Computational and Evaluation of Orthogonal Metal Cutting Process Using ALE Method

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Abstract: ***The commercial success of a new product is influenced by the time market product. New cutting inserts are developed by time consuming trial and error process guided by the empirical knowledge of the mechanical cutting process. One of the state–of-the-art efforts in manufacturing engineering is the finite element simulation of the mechanical cutting process. These computational models would have greater values in increasing the understanding of the cutting process and in reducing the number of experiments which traditionally are used for the tool design, process selection etc. This project work focuses on the development of a finite element model for the cutting process, which can predict chip formation, cutting forces and stress – strain distribution on the work piece. A dynamic explicit time integration technique with Arbitrary Lagrangian Eulerian (ALE) adaptive meshing finite element method (FEM) is employed to simulate the model. The Johnson-Cook material model is used to describe the work material behavior. Two basically different modeling approaches have been used for the chip separation, geometrical and physical model. The automatic control of the mesh quality is managed by using the ALE. The implemented combined penalty-barrier contact algorithm has been found to be efficient in conjugation with the adaptive meshing.***

Keywords: ALE, FEM, Johnson-Cook, Mesh, Chip

1. Introduction

The study of metal cutting focuses on the features of the behavior of tool and work materials that influence the efficiency and quality of cutting operations. Development of cutting tool materials has held a key position. The technology of metal cutting has been improved by contributions from all the branches of the industry with an interest in machining. Productivity has been increased through the replacement of carbon tool steel by high-speed steel and cemented carbide which allows cutting speed have led to the development of the most advanced tool materials. These development continuous today with the use of ceramic with multiple coating technologies and ultra hard tool materials. Machine tool manufactures have developed machines capable of making full use of the new tool materials, with computer control (CNC), and transfer machines greatly increases the output per worker employed. Tool designer have optimized the shape of tool to give long tool life at high cutting speed. FEA simulation of the machining is a typical dynamic non/linear problem for use of the explicit method. In FEM continuum modeling there are four formulations: Lagrangian, Eulerian, Arbitrary Lagrangian Eulerian (ALE) and Smooth particle Hydrodynamics (SPH). Most common formulation based on the early works, and with simplest code, is the Lagrangian one, which was also used in this research. A separation criterion is important to describe the chip separation in the Lagrangian formulation. Several of them have been implemented into commercial FE software. Another method called as a remeshing (adaptive remeshing) or contact break criteria can be used for the chip separation.

2. Literature Survey

Several studies on residual stress induced by machining have been performed. Unfortunately, due to limitations in finite element (FE) modeling of the metal cutting process and the complex physical phenomenon involving the formulation of machining residual stress, most of these studies remain experimental in nature.

Liu and Guo [1] proposed an FE model to investigate the effect of sequential cuts and tool-chip friction on residual stress in a machined layer of AISIS 304 steel. They reported a reduction in the superficial residual stresses when the second cut is performed. Moreover, the residual stress can be compressive, depending on the uncut chip thickness of the second cut. They also found that residual stress on the machined surface is very sensitive to the friction condition of the tool-chip interface. Later, using the same work material, Liu and Guo presented a similar study on the effect of sequential cuts on residual stresses. They showed that decreasing the uncut chip thickness below a critical value in the second cut may result in favorable compressive residual stresses.

Yang and Liu [2] performed a sensitive study of the friction condition on the tool-chip contact, the cutting forces and the residual stresses in machining-affected layers of AISI 304 steel. In this study they proposed a new stress based polynomial model for modeling the tool;-chip contact, which represents a simple curve fitting the experimentally obtained shear and normal stresses acting at the tool-chip interface, When comparing this new friction model with other friction models based on an average friction coefficient deduced from cutting forces or from stresses, they found significant differences among the predicted residual stresses. They concluded that the conventional force based friction model is inadequate to predict the residual stresses induced by machining, and they showed the potential for improving the quality in predicting machining residual stress by adopting the stress based polynomial model. Although it is widely accepted that friction conditions will change along the tool-chip contact length, the authors did not present any experimental evidence to support their conclusions.

Ozel and zeren [3] have presented FE-models for the 3D case in their studies. Unfortunately they only consider the one dimensional motion of either tool or work piece in their proposed 3D models of orthogonal machining simulation, which makes their models 3D turning operation instead of 3D orthogonal machining. Also it keeps the model bit apart from the reality of orthogonal machining.

3. Objectives

- To develop a finite element tool to give a better understanding of the cutting process. The effect of the cutting parameters on the tool and work piece, as the process zone will be studied in detail. Additionally, the stress state of the work piece will be calculated.
- Different finite element modeling and simulation approaches for the cutting process will be developed and evaluated. The chosen geometry (orthogonal cutting) makes it possible to use 2D and 3-D model. The numerical data will be evaluated with the standard journal (experimental data).
- In order to obtain an accurate prediction of machining cutting process, the finite element model should be able to deal with the extremely large and localized deformations, Crack initiation and Chip Formation, Contact algorithm and Ductile fracture.
- Different finite elements codes are evaluated. The commercial FEA solver ABAQUS/ Explicit is used for cutting simulation.

4. Methodology

- Choice of Element Type
- Modeling of Work Piece and Tool
- Boundary Condition
- Contact Algorithm
- Time Integration Technique

5. Input Data for Simulation:

Constitutive Material Model

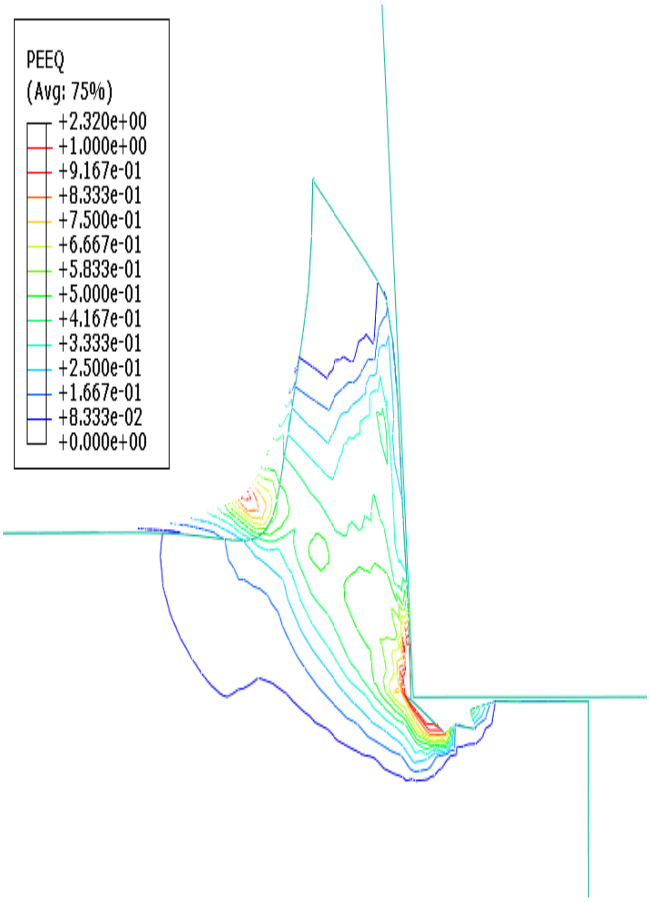
Material	AIS1045
A(Mpa)	375
B(MPa)	552
n	0.457
C	0.02
m	1.4
T melt	1733

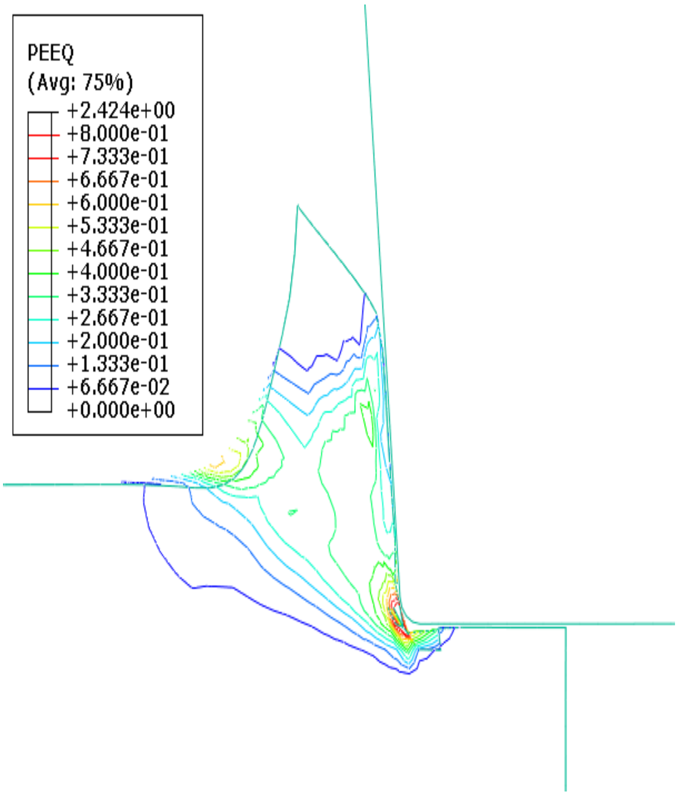
Where,
A- Initial yield Strength (MPa).
B- Hardening Modulus (MPa).
C- Co-efficient Dependent on Strain Rate
n- Work Hardening Exponential.
m -Thermal Softening Co-efficient.

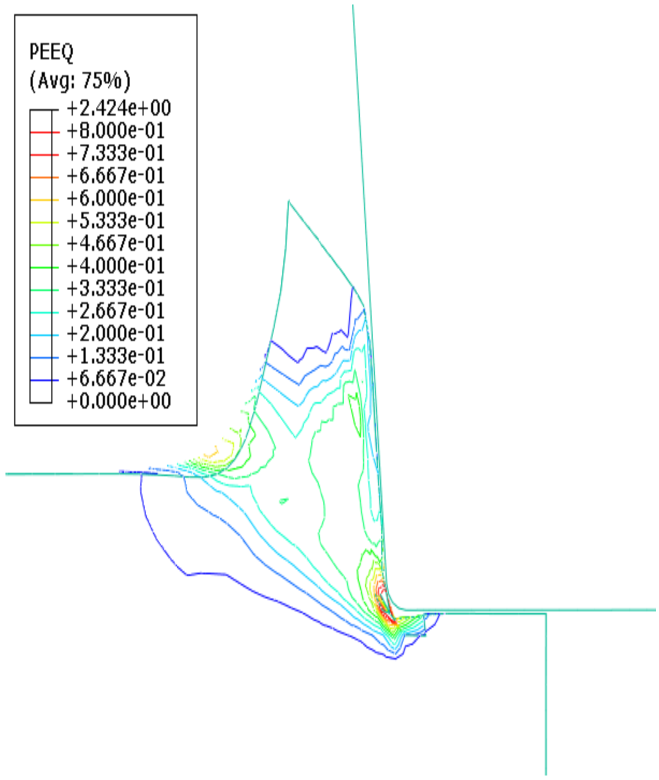
Material Physical Property

Property	*Work Material (AISI1045)*	*Tool material*
Young's modulus	210 e3 MPa	800e5 Mpa
Density (T/mm3)	7700e-12	1.5e-8
Poisson's ratio	0.3	0.2

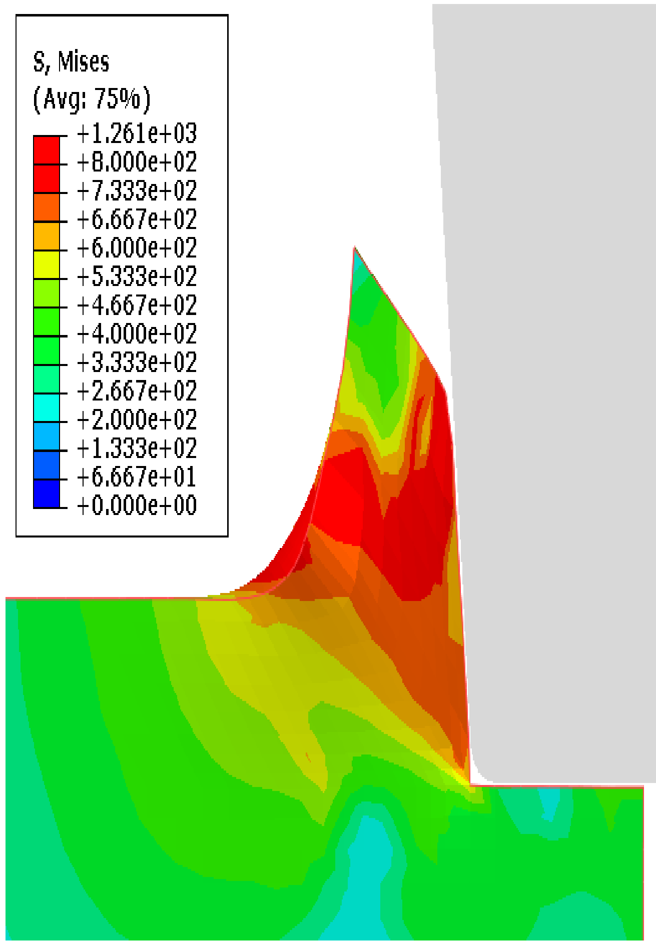
6. Stress & Strain Simulation In Cutting Process



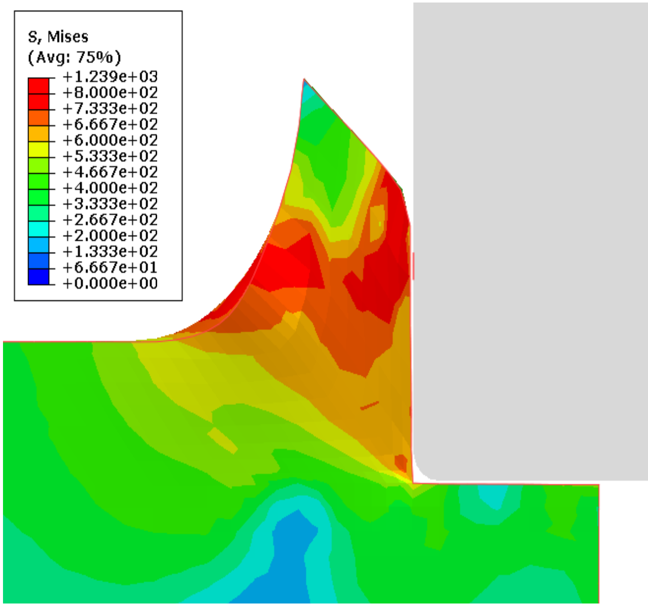


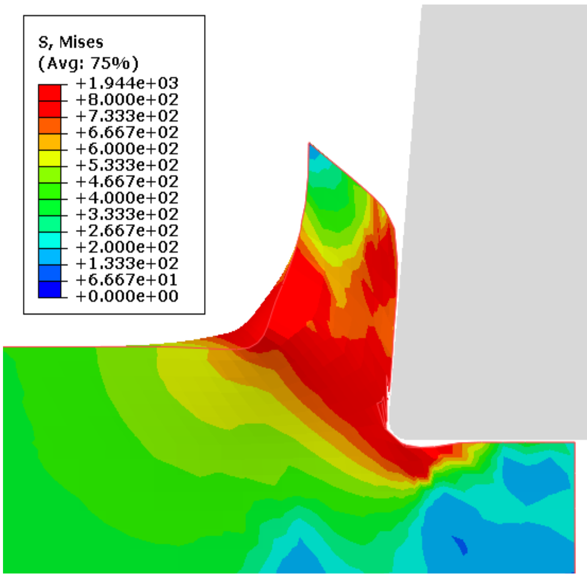


Contour plot of plastic strain for 0 edge Contour plot of plastic strain for 0.1 edge radii obtained during simulation. radii obtained during simulation.

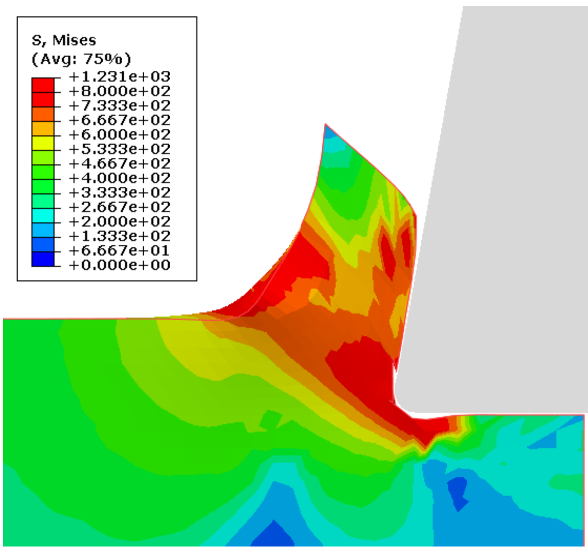


Contour plot of plastic strain for 0.2 edge von mises stress distribution for -5 rake angle radii obtained during simulation obtained during simulation.





Von mises stress distribution for 0 rake angle von mises stress distribution for 5 rake angle obtained during simulation. obtained during simulation



Von mises stress distribution for 10 rake angle obtained during simulation.

7. Conclusions and Scope for Feature

Finite element simulations will improve the design of the cutting tools by reducing the testing. Thereby, it will also reduce the time to market for the new designs. Johnson-cook parameters (plasticity model & damage law) are suitable for the elements that are subjected to high strain rate and large distortion, also help full in initiation of damage in the work piece. The construction of an appropriately refined mesh is a challenge, for highly non-linear, transient problems such as the cutting process. The ALE adaptive meshing helps in maintaining the quality of the elements that are subjected to high rate of distortion, which may leads to analysis error. The implemented combined penalty-barrier contact algorithm has been found to be efficient in conjunction with the adaptive meshing.

This analysis can be carried to the multi point cutting tools, which are widely used on industrial CNC machines, where huge amount of tools are mounted.

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