

Mathematical Simulation of Tungsten Carbide Machining Using Finite Elements Method

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Abstract: Presented article is focused simulation and visualization of the turning process of hard metal material. The main purpose is to describe the phenomena occurring during the process of chip machining in various cutting conditions. In this work, simulation software is used to analyze an actual process of the simulation and its concomitant circumstances. The use of modeling and simulation software is cost and time efficient. The article is divided into two main parts. The first part focuses on characterization and description of the turning process. The second part concentrates on explanation and simulation of the chip machining process of hard metal material by means of FEM analysis software.

Keywords: simulation, FEM, machining, workpiece

1 Introduction

Turning belongs between most wide spread technologies of chip machining. This lead to necessity of instant improving of mentioned machining process. Important factors are decreasing of operating costs, shortening of production time, increasing of surface quality and dimensional accuracy, increasing of tools durability and many others. Presented article is focused on simulation and visualization of turning of hard metal workpiece based on FEM analysis. Simulation process is created to analyze several machining conditions for selected material [1].

2 Technological conditions and material properties

Input values are very important for successful simulation with appropriate results which are applicable in practical conditions. Input factors used in presented simulation were cutting speed v_c [$\text{m}\cdot\text{min}^{-1}$], feed rate f [mm/rev], depth of cut a_p [mm], initial temperature [$^{\circ}\text{C}$]. Following parameters were selected tool geometry, material of tool, material of workpiece [1], [2].

Machining conditions used for simulation were as listed below:

Workpiece material: CTE 60M

Cutting plates: CBN (diameter 12,6 mm)

Roughing

New cutting plates:

Cutting speed: $v_c = 75 \text{ m}\cdot\text{min}^{-1}$

Feed rate: $f = 0,25 \text{ mm/rev}$

Depth of cut: $a_p = \text{max. } 1,0 \text{ mm}$

For used cutting plates:

Cutting speed: $v_c = 65 \text{ m}\cdot\text{min}^{-1}$

Feed rate: $f = 0,30 \text{ mm/rev}$

Depth of cut: $a_p = \text{max. } 1,0 \text{ mm}$

Finishing

Finishing operation is performed exclusively using new never used cutting plates.

Cutting speed: $v_c = 80 \text{ m}\cdot\text{min}^{-1}$

Feed rate: $f = 0,20 \text{ mm/rev}$

Depth of cut: $a_p = \text{max. } 0,5 \text{ mm}$

Table 1. Mechanical properties of CTE 60M

Hardness HV 10	610
Elasticity modulus [GPa]	420
Fracture toughness [MPa/m ²]	29,0
Compressive parameter [MPa]	3000
Density [kg/m ³]	12,70
Thermal conductivity [W/mK]	95

Table 2. Properties of CBN material

Knoop hardness [GPa]	55-60
Elasticity modulus [GPa]	500-550
Critical load [N]	25
Density [g/cm ³]	3,45

Mesh can be generated on both tool and workpiece after all necessary parameters are set. On following figures are shown selected tool (Figure 1.) and workpiece and generated mesh (Figure 2.) [4], [5].

Boundary conditions have to be set for both tool and workpiece due to mutual interaction. Workpiece is bonded in all axes x, y, z due to machining simulation stability. Heat transfer is selected for interaction between tool and workpiece and environment. Starting temperature was set to 20°C [2], [3], [7].

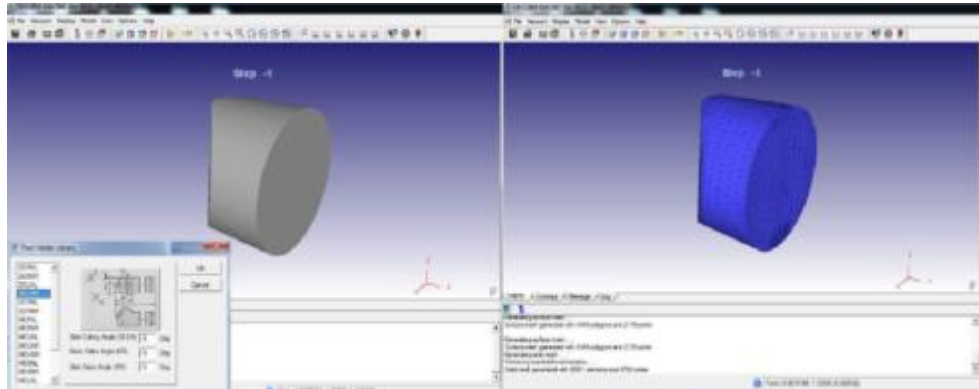


Fig. 1. CBN tool and finite elements mesh

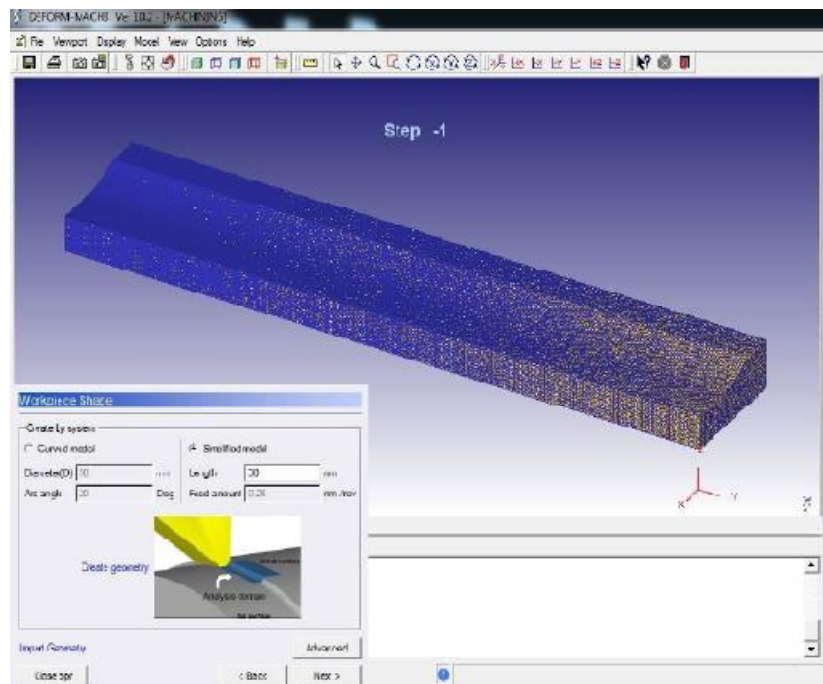


Fig. 2. Simplified model of workpiece

3 Simulation

Machining process is divided to 1850 steps. Tool wear is calculated using *Usui method* based on equation (1) [6], [8]:

$$w = \int a \cdot p \cdot V \cdot e^{-bt} \quad (1)$$

Where:

a, b – experimental coefficients [-]

p – pressure [Pa]

t – temperature [°C]

v – speed [$\text{m}\cdot\text{s}^{-1}$]

Strain – effective– shear strain was observed in four stages. On following figure (Figure 3.) are displayed values of shear strain for steps 650, 900, 1250 and 1850.

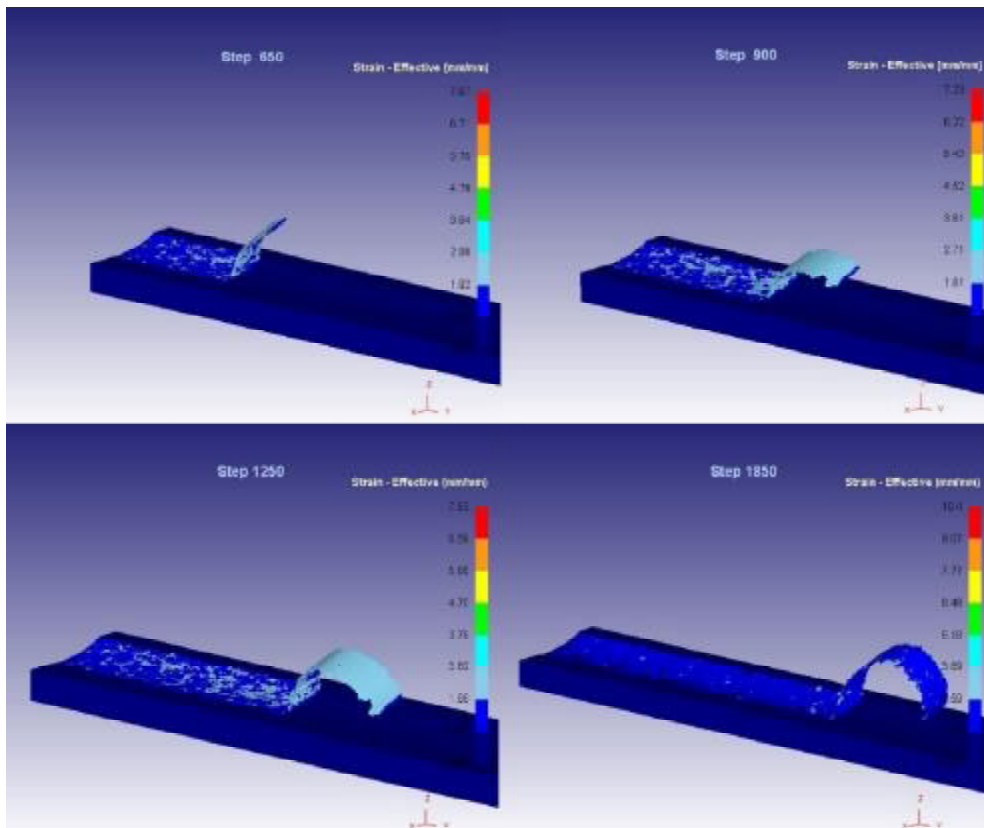


Fig. 3.Strain effective

Damage– is used to predict fracture in every step of simulation. Damage is defined by damage factor. Damage factor is defined by equation (2):

$$Df = \int \sigma_+ / \sigma d\epsilon \quad (2)$$

Where:

σ_+ - maximum tensile principal stress

σ - effective stress

$d\epsilon$ - effective strain increment

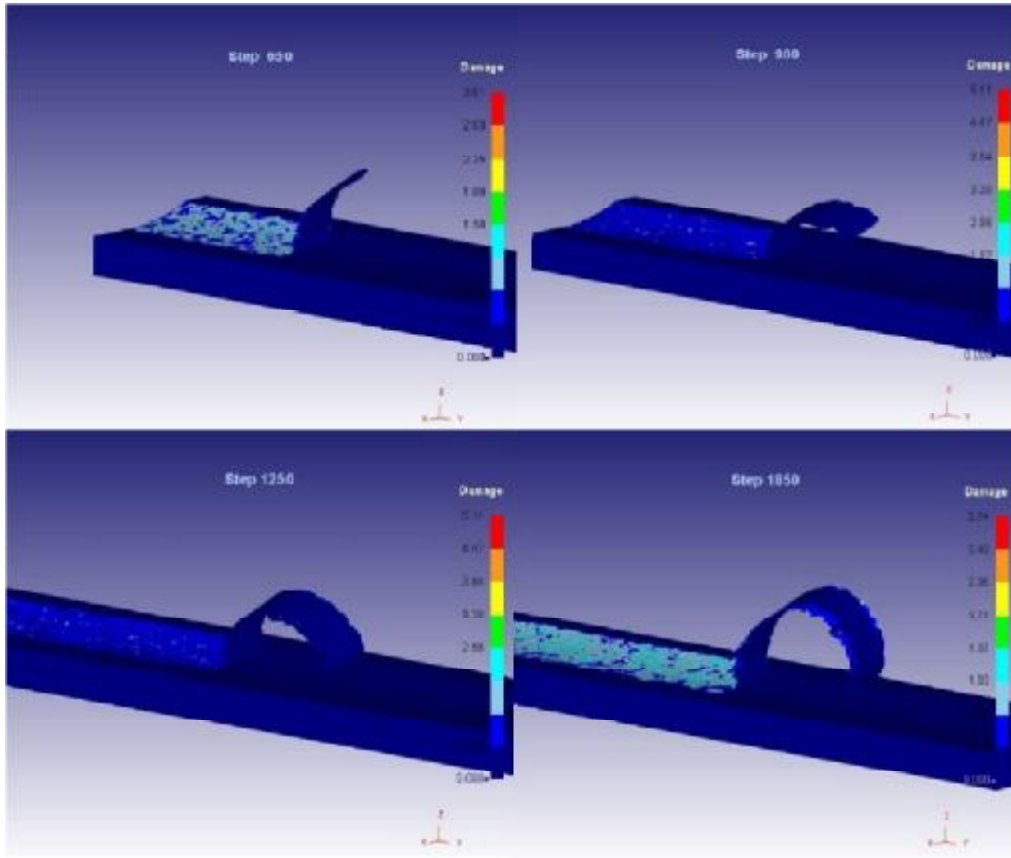


Fig. 4. Damage in machining process

Stress-effective – can be characterizes as a force acting on specific area of material. Stress is divided to two categories. Normal stress is acting perpendicular to workpiece surface and shear stress is acting in longitude direction to workpiece surface. In the fact of this total stress is characterized by three normal stresses σ_x , σ_y , σ_z and sheer stress components σ_{xy} , σ_{yx} , σ_{zy} , σ_{yz} , σ_{xz} , σ_{zx} .

Stress can be calculated using *Von Mises method*:

$$\sigma_v = \sqrt{12[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} \quad (3)$$

Following figure (Figure 5.) shows behavior of stress in machining process of hard metal sample. Maximal stress occurs in root of the chip due to material removal on the contact area. Maximal compressive stress obtained during simulation process was 1380 MPa. During whole simulation maximal value of pressure varied towards to maximal value of compressive stress.

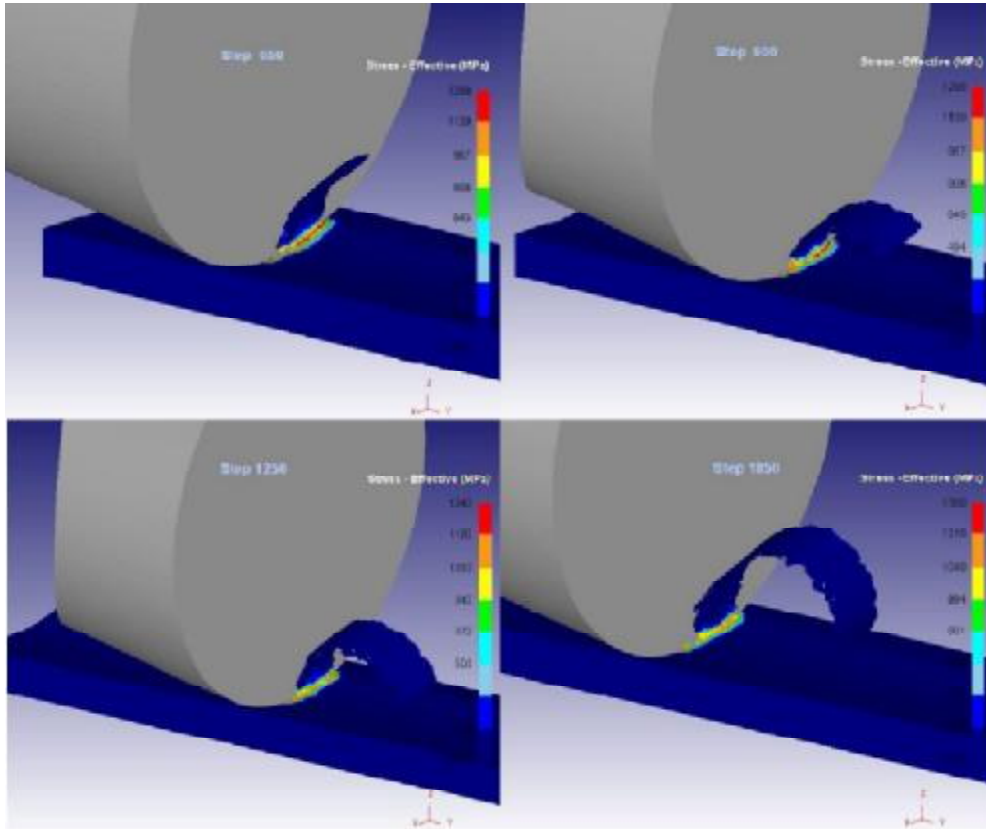


Fig. 5. Von Mises stress

Temperature

Temperature is very important factor in machining process, which affects tool durability, surface quality, heat affected zone (HAZ) and many other parameters. Simulation allows observation of temperature changes during whole machining process. Figure 6. shows progressive increment of temperature, from starting ambient temperature 20°C to temperatures above 500°C. As is evident from figure 6. majority of temperature is removed via created chip.

Three different cutting speeds were used for simulation, with constant feed rate and depth of cut. Cutting conditions are listed in table 3. Variant no. 3 represents original cutting conditions, which were used in practical conditions.

Table 3. Machining conditions

	1. Variant	2. Variant	3. Variant
Cutting speed v_c [m.min ⁻¹]	60	70	80
Feed rate f [mm]	0,25	0,25	0,25
Depth of cut a_p [mm]	1	1	1

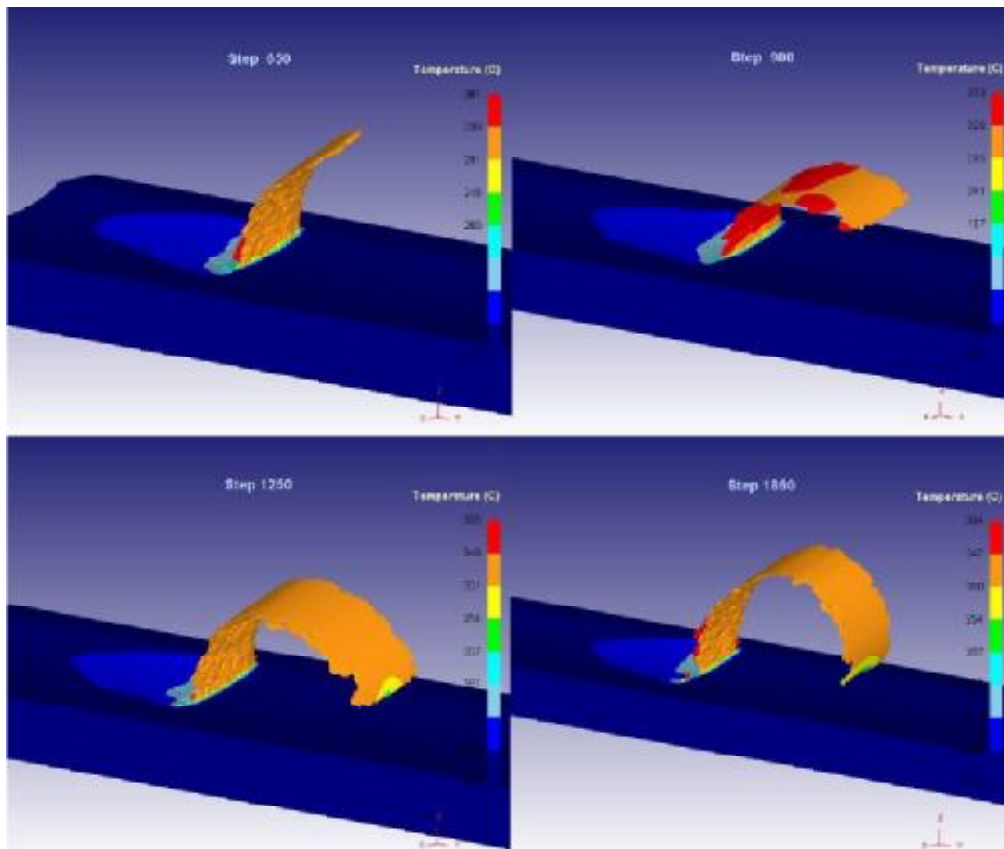


Fig. 6 Temperature

Simulation results show that optimal parameters for machining hard metal samples are cutting speed from variant no.1. Using the lowest cutting speed $60 \text{ m}\cdot\text{min}^{-1}$ results in optimal chip formation and thus a lower wear rate of the tool. Also, stress, damage, and temperature values were for variant no.1 most appropriate for a stable cutting process. Simulated parameters will be subsequently tested in practical conditions for correctness confirmation.

4 Conclusion

The presented article shows the simulation process of hard metal manufacturing using CBN cutting plates. The simulation was performed based on the demand of the manufacturing company. Results of the experiment in the form of pressure values, deformation values, maximal stresses in the cutting process, and obtained temperatures will help to improve the machining process in practical conditions and thus save money.

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