Tribological Mechanism in Machining and Its Use

Karol Vasilko
Faculty of Manufacturing Technologies Technical University of Košice, Bayerova 1, 080 01 Prešov, Slovakia, karol.vasilko@tuke.sk

It is a well-known fact that during cutting there occurs an extremely high degree of chip plastic deformation [1,4,5,11] These deformation structures require attention as they influence technical and economical results of cutting (cutting forces, quality of machined surface, tool wear, cutting temperature) [8,9,15,21]. The paper analyses the options of influencing the deformation field in chip with the aim to improve cutting proces.

Keywords: machining, plastic deformation, chip forming,cutting force

1 Introduction

In *Fig. 1* there is a metallographic thin section of the zone of chip creation when cutting carbon steel C45.

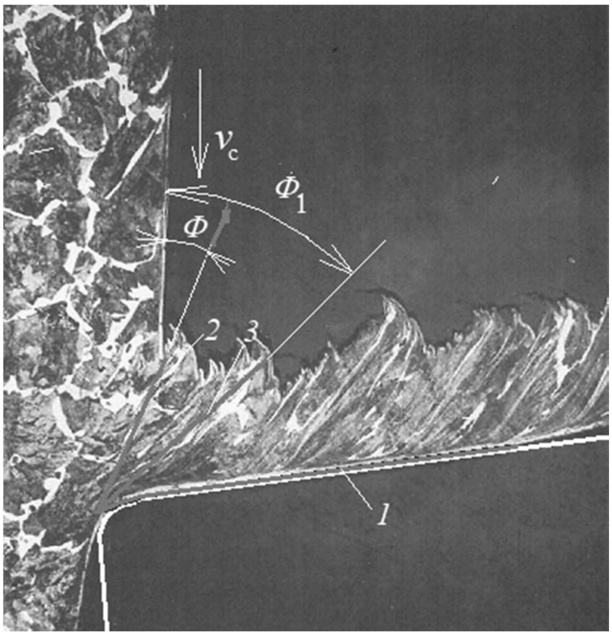

Fig. 1 *Metallographic thin section of chip creation. Material C45, 1- external friction between the tool face and chip, 2 – intercristalline friction, 3 – internal cristalline friction. ϕ - angle of „slide plane“, ϕ_1 - angle of texture in chip. γ_n = -6^0, v_c=120 m.min^{-1}*

Three areas of friction can be characterised.

Intensiveness of outer friction on the surface *1* depends on the size of friction coefficient between the cut and cutting materials. It is a source of heat which warms up the tool and the chip, it causes the decrease of hardness of tool cutting wedge and its wear on face. The friction along the slide line *2* , inclined under angle ϕ takes place primarily along grain borders, it takes place cold and is in fact the reason why the chip is formed in given configuration. The heat which is created there spreads into the chip and cut-off layer which changes into the chip. The friction along line *3*, oriented under texture angle ϕ_1 takes place inside metal grains under the conditions of high temperature, probably with small coefficient of internal friction. The result is the texture of elongated metal grains in the chip and much larger thickness of chip h_1 than the thickness of cut-off layer h. It can realistically be supposed that in this area, the cut material provides the least resistance against deformation. This fact leads to the suggestion to transfer the area of plastic deformation into the zone of internal friction in the grains of cut material. The next chapter presents the way into realistic form.

2 Project to influence the character of plastic deformation inside chip

It is possible to limit the outer friction between the chip and tool face by the adjustment of tool geometry according to *Fig. 2* [20]. The basics of the adjustment is shortening of active surface of tool face to value l_c, close to the thickness of cut-off layer h. The surface is inclined against the basic plane by angle γ_{lo}.

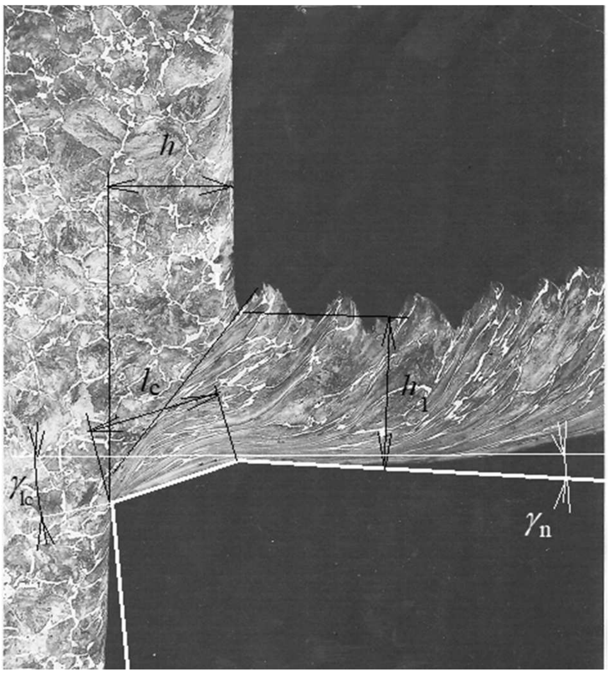

Fig. 2 *Metallogarphic thin section of the area of chip formation when cutting with a tool with shortened face. h-thickness of cut-off layer, h_1-chip thickness, l_c – width of shortened surface of tool face, γ_{lc}- angle of shortened face surface, γ_n - angle of tool face in standard plane. v_c = 100 m.min^{-1}*

As it can be seen, outer friction between the tool face and chip is considerably limited by this adjustment. Internal friction is limited into the slide zone (*2*) and intercristallic friction (*3*). On shortened face area, there was a plastic layer made of cut material formed which moves in small or zero (right after the contact with the tool) speed along the tool face. The speed of elements towards the chip increases until they reach the speed of chip leaving, which is defined as follows [10,18,].

$$v_t = \frac{v_c}{k} = \frac{v_c . h}{h_1}, \qquad (1)$$

where h is the immediate thickenss of cut-off layer, mm,

h_1 – mean thickness of cut-off chip, mm,

$k = \frac{h_1}{h}$ - chip compression.

Experimentally it has been found out that at higher values of angle γ_n there gradually occurs a limited contact of the chip with tool face. In *Fig. 2* the angle of the face is straight 5^0. When this angle increases to 30^0 , a situation according to *Fig. 3* occurs.

It can be seen that the chip freely slides along the tool face. The contact of the cutting edge with the transfer area of the workpiece is limited also from the side of the tool rear because the material slides along the plastically broken off metal layer. This provides a precondition to limit the tool wear on the rear because the „plastic tip“ overpasses the position of the cutting edge. The size of l_c probably has influence on the mechanism of cutting. Therefore, experiemental tests of cutting with different values of l_c have been performed.

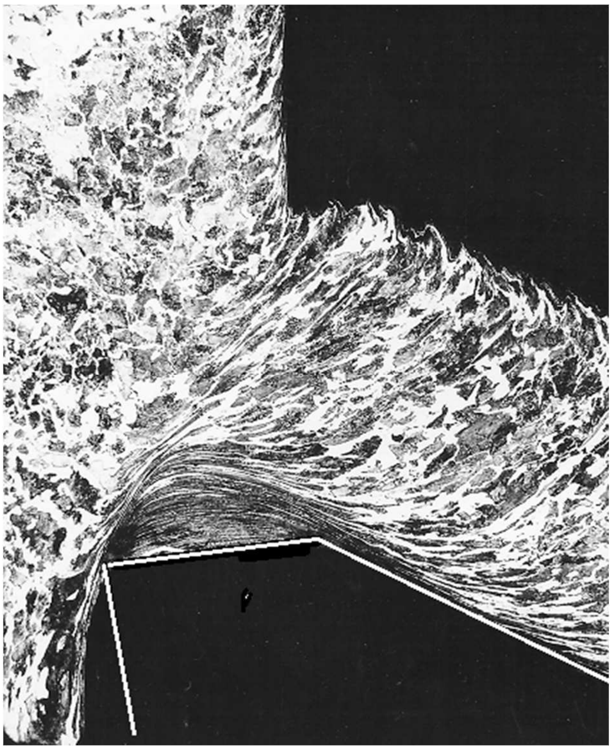

Fig. 3 *Metallographic thin section of the area of chip creation when cutting with a tool with face angle* $\gamma_n = 30^0$

Experimental verification of the influence of value l_c on tool durability

The result of experimental tests of cutting shown as a dependence of tool wear on the back on machining time at different values of l_c is presented in *Fig. 4*.

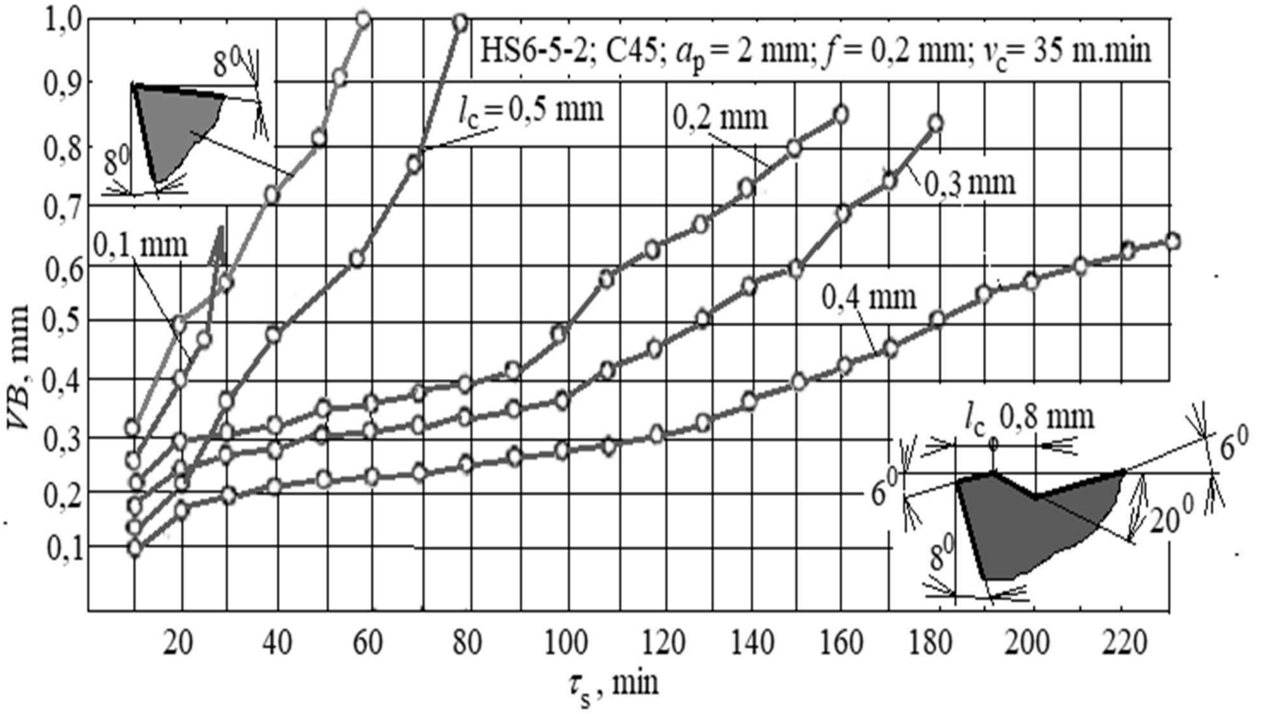

Fig. 4 *Experimental dependence of tool (high-speed steel on the back) wear width on machining time with classical tool geometry and tools with different widths of shortened face*

As it can be seen from the graph, the shortening of tool face has considerable influence on the intenseness of tool wear. For value l_c = 0.1mm the tool behaves like a standard tool with a phase on the face. On the contrary, the tool with area width 0.5mm is actually a tool with negative face angle. That is why both wear curves have similar course.

Tool durability steeply grows with the increase of shortened area to 0.2, 0.3 and 0.4mm. For instance, for blunting criterion VB_k = 0.6mm, durability of 30mins has been recorded for the tool with straight face, for tool with l_c = 0.4mm it has reached the value 210 mins, which presents 7-times increase of durability! The geometry of testing tool is shown in the right corner of diagramme. Weakening of cutting wedge and the occurence of stiff, ribbon-like chip are the negative results of using a large face angle. Therefore an adjustment of tool face which secures turning the chip into a helix has been applied.

In *Fig. 5* there is a view of the actual testing tool.

Fig. 5 *View of the tool with geometry according to Fig. 3*

It can be supposed that cutting speed can have a great influence on the size of plastic „protection“ zone on shortened face area.

3 Influence of cutting speed on the inteseness of adjusted tool wear

The experiments have been performed by a cutting tool made of sintered carbid at three different cutting speeds. The result is shown in *Fig. 6 - 8*.

The geometry of both tools is a part of the figure. The result is obvious. The tool durability increases from 17 to 62mins for blunting criterion VB_k = 0.3mm.

In Fig. 7 there is a dependence obtained at cutting speed 82 m. min^{-1}.

Similarly, at this cutting speed there occured a great prolonging of tool durability, e.g. at blunting criterion VB_k = 0.3mm, tool durability increased from 30 to 110mins.

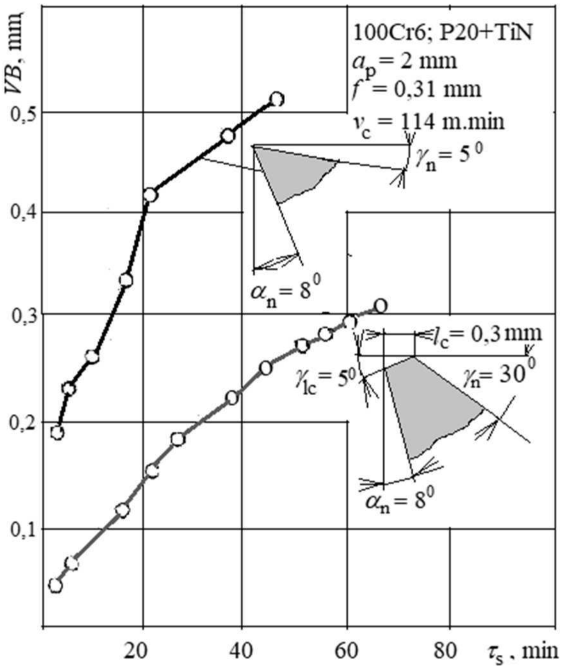

Fig. 6 *Experimental dependence of tool wear on the back on machining time at cutting speed 114 m.min^{-1}*

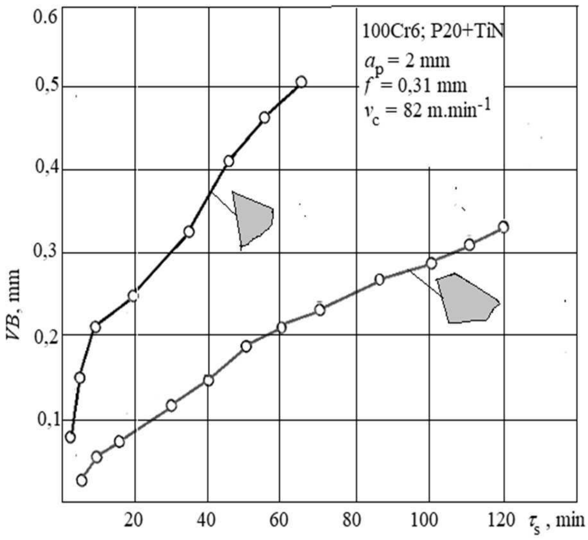

Fig. 7 *Experimental dependence VB - τ_s , obtained at v_c= 82 m. min^{-1}*

In *Fig. 8* there is a dependence at v_c = 58m.min^{-1}

The result is similar to the previous cases. An increase of durability from 45 to 240mins has been recorded.

Therefore it is obvious that there occured a large limitation of outer friction among the tool, chip and transfer workpiece area.

In *Tab.1* there is a comparison of the increase of tool durability with used cutting speeds for blunting criterion VB_k =0.3mm.

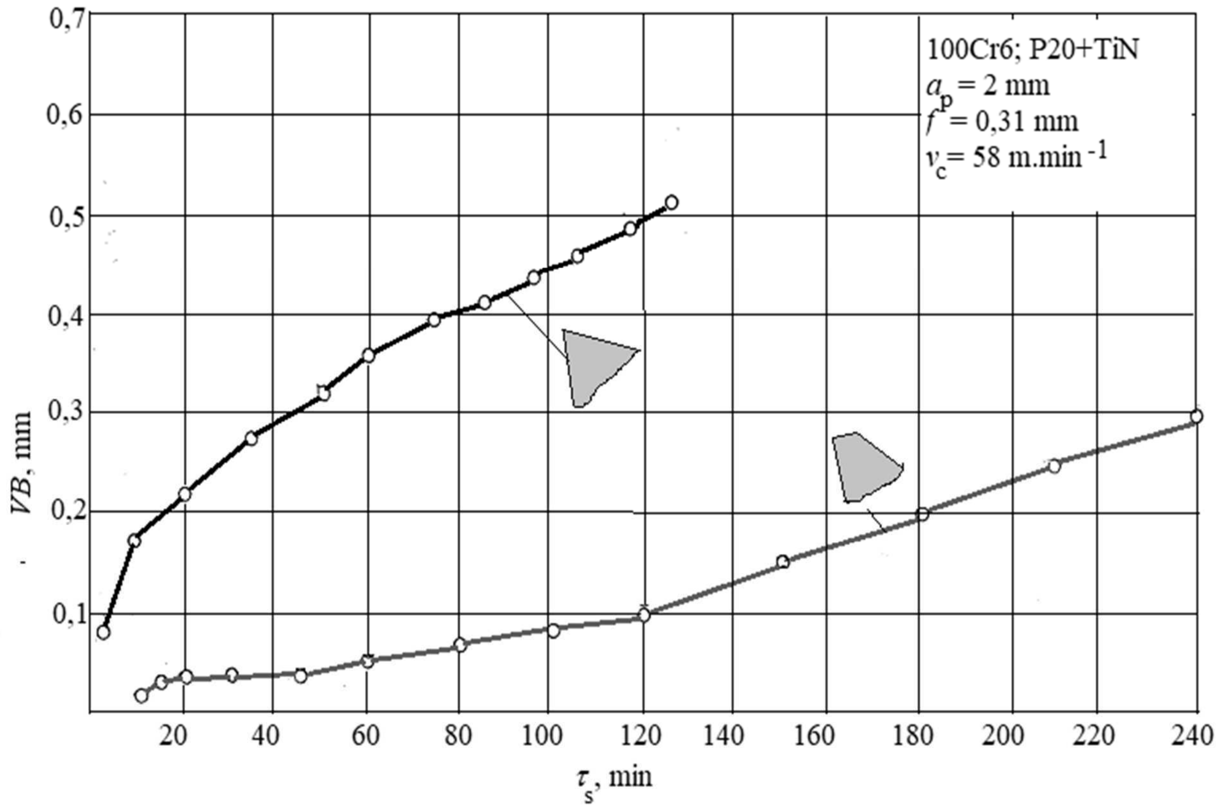

Fig. 8 *Experimental dependence VB - τ_s at v_c = 58m.min^{-1}*

Tab. 1 *Dependence of the increase of tool durability at different cutting speeds*

v_c, m.min^{-1}	classical geometry	adjusted geometry	$\frac{T_u}{T_{kl}}$
58	43	240	5.6
82	30	140	4.6
114	15	60	4

The increase of durability with different cutting speed slightly decreases, however, it is important and proves that there is a transformation of the area of friction from the contact of the chip with tool face into the broken-off, deformed zone inside the chip. No wear has been recorded on the face of adjusted tool.

4 Analysis of cutting forces

Cutting forces have been measured simultaneously with presented cutting conditions (from *Fig.6)* when machining with classical and adjusted tool. The result is shown in *Fig. 9*.

As it can be seen, the elimination of tool friction against the tool face has lead to the considerable decrease of all elements of cutting forces. If the force F_f is considered to be a friction force, mean coefficient of friction of chip against tool face can be determined from ratio F_c and F_f. Its values are presented in *Fig. 9*.

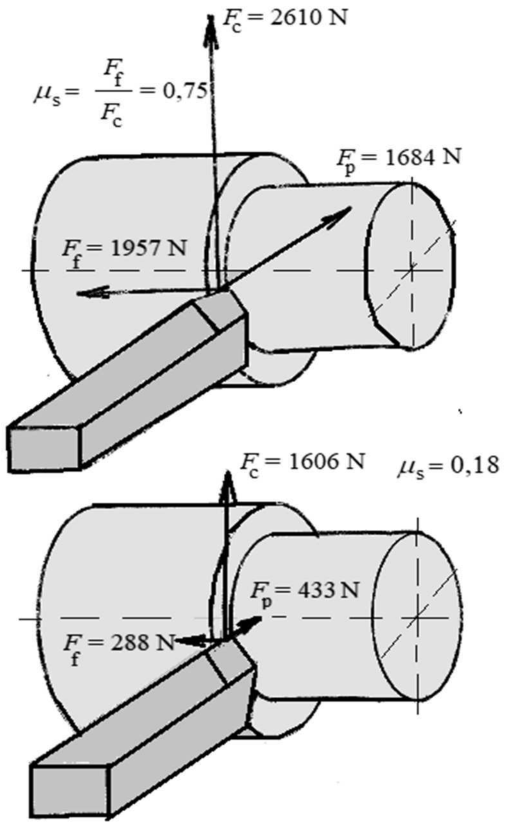

Fig. 9 *Scheme of measured three elements of cutting forces when machining with classical and adjusted tool*

5 Conclusion

Observation of the mechanism of chip creation and machined surface can bring positive results when considering cutting tool durability, quality of machined surface, shortening of the machining times. During the cutting process it can be seen that a structure with extreme degree of deformation, which cannot be obtained not even during extreme shaping, is formed. This plastic field replaces the function of the cutting edge and under certain conditions, this can secure complete elimination of direct contact of the chip with tool face. According to performed experiments it can be reached at face angle 50^0. A very stiff ribbon-like chip is the problem in this case because it cannot be shaped. No coolant or lubricant are necessary during cutting, they would even have negative effect, because the friction between the plastic „pyramid" and the chip must be performed when hot. It is an interesting problem from the viewpoint of material characteristics in the conditions of extreme deformations as well as the theory and practice of material cutting which deserves attention of further research.

References

[1] AHN, A. H et all. (2006). Investigation of cutting characteristics in side-milling a multi-thread shat on automatic lathe. *Annals of the CIRP* Vol. 55/1/2006, pp.63-66

[2] BLAŠKOVIČ, P., BALLA, J., DZIMKO, M. (1990). *Tribológia*. Bratislava: ALFA,1990, 360 s., ISBN 80-05-00633-0

[3] GRANOVSKIJ, G. I., GRANOVSKIJ, V. G. (1985). *Rezanije metallov.* Moskva: vyššaja škola, 1985, 304 s.

[4] GRZESIK, W. (1998). *Podstawy skawania materialow metalowych.* Warszawa: Wydawnictwa Naukowo-Techniczne, 1998, 380 s.,ISBN 83-204-2311-2

[5] HOSHI, K., HOSHI, T. (1969). On the metal cutting mechanism with the built-up edge. *Mem.Fac. Engng. Hekkaide University* 12, č.3, 1969

[6] HRONEK, O., ZETEK, M., BAKSA, T.,ADÁMEK, P. (2018). Surface quality analysis of cutting tool microgeometry to achieve higher durability. *Manufacturing Technology*, 2018, Vol. 18, No.1, pp. 30-46.

[7] KACZMAREK, J., WOJCIECHWICZ, B. (1995). Zmjany w strategii badań eksloatacyjnej warstwy wierzchniej. *Tribologia* č. 6, 1995, s. 629 – 654.

[8] KALPAKJIAN, S. (1999). *Manufacturing engineering and technology.* New York: Addison Wesley Publishing Company, 1989, pp.1999, ISBN 0-201-12849-7

[9] KOCMAN, K.. PROKOP, J. (2008). Cutting Tools for Matral Turning. *Manufacturing Technology*, 2008, Vol IV., pp. 5-10.

[10] KOVAČ, P., MILIČIČ D. *Rezanje metala* Novi Sad: Univerzitet u Novom Sadu, 240 s., ISBN 86.899-0015-1

[11] LOLADZE, T. N. (952). *Stružkoobrazovanije pri rezanii metallov.* Moskva, Mašgiz, 1952

[12] MASUDA, K. (1970). Compressive strenght of the cutting edges of the WC-Co cemented carbides. *Bulletin ASME,* 13, č. 56, 1970

[13] MRKVICA, I et al. (2012). Cutting ceramic by turning of nickel alloy. *Manufacturing Technology*, Vol 12, No. 13, 2012, pp. 174-186.

[14] OPITZ, H., SCHILLING, W. (1967). Untersuchung der Verschleiβreaktionen bei der Bearbeitung von Stahl mit Echnellarbeitsstahlwerkzeugen. *Forschungsber Lande s Nordhein-Westfalen*, 1967, Nr. 1796, 95 s.

[15] REZNIKOV, A. N. (1969). *Teplofizika rezanija.* Moskva, Mašinostrojenije, 1969. 286 s.

[16] SALVO, G. J., SHAW, M.C. (1968). Hydrodymanic action at a chip-tool interface. *Advance s Machining Tool Design and Research*., Part. 2, 1968

[17] SIMONEAU, A., ELBESTAWI, M.A. (2006). The effect of Microstructure on chip formation and surface defect in microscale, microscale, and macroscale cutting of Steel. *Annals of the CIRP* vol. 55/1/2006, pp.97-102.

[18] STEPHENSON, D. A., AGAPIOU, J. S. (2006). *Metal Cutting Theory and Practice.* Taylor &Francis, USA, 2006, 846 pp.

[19] TRENDT, E. M. (1991). *Metal Cutting*. London – Boston: Ed. Oxford, Butterworths – Helnemann, 1991, 273 s., ISBN 0-7506-1068-9

[20] VASILKO, K. MÁDL, J. (2012). *Teorie obrábění*. Ústí n. Labem: UJEP, 2012, 526 s.,

[21] WRIGHT, P. K. (1977). Applications of the Experimental Methods Used to Determine Temperature Gradients. In: *Cutting Tools. Austrial Conference Manufacturing Engineering*., Adelaide, 1977. Barton, 1977, pp. 145-149

10.21062/ujep/162.2018/a/1213-2489/MT/18/4/692