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Influence of Thermal and Mechanical Shocks to Cutting Edge Tool Life

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Abstract**—**This paper deals with the problem of thermal and mechanical shocks, which rising during operation, mostly at interrupted cut. Here will be solved their impact on the cutting edge tool life, the impact of coating technology on resistance to shocks and experimental determination of tool life in heating flame. Resistance of removable cutting edges against thermal and mechanical shock is an important indicator of quality as well as its abrasion resistance. Breach of the edge or its crumble may occur due to cyclic loading. We can observe it not only during the interrupted cutting (milling, turning areas abandoned hole or slot), but also in continuous cutting. This is due to the volatility of cutting force on cutting. Frequency of the volatility in this case depends on the type of rising chips (chip size element). For difficult-to-machine materials such as austenitic steel particularly happened at higher cutting speeds for the localization of plastic deformation in the shear plane and for the inception of separate elements substantially continuous chips. This leads to variations of cutting forces substantially greater than for other types of steel.

Keywords**—**Cutting Tool Life, Heating, Mechanical Shocks, Thermal Shocks

I. INTRODUCTION

THE influence of temperature and mechanical shocks on the resistance of the tool cutting edge made of sintered carbide is significant, and the ability of the cutting edge material to resist theses influences is one of the key indicators of quality. The toughness of sintered carbides is lower in comparison with speed-cutting steels. This is due to a larger ratio of included carbide cutting component against the volume of joining cobalt phase.

The wear (damage) of the cutting edge by fracturing and crumbling away is due to cyclical loads on the cutting edge in the cutting process. This phenomenon occurs both during classical uninterrupted machining, and especially during the interrupted one, for example during milling, slot milling etc. During the uninterrupted cutting the cutting edge is cyclically loaded due to period oscillation of the cutting force main component. The frequency is given by the character of shaving element size [1].

Experiments have shown that during cutting of hard to machine materials with higher cutting speeds, for example austenitic steel, plastic deformation occurs in the shearing plane, in which the elements of continuous shaving are removed. This leads to large variations in the cutting force in these types of steels under the given cutting conditions. The amplitude of the main cutting force component in comparison with a different type of steel is shown on the fig. 1 to illustrate characteristics of a fatigue failure, abrasive wear and cutting edge crumbling away.

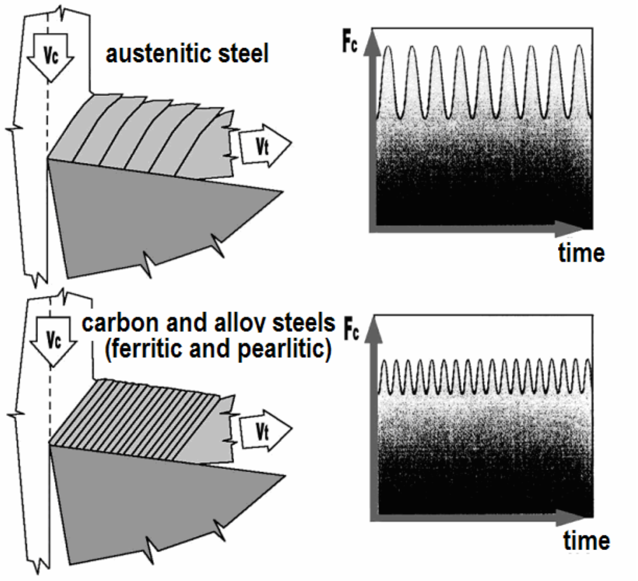

Fig. 1 Amplitudes of cutting force component [1]

II. MECHANICAL SHOCK

There is a short period increase of the main cutting force component Fp during entrance of the tool cutting edge into a work piece. This increase can exceed a mean value several times after entrance of the cutting tool (cut in). The amplitude of the main cutting force component increase depends on time from the first contact to the full shaving profile [2]. This time is given by relative positions of a tool and a work piece. If the contact of a cutting tool edge occurs by its whole length and along the whole length of the shaving, we consider this time to

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be zero and the mechanical shock or the cutting force component reaches the maximum, see the Fig. 2. In case of slower entrance of the cutting tool into a work piece to the full profile of the shaving, the increase of the cutting force component is smaller; see the Fig. 2 (bottom part). For exchangeable cutting edges the most important part, considering the first contact, is the leading edge, where the dangerous contact occurs.

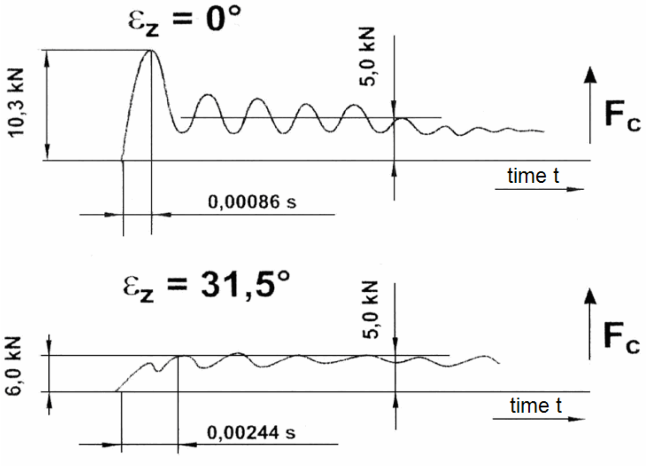

Fig. 2 Main cutting force component depending on time and bite angle [1]

The Fig. 2 shows the measured values of main cutting force component increase depending on the time of the cutting edge entrance and the specific bite angle ε_z. The bite angle is the angle between the exchangeable cutting edge front and the tangent to the work piece, see the Fig. 3. The mechanical shock is demonstrably smaller in case of gradual entrance into the work piece, as it is shown by the measured values.

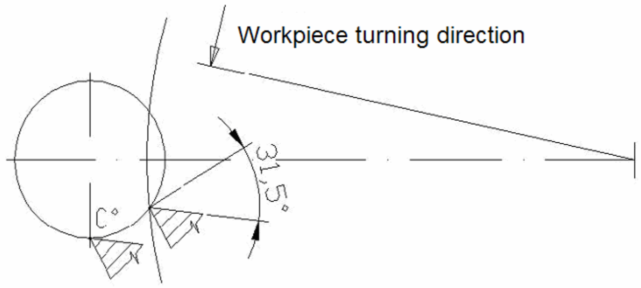

Fig. 3 Change of bite angle ε_z

III. TEMPERATURE SHOCK AND ITS ANALYSIS

The tool cutting edge is exposed to mechanical and also temperature influences during cutting. The cutting edge is being heated during cutting and then cooled back when it exits the cut, which loads the edge by cyclical temperature shocks. The temperature shock is the cause of alternate changes in pressure and tension stresses in the surface layers of the exchangeable cutting edge plate. These stress changes cause microscopic fractures in the cutting edge and can cause a brittle failure of the edge [3].

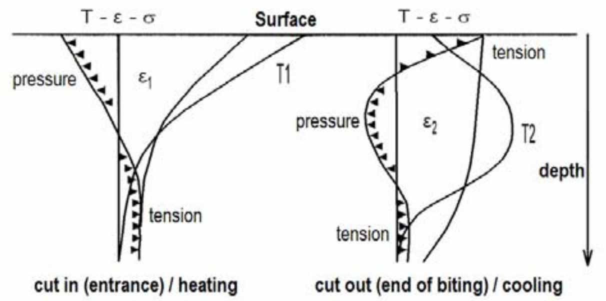

Fig. 4 Influence of stresses on the tool cutting edge [1]

Creation of small fractures is shown on the Fig. 4, where the tool cutting edge is heating, while entering (cutting in) to a work piece. The surface layer temperature significantly increases; neighboring layers further away from the surface are cooler and prevent the surface layers from transfer of the cutting heat. This creates a stress imbalance, in which the pressure stress on the surface changes into the tension stress in the neighboring layers. At the moment when the tool comes out of the work piece (end of cutting) the surface layer will cool down intensely. The mentioned neighboring layers under surface cool down more slowly. The opposite case occurs with tension on the surface and pressure in the lower layers [4].

Such tension oscillation with mechanical shocks can cause fractures and a brittle failure of the cutting edge. The tension can be calculated based on the equation from the elasticity and rigidity theory.

$$\sigma = \gamma . E . \Delta T \tag{1}$$

where:

γ : coefficient of temperature expandability $[K^{-1}]$
E : elasticity modulus [MPa]
ΔT: temperature gradient [K]

The relationship implies a direct proportion; the larger the individual elements, the larger the temperature stress. In order to provide resistance against temperature shocks the tensile strength and temperature conductivity needs to increase and elasticity modulus and the temperature expansion coefficient need to decrease. The tool cutting edge destruction can be caused by the mechanical shock during entering (biting in) into a work piece and due to the temperature shock during coming out (end of biting).

A relationship to calculate the resistance against temperature shocks (2) based on experiments was created in the past, with the physical and mechanical properties of the tested material included. However, it was not used in practice due to the demanding preparation of input values and time demands.

$$TR = \frac{\lambda . R_m}{\gamma . E} \tag{2}$$

where:

λ : temperature conductivity $[Wm^{-1}K^{-1}]$,
Rm : strength limit [MPa],
γ : temperature expansion coefficient $[°K^{-1}]$,
E :elasticity modulus [MPa].

Another disadvantage of this relationship was that it did not include influence of tool homogeneity in the cutting edge area. The physical and mechanical properties of sintered carbides do not have negative effect on resistivity against shocks other than unhomogenity at the tool cutting edge. The relationship does not include the effect of coating, modification of the cutting edge by sharpening etc. These processes fundamentally determine the real resistance against the temperature shocks.

IV. INFLUENCE OF COATING TECHNOLOGY

The effect of coating and the coating technology is another criterion for evaluation of the resistance against temperature and mechanical shocks. The CVD (MTCVD) coating technologies and PVD or PACVD coatings are used at the present time. A lot of literature is dedicated to the principles of individual coating technologies. The mentioned deposition processes vary both in working temperatures and properties of deposited layers, like temperature stability, adhesion and tension. The tension decreases with higher working temperatures. PVD layers have a character of pressure tension, which leads to closing of fractures created due to mechanical and temperature shocks. On the other hand the CVD and MTCVD deposition layers are characterized by internal tension that contributes to expanding of fractures. The difference in depositions and tensions is seen on the Fig. 5.

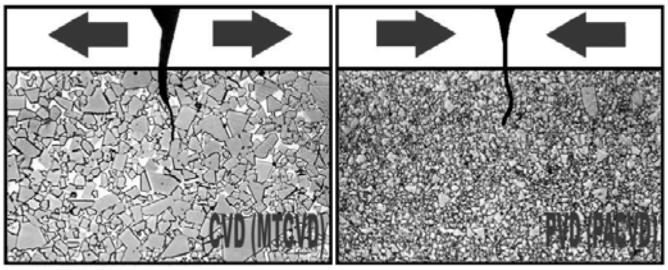

Fig. 5 Effect of coating and tension

The resistance of exchangeable cutting edge plates against shocks and the trend of effects of used technologies and coatings can be evaluated using the long term manufacturer tests. The best coatings to resist the cyclical loads during the interrupted cutting test are the PVD deposition coatings. The worst are the CVD layers. This trend is shown on the Fig. 6

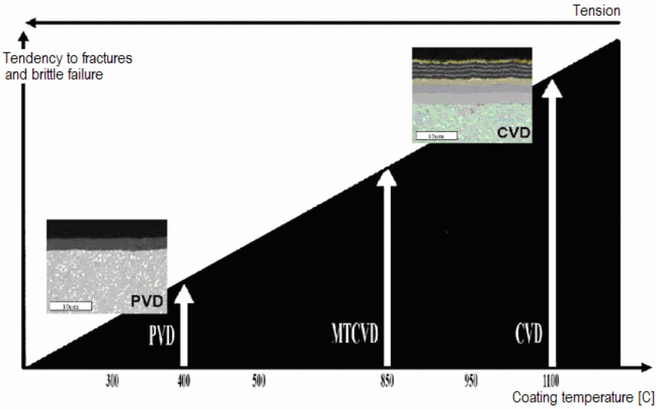

Fig. 6 Effect of deposition on tension and fractures [1]

V. DURABILITY OF TOOL HEATED BY A FLAME TORCH DURING INTERRUPTED CUTTING EFFECTS OF TEMPERATURE AND MECHANICAL SHOCKS

This is the experimental determination of the tool back side wear depending on the heating of the tool by flame according to prof. Vasilko.

Thinking of significance of the temperature changes influence on durability of a tool during interrupted cutting led to the idea of controlling the heating process during cutting. The tests were made during cutting of a work piece with fins, without heating of the tool and with heating using a flame torch. The cutting tool was made from the sintered carbide P20 and the work piece from 12 050.3 (C45) material. The temperature near the cutting edge was measured by a thermocouple. [5]

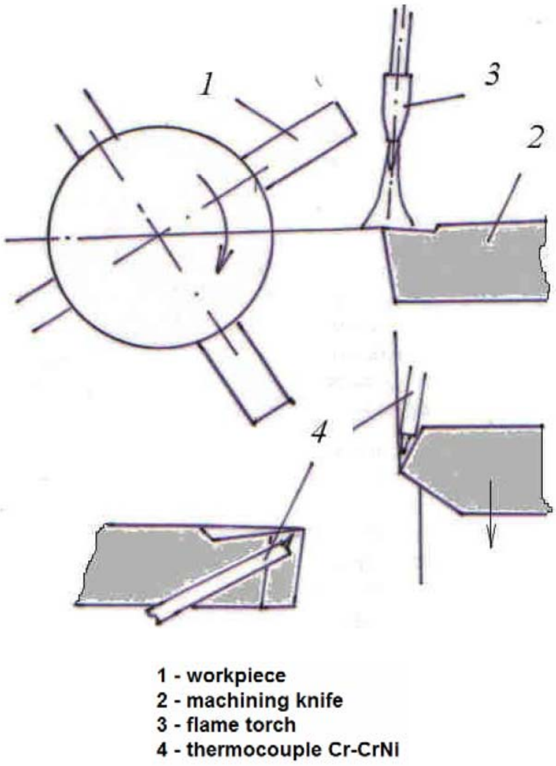

Fig. 7 Control of temperature near the cutting edge [5]

Using the wear criterion VBB = 0.4mm the durability of the tool could be determined depending on the heating temperature.

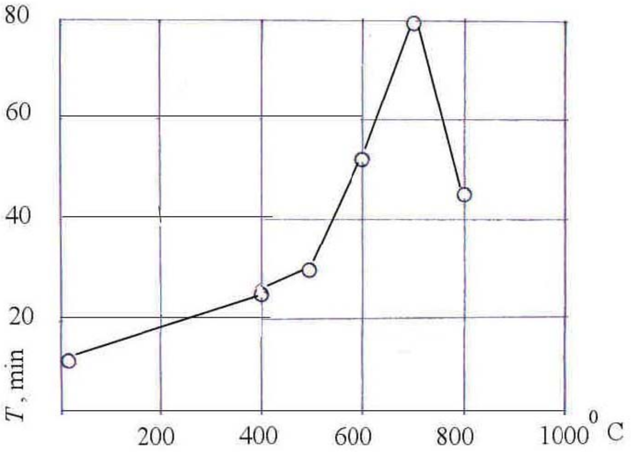

Fig. 8 Experimental chart of the tool durability during interrupted cutting in dependence on the tool heating [5]

The diagram and the test according to Vasilko [5] show that the least wear of the tool the cutting edge plate back is occurring at the temperature of about 700°C. Further increasing of the temperature leads to decrease in strength of the cutting material. The increase in durability during heating of the tool to 700°C is significant in comparison with cutting in 20°C. It represents eight fold increase in cutting time. This proves that the temperature and not the mechanical shock are decisive concerning damaging of the tool during interrupted cutting [5].

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REFERENCES

[1] J. Houdek, K. Kouril. “Sintered Carbides Resistivity against Thermal and Mechanical Shocks 3 parts (in Czech),” in *MM Prumyslove Spektrum 04,05,06/2004.* Available: http://www.mmspektrum.com/clanek/odolnost-slinutych-karbidu-proti-teplotnim-a-mechanickym-razum.

[2] A. Czan, D. Steklac, D. Stancekova, “Tools for High Productive Machining of Bearing materials by Turning (in Slovak),” in *Tools 2005*. Zlin, 2005.

[3] I. Mrkvica. “Utilization of Fine-grained Cemented Carbides for Gear Manufacturing,” in *Manufacturing Technology*, 2002, vol. 2. ISSN 1213-2489.

[4] J. Dobransky, M. Hatala. “Influence of selected technological parameter to quality parameters by injection moulding, ” in *Annals of DAAAM for 2007 & proceedings of the 18th International DAAAM Symposium : Intelligent Manufacturing & Automation: Focus on Creativity, Responsibility, and Ethics of Engineers,* Zadar, Croatia. Vienna : DAAAM International, 2007. 2 p. ISBN 3-901509-58-5.

[5] K. Vasilko. *Analytická teória trieskového obrábania.* (In Slovak). 1.vyd. Prešov 2007. 338 p. ISBN 978-80-8073-759-7