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MILLING ANALYSIS BY 3D FEM AND EXPERIMENTAL TESTS

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Abstract: *This paper presents a modelling and simulation analysis with FEM for a milling process and an experimental validation of the simulated cutting forces. The authors describe the FEM analysis steps: pre-processing, simulating and post-processing of data for the established machining process and the milling experiments. An analysis of the most important simulation and experimental results is made.*
Key words: *FEM, milling, simulation, data processing*

1. INTRODUCTION

Milling is a common form of machining designated for creating a great variety of surfaces. It becomes very important to have an approach for predicting cutting forces, chip formation, thermal aspects, etc. The importance comes from the necessity of using optimum technological parameters for processing by milling different materials, and also for determining loads (forces and torque) during operation. They are useful for tool designing and also in tool functioning (damage and wear rate). The analysis by FEM modelling and simulation becomes very powerful in this field. It still needs for the confirmation of the method the support of experimental tests for validation.

Finite Element Method (FEM) permits prediction of cutting forces, stresses, tool wear, and temperatures of the cutting process so that the cutting tool can be designed. FEM has some advantages such as (Kirichek & Afonin, 2007): solves contact problems, uses bodies made from different materials, a curvilinear region can be approximated by means of finite elements or described precisely etc. There are two types of finite element formulations to describe a continuous medium: Lagrangian and Eulerian (Bareggi & O'Donnell, 2007). Based on the success of FEM simulations for different processes, many researchers developed their own FEM codes to analyze metal cutting processes (Cerenitti et al., 1996).

Applications of FEM models for machining can be divided in six groups: tool edge design, tool wear, tool coating, chip flow, burr formation plus residual stress, and surface integrity (H. Yanda et al., 2009).

The right choice of finite element software is very important in determining the scope and quality of the analysis that will be performed. The most important software codes used for simulation of metal cutting are: Abaqus, Deform 2D and 3D (Uhlmann et al., 2007), and AdvantEdge.

In this paper the Deform 3D commercial software is used to simulate the milling process (www.custompartnet.com).

2. FEM ANALYSIS AND EXPERIMENTAL VALIDATION

The FEM analysis consists of three steps: pre-processor, simulation and post-processor (Deform 3D-V6.1, User's Manual). In the pre-processor the initial data for modelling and simulation must be set. The process parameters and cutting conditions are described in Table 1. The next steps are tool and workpiece setup, material choice, and mesh generation. For the studied process, a milling tool Sandvik R365-080Q27-S15M (www.sandvik.com) of 80 mm diameter with inserts was designed in AutoCAD and then imported in the software.

The software generates a workpiece based on the properties presented in Table 2. The tool is made of WC and the workpiece material is AISI1045 (Steel).

The mesh generation is very important for accuracy of the simulation. The mesh is reformulated at nearly every time step, in order to manage the material deformation. Fig. 1 shows an example of deformed workpiece mesh for the milling process.

The end of the pre-processor step contains the simulation controls and data base generation (Table 3). After completing these steps, the database can be generated. At this step, the simulation can be started. The simulation initiates a series of operations and generates a new mesh if necessary.

The last step is the post-processor. The user can check and use the simulation results after the data extraction.

The most important data obtained from the FEM simulation are: geometry of workpiece and tool after the simulation; tool movements and deformed mesh at each saved step (Fig. 1); distribution of state variables: stress, strain, temperature, wear, damage (Fig. 2); displacement and velocity; chip formation; predicted cutting forces and torque (Fig. 3).

Process and condition parameters	Milling
Cutting speed	75.36 m/min
Feed	2.4 mm/sec
Depth of cut	0.5 mm
Shear friction coefficient	0.5
Interface heat transfer coefficient	45°C
Convection coefficient	0.02
Environment temperature	20°C

Tab. 1. Process and condition setup

Workpiece parameters	
Geometry	Modelled as plastic
Length	20mm
Material	AISI1045 (Steel)

Tab. 2. Workpiece properties

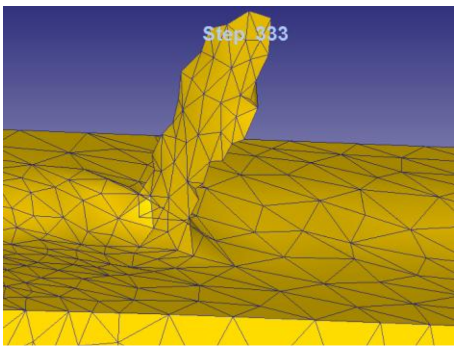


Fig. 1. Deformed mesh

For an assessment of the cutting simulations, experimental tests have been carried out. The experimental setup consisted of a vertical machining centre FIRST MCV 300, a Kystler dynamometer, an amplifier connected to the computer acquisition motherboard, a workpiece of pre-shaped of AISI 1045 steel and a Sandvik R365-080Q27-S15M milling head.

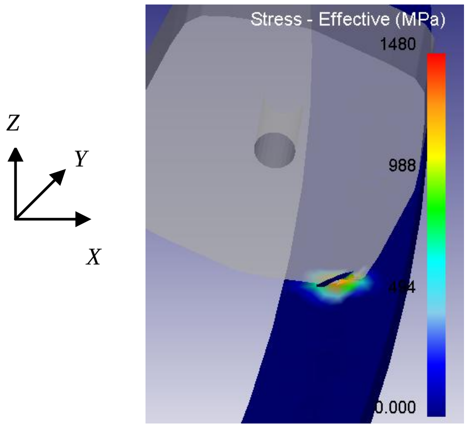
The cutting conditions were the same as those presented in Table 1. The difference between the simulation and experiment was the following: the simulation was conducted with a tool with one tooth and the tool used in experiments had 6 teeth.

The measured cutting forces are presented in Fig. 4: the feed force $F_X = 50$ N, cutting force $F_Y = 110$ N and axial force $F_Z = 60$ N.

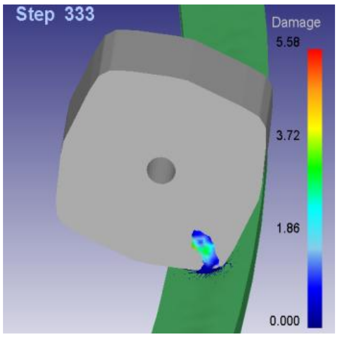
To be able to compare the calculated cutting forces with the measured ones, the user had to determine the simulated specific cutting forces. For this, the integral average was computed. After that, the quotient of the integral and the time fragment was calculated. The simulated and the measured cutting forces show small differences; this can be ascribed to problems concerning the model.

Simulation controls	
Nr. of steps	10 000
Steps to save / steps def.	25
Tool wear calculation	Usui's Model:

Tab. 3. Simulation controls



a



b

Fig. 2. State variables: *a* − stress; *b* − damage

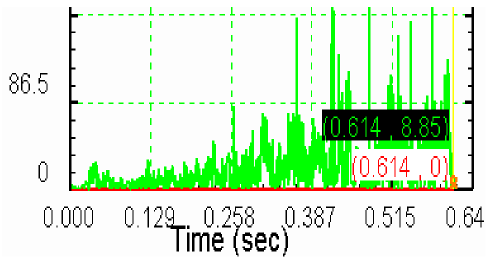


Fig. 3. Predicted cutting force in [N] on *Y* direction

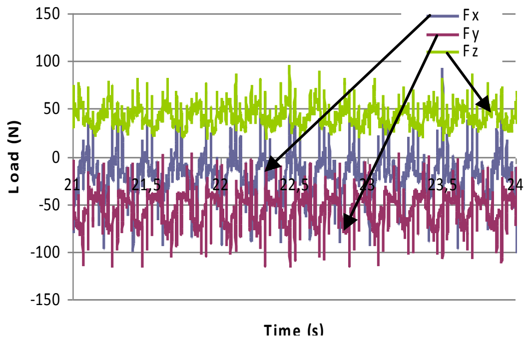


Fig. 4. Experimental resulted cutting forces

Besides model improvement, also the model validation vill have in view the friction parameter establishing for different tool-part material couples in high speed.

As a future research goal we can mention the use of 3D FEM analysis for inverse simulation to deduce the Johnson-Cook parameters that describe the material law (Shrot & Bäker, 2010) used in machining simulation for high speed processes. This will be done on the basis of the adiabatic stress-strain curves obtained by FEM.

3. CONCLUSION

This paper proposed an overview of the approach of FEM analysis of a milling process considering 3D modelling and also an experimental validation. The simulation was conducted with a single tooth tool and the program generated the workpiece. The tool used in the experiment was a Sandvik milling tool with 6 inserts. The experimental results validate in a largely way the measured cutting forces but for a better agreement the model can be improved. Building improved models and further experiments on different materials will be among the main tasks for further work including material law parameter finding.

4. ACKNOWLEDGEMENTS

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