HUNGARIAN JOURNAL
OF INDUSTRIAL CHEMISTRY
VESZPRÉM
Vol. 38(2). pp. 163-167 (2010)

RESEARCH OF THE MECHANISM OF PLASTIC STRAIN IN CASE OF TEMPERED STEEL IN HARD TURNING

G. SZABÓ

Department of Production Engineering, University of Miskolc, 3515 Miskolc, Egyetemváros, HUNGARY
E-mail: gergely.szabo@uni-miskolc.hu

The paper deals with the strains of removed chip and the root of the chip occurring in hard turning as finish manufacturing procedure, in case of orthogonal cutting. It examines the connections of thermal occurrence and plastic strains by the means of Finite Element Method simulation. For the simulation the data of experiments done previously were used. In the paper the change of the morphology of chip formation is compared depending on the cutting speed.

Keywords: hard turning, plastic strain, chip morphology

Introduction

Nowadays, because of the increased loads, engineering industrial products require better and better accuracy, quality (e.g. wear resistance, etc.). One fulfilment method of this requirement can be solved by the increase of the number of hard, hardened surfaces (>45 HRC) on the components. As conventional finish machining, grinding has a tested, well established technology, although it can be noted that the material removal rate and the possibility of concentration of operations are relatively low. The appearance and spread of super hard tool materials (e.g. PCBN) opened way to finish machining (e.g. hard turning) of hardened steels by cutting tools having single point cutting edges. Because of the physical and mechanical characteristic of hardened steels and the PCBN tool material and also the needed edge formation and the applied cutting conditions, the process of chip removal differs from the traditional turning. By the Finite Element (FEM) simulation we wish to prove, on the base of scientific literature [1, 2, 3], the special shape of the chip and the mechanism of chip removal.

Chip removal in case hard turning

In the case of hard turning the removed chip leaves with special mechanism usually [3]. The shape of the chip removed, according to the scientific literature, can be seen in *Fig. 1* [2]. The negative tool rake angle creates high compressive stresses both on the cutting edge and in the material. As a result, the material is parted by cracking and plasticisation and chips are formed *(Fig. 2)*. It removes from the chip root as a chip segment.

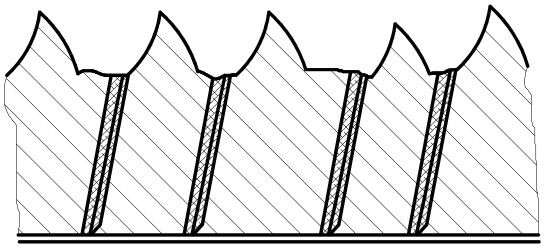

Figure 1: Shape of chip can be removed at hard turning [2]

Owing to the brittleness of the material, the high compressive stress initially leads not to a material flow but to formation of a crack. This crack releases the stored energy and thus acts as a sliding surface for the material segment, allowing the segment to be forced out between the parting surfaces [4].

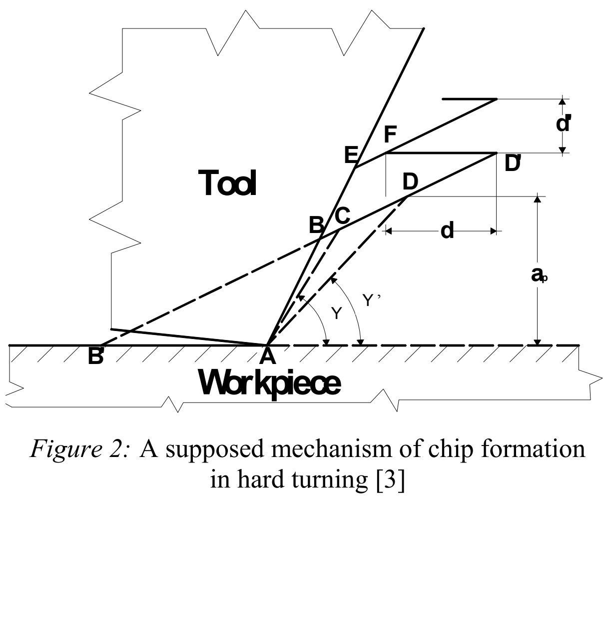

Figure 2: A supposed mechanism of chip formation in hard turning [3]

While the tool reaches point A from B', there is a thermal tempering for a while in interval BD, later this interval gets back to its original strength and along the BE interval it bonds into the direction of the flank of the tool. The extent of the bulge of the tooth shape depends on the values of Ψ [3]. As the Ψ changes periodically, according to the designation in Fig. 2, in case of $\Psi < \Psi'$ point C is situated on interval DD', while in case of $\Psi > \Psi'$ it remains on BD interval Once the chip segment has slid away, renewed cutting pressure results in formation of a fresh crack and chip segment. The heat created in the cutting process supplies the temperature increase needed for plastification of a small section of the chip material [3].

Modelling of chip formation with FEM-simulation in case of hard turning

Nowadays one of the most effective analysing, simulation procedures of physical processes is the Finite Element Method (FEM). For investigation of plastic strain rates at the root of the chip we have the 2D version of the Third Wave AdvantEdge^{TM} 5.3 program package, which is optimised for cutting processes. By this program package we can examine the process characteristics in orthogonal cutting, that is why the input data have to satisfy these requirements. That is, the geometrical data of the cutting tool need to be defined in the tool-orthogonal plane. The program starts from the Johnson-Cook equation for calculation of the strain and strain rate [5, 6, 7, 10].

$$\sigma_{red} = \left(A + B \cdot e^n\right) \cdot \left(1 + C \ln\left(\frac{\dot{\varepsilon}}{\varepsilon_0}\right)\right) \cdot \left(1 - \left(\frac{T - T_{room}}{T_m - T_{room}}\right)\right)^m$$

Where σ_{red} is the reduced, ε is the plastic strain, $\dot{\varepsilon}$ is the plastic strain rate, $\dot{\varepsilon}_0$ is the reference plastic strain rate, T is the temperature of workpiece, T_m 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 [5]. The Johnson-Cook parameters of the material quality of the workpiece are the following: $\sigma_{red} = 400$ MPa; $A = 588$ MPa; $B = 680$ MPa; $C = 0.057$; $n = 0{,}4$; $m = 0.7$ [6]. During the Finite Element Simulation we intended to prove chip formation mechanism described in paragraph 2, for steels with hardened inserts. It was examined how the change of the v_c cutting conditions affects the frequency chip segment to be forced out. Besides the segment formation and the characteristic of the emerging force components (passive force and main cutting force) were compared.

Experimental condition

The input parameters (for the simulation) of the machining operation can be found in *Table 1.*

Table 1: Research input parameters

Workpiece	
Workpiece length	5 mm
Workpiece height	3 mm
Workpiece material	Cubic Boron Nitrid
Tool	
Rake angle	-6°
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)	0.1…0.2 mm
Length of cut	3 mm
Feed	0.05…0.2 mm/rev
Cutting speed	90…240 m/min
Friction coefficient	0.35
Coolant	Not used

Results of the FEM-simulation

Having completed FEM runs the size of plastic deformation connected to different cutting conditions *(Figs. 3, 4, 5)* and the morphology of the related cutting force (F_c) as well as passive force (F_p) were examined. (Because of the simpler demonstration, the change of the cutting forces will be presented only after the temperatures that become stable, therefore the initial stages cannot be seen).

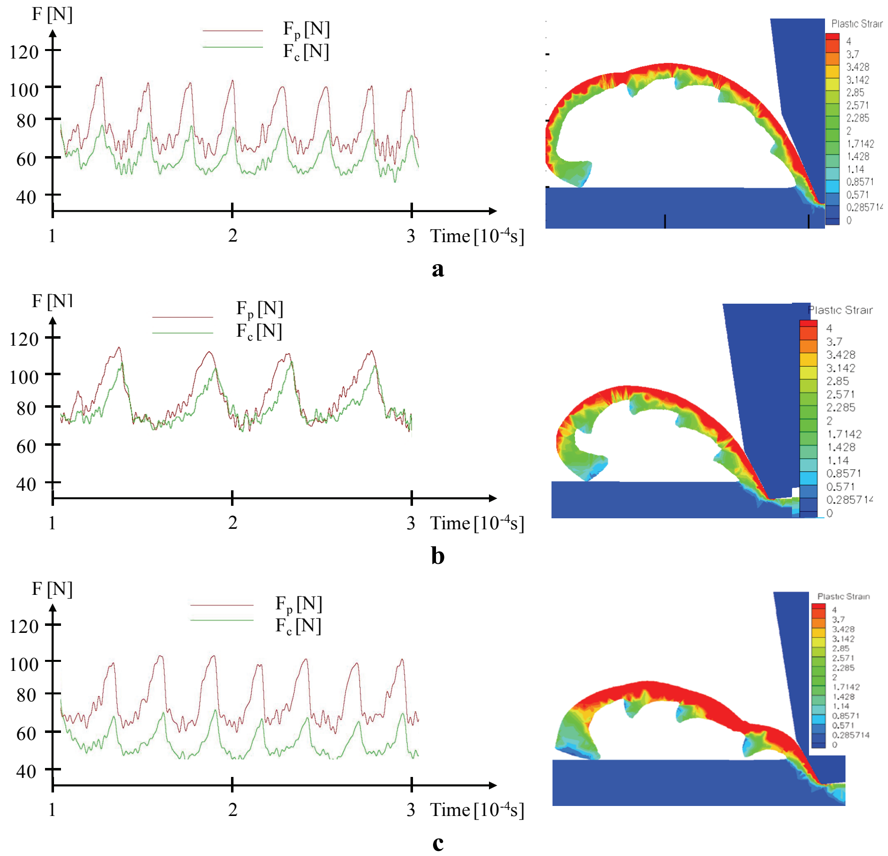

Figure 3: The size of plastic strain, the morphology of chip formation and cutting force components in the case of v_c = 120 m/min. **a**, a_p = 0.10 mm, f = 0.1mm/ford; **b**, a_p = 0.15 mm, f = 0.1 mm/ford; **c**, a_p = 0.2 mm, f = 0.1 mm/ford

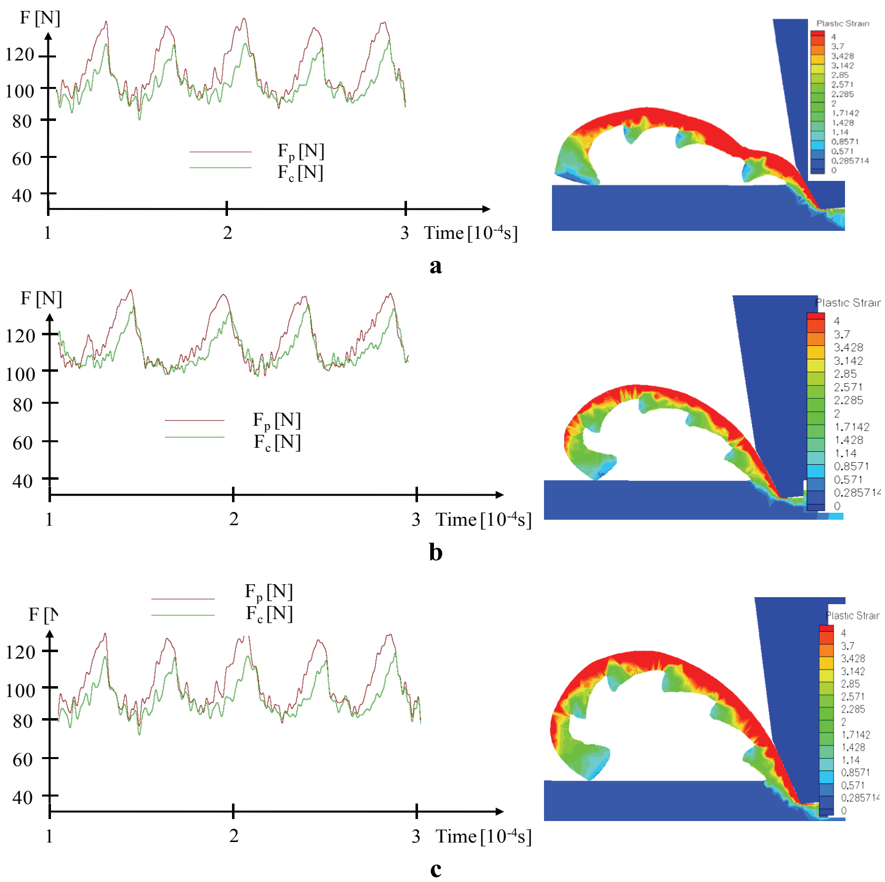

Figure 4: The size of plastic strain, the morphology of chip formation and cutting force components in the case of v_c = 150 m/min. **a**, a_p = 0.10 mm, f = 0.1mm/ford; **b**, a_p = 0.15 mm, f = 0.1 mm/ford; **c**, a_p = 0.2 mm, f = 0.1 mm/ford

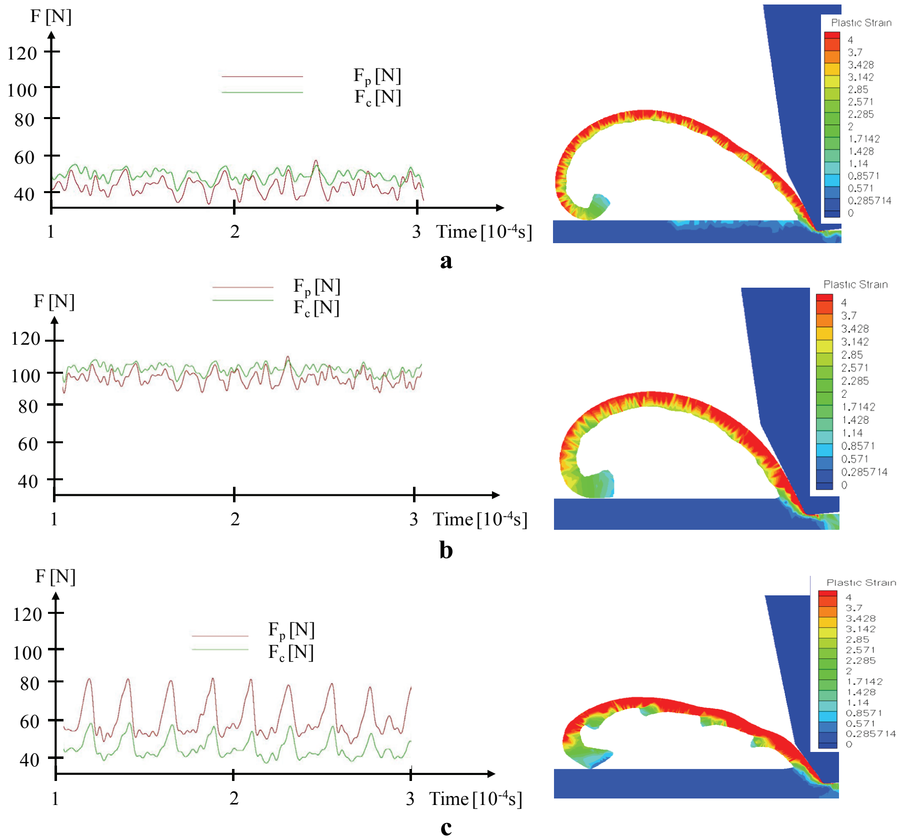

Figure 5: The size of plastic strain, the morphology of chip formation and cutting force components in the case of v_c = 240 m/min. **a**, a_p = 0.10 mm, f = 0.1mm/ford; **b**, a_p = 0.15 mm, f = 0.1 mm/ford; **c**, a_p = 0.2 mm, f = 0.1 mm/ford

The chip shapes seen in Figs. 3, 4, 5 are shown under different cutting speeds. One speed goes with three combinations of the cutting parameters. It can be observed that with the increase of the cutting speed the number of bulges of the removed chip also increases. However, with the increase of the depth of cut, the size of the bulges increases. The effect of the cutting parameters on the bulges of the chip can be examined by the spacing length of the bulges. The frequencies of the bulge of chip segments are characterized by the length of spacing belonging to the different adjusted parameters. Their values can be approximately calculated from the coordinates of the rectangular triangles, expressed in mm-s, being in *Fig. 6.* The changing of shape of the chip having almost regular periodicity and the chip formation mechanism allow to conclude that cutting forces have to emerge with similar periodicity during chip removal (Figs. 3, 4, and 5.) The connections between cutting speed and the spacing length of bulge originating from the shear can be seen in *Fig. 7.*

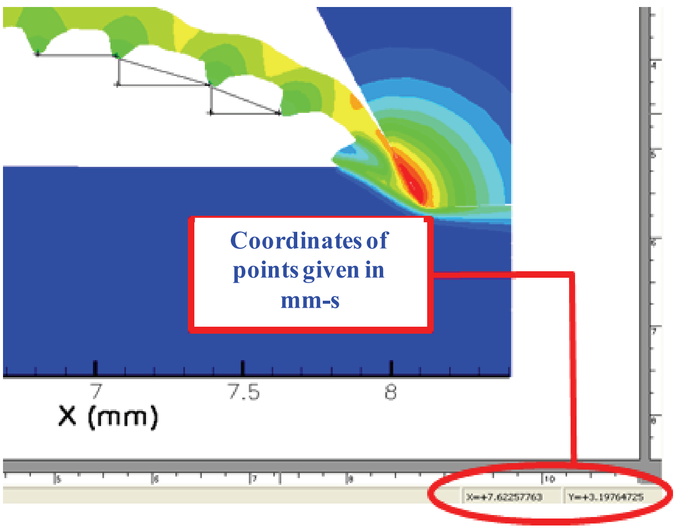

Figure 6: The calculation of the length of spacing between the originating „saw-teeth” of the developing chip

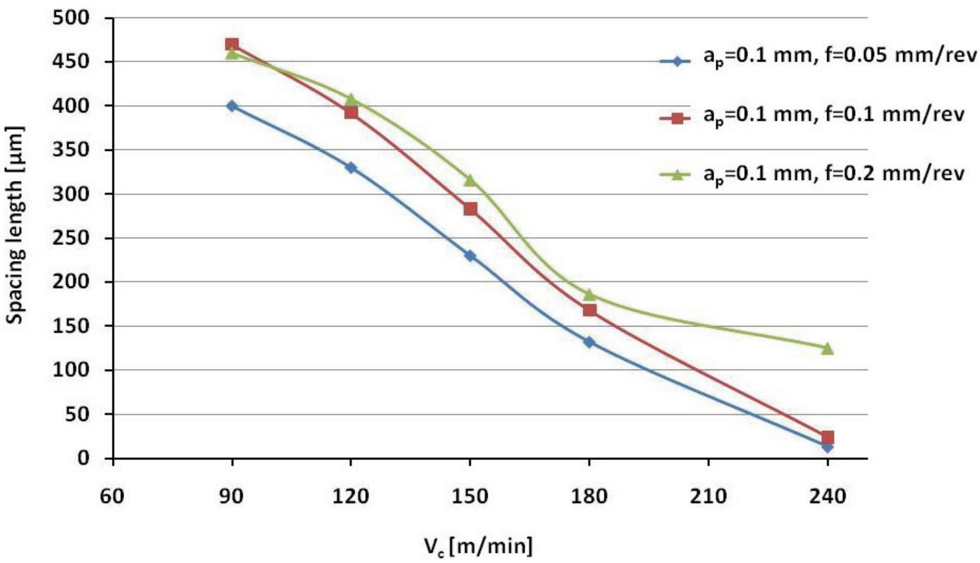

Figure 7: Connection between chip bulge and cutting speed

Conclusion

FEM simulation for case hardened steel was carried out to examine the mechanism of chip formation. As a consequence of the simulation it can be stated that the „saw-tooth" structure forming in chip removal depends on the cutting parameters. In the case of high enough cutting speed (v_c = 240 m/min), however, it decreases to its minimum, or even disappears. This morphology of formation can be related to the heat formation characteristic of removal process, thus may affect the state of the surface layer of the workpiece. The research of these relationship needs furtherexperiments.

ACKNOWLEDGEMENT

The work was presented by the support of the Hungarian Scientific Research Fund (Number of Agreement: OTKA K 78482), which the authors greatly appreciate.

REFERENCES

1. Z. PÁLMAI: Fémek forgácsolhatósága, Műszaki Könyvkiadó, Budapest, 1980, 61–69.
2. I. AL-ZKERI: Finite Element Modeling of Hard Turning. VDM Verlag Dr. Müller. Saarbrücken, 2008, ISBN: 978-3-639-110340.
3. M. A. DAVIES, C. J. EVANS, Y. CHOU: On Chip Morphology, Tool Wear and Cutting Mechanics in Finish Hard turning. Annals of the CIRP Vol. 45/1, 1996, 77–82.
4. W. KÖNIG, R. KLINGER, R. LINK: Machining Hard Materials with Geometrically Defined Cutting Edges- Field of Applications and Limitations. Annals of the CIRP Vol. 39/1/1990, 61–65.
5. Third Wave AdvantEdge™ User's Manual, Version 5.1.
6. ČSN 41 4220/ISO 683/11-70.
7. A. G. MAMALIS, J. KUNDRAK, A. MARKOPOULOS et al.: On the finite element modelling of high speed hard turning, International Journal of Advanced Manufactoring Technology, 38/5-6, 2008, 441–446.
8. W. ZEBALA: Simulation of Cutting with the Defined Tool Geometry, Journal of Machine Engineering (ISSN 1642-6568), 5/3-4, 2005, 109–119.
9. J. KUNDRAK, A. G. MAMALIS, A. MARKOPOULOS: Finishing of hardened boreholes: Grinding or hard cutting? Materials and Manufactoring Processes, 19 (6), 2004, 979–993.
10. J. KUNDRAK, W. ZEBALA, V. BANA: Examination of cutting zone deformation occurring in hard turning by FEM simulation. Manufacturing Technology, Journal for Science, Research and Production, 3, 2003, 3–7.