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FINITE ELEMENT MODELLING OF SHEAR IN HARD TURNING

Вирішено найважливішу проблему вибору оптимальної фінішної операції при обробці внутрішніх поверхонь загартованих сталей. Запропоновано параметри, за допомогою яких представляється можливим здійснювати вибір оптимальної операції точіння або шліфування. Порівняльний аналіз ефективності застосування цих операцій показав, що операція точіння внутрішніх отворів, у яких відношення довжини до діаметра не перевищує 1,1 є кращою.

Решена важнейшая проблема выбора оптимальной финишной операции при обработке внутренних поверхностей закаленных сталей. Предложены параметры, с помощью которых представляется возможным осуществлять выбор оптимальной операции точения или шлифования. Сравнительный анализ эффективности применения этих операций показал, что операция точения внутренних отверстий, у которых отношение длины к диаметру не превышает 1,1 является предпочтительной.

The major problem of a choice of optimum finishing operation is solved at processing internal surfaces tempered of steels. Parameters by means of which it is obviously possible to carry out a choice of optimum operation turning or grindings are offered. The comparative analysis of efficiency of application of these operations has shown, that turning operation internal apertures at which the attitude of length to diameter does not exceed 1,1 is preferable.

1. 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 characteristics (e.g. strength, etc.) of the material of workpiece and the material of the PCBN tool, the process of chip removal is entirely different from conventional turning. The mechanism of chip removal in hard turning can be explained by mechanic and thermo dynamic processes. By the Finite Element (FEM) simulation we wish to prove, on the base of scientific literature [2, 3, 11], the special shape of the chip and the mechanism of chip removal [3].

2. CHIP REMOVAL IN HARD TURNING

In hard turning chips with special morphology can be removed. The shape of the chip removed, according to the scientific literature, can be seen in Figure 1 [2].

The shape of the removed chip is segmented (like a saw-tooth), the formation mechanism of which can be explained on the base of Figure 2 as well [3]. The chip removal begins with shearing from point B' being at the tip of the tool and it is accomplished along the B'D' line. While the tool reaches point A from B', there is a thermal tempering for a while, 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 bulge of the tooth shape depends on values of Ψ [3]. As the Ψ changes periodically, according to the designation in Figure 2, in case of $\Psi<\Psi'$ point C is situated on interval DD', while in case of $\Psi>\Psi'$ it remains on BD interval according to the designation in Figure 2.

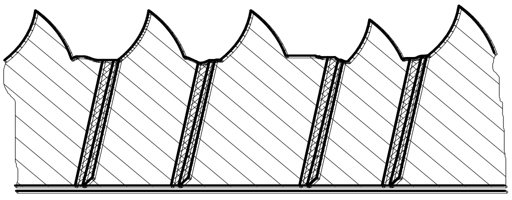


Figure 1 – Shape of chip can be removed at hard turning [2]

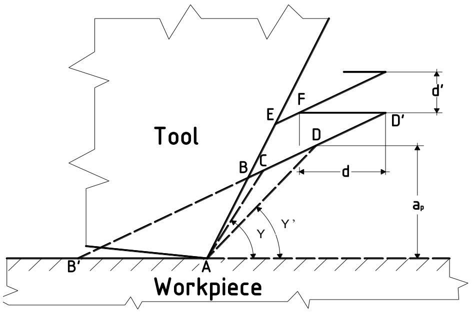


Figure 2 – A supposed mechanism of chip formation in hard turning [3]

3. MODELLING OF CHIP FORMATION IN 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 [4, 6]:

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

Where σ_{red} is the reduced, ε is the plastic strain, $\dot{\boldsymbol{\varepsilon}}$ is the plastic strain rate, $\dot{\boldsymbol{\varepsilon}}_0$ 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 values of Johnson-Cook type parameters of workpiece material are summarised in Table 1.

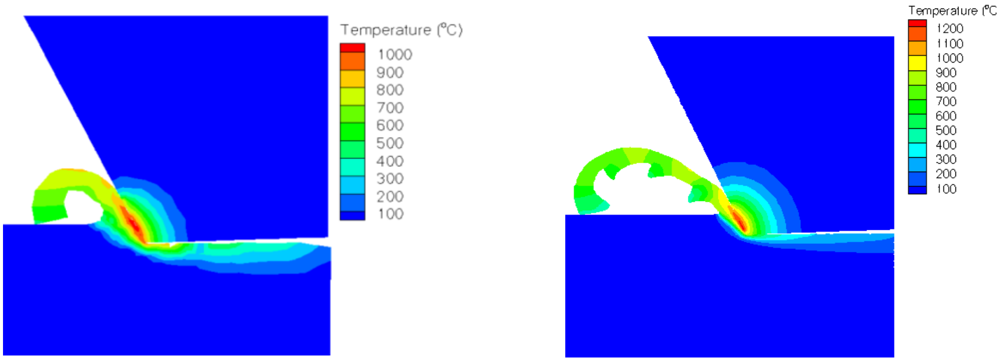
Table 1 – The values of parameters of Johnson-Cook equation for material 16MnCr5 [6]

σ_{red} *[MPa]*	*A [MPa]*	*B [MPa]*	*C*	*n*	*m*
400	588	680	0.057	0.4	0.7

In the simulation the data of our previous experiments were used as follows [7]:

Material of the workpiece:	16MnCr5 (60±2HRC),
Sizes of the workpiece:	d_w=48 mm, ℓ_w=27.35 mm
Tensile strength of the workpiece:	R_m=900 MPa
Machine tool:	EEN-400/HUNOR PNC-712
Insert:	CNGA 120408 S01020 Sandvik Coromant
Shank:	S32U PCLN L12 TIZIT
Edge geometry:	γ_{n1}= –26° γ_{n2}= –6°, α=6°, κ_r=95°, ε_r=80°, r_ε=0.8 mm (facet: –20°x0.15mm)
Cutting data:	v_c=90…150m/min f=0.05…0.25 mm/rev; ap=0.1…0.5 mm

During the Finite Element Simulation we intended to prove the correctness of chip formation which was published by [3] and can be seen in Figure 2. In Figure 3 an example is shown – by the help of Finite Element Simulation – for isotherm (Fig. 3a) and a developing adiabatic (Fig. 3b) chip removal process. The theoretic basis of this is that the cutting tool, penetrating into the hardened steel, first shears the material along the supposed first shear zone according to Figure 3. Then, the hardened steel creeps, so a significant amount of heat emerges in this phase of chip removal. This amount of heat, at the moment of chip separation, practically sticks in the material between the two „saw-teeth” and the heat transmission in the direction of sheared „saw-teeth” is minimal only, so it can be named approximately as adiabatic chip removal.



a) b)

Figure 3 – Examples for the „isotherm” and „adiabatic” chip removal

The results of FEM calculations can be seen in Figures 4-6 with different values of cutting speed in case of constant value of feed (f=0.1mm/rev) and depth of cut (a_p=0.2 mm).

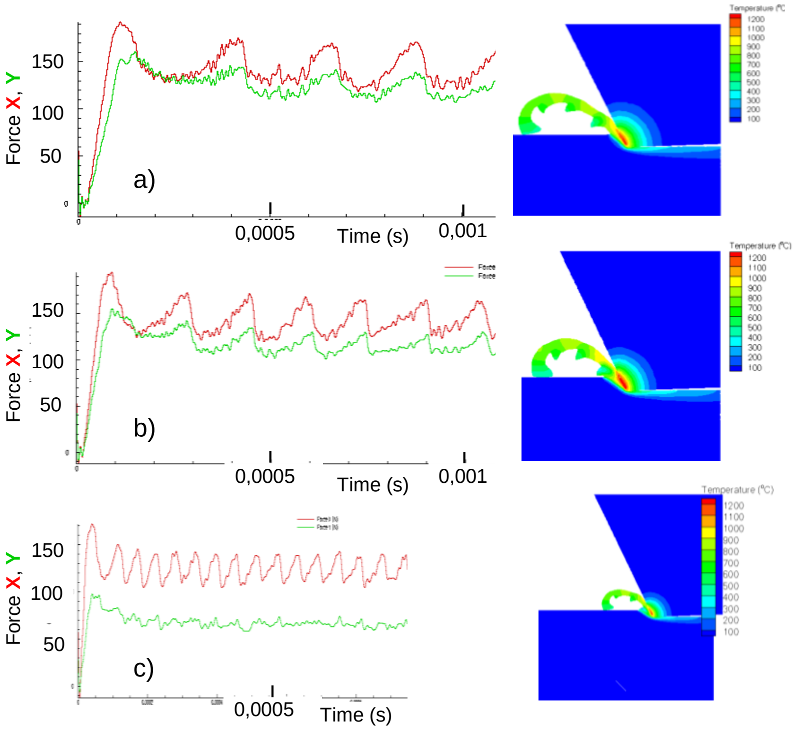
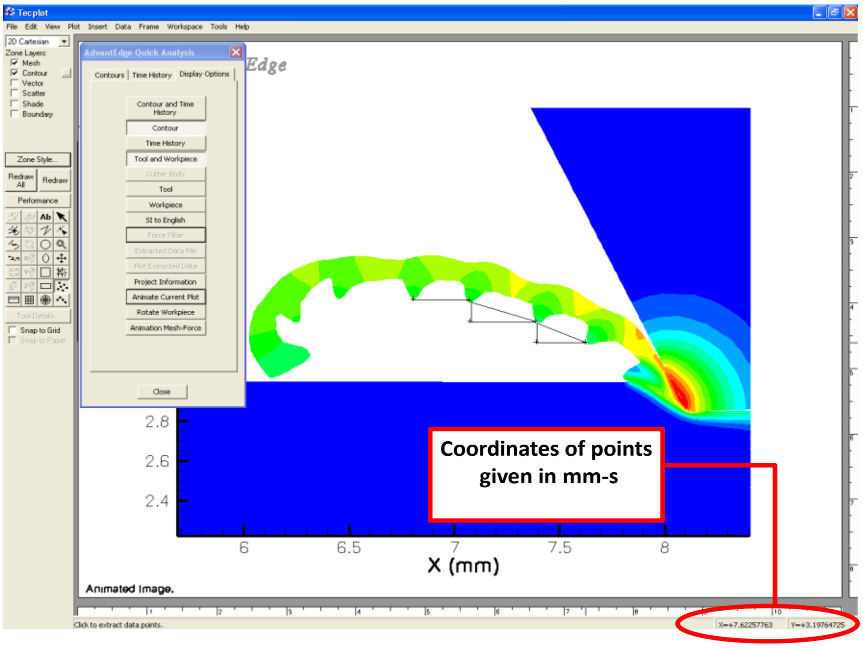


Figure 4 – Development of main cutting force and axial cutting force components versus the main cutting speed (v_c) and the change of length of spacing of saw-tooth originating from shear, as the function of cutting speed (f=0.1mm/rev, a_p=0.2 mm): a) v_c=90m/min; b) v_c=120m/min; c) v_c=150m/min

The length of spacing belonging to the different adjusted parameters can be approximately calculated from the coordinates of the rectangular triangles, expressed in mm-s, being in Figure 5.



X=+7.62257763 Y=+3.19764725

Figure 5 – Calculation of length of spacing between the originating „saw-teeth” of the developing chip

The connections between cutting speed and the spacing length of bulge originating from the shear can be seen in Figure 6.

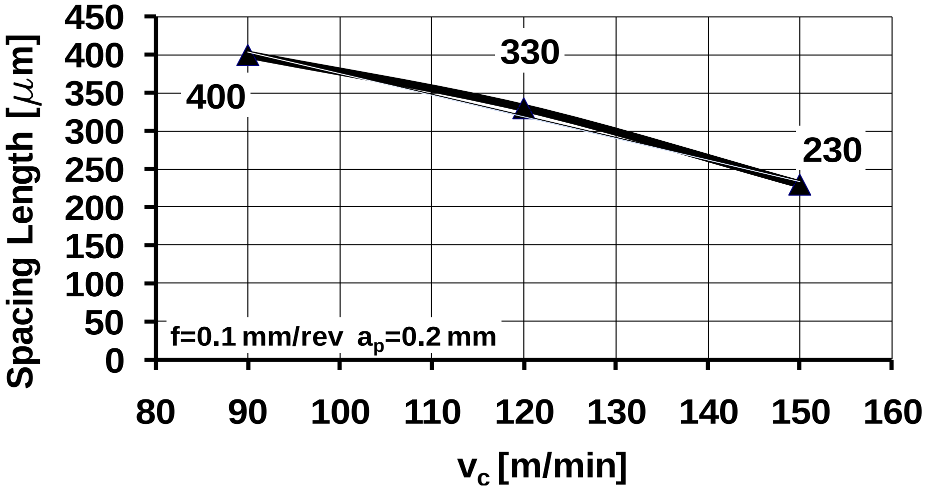


Figure 6 – Connection between chip bulge and cutting speed

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 (Figure 4). In this figure the momentary values of cutting forces as the function of the constant value of feed, depth of cut and cutting speed are demonstrated.

SUMMARY

Some features of chip formation in hard turning were examined by the FEM simulation. The adiabatic chip formation can have a significant effect on the transformation of texture, so the formation of white layer as well. The research of these relations needs further examinations.

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