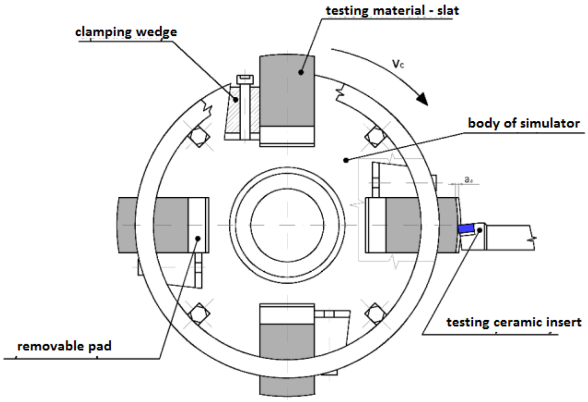


Figure 2. Face view of the simulator

Mechanical properties	$Rp_{0,2}$ [MPa]	Rm [MPa]	A_5 [%]	Hardness [HB]
C45	min 325	min 540	min 17	max 225
14MoV6-3	min 320	460 – 610	20	197

Table 1. Mechanical properties of machined materials

Fig. 3 shows non-machined slats, which are prepared for the experiment. The slats were machined under conditions with a constant cutting speed and cutting depth (Tab. 2). The machining was done under the conditions of a different feed. For the whole experiment there were used ceramic cutting inserts, marked IN23 ISCAR with a tool holder (25x25) M12 – K CSRNR. The insert was made from black oxidic ceramic Al2O3, TiCN. The set of experiments that were carried out included workpiece material C45. It was used as a reference material. A ceramic tool machined these surfaces so that a comparison could be made of all the results with another selected material. [Cep 2011]

Figure 3. Testing slats

Tool holder geometry:

Orthogonal rake	$\gamma_o = -6^\circ$
Clearance angle	$\alpha_o = 6^\circ$
Cutting edge angle	$\kappa_r = 75^\circ$
Cutting edge inclination	$\lambda_s = -6^\circ$
Included angle	$\varepsilon_r = 90^\circ$

Cutting parameters		
Cutting speed	v_c [m ·min^{-1}]	204
Cutting depth	a_p [mm]	1
Feed	f [mm]	0.11; 0.20; 0.32

Table 2. Cutting parameters

2.2 *Evaluation of residual stress*

The residual stress was measured and evaluated by the non-destructive method on the principle of X-ray diffraction. The device PROTO iXRD is a portable non-destructive residual stress measurement system. Due to the modular design, powerful software and the wide variety of options and accessories, this device is suitable for miniature components or because of its portability, it can be used for dimensionally-hard, portable applications. The device is show in Fig. 4.

This device contains a tube for emitting X-rays. For the measuring of ferrite steel there was used a chrome tube (Cr). The device was set up with a voltage 40 kV and current 4 mA. This device enables the measuring of stress in all-crystalline materials. The main advantages of this is the evaluation of residual stress at the absolute physical unit MPa, but this method is time-consuming. The beam penetrated into 12 µm and then it diffracted into a cone and was caught by the detectors. [Piesova 2017]

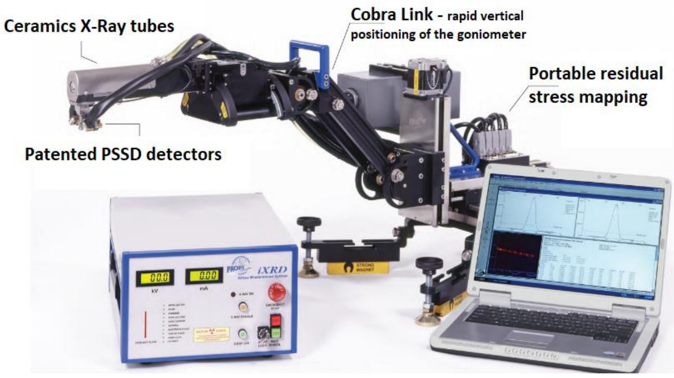


Figure 4. X-Ray diffractometer Proto iXRD

The X-ray beam was transmitted in several inclination intervals from + 30 ° to -30 °. The signals were caught and evaluated by software XrdWin. All samples were measured at the side where the cutting insert entered into the material and at the end of the sample, where the insert left the material (Fig. 5). [Pagac 2016]

Figure 5. Measured points

3 THE RESULTS OF MEASUREMENT

All samples were measured at the input, where projection of residual stress was is the biggest. For us it was very important to evaluate normal stress, which is caused by manufacturing.

- **Steel 14MoV6-3**

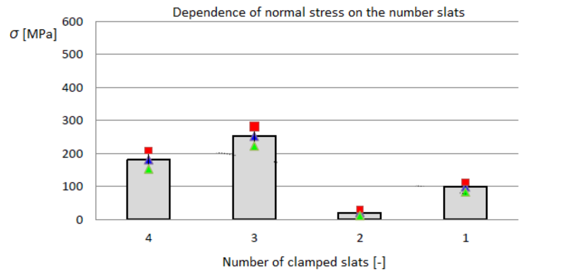
At first time, we compared the normal stress of steel 14MoV6-3. Normal stress at the lowest feed (*f* = 0.11mm) showed the highest values for the irregular interrupted cut. The highest value was achieved with three clamped slats. The lowest value was achieved with two clamped slats and was an irregular interrupted cut. Irregular interrupted cutting with the lowest feed indicated a direct and significant impact on the residual stresses of the machined material.

Normal stress at medium feed (*f* = 0.20mm) has a similar character and is dependent on the irregular interrupted cutting process of the residual stresses. The achieved values of normal stress are significantly bigger. The highest values of normal stress were achieved with three clamped slats. The lowest values were achieved with two clamped slats, as in the previous case.

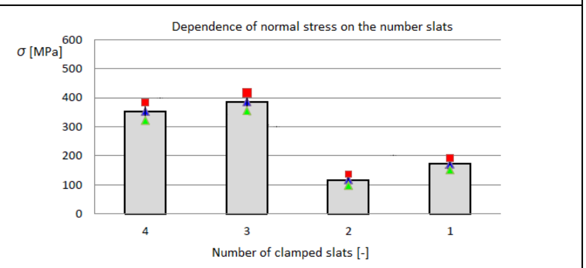
Normal stress at maximum feed (*f* = 0.32mm) shows different values than in both the previous cases. These changes were influenced by the interrupted and non-interrupted process. There were big shocks, which can caused the increased values of normal stress. With the decreasing of the number of clamped slats the residual stress increased. The graphic results are shown in Tab. 3.

Dependence of normal stress on the number of clamped slats steel - 14MoV6-3

***f* = 0.11 mm**



***f* = 0.20 mm**



***f* = 0.32 mm**

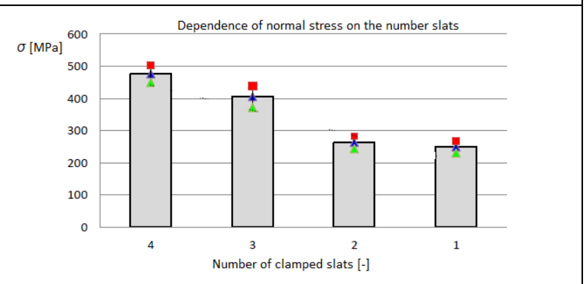


Table 3. Dependence of normal stress on the number of clamped slats – 14MoV6-3

In summary, Fig. 6 shows the influence of feed on the normal stress for individual clamping (4, 3, 2 or 1 clamped slats). The figure generally shows that with increasing the feed the value of the normal stress is increasing too. Generally, we can say that the irregular interrupted cut has an influence on the value of normal stress.

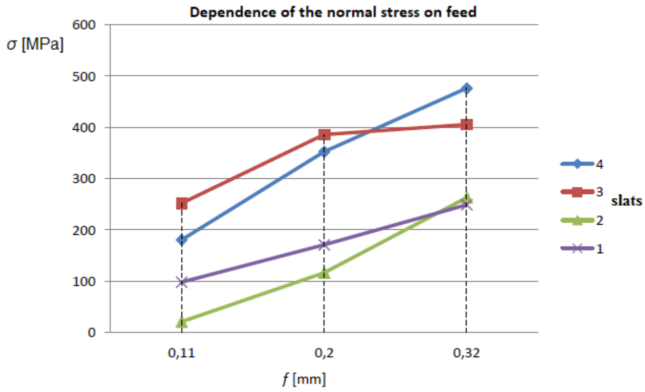


Figure 6. Dependence of the normal stress on feed

- **Steel C45**

The same influence process was for another material, steel C45. Normal stress with the lowest feed (*f* = 0.11mm) has a completely different character of normal stress than the previous material. With a higher number of clamped slats it should proportionately increase the value of normal stress. For one and two clamped slats there are even negative values indicating compressive stresses. For machining with one clamped slat, with long-time delays between shocks and with the lowest feed, this value is close to 300 MPa, which indicates a very high compressive stress that has a negative effect on the durability of a machined piece.

Normal stress at medium feed (*f* = 0.20 mm), increases with the number of clamped slats, e.g. the number of mechanical shocks. The character of increase has a constant increase / decrease. The highest value is achieved with four clamped slats in the simulator of the interrupted cut.

Normal stress at the conditions of the highest feed (*f* = 0.32mm) has a similar character as the previous two lower feeds. With an increasing number of slats in the simulator there increases normal stress. The growth character of normal stress is almost constant. The highest value was reached with four clamped slats, the minimum value was reached with 1 clamped slat. (See in Tab. 4)

The Fig. 7 clearly shows that values of normal stress in the material increases proportionately to the increasing feed. For material C45, it is also true that the number of slats has an impact on the increasing value of the normal stress. Some values at the lower feed also reached negative numbers (compressive stress) which have a negative effect on fatigue resistance, increases friction and crack propagation.

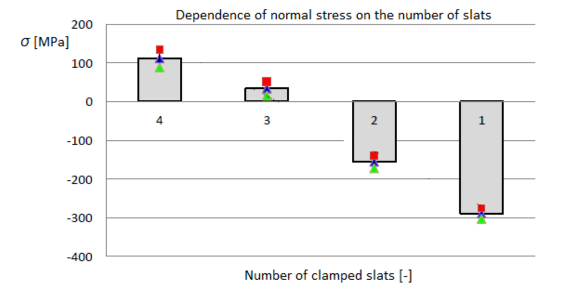
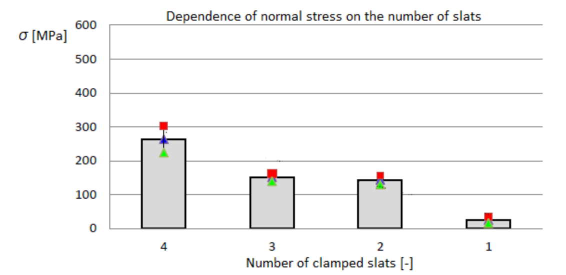
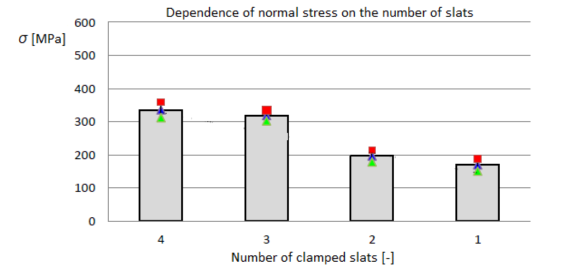
Dependence of normal stress on the number of clamped slats steel - C45	
f = 0.11 mm	
f = 0.20 mm	
f = 0.32 mm	

Table 4. Dependence of normal stress on the number of clamped slats – C45

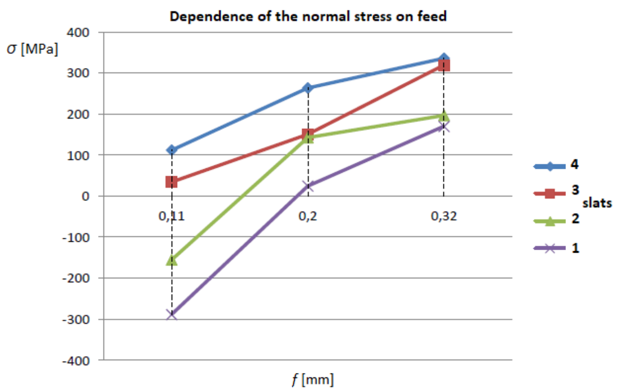


Figure 7. Dependence of the normal stress on feed

4 CONCLUSIONS

Machining and new progressive technologies are very popular. But every component has to be inspected in order to detect errors, inclusions, pores etc. The properties of samples are given by the kind of material and manufacturing method.

The investigation of residual stress is very important. Stress, especially tensile (+) is harmful and can cause changes of material properties, such as crack propagation, corrosion formation, etc. The optimal distribution of the stress in the volume of a material is a zero value, but it is not impossible.

For 14MoV6-3 (1.7715) material, it applies that with the increasing feed the values of normal stress after cutting proportionately increases. Generally, it can concluded that an irregular interrupted cut has an effect on the size of the inserted stress, and normal values are slightly higher in comparison with a conventional regular interrupted cut. The best values were obtained with two clamped slats. In all the tests, there was measured only tensile stress. These stresses are not suitable and their occurrence can cause faulty components and decrease their life.

For C45 (1.0503) material it applies that with an increasing feed the size of normal stress at the cutting area proportionately increases. Additionally, it can be concluded that the number of slats in the simulator of an interrupted cut has an impact on the increasing value of the normal stress. At a lower feed, there were also achieved negative values (compressive stresses) which have a negative effect on fatigue resistance, increasing friction or the propagation of cracks. The best value was achieved with two clamped slats, but with the lowest feed, there was also measured tensile stress, so it is not recommended to cut with a lower feed. Generally, the reference material has again proved to be seamless in conditions of the interrupted cutting process. The evaluated stress was compressive and due to cooling it was changed to tensile. The values were much smaller in all cases of the clamped slats.

The choice of technology has a big impact on the type and size of residual stress. Especially, difficult conditions like as interrupted cutting process, where there are big mechanical and thermal shocks, which in combination with workpiece material can influence the type of stress change. Residual stresses are elements belonging to the surface integrity. Knowledge and understanding of their principles, and of the machining process can be directed in such a way as to ensure a better surface quality, a longer tool life of cutting tools and, especially, an increase in the life of the components.

ACKNOWLEDGEMENT

The Article has been written in connection with the project: The education system for personal resources of development and research in the field of the modern trends of surface engineering - surface integrity, reg. no. CZ.1.07/2.3.00/20.0037 financed by Structural Founds of Europe Union and from the means of state budget of the Czech Republic and by project Students Grant Competition SP2018/150 and SP2018/136 financed by the Ministry of Education, Youth and Sports and Faculty of Mechanical Engineering VŠB-TUO.

REFERENCES

[Cep 2011] Cep, R. et al. Testing of Greenleaf Ceramic Cutting Tools with an Interrupted Cutting. Tehnicki Vjesnik-Technical Gazette, 2011, vol. 18, no. 3, p. 327 – 332, ISSN 1330-3651.

[Cep 2013] Cep, R. et al. Influence of feed speed on machined surface quality. In: METAL 2013: 22nd International Conference on Metallurgy and Materials, Conference Proceedings. Brno: Tanger, 2013, p. 1033-1038. ISBN 978-808729441-3.

[Cep 2017] Cep, R., et al. Testing ceramics inserts at irregular interrupted cut on material 14MoV6. Engineering Review, 2017, vol. 37, no. 1, p. 67-73, ISSN 1330-9587.

[James 1996] James, M., et al. Handbook of measurement of residual stresses. SEM, Fairmont Press, INC., 1996, ISBN 0-88173-229-X.

[Karpuschewski 2013] Karpuschewski, B., et al. Influence of tool edge preparation on performance of ceramic tool inserts when hard turning. ELSEVIER: Journal of Materials Processing Technology. 2013, vol. 213, no. 11, p. 1978-1988, ISSN 0924-0136.

[Pagac 2016] Pagac, M. et al. Influence of Effective Milling Strategies on the Residual Stress. 25th Anniversary International Conference on Metallurgy and Materials (METAL). Ostrava: TANGER, 2016, s. 819-824. ISBN 978-80-87294-67-3.

[Petru 2017] Petru, J. et al. The effect of feed rate on durability and wear of exchangeable cutting inserts during cutting Ni-625. Tehnicki vjesnik - Technical Gazette. 2017, vol. 24, no.1, p. 1-6. DOI: 10.17559/TV-20131221170237. ISSN 1330-3651.

[Piesova 2017] Piesova, M. et al. Experimental Quantification of the Austenitic Phase in Steels Using the Average Peak Method of x-ray Diffractometry. Procedia Engineering. ELSEVIER SCIENCE BV, 2017, 192, s. 689-694. DOI: 10.1016/j.proeng.2017.06.119. ISSN 18777058.

CONTACTS:

prof. Ing. Robert CEP, Ph.D.
VSB – Technical Univesity of Ostrava
Faculty of Mechanical Engineering
17. listopadu 2172/15, Ostrava – Poruba, 708 33
Czech Republic
+420 597 323 193
e-mail: robert.cep@vsb.cz
www.fs.vsb.cz