



NUMERIC SIMULATION OF CUTTING PROCESSES

Sorin ACHIMAȘ, Marian BORZAN, Adrian TRIF, Florin MOCEAN, Tudor MORAR

Abstract: In recent years, the finite element analysis has become an important instrument for the simulation of metal cutting processes. For improving the cutting process of metal parts, numeric modelling and simulation are needed. It is also required to numerically model the interaction at the interface tool – part such as to predict the performances of cutting process. According to research, the most used indicators in monitoring the cutting process are: cutting forces, power intake, vibrations, quality of processed surface, tool wear, processing accuracy etc.

Key words: cutting simulation, finite element analysis, monitoring of cutting process.

1. INTRODUCTION

The modern production process is a complex process involving, among others, the application of modelling and analysis methods based on high performance software applications. The finite element method (FEM) provides solutions to problems in identifying the field of variation of tensions and displacements, in principal.

Commercial applications developed in the 1970s were usually: ABAQUS, ADINA, ANSYS, MARK, PAFEC; pre-

sent day specialised applications using FEM are: NASTRAM, ANSYS, COSMOS, CATIA, etc.

FEM analysis is a complex process, implying a number of well defined stages. When preparing the analysis model, the shape and size of the model shall be taken into account, considering the fact that they affect the accuracy and duration of analysis (fig.1). For this purpose, for a given task, there are several variations of analysis models.

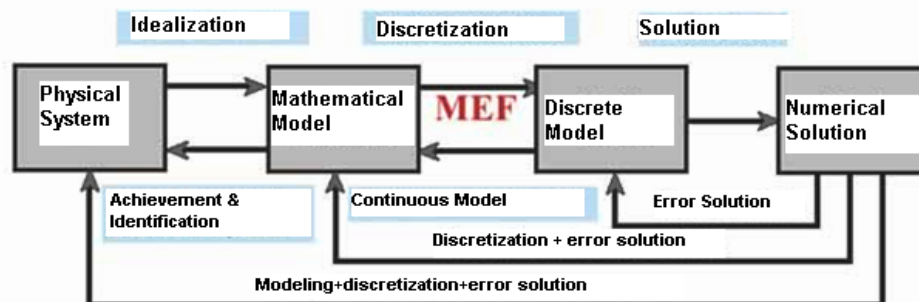


Fig. 1. Stages of the finite element (FEM) analysis process

Processing stage includes the description of the geometrical model of the task and the finite element modelling.

Analysing and resolving the finite element model initially requires the setting of parameters, then running the model and interpreting

the error and warning notifications. Post-processing is the stage when parameters variations and stages are visualised (deformation stage; animated stage; charts; printing the parameters etc.).

Final stage of post-processing involves studying the parameters for the purpose of optimisation.

In order to improve the process of cutting metal materials, numeric modelling and simulation are needed. One requirement is to numerically model the interaction at the interface tool – material such as to predict the efficiency of cutting process.

Currently there are two most used methods to analyse the cutting process [3]. The simplest method considers the metal cutting process as being continuous, with the chip geometry known in advance. The method uses an Eulerian formulation of the thermo-mechanical equations and is not using a chip forming criterion.

The other method is more realistic, as it studies the process since the cutting edge enters the material, until achieving a stationary cutting regime. In such case, the formulations of the thermo-mechanical equations are Lagrangean and better suited to the analysis requirements.

It is also required to adopt a separation criterion, enabling the predictions regarding the chip geometry.

First applications of FEM in cutting processes have been of Eulerian type [4;12]. In all situations, the analysis was limited to orthogonal cutting.

Strenkowski and Carrol [11] published the first study based on a Lagrangean formulation. Their analysis was limited to orthogonal cutting. Subsequently a series of other researchers [7;14] developed Lagrangean models with 2D and 3D finite elements for the cutting processes.

Most of these studies have been performed³ with commercially available applications such as: ABAQUS [7], MARC [8], DEFORM [1,15].

2. PRESENTATION OF DEFORM 2DV 9.01 APPLICATION

Using the DEFORM 2DV 9.01 application, an orthogonal chip may be simulated, and process conditions may be defined for every moment of cutting process. This application allows

for monitoring temperature, normal pressure, cutting speed, cutting tension and force in the cutting area.

The purpose of this paper is to present a facing process by defining the conditions for orthogonal cutting, the balance state of the part and tool during processing and the manner of representing the process parameters in the modelling parameters. After launching the application, select “Machining 2D Cutting” (Fig.2).

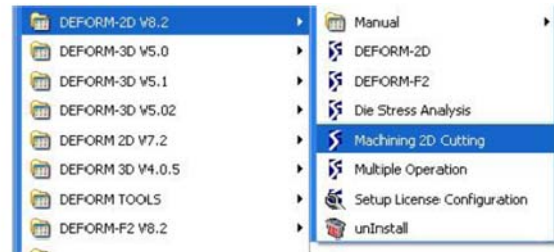


Fig.2. Menu item “Machining 2D Cutting”

2.1. Define the parameters of cutting process

Define the parameters of cutting process, including: peripheral velocity, 250 m/min; rotation speed, 1273 rpm; part diameter, 50 mm; cutting depth, 0.2 mm; advancing speed, 0.15 mm/rot.

2.2. Define conditions

Define conditions, including: temperature 22.5⁰ C; friction coefficient 0.48; heat transfer coefficient 39 GN/sec/mm⁰C.

2.3. Define geometry of cutting tip

From the menu “Insert Geometry” select “Define Primitive Geometry” choose option “Insert 1”. Enter values for angles B and C, tip radius and lengths L1 and L2.

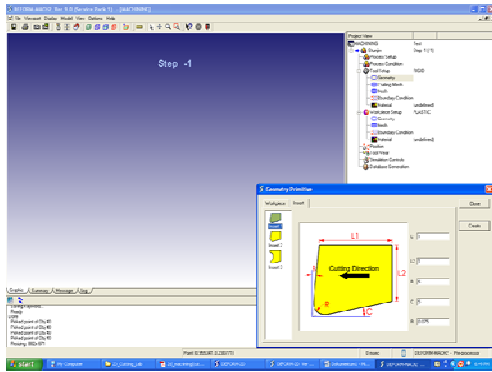


Fig. 3 Geometry of cutting tip

2.4. Define tool material

Active part of the tool is provided with two layers, as follows:

- first layer of 10 μm , material: TiN.
- second layer of 10 μm , material: Al_2O_3 .

Materials are included in the material library of the application.

Figure 4 presents the discretisation of the workpiece.

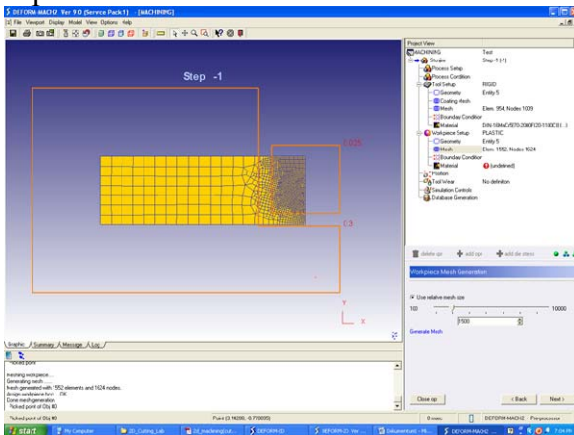


Fig.4 Discretisation of the workpiece

2.5 Discretization of the tool's active area.

With the option “Tool mesh generation” select 700 and then clicking the “Next” button, a mesh is created on the tool surface, dividing the tool area in 700 finite elements.

2.6 Define the tool's base material.

From the menu “Insert material setup” choose option “Import material from library” then from the category “Other” choose material 16MnCr5. By clicking “Load” button the material will be included in the process.

2.7 Define geometry data of the part to be produced

For the part to be produced, define part temperature “22.5⁰ C”. From the menu “Workpiece Geometry” select option “Define primitive geometry” then select parameters W=3 and N=1 to define part geometry. Click the “Next” button and data will be included in the process.

2.8 Discretisation of the workpiece

From the menu “Workpiece Mesh Generation” select the number of finite elements over the entire part area. The application divides the part in two sectors; in the first sector, subject to stress, finite elements are sized 0.025 x 0.025, while in the other sector the finite elements are sized 0.3 x 0.3. This process is activated by clicking “Next”.

2.9 Define limit conditions

The menu “View Workpiece BCC” verifies the conditions as calculated and imposed by the system. The process is validated by pressing “Next”.

2.10 Select workpiece material

From the menu “Workpiece Material Setup” select option “Import material from library”; from category “Steel” select AISI-1045 (Machining) imposed by the program. By pressing “Load” the material is imported in the process. Press “Next” for validation.

2.11 Relative position tool – workpiece

From the menu “Position” select option “Generate default positioning”, enter values for coefficients “a” and “b” as required by the program. Validate by pressing “Next”.

2.12 Generate database

From the menu “Simulation Controls” define the number of passings and the thickness of layer to be removed during simulation. Set number of passings to 250 and cutting depth to 1 mm. From the menu “Data base Generation” select option “Generate Database”.

2.13 Activate simulation process

3.SIMULATION OF SHAPING FOR STAINLESS STEEL USING DEFORM 2D
9.01 APPLICATION

3.1 Removable inserts

SECO removable inserts are metric series and standardised as per ISO 1832-2004. Inserts coding is presented in figure 5 [17].



Fig. 5 Inserts coding: 1 - shape of removable insert; 2 - rake angle; 3 -tolerance; 4 - type; 5 - length of cutting edge; 6 - thickness; 7 - tip radius; 8 - edge direction; 9 - version; 10 - description (for rough cutting R, for medium M and for finishing F).

SECO range provides inserts covered with protective layers (C.V.D and P.V.D), with high contents of TiC – cermet as well as not covered.

Stainless steel is high alloy steel with Cr or Cr-Ni, the materials considered for study were mark x40Cr13 (martensitic steel with carbon contents of 0.4% and Cr contents of 13%) and mark x12CrNi 18.9 (austenitic steel with carbon contents of 0.12%, Cr contents of 18% and Ni contents of 9%).

Taking into consideration the cutting laws and the effect of parameters on tool wear, the sequence for determining the cutting regime is the following:

- cutting depth “t” in [mm];
- advance “s” in [mm/rot];
- main cutting speed, “v_p” in [m/min].

The elements of cutting regime have been selected according to the tools manufacturer, based on recommendations from specialised literature.

3.2 Interpreting the results

3.2.1 Comparison of results between rough cutting of x40Cr13 and x12CrNi 18.9 materials

From the menu “Simulate” select option “Run simulation” to start the shaping process.

3.2.1.1 Determine part structure

Deterioration of part structure is presented in colour codes (fig. 6), so for material x40Cr13 it reaches 0.154 units, while for material x12CrNi 18.9 is around 0.1 units.

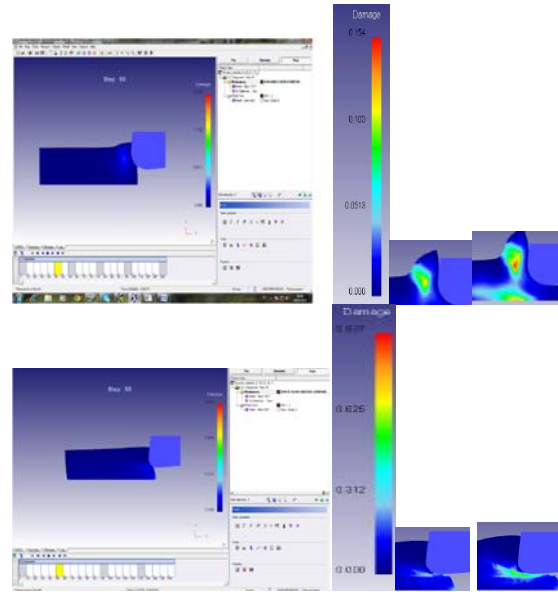


Fig.6 Determine part structure
 a) for x40Cr13
 b) for x12CrNi 18.9

3.2.1.2 Actual deformation

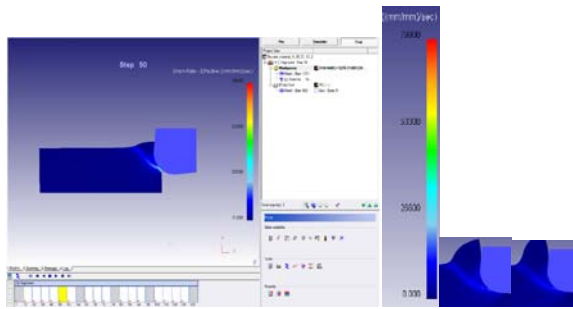
Deformability of metals and alloys represents their capacity to be permanently deformed without breaking internal links.

The amount of deformation applicable to a given material, without cracking or breaking it during deformation, at given temperature and deformation rate, is generally considered the material’s deformability.

Deformation for rough cutting material x40Cr13 was of 4.57 mm/mm, and for material x12CrNi 18.9 was of 3.84mm/mm.

3.2.1.3 Deformation rate

Deformation rate during cutting reaches a magnitude of tens and hundreds of meters per minute, the temperature in the cutting area is very high and variable, and the deformation level is high. In figure 7 the deformation rates for the two materials are presented.



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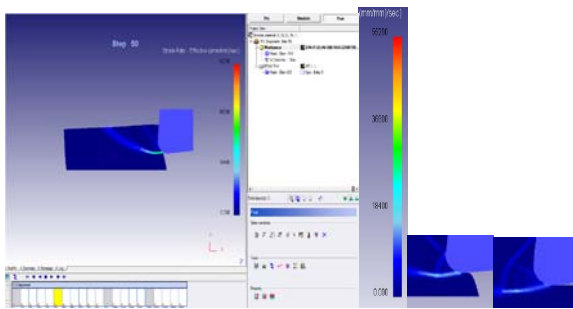


Fig. 7 Variation of deformation rate for cutting, expressed in mm/mm/sec:
a) material x40Cr13, rate of about 20,000;
b) x12 CrNi 18.9, about 18,400.

3.2.1.4 Tensions during processing

During the cutting process, the part is subject to mechanical tension.

The magnitude varies during different stages of processing. For material x40Cr13, tension reaches 800 Mpa, and for material x12CrNi 18.9 it reaches 781 Mpa.

3.2.1.5 Cutting speed

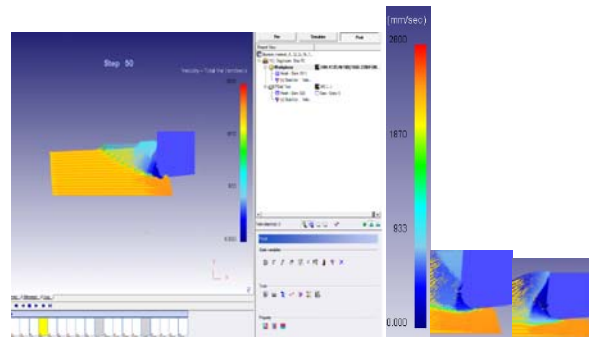
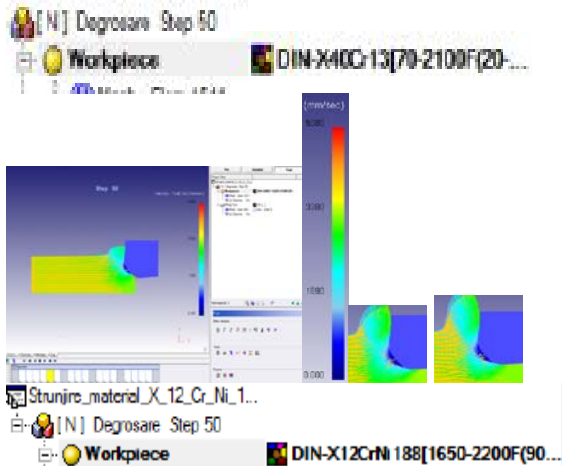


Fig.8 Cutting speed;
a) material x40Cr13
b) material x12CrNi 18.9

Cutting speed values were selected as recommended by the tool manufacturer, according to material's cutting class. For material x40Cr13 selected speed was of 195 mm/sec, and for x12CrNi 18.9 the speed was of 145 mm/sec. To be mentioned that the cutting speed is maintained constant during every cutting stage.

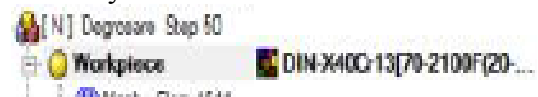
3.2.1.6 Normal pressure

Pressure represents the transmission of force or momentum from a part to the conjugated press through the surface of contact. Area of contact surface is constant, cutting force is approximately constant, therefore the pressure value is constant during every stage of processing.

3.2.1.7 Temperature

Total mechanical work consumed during the cutting process is almost completely transformed into heat (only a small amount of work is stored as potential energy, namely internal tension, in the processed material).

Regarding the tool temperature, it will affect most parameters of cutting process, namely the part material, edge material, edge geometry, parameters of cutting regime, cooling-lubrication conditions (cutting media) etc. In figure 9 the temperature resulting during the cutting process is presented for the materials under study.



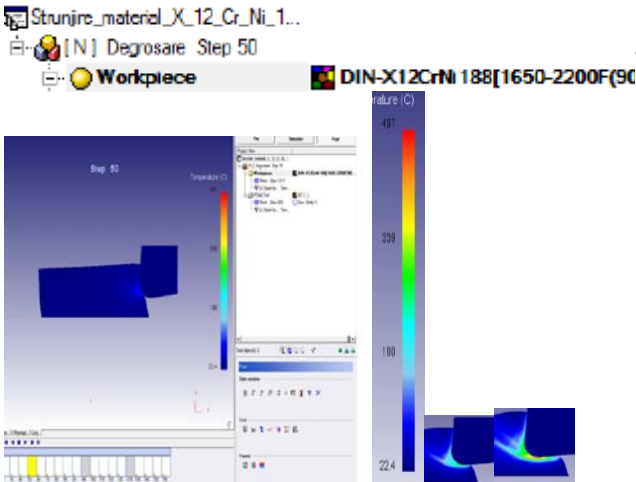
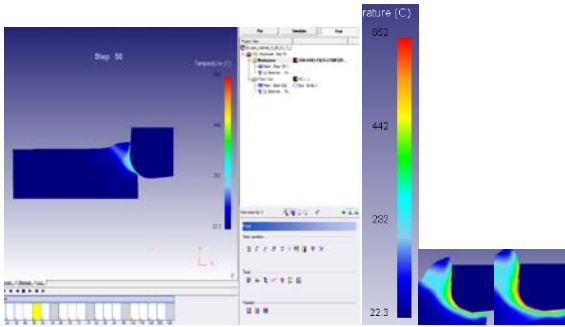


Fig. 9 Temperature achieved during cutting process:

- a) for material x40Cr13, temperature reaches 850^oC;
- b) for material x12CrNi 18.9, temperature reaches 487^oC.

3.2.2 Comparison of finish cutting for material x40Cr13 and material x12CrNi 18.9

3.2.2.1 Deterioration of material structure

Deterioration of material structure for x40Cr13 was of 0.242 units, and for material x12CrNi 18.9 was of 0.636.

3.2.2.2 Actual deformation

Deformation when finishing material x40Cr13 was of 3.18 mm/mm, and for material x12CrNi 18.9 was of 4.64 mm/mm.

3.2.2.3 Deformation rate

Deformation rate in mm/mm/sec for material x40Cr13 was approximately 100,000 mm/mm/sec, and for material x12CrNi 18.9 was approximately 80,000 mm/mm/sec.

3.2.2.4 Tension during processing

Figure 10 presents the variation of tension when finishing the metals under study.

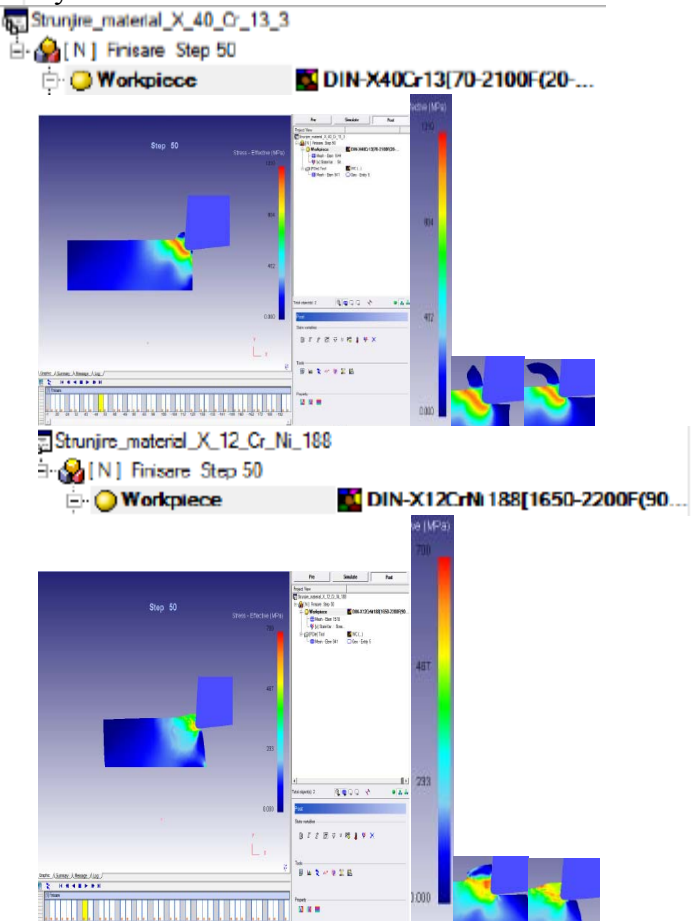


Fig. 10 Tension during finishing;

- a) for material x40Cr13, tension value reaches 1000 MPa;
- b) for material x12CrNi 18.9, tension value reaches 700 MPa

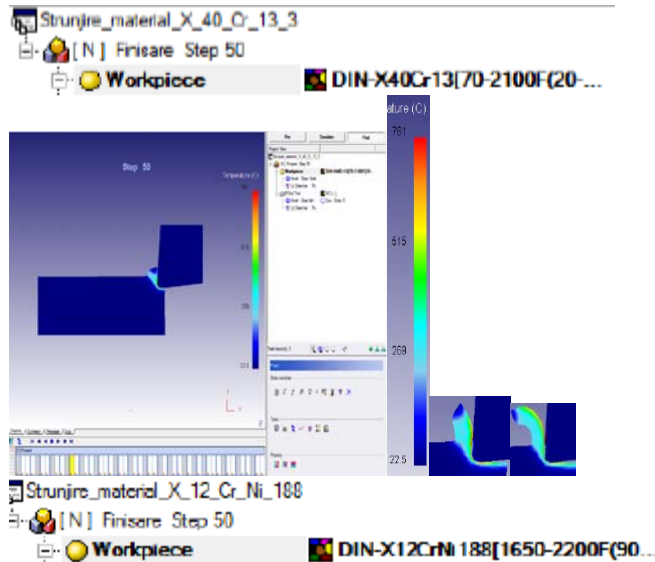
3.2.2.5 Temperature

Generation of heat is a phenomenon inevitably associated with the cutting process.

It is produced by the almost complete transformation of mechanical work used for cutting;

its intensity and the distribution of thermal flow determine the process temperature.

This temperature has a decisive influence on the nature and dynamics of phenomena specific



4. CONCLUSIONS

Using the software application DEFORM 2DV 9.01, an orthogonal cutting process can be simulated and the process conditions can be defined for every stage of the process.

With this program, the temperature, normal pressure, cutting speed, tension, cutting forces occurring in the cutting area can be monitored.

Present paper studied the physical, thermal, mechanical etc. phenomena occurring in the cutting area for two stainless steel alloys, using removable SECO inserts. Resulting values were compared according to colour scheme, which are significant for the cutting tools manufacturers and users. These aspects require permanent and in depth study of the cutting process physical grounds, a continued study of related phenomena, actions that might reveal new resources for process development and improvement.

to the cutting process, such as chip formation and tool wear.

Figure 11 presents the variation of temperature during the cutting process for finishing the materials under study.

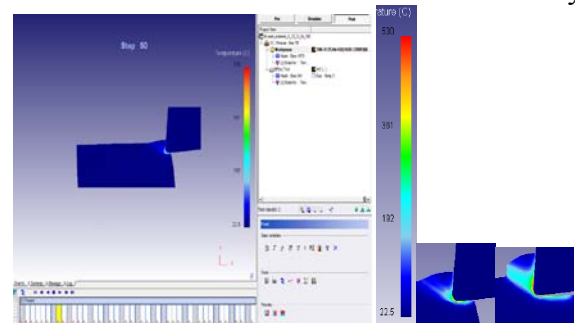


Fig. 11 Cutting temperature;

- for material x40Cr13, reaches up to 761°C ;
- for material x12CrNi 18.9, reaches up to 530°C .

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SIMULAREA NUMERICA A PROCESELOR DE ASCHIERE

Rezumat: In ultimii ani, analiza cu elemente finite devenit instrument important pentru simularea proceselor de aschiere a metalelor. Pentru imbunatatirea proceselor de aschiere a metalelor metalice este necesara aplicarea modelarii numerice si simularii acestora. O cerinta necesara este de a modela numeric interactiunea dintre interfata scula-aschie pentru a prezice performanta procesului de aschiere. In urma cercetarilor efectuate rezulta ca, indicatorii cei mai utilizati in monitorizarea procesului de aschiere sunt: fortele de aschiere, puterea absorbita, vibratiile, calitatea suprafetei prelucrate, uzura sculelor, precizia de prelucrare, etc., cuvinte cheie: simularea aschierii, analiza cu elemente finite, monitorizarea procesului de aschiere.

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