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RESEARCH OF PLASTIC STRAIN AND CHIP MORPHOLOGY IN HARD TURNING

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ДОСЛІДЖЕННЯ ПЛАСТИЧНОЇ ДЕФОРМАЦІЇ І МОРФОЛОГІЇ ПРИ ОБРОБЦІ ДЕТАЛЕЙ ПІДВИЩЕНОЇ ЖОРСТКОСТІ

У випадку декількох поверхонь/частин, шліфування загартованих сталей було замінено на механічну обробку, використовувану раніше. Знання механізмів напруги може просунути збільшення ефективності знімання матеріалу, що визначається більше новими областями застосування. У цій роботі розглядається морфологія й пластична деформація зрізує стружки, що, у випадку ортогонального (2D) різання. Була досліджена залежність між пластичною деформацією й зміною режимів різання.

В случае нескольких поверхностей/частей, шлифование закаленных сталей было заменено на механическую обработку, используемую ранее. Знание механизмов напряжения может продвинуть увеличение эффективности съема материала, которая определяется более новыми областями применения. В этой работе рассматривается морфология и пластическая деформация срезаемой стружки в случае ортогонального (2D) резания. Была исследована зависимость между пластической деформацией и изменением режимов резания.

In the case of several surfaces/parts, the turning of hardened materials replaced the machining applied before. The knowledge of strain mechanisms may advance the increase of material removal efficiency this appoint newer fields of application. This paper introduces the morphology and the plastic strain of the removed chip in the case of orthogonal (2D) cutting. The relationship between plastic strain and the change of cutting data has been investigated.

INTRODUCTION

Nowadays the development of the finish machining of hardened parts with high productivity is very important in the engineering industry. There is great need for this because of today’s ever increasing loads of components, higher and higher demand for accuracy, quality (eq. wear resistance, etc.) is required. One fulfilment method of this requirement can be solved by the increase of the number of hard, hardened surfaces (>45 HRC) on the components. Hard turning with geometrically defined edges is the most effective procedure, among different types of finishing hard machining. The appearance and spread of super hard tool materials (e.g. PCBN) however opened way to finish machining (eq. 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 as well as the needed edge formation and the applied cutting conditions, the process of chip removal differs from the traditional turning. The most frequently hard turned workpiece- material qualities can be found in Figure 1 [11].

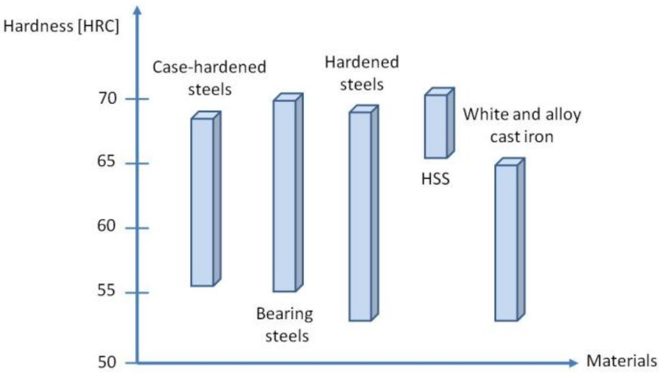

Figure 1 – The most frequent hard materials in engineering [11]

1. CHIP REMOVAL IN CASE HARD TURNING

In the case of chip removal in hard turning, special plastic deformation mechanisms take place in the chip root. This mechanism- similarly to other types of material removal- can be examined well in free cutting. The characteristic shape of the removed chip morphology can be seen in Figure 2 [2].

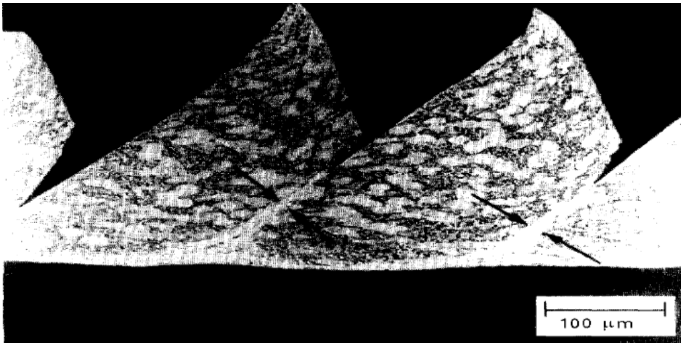

Figure 2 – Characteristic "sawtooth" shaped chip removed by hard turning [2]

The chip formation mechanisms in hard turning were first investigated by Ackerschott [31], who postulated high compressive stresses in the surface layer causing cracks in front of the cutting tool under an angle of 45°to the surface. At the same time the material is plastically deformed by the rounded cutting edge [24]. The removed chip is „sawtooth" shaped, the creation mechanism of which is explained in technical literature as follows [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. It removes from the chip root as a chip segment (Figure 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. In high speed cutting of steels segmented chips have also been observed [32]. 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 surface. The sliding of a chip segment along the crack reduces the compressive stresses until a further crack is induced due to the continuous movement of the tool [24]. Simultaneously, plastic deformation and heating of the material occur at the leading edge of the cutting tool. The individual chip segments are linked by the small proportion of the material, which is plastically deformed and heated to a high temperature. A continuous chip is formed [1].

2. RESEARCH OF THE PLASTIC STRAIN WITH FEM- SIMULATION

According to technical literature [1, 2, 3, 4, 7, 9, 11, 12] on effective method for the research and modelling of chip removal mechanisms is the Finite Element Method (FEM). For investigation of plastic strain at the root of the chip we have the 2D version of the Third Wave AdvantEdge™ 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 such as 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 numerical calculation of the plastic strain and strain rate [1, 3, 5, 7]:

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

Where σ_{red} is the reduced stress, 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. The Johnson-Cook coefficients regarding the workpiece can be found in the Table 1.

Table 1 – Johnson-Cook parameters of 20MnCr5 [6]

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

The theoretical diagram of the operation Third Wave AdvantEdge™ 5.3 2D program can be seen in Figure 3 [4, 25].

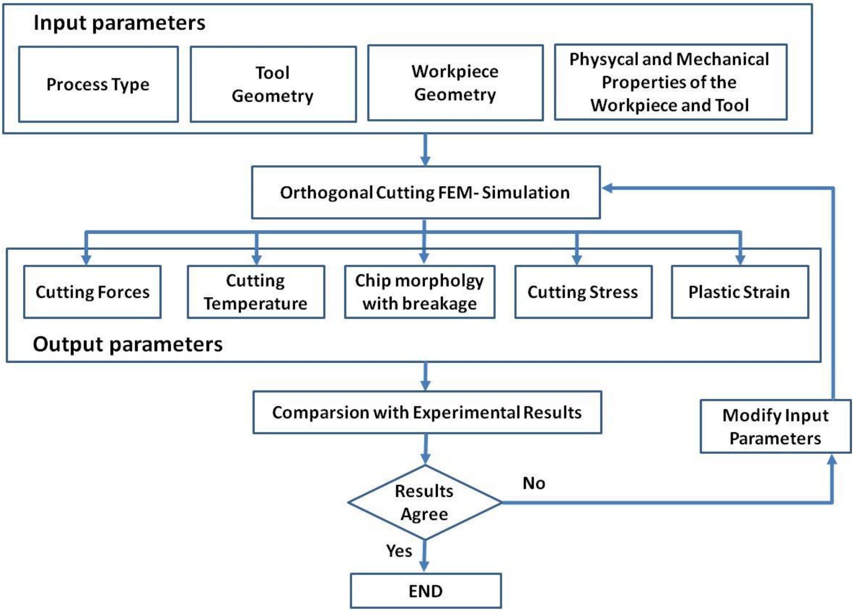

Figure 3 – The utilized iterative numerical procedure scheme of Third Wave AdvantEdge™ 5.3 [4, 25]

3. *EXPERIMENTAL CONDITIONS*

The input parameters (for the simulation) of the machining operation can be found in Table 2.

Table 2 – Software input parameters

Workpiece		*Process*	
Workp. length	5 mm	Depth of cut	0.1÷0.2 mm
Workp. height	3 mm	Length of cut	3 mm
Workp. material	20MnCr5	Feed	0.05÷0.2 mm/rev
Tool		Cutting speed	90÷240 m/min
Rake angle	-26°	Friction coefficient	0.35
Rake face length	1.2 mm	Coolant	Not used
Relief angle	6°	*Simulation*	
Relief face length	2 mm	Max. nodes	24000
Cut. edge radius	0.01 mm	Max. element size	0.1 mm
Material	CBN	Min. element size	0.01 mm

4. RESULTS OF THE FEM- SIMULATION

The FEM simulations gained by calculation are divided into three groups. The three groups are the combinations of the feed (f) and depth of cut (a_p) in the three revolutions. In the case of these combinations of cutting data, the characteristics of chip segment creation depending on the cutting speed (v_c) is investigated.

The chip segmentation is characterized by the spacing occurring between the chip segments, which is on accepted method for this research in technical literature as well [1, 2, 3, 4, 13]. The results of the investigation can be found in Figures 4, 5, 6.

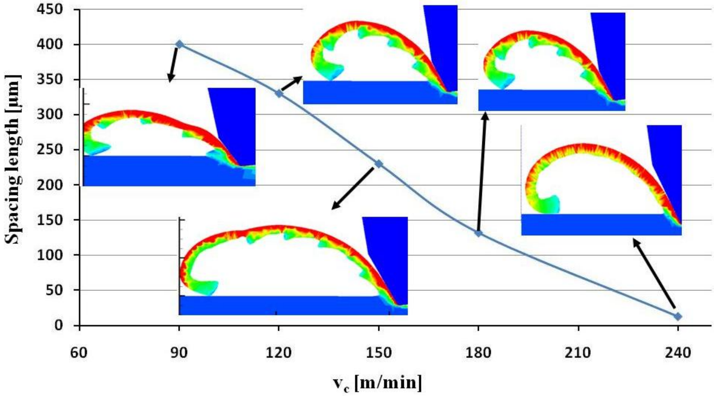

Figure 4 – Frequency of chip segment creation f=0.1 [mm/rev], in the case of a_p=0.2 [mm] depending on the cutting speed

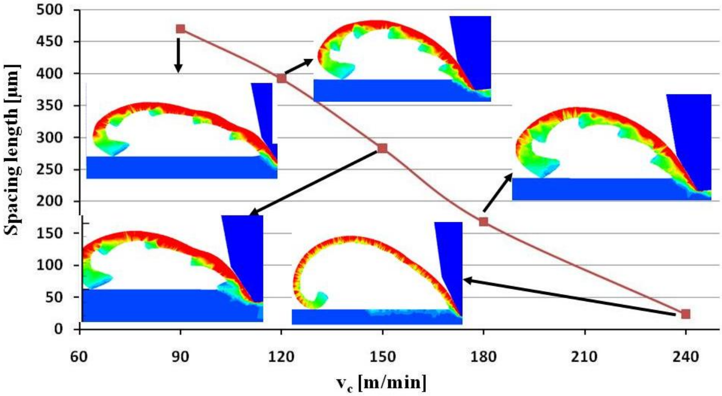

Figure 5 – Frequency of chip segment creation f=0.1 [mm/rev], in the case of a_p=0.1 [mm] depending on the cutting speed

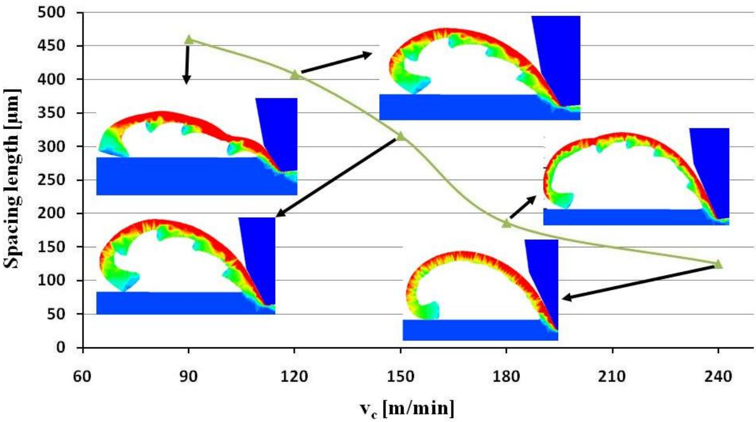

Figure 6 – Frequency of chip segment creation f=0.1 [mm/rev], in the case of a_p=0.2 [mm] depending on the cutting speed

Analyzing FEM runs it was experienced that increasing the cutting speed the size of extrusions decreases and the spacing between the „sawtooth” shaped chip segments becomes smaller. It can be explained by the following: the strain and segment creation mechanism that is dealt with in point 2 takes place with higher and higher intensity if increasing the cutting speed, while at 240 [m/min] speed rate these extrusions even disappear. In the case of high cutting speed practically in the whole cross section, the removed chip strains. This high strain may involve high heat generation, which can even modify the state of the workpiece's surface layer [21, 22].

CONCLUSION

As a consequence of FEM simulation it can be stated that the „sawtooth” structure appearing in chip removal depends on the cutting parameters. This morphology may relate to the heat generation characteristic of the removal process and themes it may effect the state of the workpiece's surface layer. The research of these relationships requires more experiments.

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