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USING VIRTUAL MANUFACTURING SIMULATION IN 3D CUTTING FORCES PREDICTION

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Abstract: This paper present a FEM model for 3D simulation of turning process with chip breaker tools. The model uses Oxley's machining theory to predict cutting forces for square inserts. Inserts were modelled with CATIA V5R8 and exported as STL files to import them in DEFORM 3D™ software. A comparison made between predicted and experimental results shows good agreement.

1. A GENERAL VUE ON VIRTUAL MANUFACTURING

Virtual manufacturing has been an expanding field being used in research studies and increasingly used in industrial applications for tool wear. Many companies have software on the market to simulate tool wear for a wide variety of machining operations. These simulations provide information on how the cutting tool will react and respond to the workpiece properties. The simulation outcome depends largely on the model and laws it follows. To use a simulation, there needs to be a model to predict the outcome of specific inputs to that model. Several different laws are applied to a model in order to describe the workpiece properties, cutting tool properties, cutting surface speed, and cutting feedrate. The model was used to describe and predict the outcome of orthogonal cutting. There are different criteria in simulating the orthogonal cutting process. Many of the simulations use finite element analysis as a base to evaluate the phenomena [2], [4].

Development of new geometries for inserts occurs through, extensive time and resource consuming, prototyping and evaluating [5], [6]. Because of a highly hostile environment, high temperature, pressure, and vibration, in the cutting zone, study of the cutting process is very complicated. This hampers rapid product development in tools for metal cutting for the industry. Cutting simulations are developed to become an instrument for design of cutting tools. These computational will increase the understanding of the cutting process. Simulations can reduce the number of experiments required during the design process. It is also possible to perform parametric studies in a way that is difficult to achieve by experiments. The simulations can also provide a prediction of the state of residual stresses in the work piece [7].

The current study is part of a project with the aiming at developing finite element models that can be used to predict the chip formation process and cutting. Different modelling approaches have been implemented and evaluated in this study. The orthogonal cutting process has been simulated by the finite element program DEFORM 3D [1]. This code is using a remeshing technique for the chip formation. The computed chip morphology and the cutting forces are compared with experimental results. It is shown that all modelling approaches give similar cutting forces for the same material and a low friction coefficient, but lower than the measured values. However, it is needed to use a high friction coefficient to obtain better agreement between the computed and the measured forces. This can only be handled by the approach using continuous remeshing.

The remeshing operation occurs when the elements of the mesh are too distorted or at a regular limiting range of steps defined by the user. The database of the simulations is opened and a keyword (ASCII) file is generated, saving all the data of the actual step. For each element of the workpiece mesh the damage is evaluated. When the damage criterion used is satisfied by an element, the code of the element is stored in a temporary file. A new sub-routine opens the temporary file and deletes all the coded (listed) elements. Then the border of the workpiece is extracted and it is smoothed. This smoothing operation reduces the loss of volume in the workpiece determined by element deletion and helps in the convergence of the FEM solver. A new mesh is generated and the interpolation gives the new elements of the mesh the corrected properties. The mesh density is increased in the area affected by the cutting process in order to reduce time consumption and storage space. Several data have to be provided to the pre-processor of the FEM program: the geometry of the tool and the workpiece, the material properties (flow stress as a function of strain, strain rate and temperature), the thermal properties, the boundary conditions and the interaction between the tool and the workpiece. The main data requirements to model the machining process are material flow stress data for the work piece material and geometric data for the insert. The material flow stress data should cover the strain rate, strain and temperature range for metal cutting process.

Special material characterizing techniques are required to address this range of loading conditions. The pre-processor of the FEM code DEFORM 3D provides output such as: material flow (velocity, strain and strain rate fields), loads (stresses, forces and power), temperatures and damage.

2. FEM SIMULATION FOR TURNING WITH SQUARE INSERTS WITH CHIP BREAKER

For turning applications the rotating workpiece and insert and it's relation to the analysis domain are shown in fig. 1 [1]. Typical analysis model generated using the current system is shown in fig. 2. For simulation of turning process I use a plane strain deformation model. The insert and a part from workpiece were meshed in order to have a practical number of elements for calculations. Workpiece was made from OLC 45 steel and it has 175 mm diameter. The square insert type T-MAX U with UR geometry was made available in STL form, generated from CATIA V5R8 system (fig. 3 and 4).

The simulation software DEFORM3D^{TM}, specifically developed for large strain deformations, automatically separates the chip from the workpiece around the tool tip based on metal flow, material properties and tool geometry. The workpiece material is OLC45 steel. Different cutting tools were used and different cutting speeds were selected. No lubricant is used at the tool-workpiece interface.

Table 1. Cutting conditions

Test No	Rake angle, γ [deg]	Clearance angle, α [deg]	Cutting speed, v [m/min]	Feed, s [mm/rot]	Cutting depth, t [mm]
1	0	7	133	0,125	1,5
2			133	0,25	
3			209	0,125	
4			209	0,25	
5	10	7	133	0,125	
6			133	0,25	
7			209	0,125	
8			209	0,25	

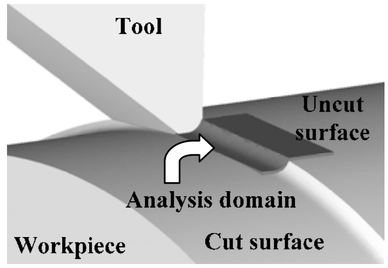

Figure 1. Basic components of turning and it's relation to analysis domain.

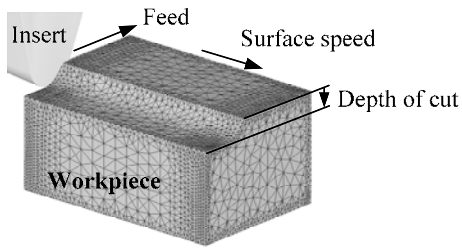

Figure 2. Simulation model and basic cutting parameters defined.

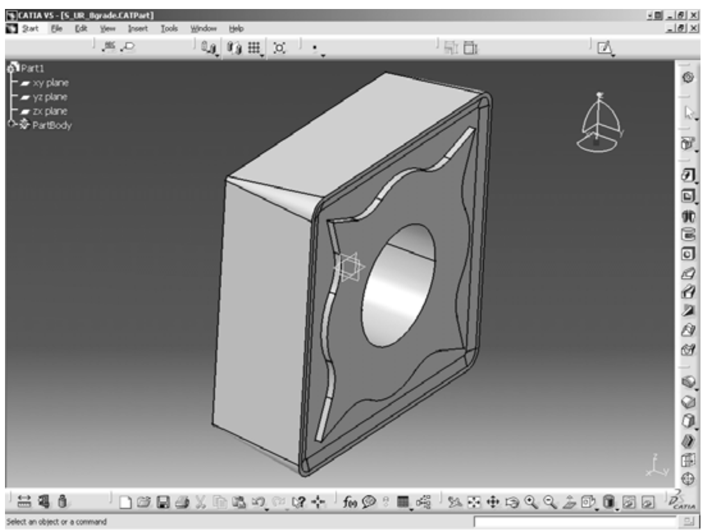

Figure 3. T-MAX U insert with UR geometry modelled in CATIA V5R8.

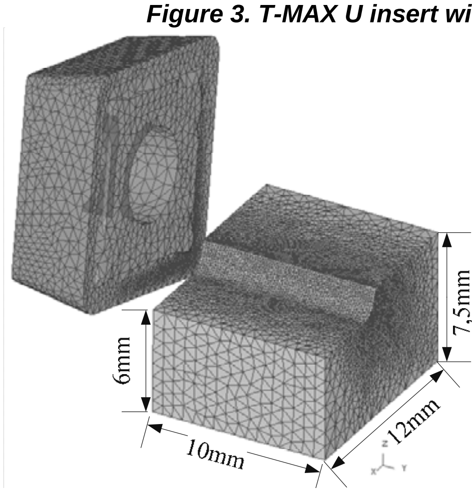

Figure 4. Process model in DEFORM 3D.

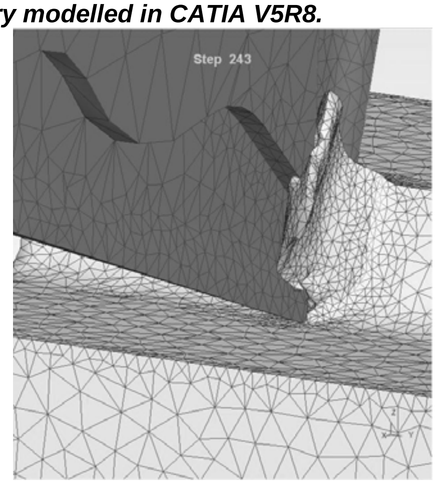

Figure 5. 3D chip formation for T-MAX U with UR geometry.

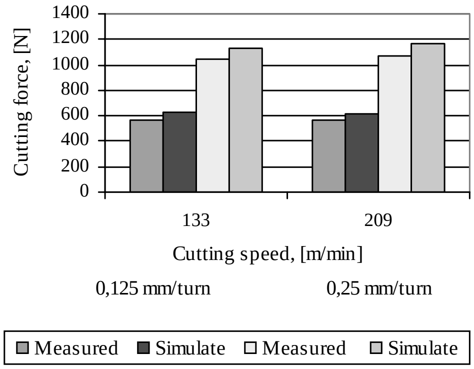

Figure 6. Comparison between measured [35] and simulation cutting forces for T-MAX U with UR geometry.

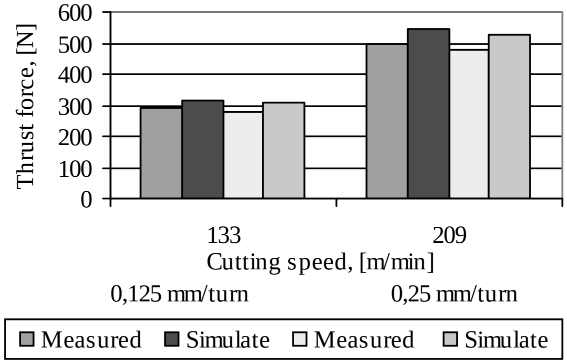

Figure 7. Comparison between measured [3] and simulation thrust forces for T-MAX U with UR geometry.

3. CONCLUSION

The predicted and measured cutting forces are compared for OLC 45 in figures 6 and 7. The cutting conditions vary over a sufficiently large parameter space and establish confidence in the model results. Cutting forces generally agree within 10% of the measured values, as well as the corresponding trends with changes in cutting conditions.

Development of an accurate metal cutting model is a complex task, which requires a very good understanding of the mechanical response of the material and the numerical modelling. The null hypothesis states that: There is no significant difference between computer simulation wear and experimental cutting wear in metal cutting. This thesis used a comparison analysis to prove the null hypothesis. The analysis compared several different values from the experimental and simulation results. The comparison analysis provides positive results to continue future research in the computer simulation program to validate the use of this model for tool wear prediction. The trend between the experimental and simulation data did have a positive correlation in all of the results. The cutting force values were in close approximation.

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