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NUMERICAL SIMULATION OF METAL CUTTING PROCESS USING FINITE ELEMENT METHOD (FEM)

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ABSTRACT

The aim of this study is to determine the effect of machining parameters using numerical simulation. The turning operation is carried out by considering cutting speed, feed rate and depth of cut as input parameter and temperature, cutting forces and stress distributions as output parameters. The AISI 1045 steel the simulation model is developed by using DEFORM 3D software. For this purpose, orthogonal cutting simulations are studied by using dynamics explicit Arbitrary Lagrangian Eulerian method. The simulation model utilizes the advantages offered by ALE method in simulating plastic flow around the round edge of the cutting tool and eliminates the need for chip separation criteria. Johnson- Cook work material model is used for elastic plastic work deformations. A methodology developed to determine friction characteristics from orthogonal cutting tests is also utilized for chip-tool interfacial friction modeling. The mechanical and thermal analyses are performed. The effects of rake angle, depth of cut, feed rate, cutting speed and tool tip radius on strain, temperature and stress distributions are investigated. The effects of work piece flow stress and friction models on cutting variables: cutting forces, chip geometry and temperature are investigated are compared with simulation results with experimental results. The results obtained by this method will be useful to other researches for similar type of study and may be better opportunity for further study.

Key words: Cutting speed, Feed rate, Depth of cut, FEM, Turning, Deform 3D

1. Introduction

The machining is one of the most essential manufacturing processes to remove material from a workpiece or part in the form of chips. In turning operation the machining depends on spindle speed, cutting speed, feed rate, depth of cut, tool angles, type of lubrication of used, etc. While turning the work piece small changes in the above mentioned factors may have a significant effect on the workpiece. Recent days many numbers of researches is done to select the optimal cutting parameters to predict temperature rise, surface roughness, tool wear, chip morphology, stress etc. The wear in tool and surface finish waviness occurred when cutting force and vibration of the machine is increased. Increase in temperature during machining results decrease in dimension accuracy, production efficiency and product quality. Experiment is conducted to minimize flank wear, surface finish and cutting zone temperature, using DOE and ANN technique considering cutting speed rate of feed and cutting depth as input response [1]. The machining of workpiece, very large stresses and strains in a small volume and at a high speed. The mechanisms of chip formation are quite complex, leading to equally complex theories and models that represent these theories [2]. The influence of machining parameters is studied to measure surface roughness using RSM technique while dry turning of aluminium 6061 – T6 alloy [3].The author developed a predictive model to observe the effect of nose radius to predicttemperature rise on the CNC turning process by considering machining parameters ascutting speed, feed rate, depth of cut and nose radius. The experiments are conducted as per of response surface methodology (RSM) by taking into consideration of aluminium - Al 6061 as workpiece material and Al2O3 coated carbide tool as a cutter [4].

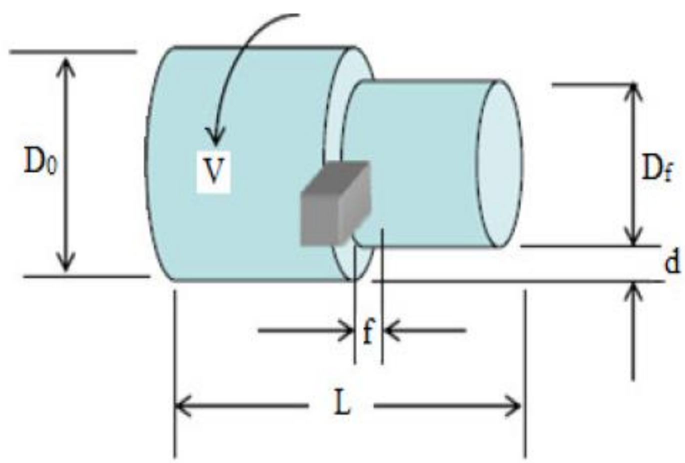


Fig.1. Tuning operation considering parameters

The author focused on the understanding of the mechanisms inducing tensile and compressive residual stresses in the workpiece after machining cutting operations, pure mechanical effects can also contribute to the development of tensile residual stresses. Indeed, it was demonstrated that tensile residual stresses could be generated near the machined surface even in the absence of thermal expansion [5].The experimental validation is done for 3D-FEM model of the longitudinal turning processwith an extended modified Bai–Wierzbicki material model. The developed material model estimates the influence of state of stress as well as damage on the strain hardening behavior considering temperature and strain rate effects, whose influences are both typically higher in cutting processes than in structural–mechanical problems [6].A new 3D multiphase FE computational model is developed. The models arevalidated for micro drilling carbon steels. A model has been developed to predict thermo-mechanical material behavior including the effect of the microstructure using Split-Hopkinson-Pressure-Bar techniqueand verified using 3D FE computation model regarding chip formation, feed force, and torque [7].The author developed an Sophisticated contact algorithms using Lagrangian calculations, the comparison is made between, the Eulerian finite element method lags and Lagrangian finite element method in modeling contact while machining to investigate the strength and weakness of the different approaches to implementing contact in multi-material Eulerian calculations [8].The study has been conducted to compare various simulation models of orthogonal cutting process using finite element codes MSC. Marc, Deform2D and the explicit code ThirdwaveAdvant Edge and also simulations with Deform2D, the Cockroft-Latham damage criterion is used to estimate cutting and thrust forces, shear angles, chip thicknesses and contact lengths on the rake face. The three codes are compared with experiments [9].The finite element analysis is used to develop and to simulate the thermal behavior of a carbide cutting tool in three-dimensional dry machining results the reduction of tool wear require to maintain the temperature of cutting tool inserts. Finite Element Analysis result outcomes that the temperature drops reduced at the tool-chip interface [10].A mathematical model is developed to record the system responses of the servo valve, and open loop HSS are given step and sinusoidal inputs. The closed loop system is based on linearized model of feedback regulator of PD controller for high-speed control. All models and controllers are simulated using MATLAB and SIMULINK computer program [11].The residual stresses generated while machining a workpiece. Residual stresses directly influence the deformation of workpiece, their static and dynamic strength, and their chemical and electrical properties [12].The author reviews the application of finite element modelling (FEM) to resolve the orthogonal machining performance. An FE model is developed using ABAQUS/Explicit to simulate continuous and segmental chip formation when machining AISI H13 die steel to find the shear failure criteria and element adaptive re meshing modules [13].The researcher use the strain rate important parameter and deformationmodels aredeveloped [14]. The author compared the various simulation models of orthogonal cutting process. The Deform2D have been used for simulation.The cutting force, thrust forces, shear angles, chip thicknesses and contact lengths on the rake face are considered for experimental study using simulation and the results are compared with experiments performed [15].An experiment is conducted to determine the flow stress in metal cutting process to find flow stress is the intense circumstances under which deformation takes place in the chip root only where as Large deformations are imposed on the workpiece material at high speed in a very small area [16].

2. Experimental study

A experimental numerical simulation of metal cutting processes is developed usingFinite Element Method by the aid of DEFORM 3D software using AISI 1045 steel as work material.

3. Development of model

For this study, orthogonal cutting simulations are developed using dynamics explicit Arbitrary Lagrangian Eulerian method. Johnson- Cook work material model is used to find the elastic plastic work deformations of the work piece. The mechanical and thermal analyses are carried out to determine effects of rake angle, depth of cut, feed rate, cutting speed and tool tip radius on strain, temperature and stress distributions and also the effects of work piece flow stress, friction models on cutting variables: cutting forces, chip geometry and temperature are investigated. The experimental methodology model is shown in figure 2.

4. Discussion of Results

A series of virtual cutting tests were carried out to achieve the objectives for this study by changing the machining parameters such as cutting speed, feed rate and depth of cut.The results of Finite Element Simulations are presented.

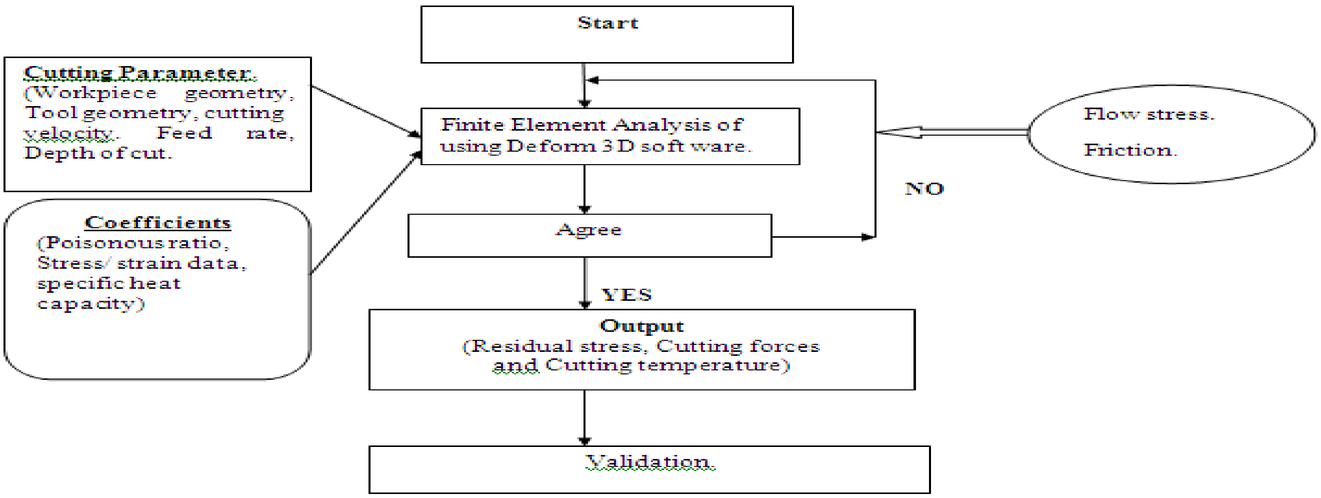


Fig. 2. Experimental Methodology flowchart

The simulation results and experimental results available in the literature are compared. Mechanical and thermal parameters while cutting such as strain, strain rate, stress and temperature are investigated.

4.1. Feed rate analysis

In this study, the feed rate effect on residual stress is presented. Feed rates are tested; 0.2 mm/rev, 0.45 mm/ rev and 0.8 mm/rev are taken as consideration. The results for each test are presented and then the tests are compared to each other in order to evaluate the results. Thefeed rate affects the induced residual stress in a machined Component.

4.1.1. Feed rate 0.2 mm/rev analysis

The 0.2 mm/rev feed rates are investigated and the chip formed is presented in Figure 3.

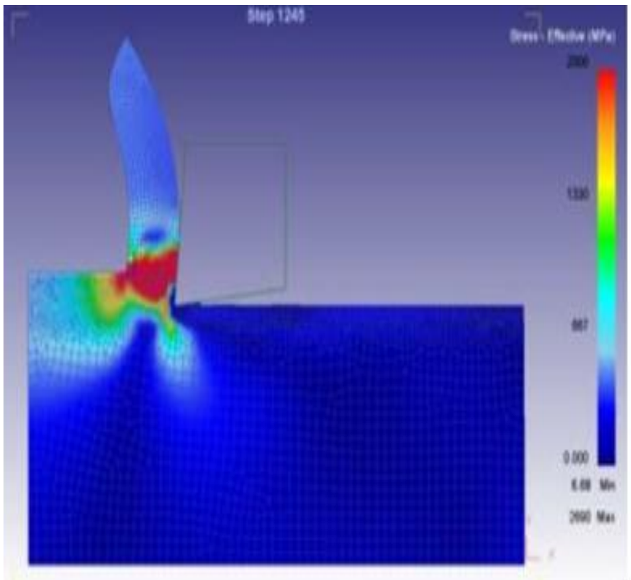


Fig.3.Feed rate 0.2mm/rev simulation.

4.1.2. Feed rate 0.45 mm/rev analysis.

The feed rate 0.45 mm/rev is investigated and the chip formed is presented in figure 4.

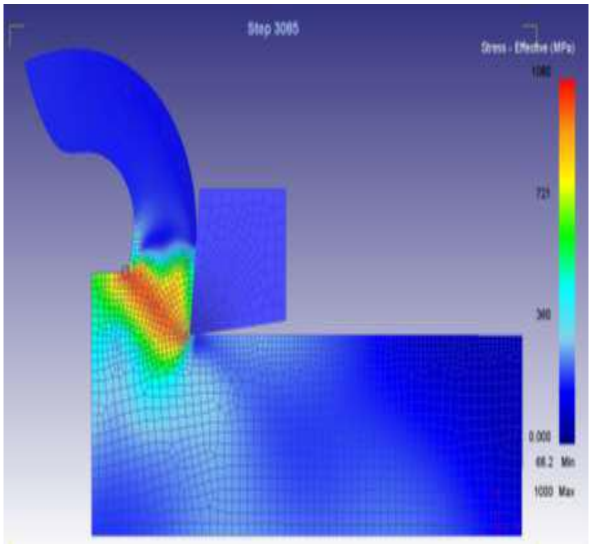


Fig.4. Feed rate 0.45mm/rev simulation

4.1.3. Feed rate 0.8 mm/rev analysis

The feed rate 0.8 mm/rev is investigated and the chip formed is presented in figure 5.

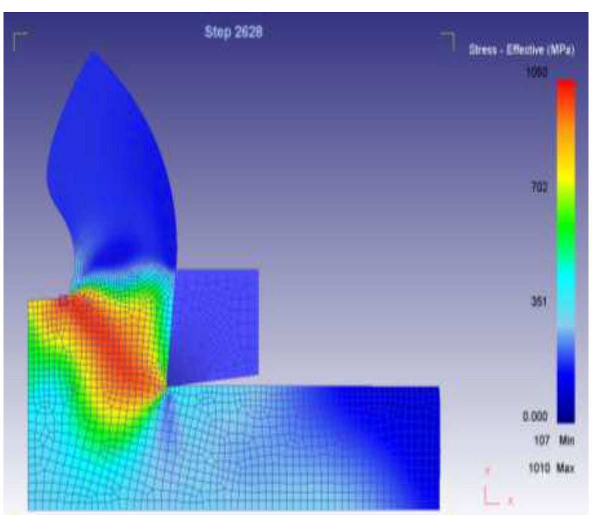


Fig.5. Feed rate 0.8 mm/rev simulation

4.2. Feed rate simulation comparison.

The influence of the feed rate on the residual stresses induced in a machined component is analyzed and is compared with the test result, run at feed rates; 0.2 mm/rev, 0.45 mm/rev and 0.8 mm/rev are as shown in figure 6 and are tabulated in table 1.

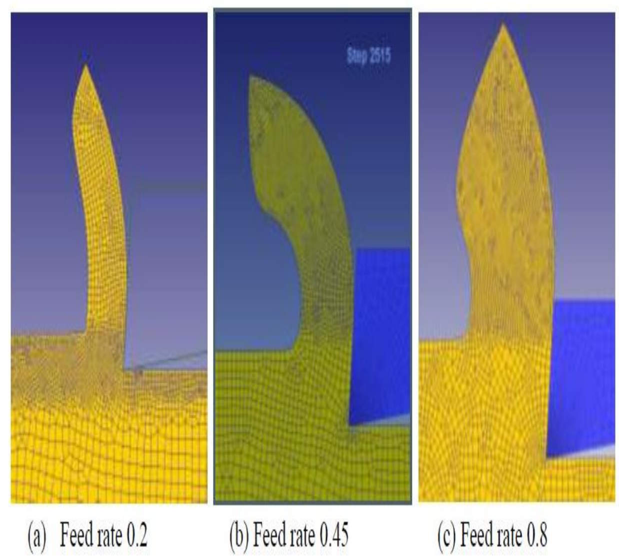


Fig.6. Feed rate simulation comparison

Feed rate.	Experimentally measured chip thickness.
0.2 mm/rev	0.312 mm
0.45 mm/rev	0.870 mm
0.8 mm/rev	1.11 mm

Table .1. Simulation results

The chip thickness is measured and average result along the chip in the three simulations and it was compared with the chip thickness measured experimentally and also tabulated in table 2. Chip thickness measured for each feed rate simulation.

Feed rate	**Average chip thickness obtained from simulations.**
0.2 mm/rev	0.41mm
0.45 mm/rev	0.793 mm
0.8 mm/rev	1.38mm

Table 2. Experimental results

4.3 .Cutting speed Analysis.

The influence of the cutting speed on the residual stresses induced in a machined component is analyzed by considering the feed rate 0.2mm/rev as constant. The tests are run at four different cutting speeds; 400 m/min, 260 m/min, 100 m/min and 40 m/min.

The chip formed in the cutting speed tests are shown in Figure **7**(a) at Speed 400 m/min, Figure 7(b) at Speed 260 m/min, Figure 7(c) at Speed 100 m/min, Figure (d) at Speed 40 m/min.

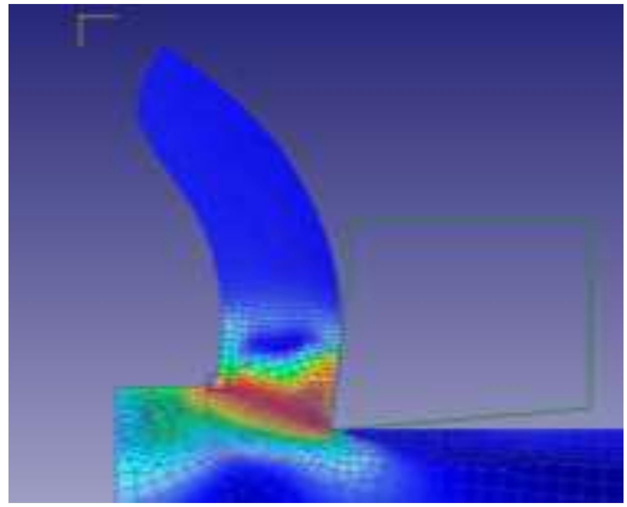
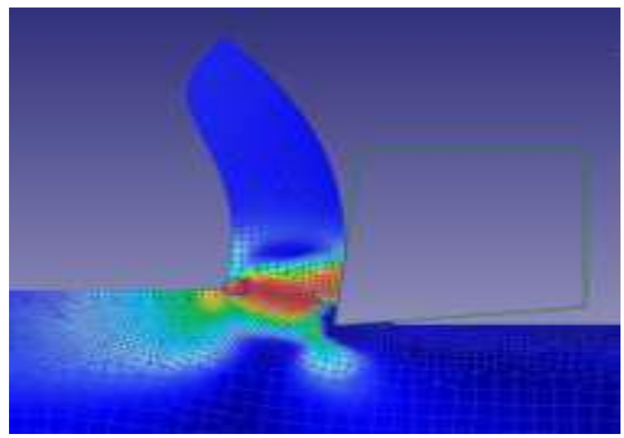
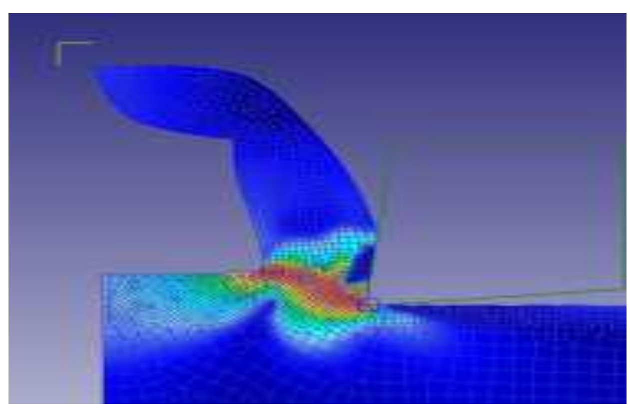


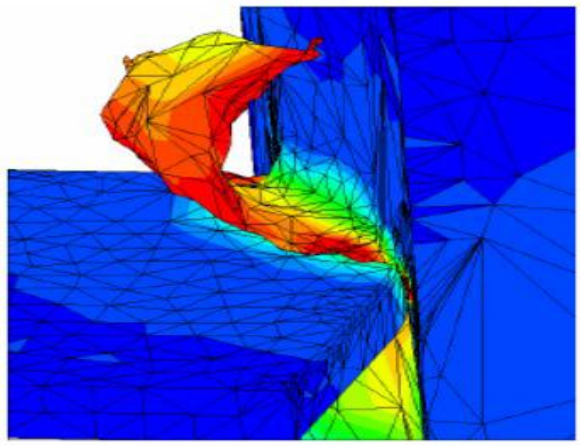
Fig.7(a). 2D Modeling Turning at Speed 400 m/min



7(b) 2D Modeling Turning at Speed 260 m/min



7 (c) 2D Modeling Turning Speed 100 m/min



7 (d) 3D Turning simulation Modeling at v=300 m/min

NO	Depth of cut (mm)	Force (N)	Power (kw)	Tool life (min)
1	0.5	392	205.86	472.55
2	1	784	397.75	128.09
3	1.5	1176	565.06	72.96

Table 3.Resultsof varying depth of cut

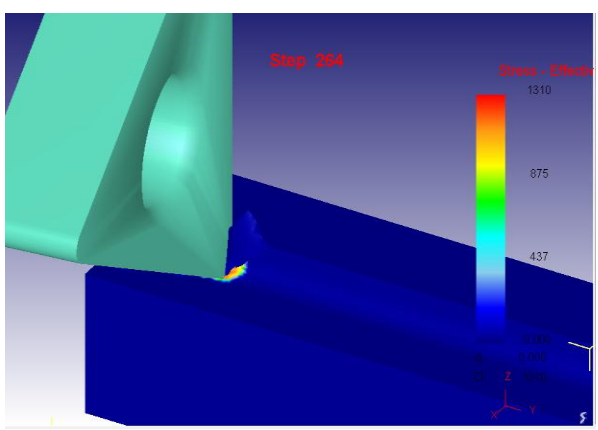


Fig.8. Temperature vs. time at different feed rates

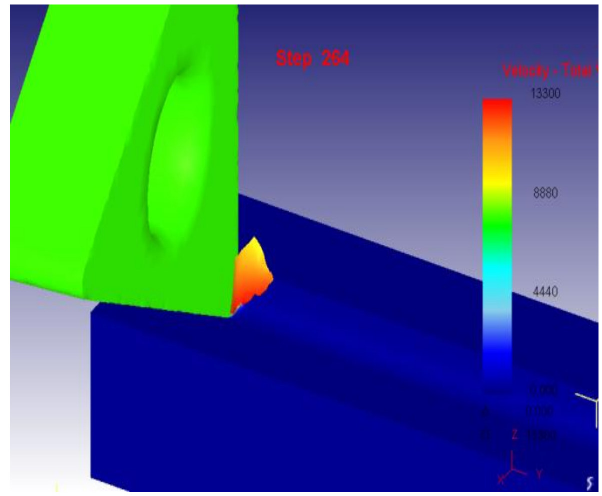


Fig.9. Stress –effective at different cutting speed (200 m/min)

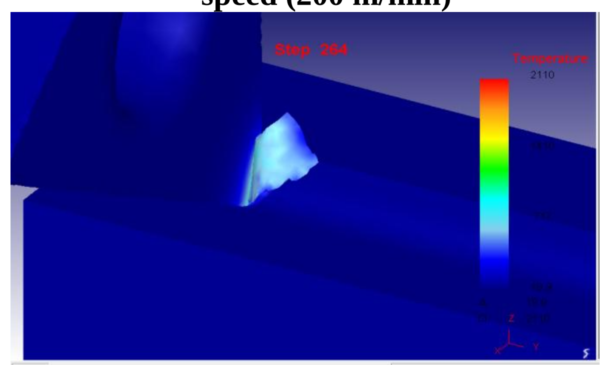


Fig.10.Temperature vs time at different cutting speed (V=200 m/min)

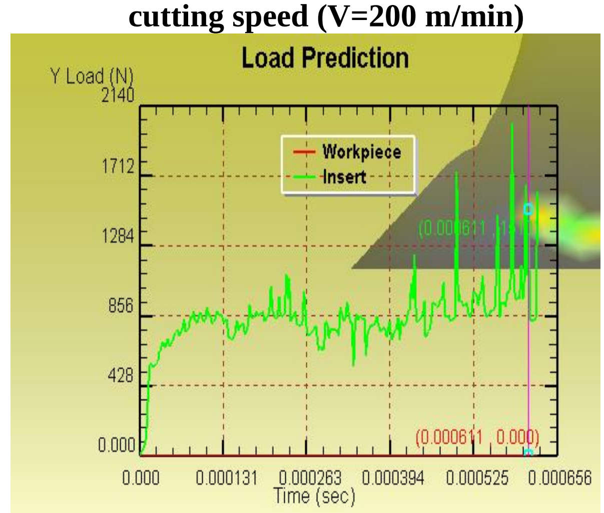


Fig.11.load vs time at different cutting speed (V=200 m/min)

Along the chip, and it was observed that the cutting speed increases, the chip thickness also increases as shown in figure 8,9,10. The result shows evidently from graph as shown in figure.11.

Conclusions

The following are concluded from the simulationsperformed in this study;

- The fracture criteria critical value governed by the chip form and the coefficient offriction varies the chip thickness; as the coefficient value decreases, the chipthickness is also decreased
- The finer the mesh distribution the more accurate results are obtained from thesimulations.
- The feed rate influence on the induced residual stress in machining was not clear inthe simulations compared to the experimentally measured data; therefore moreinvestigations should be made on a wider range of feed rates.
- Residual stresses remained unchanged with the changing cutting velocities. This can be attributed to the minimal effect of cutting velocity on cutting force in the selected range.

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