Organisation of Islamic Cooperation

FEM BASED SIMULATION AND ANALYSIS OF STAINLESS STEEL TURNING

A thesis submitted to the department of Mechanical and Chemical Engineering (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering

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CERTIFICATE OF RESEARCH

This is to certify that the work presented in this thesis paper is a unique work on ‘‘Fem based simulation and analysis of stainless steel turning’’. Actually this thesis is an outcome of the experiment and research carried out by the candidates under the guidance, helpful suggestions and supervision of **Dr. MOHAMMAD AHSAN HABIB**, Assistant Professor, Department of Mechanical and Chemical Engineering (MCE), Islamic University of Technology (IUT). It is also declared that neither this thesis nor any part thereof has been submitted anywhere else for the award of any degree or any judgment.

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Although we tried our best to complete this thesis flawlessly, we seek apology if there is any mistake found in this report.

ABSTRACT

In this paper, an attempt has been made to study the effect of cutting speed and feed rate on the cutting forces and chip breakage in turning process. Nowadays researches on metal cutting processes are being done in different laboratories as it is of importance not only for understanding the fundamentals of metal cutting processes but also for the design of different metals used in laboratories both for scientific and engineering purpose. Understanding of the fundamentals of metal cutting processes through the experimental studies has some limitations. Metal cutting modeling provides an alternative way for better understanding of machining processes under different cutting conditions. Using the capabilities of finite element models, it has recently become possible to deal with complicated conditions in metal cutting. Finite element modeling makes it possible to model several factors that are present during the chip formation .As simulation tool for the purpose of this study; the FEM software used is AdvantEdge FEM. AdvantEdge FEM is a CAE (Computer Aided Engineering) software solution for the optimization of metal cutting. This modeling software is used by those looking to improve tool design, increase material removal rates, extend tool life, improve part quality, and much more. We use AdvantEdge FEM to decrease the need for trial and error testing. The simulation results on cutting forces and chip thicknesses are compared with experimental data in order to indicate the consistency and accuracy of the results when conducting the comparison. Actually this paper presents the advantage of using software for simulation of cutting process and study of stainless steel turning. To complete our research wok we use 2D Finite Element Model (F.E.M.) of chip formation process, proposed in the software named AdvantEdge FEM with an experimental set up in the laboratory. The experimental validation showed a good qualitative agreement. Thus, FEM of cutting process can be considered as a promising and reliable tool for machining development within the near future.

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Chapter 1

INTRODUCTION:

1.1 Overview

Machining process such as turning, milling, boring and drilling are among others the most important process for discrete part manufacturing. Researchers have been studying machining processes for more than a century to gain better understanding and develop more advanced manufacturing technology.

The study of turning has lasted more than a century, but it still attracts a large amount of research effort. This is because turning is not only most frequently used machining operation in the modern manufacturing industry, but also because it is typical single-point machining operation. Other machining operations, such as milling, drilling and boring are multiple-point machining operation that can be investigated based on the combinations of single-point machining operation. Thus, the study of turning can contribute greatly to the knowledge of metal cutting principles and machining practice.

The turning process is used widely in industry and has countless applications. Traditionally, the process has been used to reduce the diameter of cylindrical work piece, or to change a work piece of non-circular cross-section. This is done by rotating the work piece about this of the machine’s spindle and removing the work piece material with the cutting tool which is fed in the perpendicular direction. For the past fifty years metal cutting researchers have developed many modeling techniques including analytical techniques, slip-line solutions, empirical approaches and finite element techniques. In recent years, the finite element analysis has particularly become the main tool for simulating metal cutting processes. Finite element analysis are widely used for calculating the stress, strain, strain-rate and temperature distributions in the primary, secondary and tertiary sub-cutting zones. In consequence, temperatures in the tool, chip and workpiece, as well as cutting forces, plastic deformation (shear angles and chip thickness), chip formation and possibly its breaking can be determined faster than using costly and time consuming experiments. In this work, mechanically based models are developed that are able to predict the effect of cutting speed and feed rate on the cutting forces in turning process.

1.2 The Turning Process

Turning is the process whereby a single point cutting tool is parallel to the surface. It can be done manually, in a traditional form of lathe, which frequently requires continuous supervision by the operator, or by using a computer controlled and automated lathe which does not. This type of machine tool is referred to as having computer numerical control, better known as CNC, and is commonly used with many other types of machine tool besides the lathe.

When turning, a piece of material (wood, metal, plastic even stone) is rotated and a cutting tool is traversed along two axes of motion to produce precise diameters and depths. Turning can be either on the outside of the cylinder or on the inside (also known as boring) to produce tubular components to various geometries. Although now quite rare, early lathes could even be used to produce complex geometric figures, even the platonic solids; although until the advent of CNC it had become unusual to use one for this purpose for the last three quarters of the twentieth century. It is said that the lathe is the only machine tool that can reproduce itself.

The turning processes are typically carried out on a lathe, considered to be the oldest machine tools, and can be of four different types such as straight turning, taper turning, profiling g or external grooving. These types of turning processes can produce various shapes of materials such as straight, conical, curved, or grooved workpiece. In general, turning uses simple single-point cutting tools. Each group of workpiece materials has an optimum set of tools angles which have been developed through the years. The bits of waste metal from turning operations are known as chips.

In deed Turning is a very important machining process in which a single-point cutting tool removes material from the surface of a rotating cylindrical work piece. The cutting tool is feed linearly in a direction parallel to the axis of rotation. Turning is carried out on a lathe that provides the power to turn the work piece at a given rotational speed and to feed the cutting tool at a specified rate and depth of cut. Therefore, three cutting parameters, i.e. cutting speed, feed rate, and depth of cut, need to be determined in a turning operation. Two basic models are in focus: orthogonal (two force) models, and oblique (three-force) models. Most machining processes are oblique but the orthogonal model studies are easier to simulate and they can be useful: adequate for understanding the basic mechanics of machining processes.

1.2.1 Turning operations

Turning specific operations include:

Turning:

This operation is one of the most basic machining processes. That is, the part is rotated while a single point cutting tool is moved parallel to the axis of rotation. Turning can be done on the external surface of the part as well as internally (boring). The starting material is generally a workpiece generated by other processes such as casting, forging, extrusion, or drawing.

Tapered turning:

a) from the compound slide b) from taper turning attachment c) using a hydraulic copy attachment d) using a C.N.C. lathe e) using a form tool f) by the offsetting of the tailstock - this method more suited for shallow tapers.

Spherical generation:

The proper expression for making or turning a shape is to generate as in to generate a form around a fixed axis of revolution.
a) Using hydraulic copy attachment
b) C.N.C. (computerized numerically controlled) lathe

c) Using a form tool (a rough and ready method)
d) Using bed jig (need drawing to explain).

Hard turning:

Hard turning is a turning done on materials with a Rockwell C hardness greater than 45. It is typically performed after the workpiece is heat treated.
The process is intended to replace or limit traditional grinding operations. Hard turning, when applied for purely stock removal purposes, competes favorably with rough grinding. However, when it is applied for finishing where form and dimension are critical, grinding is superior. Grinding produces higher dimensional accuracy of roundness and cylindricity. In addition, polished surface finishes of Rz=0.3-0.8z cannot be achieved with hard turning alone. Hard turning is appropriate for parts requiring roundness accuracy of 0.5-12 micrometres, and/or surface roughness of Rz 0.8–7.0 micrometres. It is used for gears, injection pump components, hydraulic components, among other applications.

Facing:

Facing in the context of turning work involves moving the cutting tool at right angles to the axis of rotation of the rotating workpiece.This can be performed by the operation of the cross-slide, if one is fitted, as distinct from the longitudinal feed (turning). It is frequently the first operation performed in the production of the workpiece, and often the last—hence the phrase "ending up".

Parting:

This process, also called **parting off** or **cutoff**, is used to create deep grooves which will remove a completed or part-complete component from its parent stock.

Grooving

Grooving is like parting, except that grooves are cut to a specific depth instead of severing a completed/part-complete component from the stock. Grooving can be performed on internal and external surfaces, as well as on the face of the part (face grooving or trepanning).

Non-specific operations include:

Boring:

Enlarging or smoothing an existing hole created by drilling, mouldingetc.i.e. the machining of internal cylindrical forms (generating) a) by mounting workpiece to the spindle via a chuck or faceplate b) by mounting workpiece onto the cross slide and placing cutting tool into the chuck. This work is suitable for castings that are to awkward to mount in the face plate. On long bed lathes large workpiece can be bolted to a fixture on the bed and a shaft passed between two lugs on the workpiece and these lugs can be bored out to size. A limited application but one that is available to the skilled turner/machinist.

Drilling:
Is used to remove material from the inside of a workpiece. This process utilizes standard drill bits held stationary in the tail stock or tool turret of the lathe.

Knurling:

KnurlingThe cutting of a serrated pattern onto the surface of a part to use as a hand grip using a special purpose knurling tool.

Reaming:

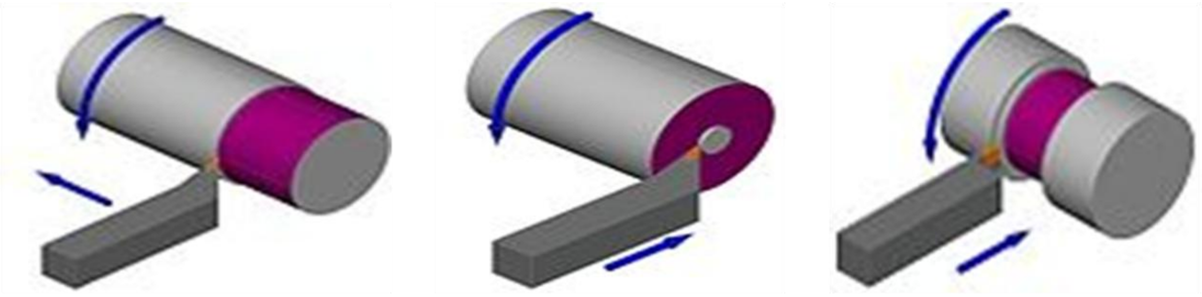
The sizing operation that removes a small amount of metal from a hole already drilled.

Threading:

Both standard and non-standard screw threads can be turned on a lathe using an appropriate cutting tool. (Usually having a 60, or 55° nose angle) Either externally, or within a bore. Generally referred to as single-point threading. Tapping of threaded nuts and holes a) using hand taps and tailstock centre b) using a tapping

device with a slipping clutch to reduce risk of breakage of the tap. Threading operations include a) all types of external and internal thread forms using a single point tool also taper threads, double start threads, multi start threads, and worms as used in worm wheel reduction boxes, leadscrew with single or multistart threads.
b) By the use of threading boxes fitted with 4 form tools, up to 2" diameter threads but it is possible to find larger boxes than this.

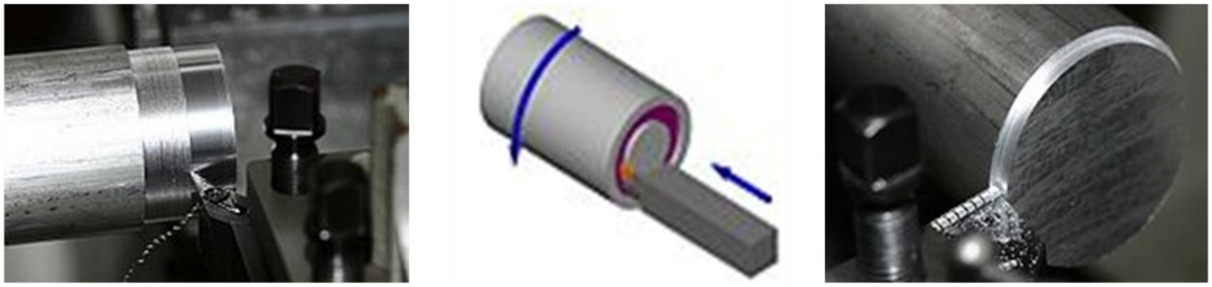
TURNING OPERATIONS



Turning

Facing

External grooving



Finish turning

Face grooving

Roughing, or rough turning

Figure1.1: Different types of turning operation

1.2.2 Turning Parameters

The characteristic parameters of a turning operation are:

- Cutting Speed
- Feed rate
- Depth of Cut
- Different types of angles such as:

  *Rake Angle

  *Clearance angle

  *Wedge Angle

<u>Cutting Speed:</u>

- The Speed at which the cutting tool passes the work, or vice versa
- In Turning….
  - Cutting Speed may be thought of as the peripheral speed of the work piece with respect to the stationary cutting tool
- An appropriate Cutting Speed is determined by considering things such as:
  - Material type and condition
  - Cutting tool material
  - Actual machine factors
  - Experience

- Cutting Speed Units:
- Feet per Minute (FPM) or sometimes SFM (Surface-feet per Minute)
- MPM (Meters per Minute)
- Cutting Speed is used to calculate spindle rotations per minute (RPM)
- RPM = (12 * CS) / (3.14 * Dia.) (Note: Inch units)
- More simply put… RPM = (4 * CS) / Dia.

Feed rate:

- The rate at which a tool travels longitudinally
- An appropriate feed rate is determined by considering things such as:
    - Surface finish requirements
    - Material type and condition
    - Actual machine factors
    - Experience
- Feed rate Units for turning:
    - Feed per revolution (IPR – inches per revolution)
    - Sometimes converted to feed per minute (IPM – inches per minute)
        - ☐ IPM = IPR * RPM

Depth of Cut:

- The distance the tool is plunged into the material

- Units
  - Inches or MM
    - ☐ (remember… in turning, the diameter of the work piece will change by twice the depth of cut)

- Selection
  - DOC is determined by machine/cutter limitations and experience

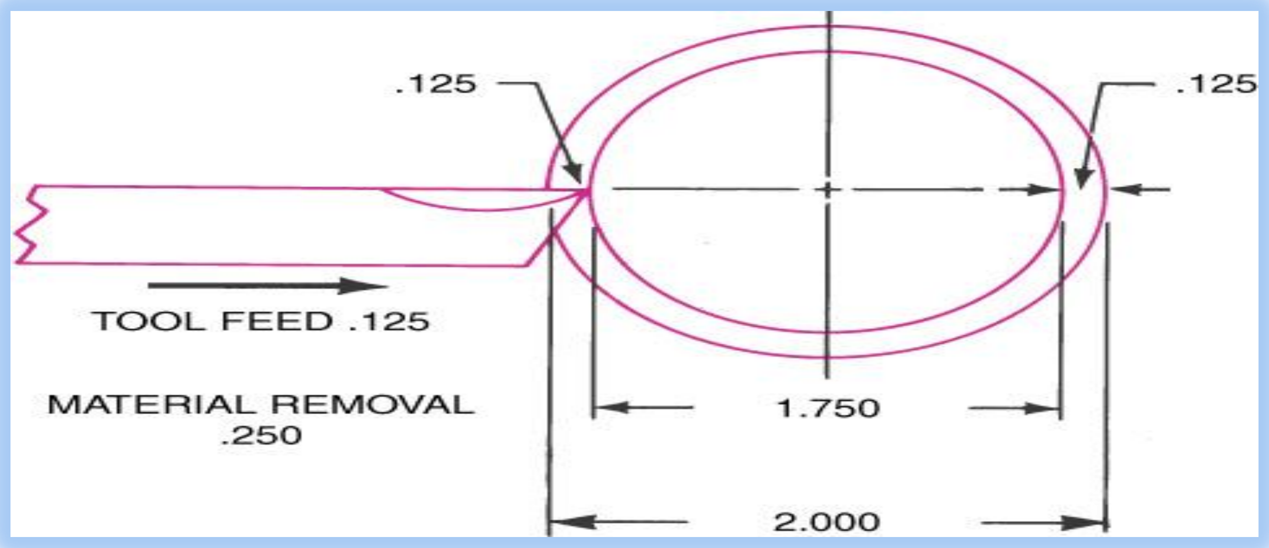


Figure1.2: Depth of cut measurement

Different types of angles:

- **Rake Angle (γ):** This is the angle between the tool face and the plane normal to the surface of the cut and pressing through the tool cutting edge.
- **Clearance angle (α):** This is also known as relief angle, it is the angle between the tool face adjacent to the surface of the cut. This angle helps to eliminate rubbing between the tool and the surface being cut and hence

reduces friction to the beeriest minimum. According to Charles' (1971) a clearance angle of 60 to 80 is large enough to prevent excessive rubbing of the tool on the work piece.

- **Wedge Angle (β):** This is the angle formed by the rake and the relief angle, which is between the rake face and the relief face or between the tool face and the tool relief face.

In general: $\boldsymbol{\alpha + \beta + \gamma = 90^0}$

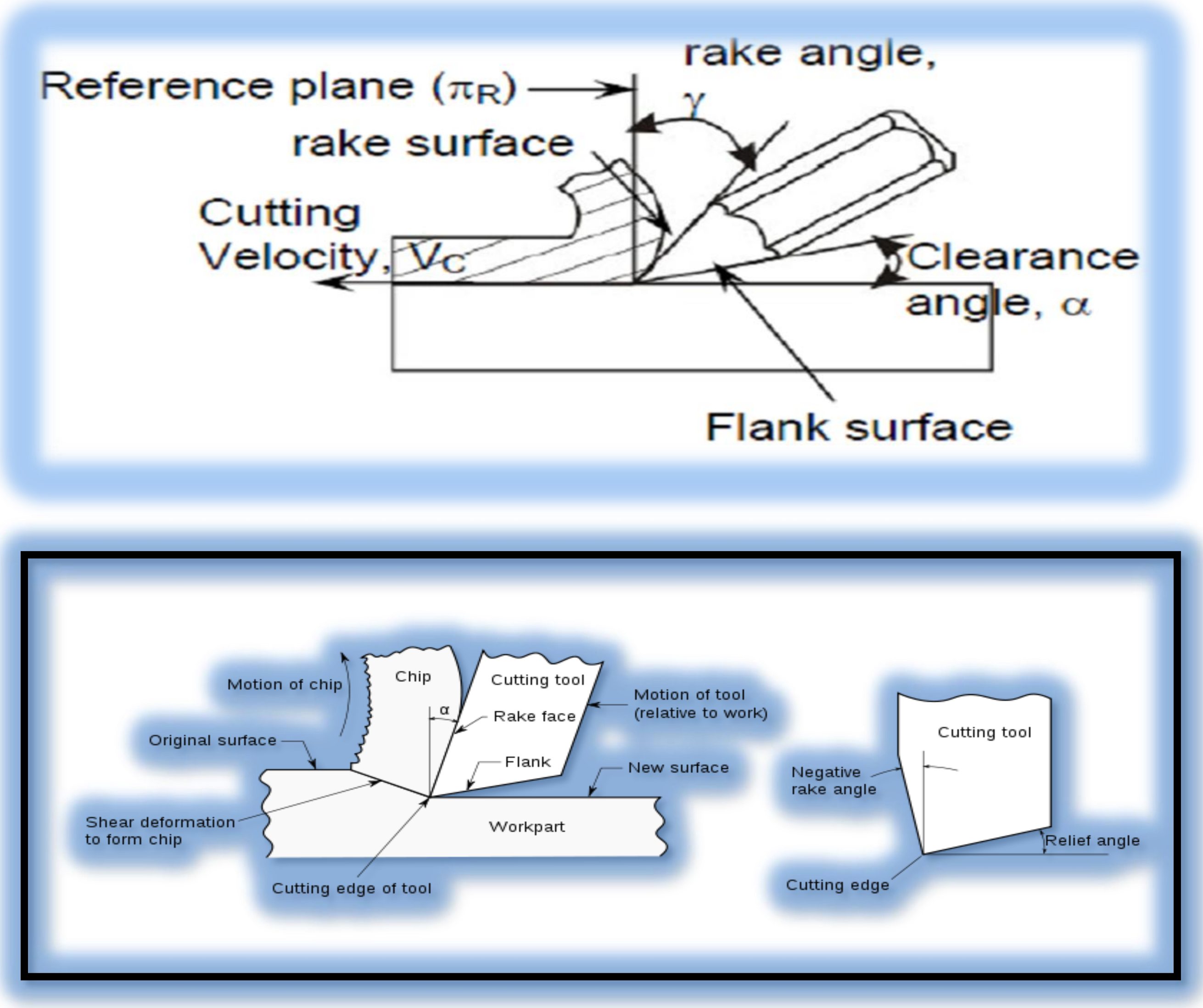


Figure1.3: Different types angles in turning

1.3 Background of the project

This research work is executed to compare the orthogonal cutting data from AdvantEdge FEMsoftware with experiments by creating numerical model to simulate the orthogonal metal cutting. 304-stainless-steel is used as the workpiece material in this study because it has been the focus of many recent modeling studies and well machinability.

Thus, this software is used to simulate the cutting process from the initial to the steady state of cutting force. The orthogonal turning data is verified and a comparison is made between experimentally and simulations to investigate the effect of cutting speed and feed rate on the cutting forces and chip breakage in turning process as a practical tool by researchers, machine and tool makers. This is the reason why the application of FEM software to cutting operations is quite common nowadays.

To simulate with the help of AdvantEdge FEM software in a 2D or 3D environment makes it possible to see the process more in detail and to make more accurate predictions even for processes that are well represented by a plane model (such as orthogonal cutting). Moreover, it allows simulating more complex operations that need to be studied by a three-dimensional model (such as oblique cutting). Actually in this thesis work we doFem based simulation and analysis of stainless steel turning with the help of AdvantEdge FEM software in 2D environment.

1.4 Problem Statement

In recent years, the application of finite element method (FEM) in cutting operations is one of the effective ways to study the cutting process and chip formation. In particular, the simulation results can be used as a practical tool, both by researchers and tool makers to design new tools and to optimize the cutting process.

Facing and turning in metal cutting of turning process, it is very complicated to determine the optimization of cutting conditions due to a lot of cutting experiments need to be execute. Further, these experimental also consider in risks condition because not all the results from the experiments could be achieved as desired. For the results which are not fulfill the optimized cutting condition, the experiments should be repeated and this will lead to high costing to the industry manufacturer worldwide in terms of time demanding, human energy and work material respectively. In order to reduce the costs and time, FEM in machining is widely used nowadays and has become main tool for simulating metal cutting process.

Based on cutting experiments, the simulation were carried out to verify using FEM to indicate that the simulation result are consistent or not with the experiments. This study aims to simulate two-dimensional cutting operations and the FEM software used for this study is AdvantEdge FEM.

1.5 Objective of study

The overall goal of this proposal is to develop methodologies using finite element simulations and to differentiate the actual value from the previous experimental result with the AdvantEdge FEM 2D simulation result. The data that have been taken into computation are cutting force, temperature and time. Thus, the objectives are to:

- Study and determine the influence of process parameters (feed rate, cutting speed, and rake angle, depth of cut and length of cut) upon cutting force and chip breakage.
- To compare between simulation and experiment cutting test to indicate the results are consistent or inconsistent.
- Demonstrate the use of AdvantEdge FEM for 2D simulation in turning processes.

1.6 Scope of Study

(I) Simulation 2D cutting test is using AdvantEdge FEM software.

(ii) Work piece are use is stainless steel of 0.1-0.3% carbon (304-stainless-steel).

(iii) Tool material use is carbide-general with rake angle -5^0.

(iv) To differentiate between the simulations conducted by using AdvantEdge FEM software with the results obtained by the previous researcher as follow:

- ✓ Experiment result; and
- ✓ Results from advantEdge software.

1.7 Importance and Significance of Study

The significance of this research work is that Finite Element Analysis (FEA) in machining process will be a great help for the researchers to understand the mechanics of metal cutting process. Furthermore, the FEA technique has proven to be an effective technique for predicting metal flow and selecting optimum working conditions such as tool and workpiece temperatures and cutting force.

In addition, the influence of several parameters such as feed rate, cutting speed, and rake angle, depth of cut and length of cut has been studied. This simulation will not involve chip elimination before the real material is cutting which indirectly lead to time and cost saving.

1.8 Expected Result

In this study, the investigation indicates the results from simulation cutting test in terms of cutting forces and chip breakage dependent on the cutting parameters such as cutting speed, rake angle, depth of cut and length of cut.

In addition, this research also includes the analysis for the results and graphs from simulation machining such as cutting force, torque, power, peak tool temperature, stress, and tool deflection versus time, thrust force versus time and contours of temperature, heat rate, stress, strain, pressure, and velocity in correlation to tool and/or workpiece. Later, make a comparison between the simulation and experiment result to predict whether the results are consistent or inconsistent.

Chapter 2

LITERITURE REVIEW:

2.1 Introduction

For years, researchers in the area of metal cutting have attempted to develop model of cutting processes that described the mechanisms involved and predict the important behaviours in the process without requiring a large amount of cutting test. Various models have developed for this purpose. In this chapter, previous publication relating to the metal cutting is reviewed. The reviewed topics are organized as follows:

- Fundamental of metal cutting
- Friction models
- Cutting force models
- Finite element models

2.2 Fundamental of Metal Cutting

The most widely used metal cutting operation is turning, milling and drilling. Turning is a process of using a single point tool that removes unwanted material to produce a surface of revolution. Figure 2.1 shows a cylindrical surface being generate on a workpiece and the movement of the cutting tool along feed direction [Kalpakjian, 2001].

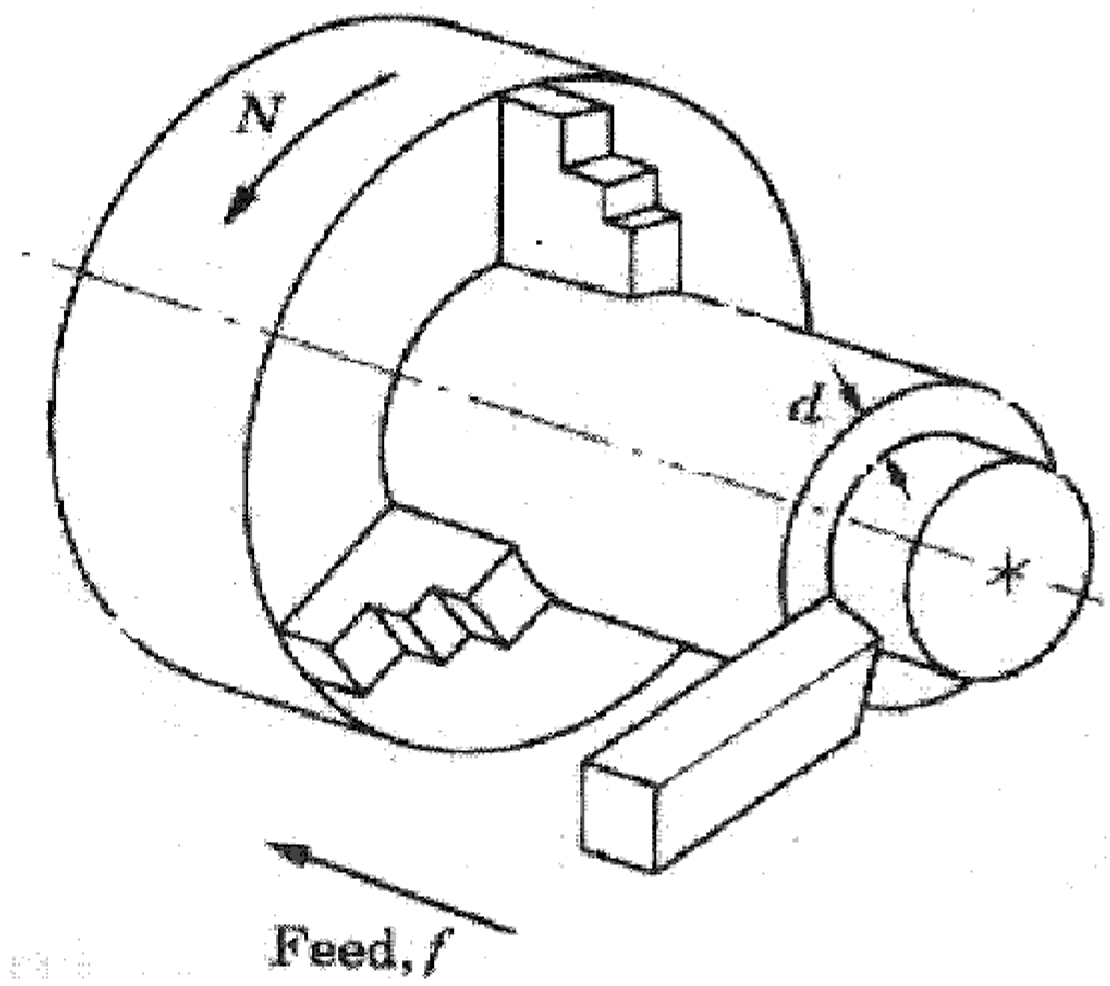


Figure 2.1: Three dimensional view of turning operation [Kalpakjian, 2001]

The need to understand and model the metal cutting process is driven by a number of technological requirements. Basically, the operation should be feasible to achieve the required quality of machined part and efficiency. Knowledge of the cutting process is also important for improvement of machine tool design. Researchers have been conducting experiments and developing models to explain the underlying mechanism of the cutting process for more than fifty year. Most of the proposed models can be classified as analytical, experimental and numerical as listed in table 2.1

Table 2.1: History of Cutting Process Modelling

	Analytical Methods	Experimental Methods	Mechanistic and Numerical methods
Before 1960	1941 Martellotti 1944 Merchant 1951 Lee et.al. 1956 Dio, Salje 1958 Tobias	1944 Kasharin 1946 Sokalov 1956 Trigger	-
1960's	1960 Albrecht 1961 Gumey, Albrecht 1963 Trusty, Zorev 1965 Tobias et.al 1966 Cook 1967 Das 1969 Kegg	1963 Zorev,Oxley 1964 Pekelharing 1965 Cumming, wallace 1966 Das, Thomas 1969 Peters	1961 Koenigsberger 1961 Sabberwal 1962 Sabberwal
1970's	1974 Hannas, Oto 1976 Szakovits	1970 Knight 1971 Peters 1972 Nigm 1973 Cook, Moriwaki 1974 Tlusty 1975 Baily, Pandit 1977 S.M Wu	1971 Okushima 1973 Klamecki 1974 Tay, Shirakasi 1975 Tlusty 1979 Gygax
1980's	1981 Trusty 1985 Rubenstein 1986 D.W. Wu 1989 Oxley	1981 Komanduri 1984 Shi, Shin 1985 Ahn, et.al 1986 Pandit 1987 Ahm	1980 Lajczok 1982 Usui 1983 Natrajan, Stevenson 1986 Carrol, Strenkowski 1987 Riddle 1988 Carroll 1989 Yang
1990 to	1990 Minis, Parthimos	1998 Arcona, Dow	1991 Komvopoulos

present	1993 Minis 1995 Altintas 1996 Arsecularatne 1998 Waldorf 1999 Moufki 2002 Becze, Elbestawi		1992 Yang 1993 Wayne 1994 Athavale 1995 Shih 1999 Ng et. Al

The importance of machining process modeling has been universally recognized in industry. Basic and applied research result has been employed to provide reliable predictions of the performance of the cutting process and the impact of the process on produce quality and process productivity [Ehmann, 1997].

In a simple way, most metal cutting operations can be described in terms of a wedge-shaped cutting tool that is constrained to move relative to the workpiece in such a way that a layer of metal is removed in the form of a chip. When the cutting edge of the tool is arranged to be perpendicular to the direction of cutting velocity, it is called orthogonal cutting. Oblique cutting involves an inclination angle [Boothroyd, 1989].

2.2.1 Orthogonal Cutting

Orthogonal cutting, as illustrated in Figure 2.2 is the simplest machining process and rarely used in industrial practice. The significance of orthogonal cutting is serving as an ideally simple cutting process model in theoretical and experimental work. It can be modeled as a two dimensional process. In orthogonal cutting, effects of independent variables have been eliminated as much as possible so that influences of basic parameter can be studied more accurately. Most of the further studies on machining process are based on the achievement from orthogonal cutting analysis. The assumptions Shaw [Shaw, 1984] on which orthogonal cutting is based to achieve simplicity include as follow:

- The tool is perfectly sharp and there is no contact along the clearance face.
- The shear surface is a plane extending upward from the cutting edge.
- The cutting edge is a straight line extending perpendicular to the direction of the cutting velocity and generates a plane-machined surface.
- The chip does not flow to either side.
- The depth of cut is constant.
- The width of cut is constant.
- The workpiece moves relative to the tool with uniform velocity.
- A continuous chip is produced with no build-up edge.
- The shear and normal stresses along shear plane and tool are uniform.

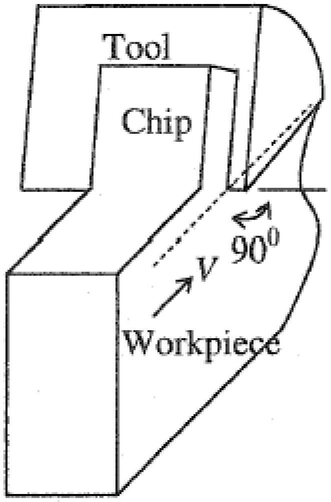


Figure 2.2: Orthogonal cutting

2.2.2 Oblique Cutting

In practice, most cutting operations involve oblique cutting, where the cutting edge is inclined. In the oblique arrangement shown in figure 2.3, the cutting edge inclines at an angle. This angle makes the cutting process modelling more complicated than that for orthogonal cutting. Three-dimensional analysis needs to be performed to study oblique cutting.

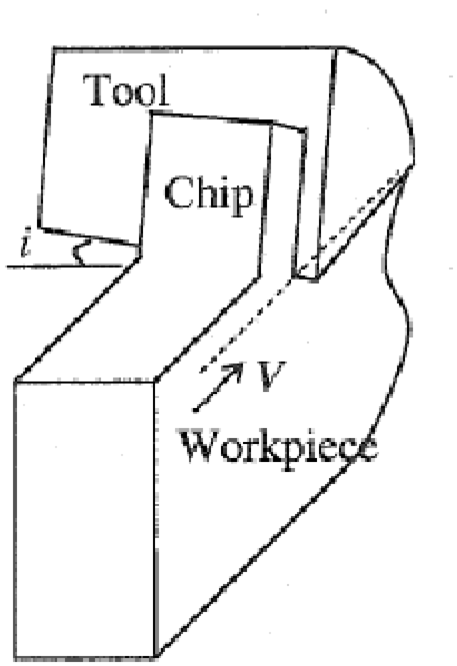
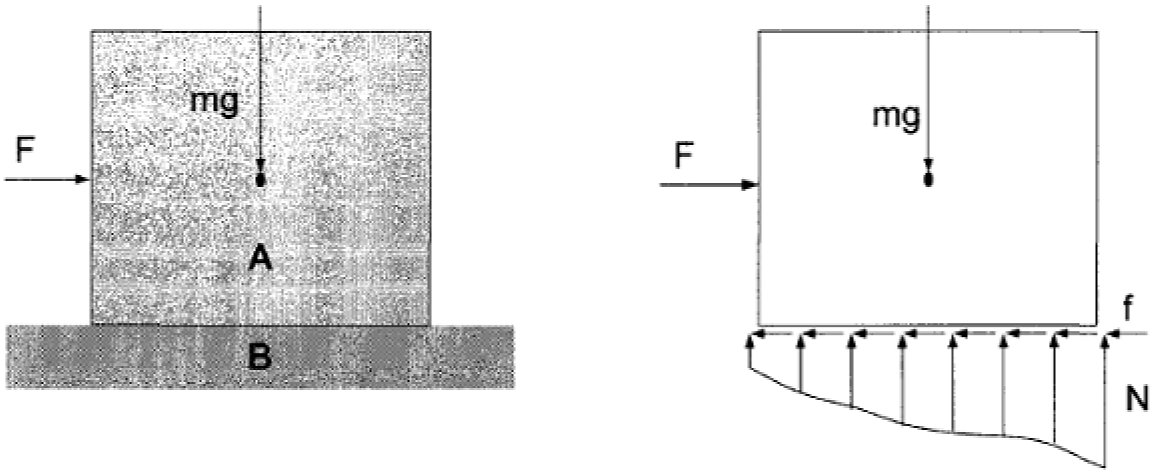


Figure 2.3: Oblique cutting

2.3 Friction model

A general conception of friction can be considered as the tangential force generated between two surfaces. Friction can be represented as a resistance force acting on the surface to oppose slipping. Figure 2.4 (a) shows a simple example of friction where a block is pushed horizontally with mass m over rough horizontal surface. As showing in the free body diagram, Figure 2.4 (b), the body has distributions of both normal force N and horizontal force f along the contact surface. From the equilibrium, the normal force N acts to resist the weight force of the mass mg and the friction force f acts to resist the force F.



(a) (b)

Figure 2.4: Explanation of contact between two surfaces:

(a) Two bodies with friction after applying the load

(b) Free body diagram for the block on a rough surface

Basically, there are two types of friction, which are static and kinetic as shown in Figure 2.5. By increasing the force F, friction force f increases too. The blocks cannot move until the force F reaches the maximum value. This is called the limiting static factional force. Increasing of the force F further will cause the block to begin to move. In the static portion, the limiting friction force can be expressed as:

$F_{static} = \mu s\ N$

Where μs is called the coefficient of static friction

When the force F becomes greater than Fstatic, the frictional force in the contact area drops slightly to a smaller value, which is called kinetic frictional force. Machining models generally just consider the kinetic friction coefficient which can be calculated by the following equation:

$F_{kinetic} = \mu k\ N$

Where μk is called the coefficient of kinetic friction

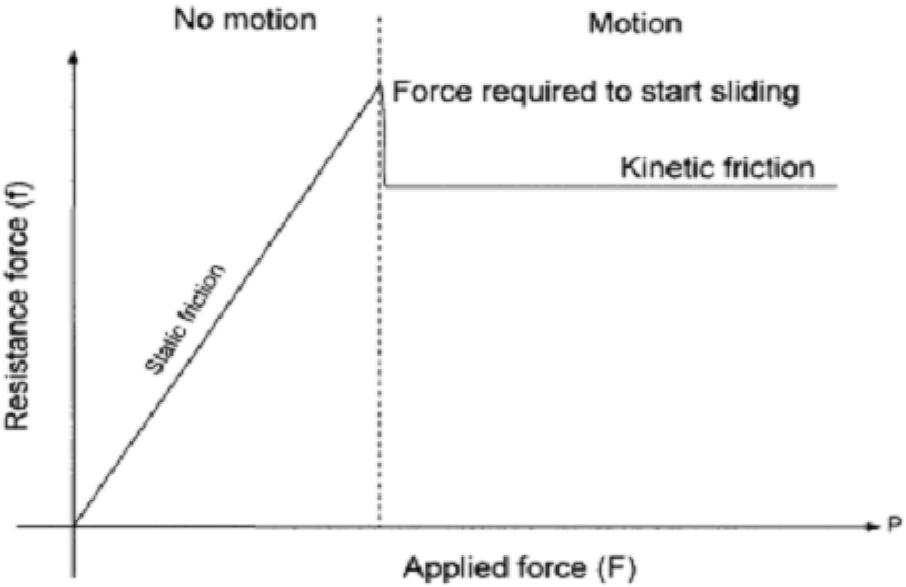


Figure 2.5: Static and kinetic friction

2.3.1 Albrecht's Coulomb friction coefficient

In the the Coulomb friction coefficient, Albrecht's analysis has been used to estimate the coefficient of friction along the chip-tool interface by eliminating the cutting edge effect [P. Albrecht,1960]. Figure 2.6 illustrates the basic concept of Albrecht's model.

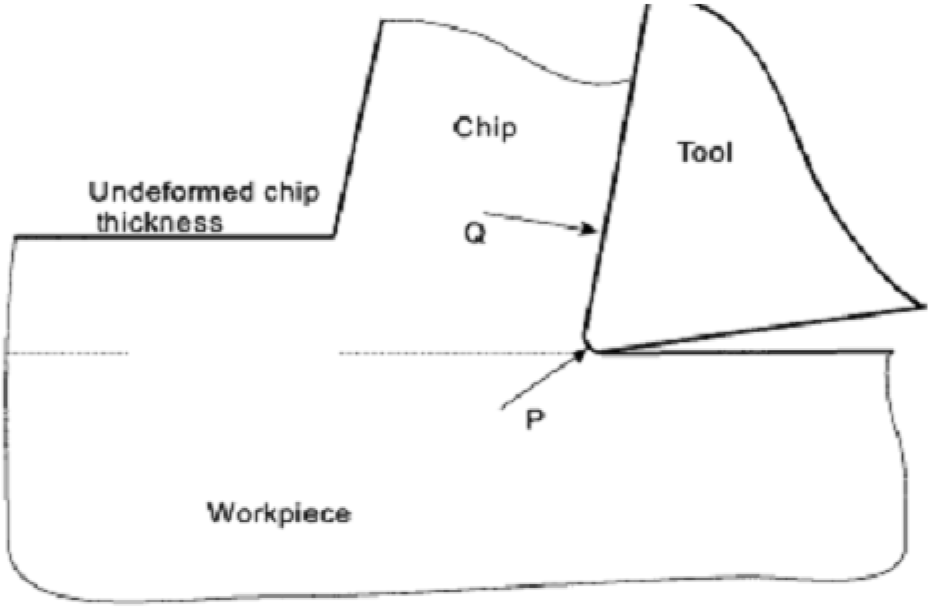


Figure 2.6: Force decomposition in the Albrecht's model

The forces are resolved into two components where P is close to the cutting edge and Q is applied on the rake face. With the sharp cutting tool, the ploughing force P has insignificant value. But for the tool that is not sharp, the force P will affect significantly the force model. For uncut chip thickness greater than the critical uncut chip thickness.

Albrecht assumes that the force P has a constant value. However, at feeds less than the critical uncut chip thickness, the force P will affect the thrust force significantly. After passing the critical chip thickness, the force P slightly affects the thrust force. Example feeds and chip thickness are shown in Figure 2.7. The sum of the two force components (cutting and feed) can be obtained by the sum of two vectors P and Q.

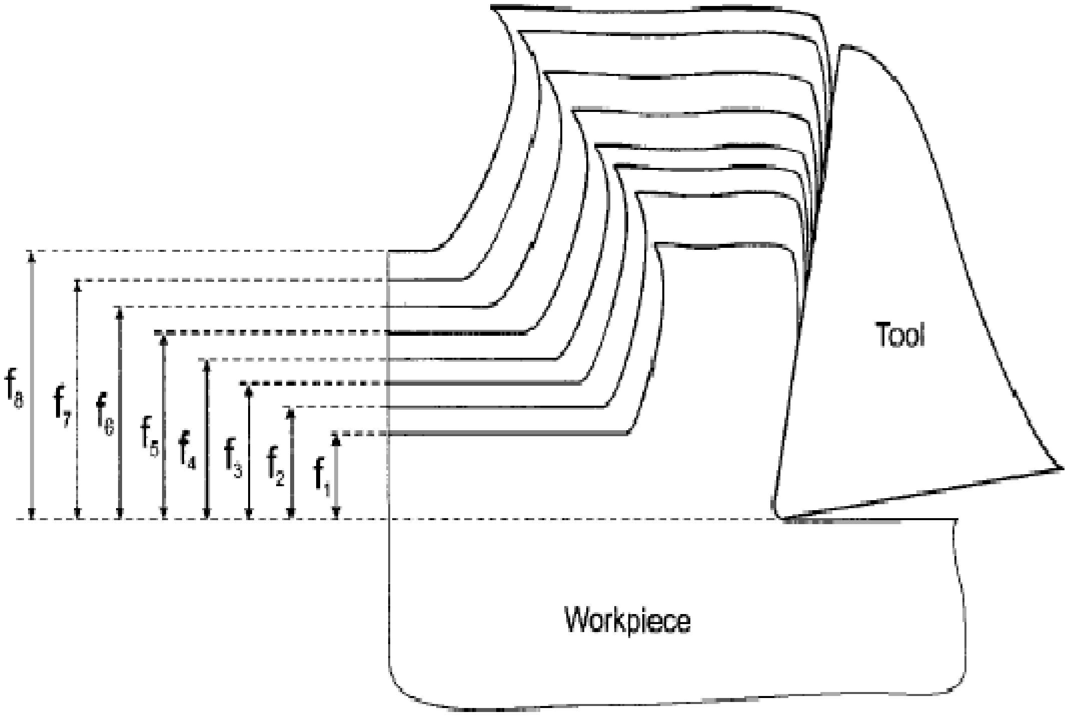


Figure 2.7: Corresponding cutting for different feeds

Figure 2.8 illustrates the cutting force and the thrust force relation at different uncut chip thicknesses. At the smallest feeds in Figure 2.8 (A and B sections), a non-linear relation will describe the behaviour of the cutting and thrust forces. Below the critical point, the P force will cause a relatively large thrust force. The section C where the relation takes a linear behaviour is used to approximate the value of the Coulomb friction coefficient. The friction coefficient along the chip tool interface can be defined by taking the slope of section C as tan (A - a) and then $\mu = \tan \gamma$.

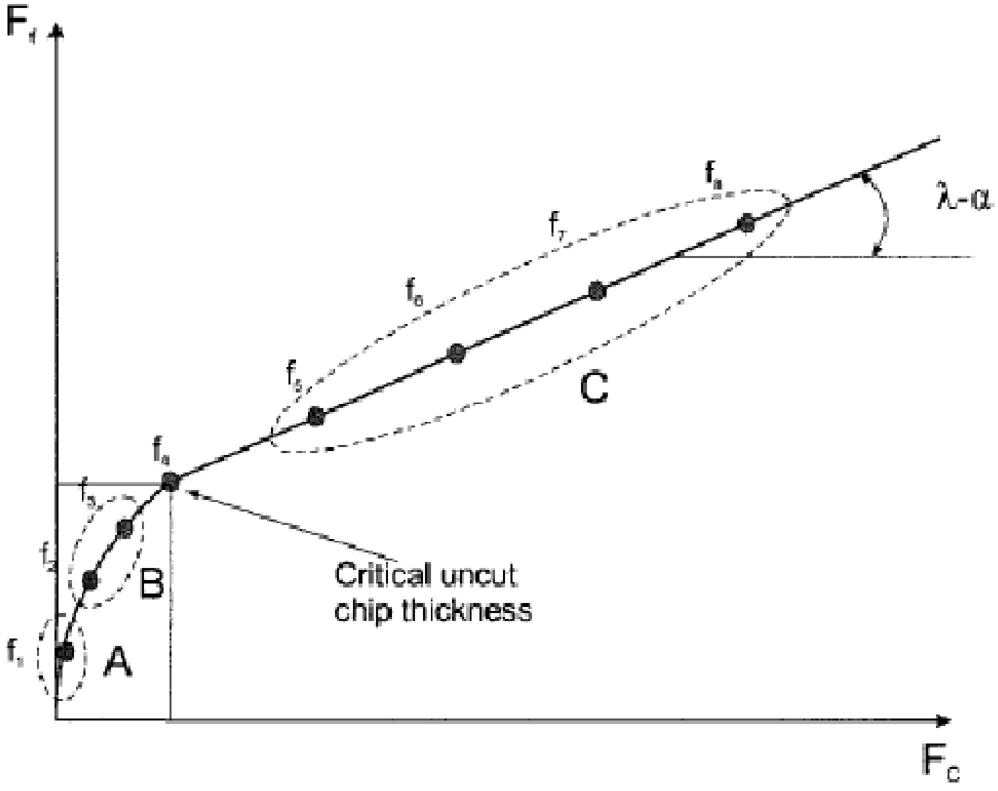


Figure 2.8: Thrust force versus cutting force are define of the critical feed rate

2.4 ANALYTICAL FORCE MODEL

Since 1930, many researchers have tried to understand the machining process under framework plasticity theory. The studies of chip formation were the main goal in order to know the cutting force, stresses and temperatures involved in the process. Various methods were proposed which are several of the study based on fundamentals of mechanical cutting process and others based on experimental. Simplified analytical approaches of orthogonal cutting were first considered by Merchant [Merchant, 1945], who introduced the concept of shear plane angle.

2.4.1 Merchant's Model

Merchant's analysis is based on the two- dimensional process geometry as show in Figure 2.9[Shaw, 1984]. An orthogonal cutting is defined by cutting velocity V, uncut chip thickness t_u, chip thickness t_c, shear angle Ø, rake angle α, and width of cut w. The width of cut w is measured parallel to the cutting edge and normal to the cutting velocity.

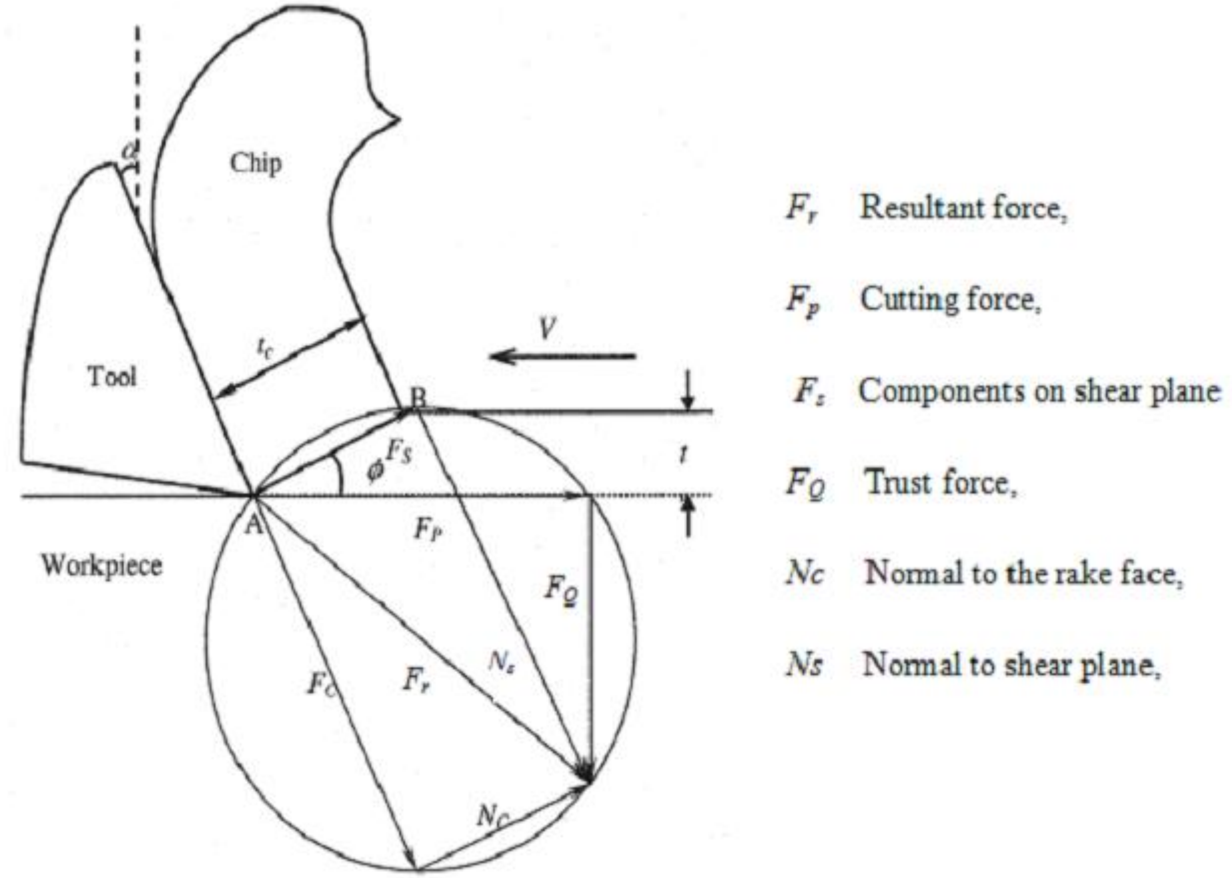


Figure 2.9: Merchant's orthogonal cutting Model [Shaw, 1984]

The workpiece material moves at the cutting velocity while cutting tool remains still. A chip is thus formed and is assumed to behave as a rigid body held in equilibrium by the action of the forces transmitted across the chip-tool interface and across the shear plane. The resultant force F_r is transmitted across the chip-tool interface. No force acts on the tool edge or flank. Fr can be further resolved into components on shear plane, rake face, on cutting direction depending upon research interest. Components on shear plane are F_s in the plane and N_s normal to shear plane. Cutting force F_p is in the cutting direction and a trust force F_Q normal to the workpiece surface. On the rake face, the friction force F_c is in direction of chip flow and the normal force N_c is normal to the rake face. The relationships between those components and resultant force can be defined by the following equations:

On the shear plane:

$$\begin{bmatrix} F_S \\ N_S \end{bmatrix} = \begin{bmatrix} \cos \emptyset & -\sin \emptyset \\ \sin \emptyset & \cos \emptyset \end{bmatrix} \begin{bmatrix} F_P \\ F_Q \end{bmatrix} \qquad (2.1)$$

On the rake face:

$$\begin{bmatrix} F_C \\ N_C \end{bmatrix} = \begin{bmatrix} \sin \alpha & \cos \alpha \\ \cos \alpha & -\sin \alpha \end{bmatrix} \begin{bmatrix} F_P \\ F_Q \end{bmatrix} \qquad (2.2)$$

Shear angle Ø can be experimental determined by:

$$\emptyset = \tan^{-1} \left(\frac{t_u \cos \alpha}{t_c - t_u \sin \alpha} \right) \qquad (2.3)$$

The concept of orthogonal cutting and all of the simplifying assumptions helped to build the fundamental cutting force analysis and left space for improvement in succeeding studies. Most analytical force models follow this shear plane theory or slip-line field theory.

2.4.2 Slip-line Field Theory

Slip-line field solution for shear angle Ø was derived based on two assumptions:

- The material cut behaves as an ideal plastic solid which does not strain-hardened.
- The shear plane represents the direction of the maximum stress.

A slip-line field ABC in front of the cutting tool, shown in figure 2.10 [Waldrof, 1996], was assumed to be plastically rigid and subjected to a uniform state of stress.

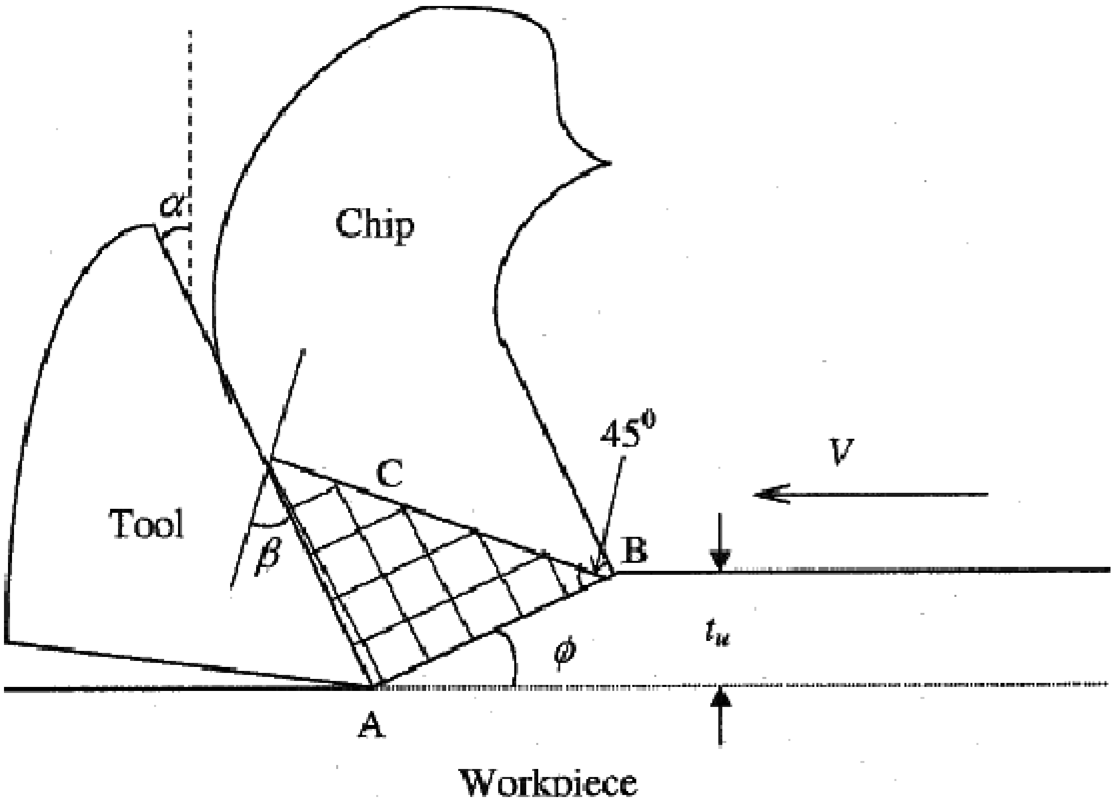


Figure 2.10: Slip-line fields in orthogonal Cutting [Waldrof, 1996]

Line BC is the line along which the stress is zero. β is the friction angle on the rake face of the cutting. Ø is shear angle. They can be determined by:

$$\beta = \tan^{-1}(F_c/N_c) \qquad (2.4)$$

$$Ø = 45^{\circ} - \beta + \alpha \qquad (2.5)$$

2.5 FINITE ELEMENT MODELS (FEM)

With the development of numerical methods and advent of digital computers, computational difficulties and model limitations were overcome. Since 1973, the finite element method has been applied to simulate machining with some successes [Komvopoulos, 1991]. Two different finite –element formulations, the Lagrangian and the Eulerian, are most commonly used in the modelling of cutting process. In the Lagrangian approach, the finite element must consist of material elements that cover the region of analysis exactly. These elements are attached to the material and deformed with the deformation of the workpiece. In the Eulerian approach, the mesh 20 consists of elements that are fixed in space and cover the control volume, and the material properties are calculated at fixed spatial locations as the material flows through the mesh [Movahbedy, 2000].

In FEM, the material properties can be handled as functions of strain, strain rate and temperature. Interaction between chip and tool can be modelled as sticking and sliding. Nonlinear geometric boundaries such as the free surface of the chip can be represented as used. Stress and temperature distribution can be obtained as well [Zhang, 1994; Shih, 1995]. However, large deformation of the material results in the distortion of the elements and deterioration of simulation results. The numerical simulation of cutting process can be extremely difficult because of unconstrained flow of material that occurs over free boundaries. As a result, most of the previous analysis used simple models such as rigid-plastic/elastic-plastic and non-hardening material behaviour, or empirical models depending on experimental data, ignored interfacial friction and tool wear on the cutting process.

2.5.1 AdvantEdge FEM software

AdvantEdge FEM is a commercial FEM software based process simulation system designed to analyze flow of various metal forming process. It is available in both Lagrangian (Transient) and arbitrary Lagrangian and the Eularian (ALE Steady-State) modeling. Additional, the software is currently capability of Steady-State function and it is required of running a transient simulation previous to steady state cutting simulation.

Actually AdvantEdge FEM is a CAE software solution for the optimization of metal cutting. This modeling software is used by those looking to improve tool design, increase material removal rates, extend tool life, improve part quality, and much more. Use AdvantEdge FEM to decrease the need for trial and error testing — ultimately getting to market faster. AdvantEdge FEM is a micro-level, physics-based finite element machining modeling software package designed to allow a user to study the tool-workpiece interface and analyze the mechanical and thermal response of the tool-chip-workpiece system. AdvantEdge FEM provides detailed information on cutting forces, chip formation, temperature, heat flow, stress, strain, workpiece residual stress, etc.

AdvantEdge simulations allow a user to reduce cutting forces, optimize cutting feed and speed and increase Material Removal Rates, to predict and manage residual stress and subsequent part distortion, to improve tool performance and life.AdvantEdge FEM enables users to analyze machining processes in 2D and 3D environments. Manufacturers across the globe find AdvantEdge FEM to be a valuable resource in the design of milling, grooving, boring, sawing, broaching, drilling, and turning processes.

How it Works:

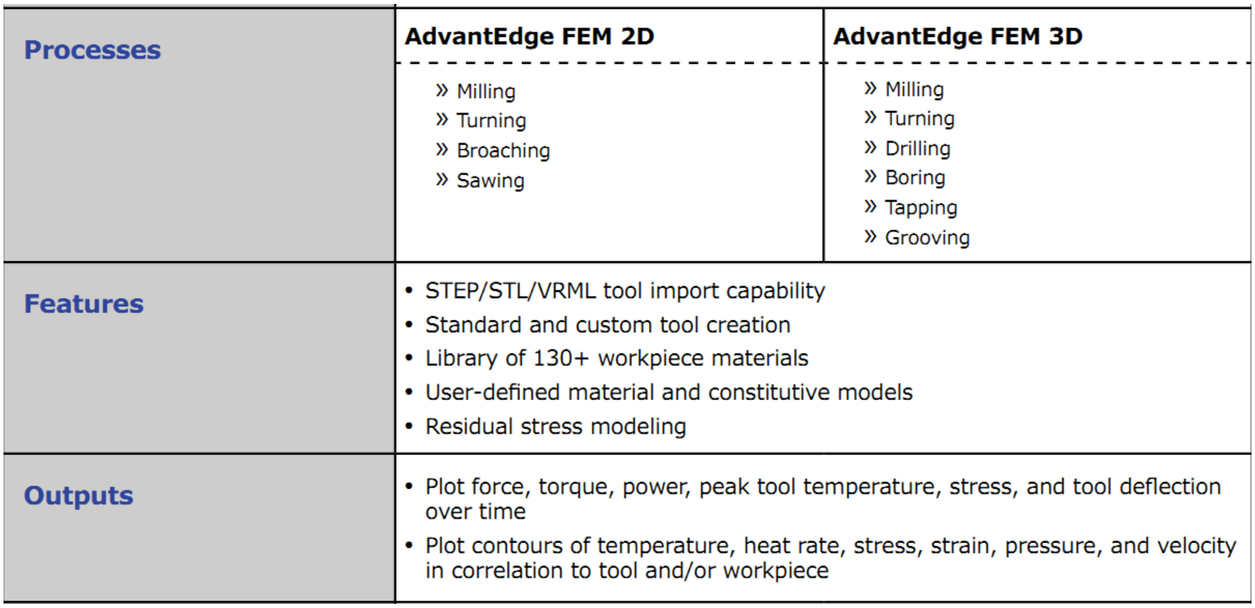
- Define tool geometry or import from CAD program
- Select tool and workpiece materials
- Input cutting conditions
- Run simulations
- Compare simulation results for different cutting conditions or tool geometries to find optimal results
    - Analyze temperature and stress profiles to gage reductions in tool wear
    - Use chip formation to predict improved chip evacuation
    - Evaluate force plots to lower cutting forces and power consumption

Ongoing software benefits experienced by AdvantEdge FEM users are:

- Increased material removal rates
- Improved tool life
- Predicted chip shape
- Shortened product design cycles
- Reduced trial and error testing

AdvantEdge FEM Product Specifications:

Table 2.2: AdvantEdge FEM Product Specifications



Processes	**AdvantEdge FEM 2D** » Milling » Turning » Broaching » Sawing	**AdvantEdge FEM 3D** » Milling » Turning » Drilling » Boring » Tapping » Grooving
Features	• STEP/STL/VRML tool import capability • Standard and custom tool creation • Library of 130+ workpiece materials • User-defined material and constitutive models • Residual stress modeling	
Outputs	• Plot force, torque, power, peak tool temperature, stress, and tool deflection over time • Plot contours of temperature, heat rate, stress, strain, pressure, and velocity in correlation to tool and/or workpiece	

Troy D. Marusich, Jeffrey D. Thiele and Christopher J. Brand conducted SIMULATION AND ANALYSIS OF CHIP BREAKAGE IN TURNING PROCESSES using FE software **AdvantEdge FEM**. The major thrust were the investigation of cutting forces, chip formation and breakage, and work-hardened surface layer of the workpiece. Further, they also study about influence of cutting parameters such as cutting speed, rake angle and depth of cut. Later, the computed cutting force, temperature, deformations and chip geometry have been compared with cutting experiments.

T. D. Marusich, S. Usui, J. Ma and D. A. Stephenson and A. Shih investigated Finite Element Modeling of Drilling Processes with Solid and Indexable Tooling in Metals and Stack-ups using FE software **AdvantEdge FEM**. Actually A three-dimensional finite element-based model of drilling were presented which includes fully adaptive unstructured meshing, tight thermo-mechanical coupling, deformable tool-chip-workpiece contact, interfacial heat transfer across the tool-chip boundary, and constitutive models appropriate for high strain-rate, large strain and high temperature deformation.

Mamalis, [mamalis, 2001] investigated FE simulation on chip formation in steady-state orthogonal metal cutting using finite element code MARC. The flow stress of the work material is taken as a function of strain, strain rate and temperature in order to know the effect of the large strain, strain rate and temperature associated in cutting process. Additional, the chip formation and the stress, strain and strain-rate distribution in the chip and workpiece, as well as the temperature fields in the workpiece, chip and tool are determined.

Referring to iqbal and friend [Iqbal. 2006], there were effects of workpiece flow stress models and friction characteristics at the tool-chip interface by predicting on different output parameters. Further, they have been performed 2D orthogonal cutting FE model by AdvantEdge FEM 2D simulation in order to predict accuracy of cutting force and shear angle. Flow stress models are used extensively in the simulations of deformation processes occurring at high strains, strain rates and temperature.

Troy D. Marusich also studied THE EFFECTS OF FRICTION AND CUTTING SPEED ON CUTTING FORCE and T. D. Marusich, S. Usui, S. Lankalapalli, N. Saini, L. Zamorano and A. Grevstad investigated Residual Stress Prediction for Part Distortion Modeling using FE software **AdvantEdge FEM.** Again T. D. Marusich and E. Askari performed Modeling Residual Stress and Workpiece Quality in Machined Surfaces by AdvantEdge FEM software.Ageneral method were presented to model the residual stress state induced by metal cutting operations which takes into account workpiece thermo-mechanical properties, cutter geometry and process parameters. The model were specifically applied to Al7050. Results indicated the magnitude and sign of the state of stress is shown to have no intuitive correlation to machining process parameters such as speed and chip load. Similar results were shown for stress-induced bending moments, a potential strong contributor to part distortion. In addition, the machining-affected layer were shown to be on the order of 1mm, easily on the same length scale as the wall thickness of aerospace structures.

2.6 Conclusion

According Merchant's shear plane analysis, the concept of friction implies that friction force and normal force are uniformly distributed over the sliding interface. However, this is not the case of metal cutting and this approach provides coefficient of friction is too simple. Additionally, the friction formula is relevant only to sliding conditions that was probably bring weakness of this analysis.

Continuous to Lee and Shaffer with their slip line theory, the most likely sources of the poor agreement are the material assumption, that is work material is rigid-perfectly plastic and the simple friction assumption. As a result, a more recent approach in the studies of metal cutting has been employed. FEM has employed to conduct simulation of cutting processes. The FEM is more accurate due to ability to incorporate more realistic assumptions of material behavior and the influence of friction.

Chapter 3

METHODOLOGY:

3.1 Introduction

The software **AdvantEdge FEM** is used in this study to simulate the two and three-dimensional orthogonal metal cutting process. The finite element model is composed of a deformable workpiece and a rigid tool. Overall, there have been a series of cutting test that will be carried out for simulation in varies machining parameters of cutting speed, feed rate and depth of cut.

The relationship exist between cutting performance such as cutting forces, residual stresses, cutting temperature and cutting condition may be established theoretically by Finite Element Methods (FEM) analysis model. The proposed workfocuses on the development model of Finite Element Analysis (FEA) procedures to achieve the research objectives as mentioned in section 1.4. Flow chart in Figure 3.1 indicates the flow of this simulation.

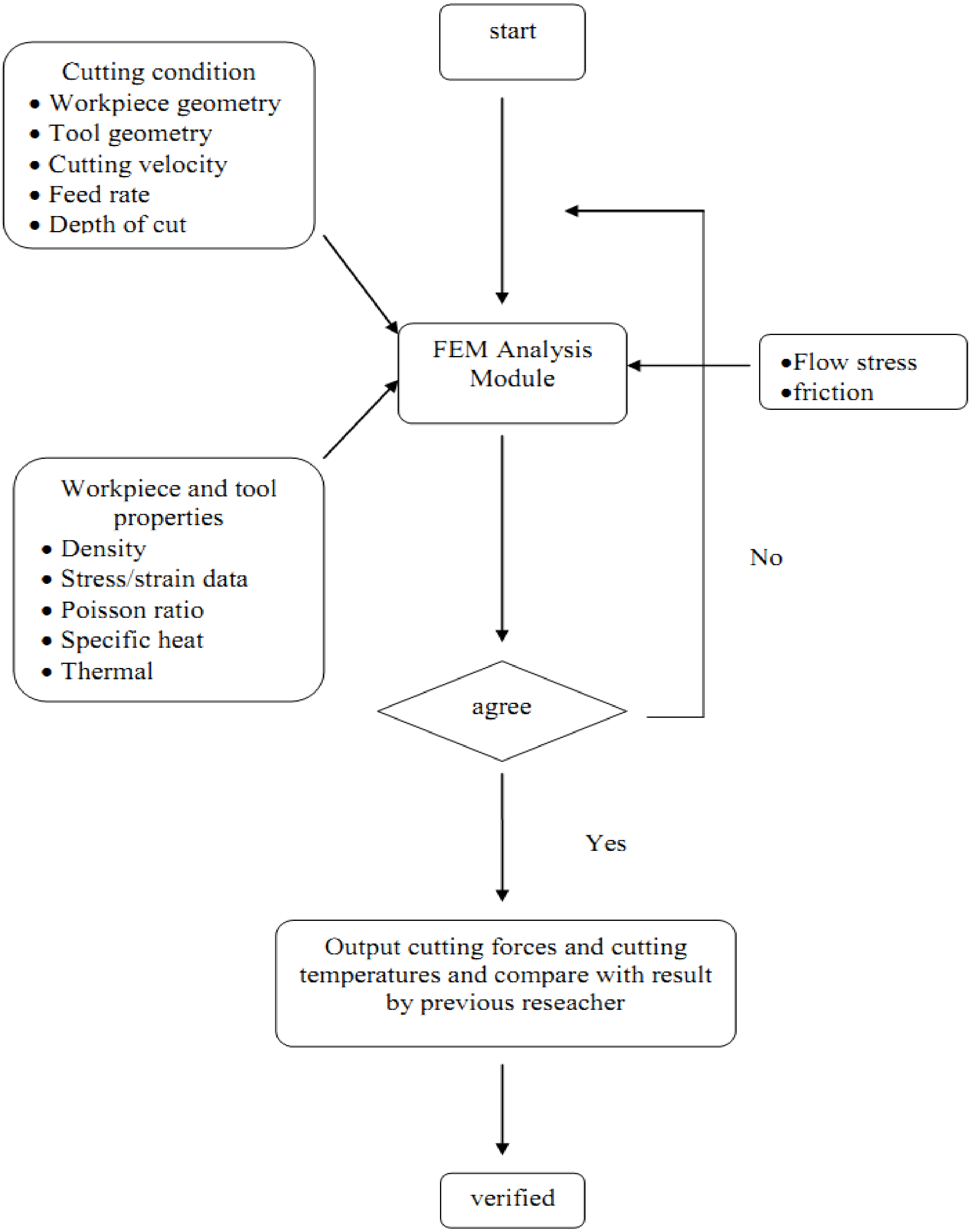


Figure 3.1: process flow chart for simulation

3.2 Finite element Systems

In order to improve metal cutting processes, i.e. lower part cost, it is necessary to model metal cutting processes at a system level (Ehmann et. a., 1997). A necessary requirement of such is the ability to model interactions at the tool-chip interface and thus, predict cutter performance. Many approaches such as empirical, mechanistic, analytical and numerical have been proposed. Some level of testing for model development, either material, machining, or both is required for all. However, the ability to model cutting tool performance with a minimum amount of testing is of great value, reducing costly process and tooling iterations. In this paper, a validated finite element-based machining model is presented and employed to calculate chip geometry, chip breakage, cutting forces, and effects in work-hardened workpiece surface layers.

Typical approaches for numerical modeling of metal cutting are Lagrangian and Eulerian techniques. Lagrangian techniques, the tracking of discrete material points, have been applied to metal cutting (Strenkowski and Carroll, 1985; Komvopoulos and Erpenbeck, 1991; Sehkon and Chenot, 1993; Obikawa and Usui, 1996; and Obikawa et.al 1997.). Techniques typically used a predetermined line of separation at the tool tip, propagating a fictitious crack ahead the tool. This method precludes the resolution of the cutting edge radius and accurate resolution of the secondary shear zone due to severe mesh distortion. To alleviate element distortions, others used adaptive remeshingtechniques to resolve the cutting edge radius (Sehkonand Chenot, 1993; and Marusichand Ortiz, 1995). Eulerian approaches, tracking volumes rather than material particles, did not have the burden of remeshing distorted meshes (Strenkowski and Athavale, 1997). However, steady state free-surface tracking algorithms were necessary and relied on assumptions such as uniform chip thickness, not allowing the modeling of milling processes or segmented chip formation.

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 ofmetal cutting are: Abaqus, Deform and AdvantEdge FEM. 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.

In this paper, a Lagrangian finite element-based machining model is applied in 304-stainless-steel to predictthe effect of cutting speed and feed rate on the cutting forces and chip breakage in turning process.chip. First, the orthogonal cutting model is validated against cutting forces and chip thickness. Second, a chip breakage criterion is implemented and validated against a range of cutting conditions and cutter geometries. Techniques such as adaptive remeshing, explicit dynamics and tightly coupled transient thermal analysis are integrated to model the complex interactions of the cutting tool and workpiece.

3.3 Machining Simulation System

Simulations were performed with Third Wave Systems AdvantEdge machining simulation software, which integrates advanced finite element numerics and material modeling appropriate for machining. The orthogonal cutting system is described in Fig. 3.2 where the observer is in the frame of reference of the cutting tool with the workpiece moving with velocity v. The cutting tool is parameterized by rake and clearance angles, and a cutting edge radius, but can also accommodate general chip breaker geometries. In the plane strain case the depth of cut into the plane is considered to be large in comparison to the feed. The cutting tool initially indents the workpiece, Fig. 3.3, the chip begins to form Fig. 3.4, and finally curls over hitting the workpiece ahead of the cut, Fig. 3.5.

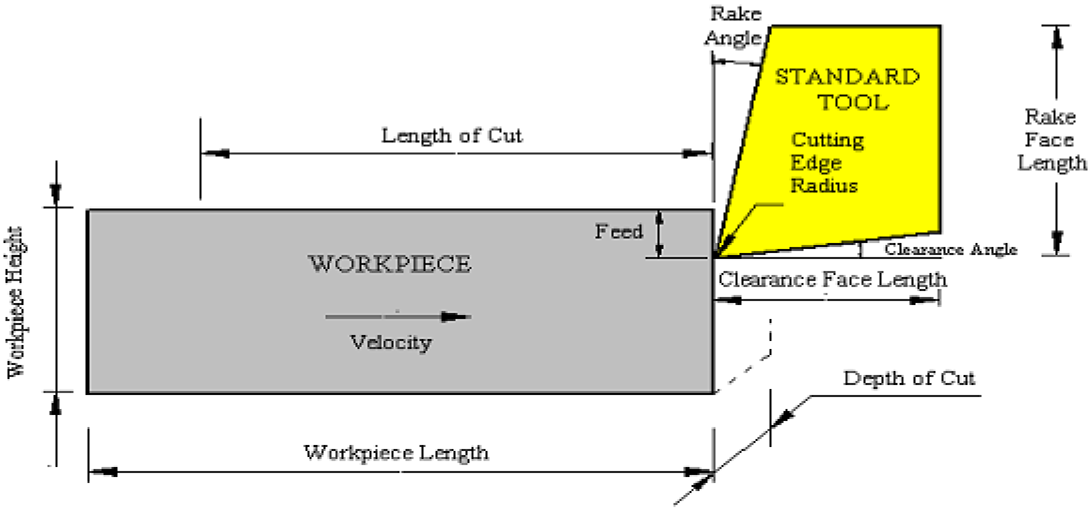


Figure 3.2 Schematic of orthogonal cutting conditions.

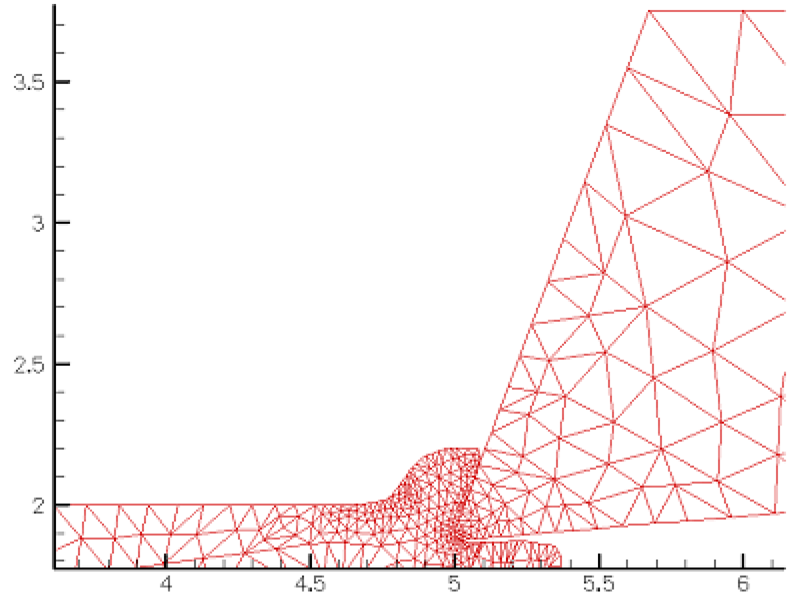


Figure 3.3 Initial tool indentation

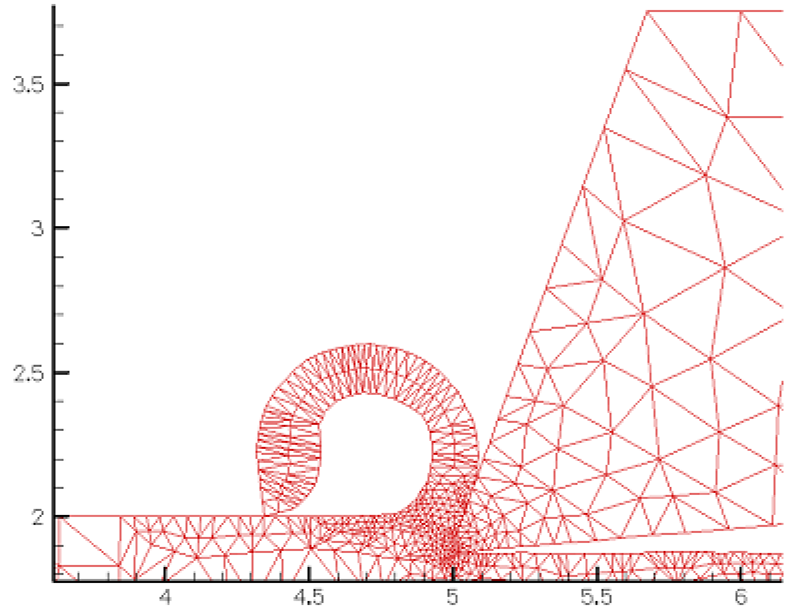


Figure 3.4 Chip formation

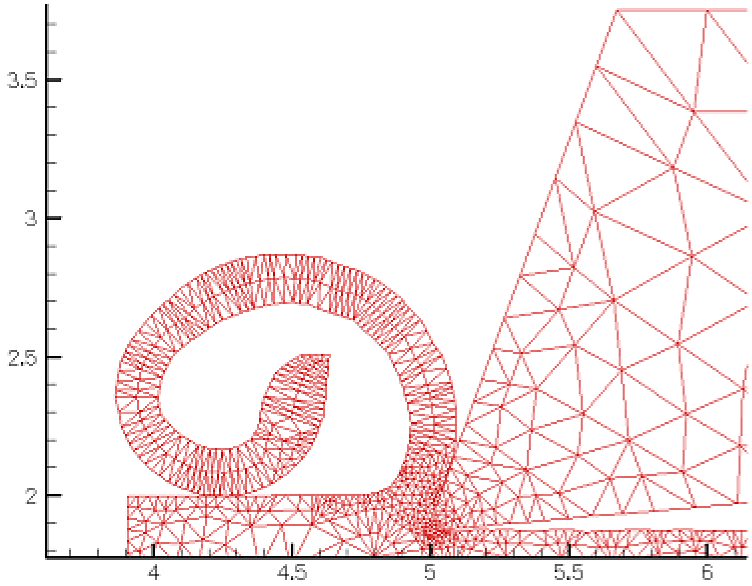


Figure 3.5Fully developed continuous chip

3.4 Modeling Approach

Third Wave AdvantEdge is an explicit dynamic, thermo-mechanically coupled finite element modeling package specialized for metal cutting. Features necessary to model metal cutting accurately include adaptive remeshing capabilities for resolution of multiple length scales such as cutting edge radius, secondary shear zone and chip load; multiple body deformable contact for tool-workpiece interaction, and transient thermal analysis.A major thrust of this paper is the investigation of cutting forces, chip formation and breakage, and work-hardened surface layer of the workpiece. In order to resolve the critical length scales necessary in the secondary shear zone and the inherent large deformations while maintaining computationally accurate finite element configurations, adaptive remeshing techniques are critical. Near the cutting edge radius, the workpiecematerial is allowed to flow around the edge radius. The initial mesh, Fig.3.6, becomes distorted after a certain length of cut, Fig.3.7, and is remeshed in this vicinity to form a regular mesh again, Fig.3.8. For a comprehensive discussion on the numerical techniques the reader is referred to Marusich and Ortiz (1995).

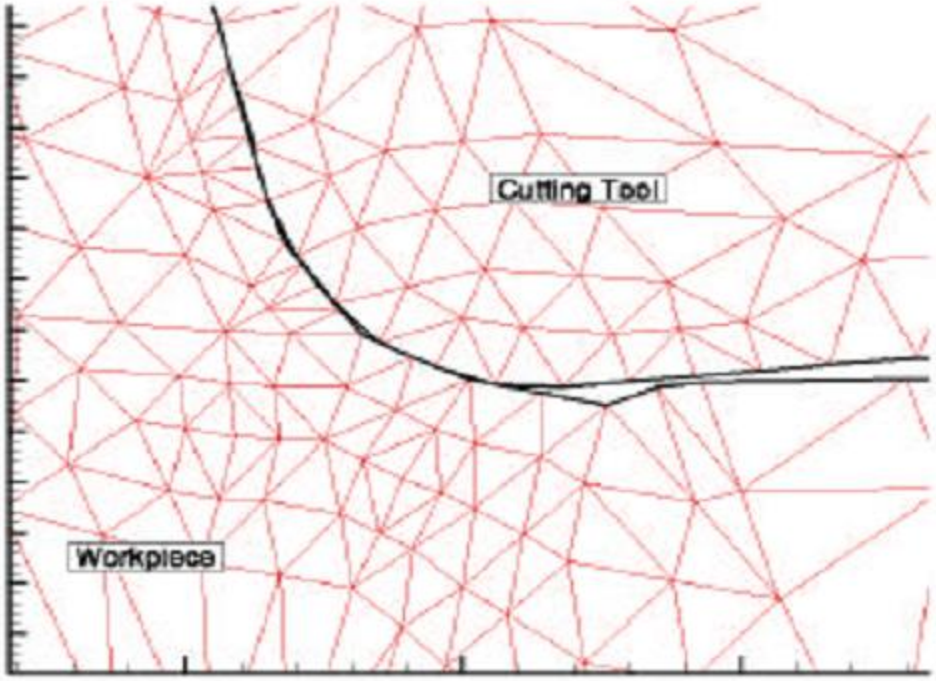


Figure3.6: Initial mesh magnified in the cutting tool edge vicinity.

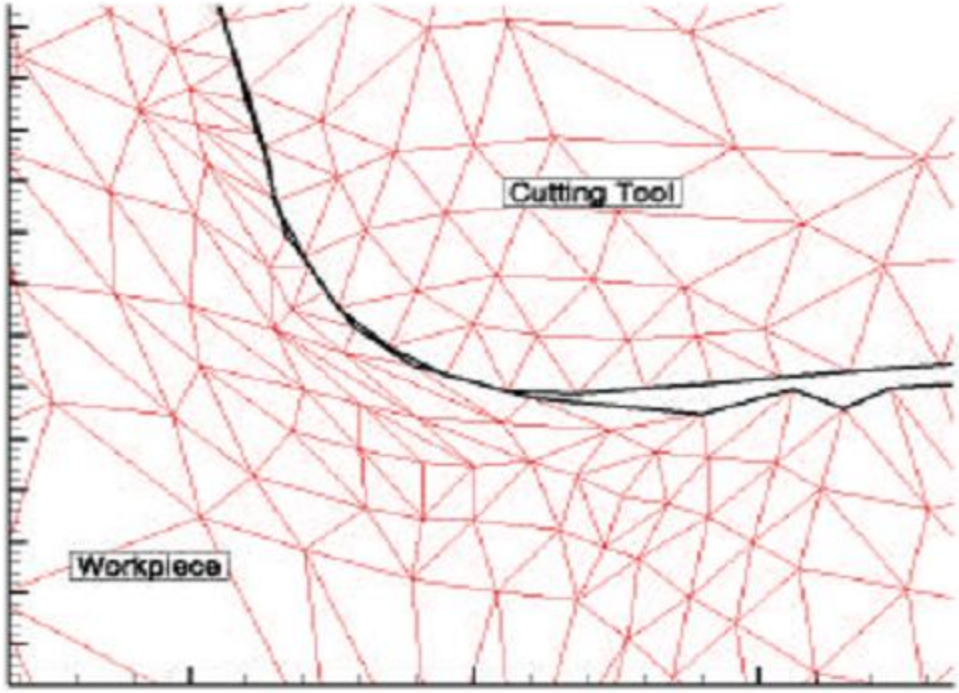


Figure 3.7: Deformed mesh

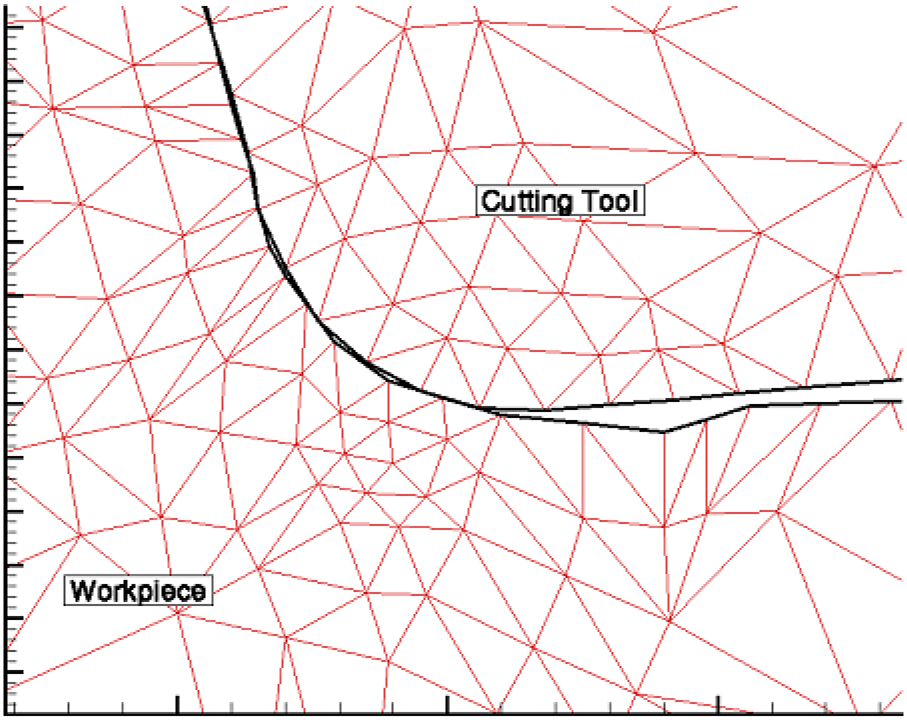


Figure 3.8: Updated mesh

3.5 Constitutive Model and Material Characterization

In order to model chip formation, constitutive modeling for metal cutting requires determination of material properties at high strain rates, large strains, and short heating times and is quintessential for prediction of segmented chips due to shear-localization (Sandstrom and Hodowany 1998; Childs, 1998). The reader is again referred to Marusich and Ortiz (1995) for specific details of the constitutive model adopted. The model contains deformation hardening, thermal softening and rate sensitivity tightly coupled with a transient heat conduction analysis appropriate for finite deformations.

3.6 Modeling using AdvantEdge FEM

Nowadays, the finite element analysis is the main tool regarding the metal cutting process modelling and simulation. It has important advantages, such as: the prediction of cutting forces and chip shape; it solves contact problems between bodies; it uses bodies made from different materials, etc.It is a well known fact that machining, especially orthogonal cutting is a common process in industry. Creating accurate models using the finite element method results in optimizing these processes, thereby a reduction of the experiments number results, implicitly of the time and costs related to these operations.

AdvantEdge FEM is an explicit commercial code for designing, improving and optimizing machining processes. The solver is optimized for metal cutting processes. Some advantages of using this software are [17]: it reduces cutting tests, extends tool life and reduces tool breakage, uses complex geometries of tools and workpieces, faster machining processes, efficient productivity, increases material removal rates and machine utilization, etc. This software has a high level of details and a simple and user friendly interface which allows users to easily set the modelling and simulation data. It is capable to model complex interactions between tool and workpiece, and covers a wide range of cutting types from turning to milling.

Before modeling and simulation, the user should set the initial data, namely process parameters and conditions: cutting speed, depth of cut, feed rate, environment temperature, whether a coolant will be present or not and friction coefficient.

3.6.1 Pre-processor module

The Simulation Setup Interface allows users to setup the entire simulation, defining tool geometries, material conditions and machining parameters.

It contains:

- a user friendly interface
- an extensive standard tools library
- an extensive material library
- offers the possibility of creating new tool and workpiece geometries within the program and also to import complex geometries form other CAD files
- offers the possibility of introducing new materials

3.6.2Simulation module

The AdvantEdge Engine performs all the hidden calculations.

Simulations can run in:

- Demonstration mode, decreases the simulation time but is less accurate
- Standard mode, requires longer simulation time but is more accurate

3.6.3Post-processor module

The Tecplot displays and assists in analyzing the simulation results.Among the displayed results there can be enumerated: chip formation, chip and tool temperature, cutting forces, steady state variables such as: strain, stress, strain von Misses, etc.

3.7 Simulation

Simulation are abstractions of reality.Often they deliberately emphasize one part of reality at the expense of other parts.Sometimes this necessary due to computer power limitations.Sometimes it’s done to focus your attention on an important aspect of the simulation.Whereas model are mathematical,logical,or some other structured representation of reality,simulations are the specific application of models to arrive at some outcome.

3.7.1Three types of simulations

Simulations generally come in three styles:live,virtual and constructive.A simulation also may be a combination of two or more styles.Within these styles, simulation can be science-based(where,for example,interactions of things are observed or measured),or involve interactions with humans.Our primary focus at IST is on the later –human-in-the-loop-simulations.

Live simulations typically involve human’s and\or equipment and activity in a setting where they would operate for real.Think war games with soldiers out in the field or manning command posts.Time is continuous,as in the real world.Another example of live simulation is testing a car battery using an electrical tester.

Virtual simulations typically involve humans and\or equipment in a computer – controlled setting.Time is in discrete steps,allowing users to concentrate on the important stuff,so to speak.A flight simulator falls into this category.

Constructive simulations typically do not involve humans or equipment as participants.Rather than by time,they are driven by the proper sequencing of events.The anticipated path of a hurricane might be “ constructed “ through application of temperature,pressures,wind currents and other weather factors.Science-based simulations are typically constructive in nature.

3.7.2 Why simulation is important

Simulation provides a method for checking your understanding of the world around you and helps you produce better results faster.A simulation program like ExtendSim is an important toll that you can use to:

- Understand why observed events occur.
- Identify problem areas before implementation.
- Explore the effects of modifications.
- Confirm that all variables are known.
- Evaluate ideas and identify inefficiencies.
- Gain insight and stimulate creative thinking.
- Communicate the integrity and feasibility of your plans.

3.8 Simulation work

Simulations were performed with Third Wave Systems AdvantEdge finite element based modeling software known as AdvantEdge FEM, which integrates advanced finite element numerics and material modeling for customize for machining applications.

3.8.1 Simulation using AdvantEdge FEM software

Third Wave systems AdvantEdge is the software leader in providing solutions for optimizing traditional and state-of-the-art machining processes.AdvantEdge suite of software allows aerospace,automotive and cutting tool companies-along with their suppliers- to reduce the cost of machine components and get to market sooner.

Machining simulations provide more information, in a timely manner,and at a lower cost than traditional trial and error testing-leading to better decisions.Whether your cost driver is reducing cycle,improving part quality,improving tool life,improving tool design ,or completely process set up and improvement ,Third wave systems can help you gain the AdvantEdge.

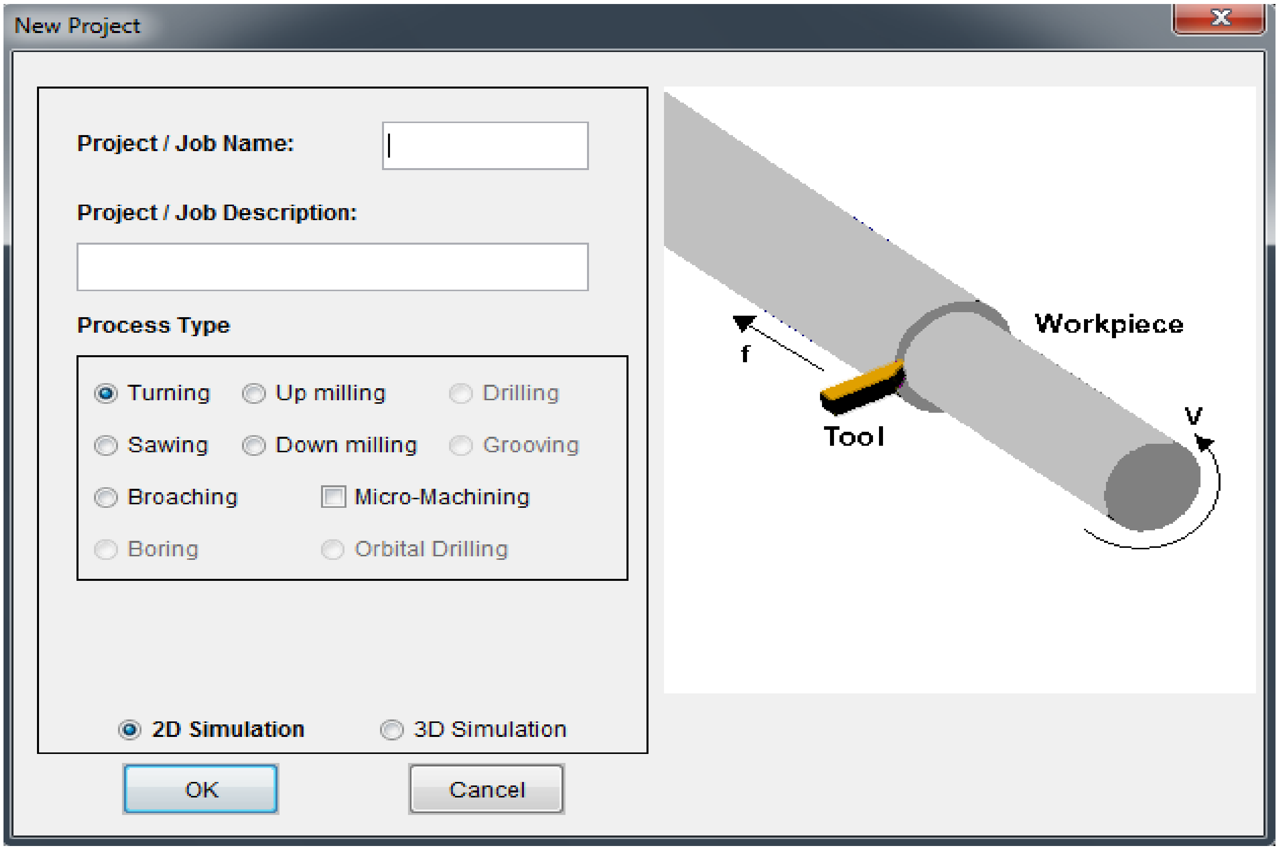
3.8.1(A) Strategy

- Complete basic steps of setting up and submitting a new job.
- Learn to import a custom workpiece and tool.
- Learn how to analyze results using Tecplot

3.8.1(B) Project Setup

- Open AdvantEdge FEM by selecting Start ► Programs ► ThirdWaveSystemsAdvantEdge ► AdvantEdge
- Click Project ► New
- Enter Example for the project name
- Select Turning for project type

- Check 2D Simulation and click OK


New Project

Project / Job Name:

Project / Job Description:

Process Type

● Turning ○ Up milling ○ Drilling
○ Sawing ○ Down milling ○ Grooving
○ Broaching ☐ Micro-Machining
○ Boring ○ Orbital Drilling

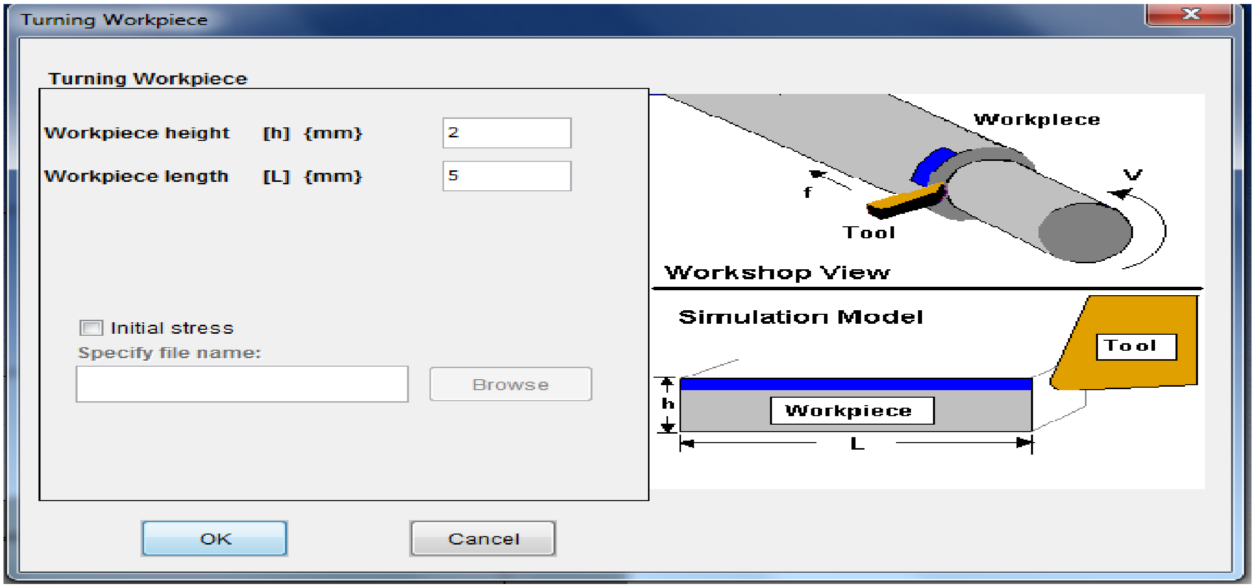
● **2D Simulation** ○ 3D Simulation

Figure 3.9: Project setup

3.8.1(C) Workpiece geometry

- Select Workpiece ► Create/Edit Standard Workpiece
- Enter a workpiece height of 1 and a workpiece length of 3(enter height and length according to the necessary ,here only example is given), and click OK
- Select Workpiece ► Material…
- From the Workpiece Material pulldown menu, select stainless steel
- Select the 304-stainless-steel material, and click OK

Note: the use of the Properties button for additional material information; the material hardness can be modified by selecting the User Define option in this window.

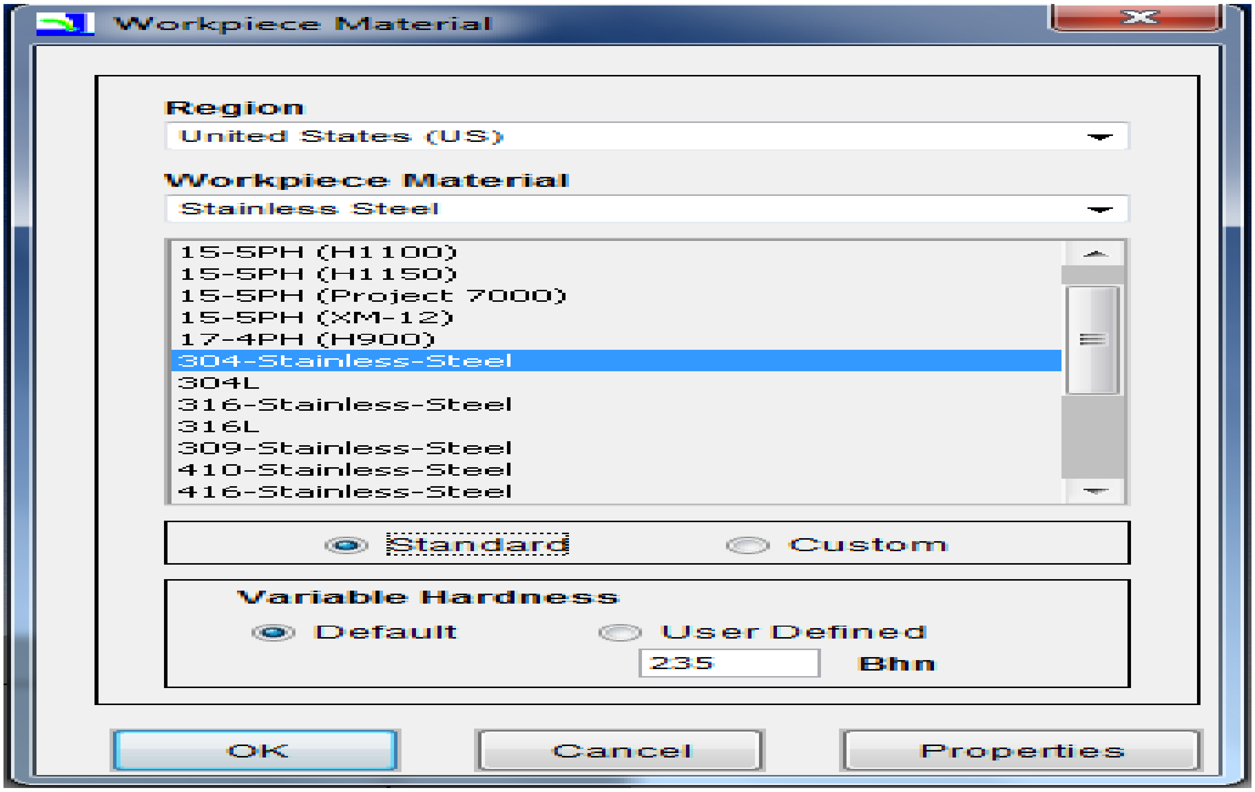

Turning Workpiece

Turning Workpiece

Workpiece height [h] {mm} 2
Workpiece length [L] {mm} 5

☐ Initial stress
Specify file name:

Figure 3.10: Turning worpiece setup


Workpiece Material

Region: United States (US)
Workpiece Material: Stainless Steel

15-5PH (H1100)
15-5PH (H1150)
15-5PH (Project 7000)
15-5PH (XM-12)
17-4PH (H900)
304-Stainless-Steel
304L
316-Stainless-Steel
316L
309-Stainless-Steel
410-Stainless-Steel
416-Stainless-Steel

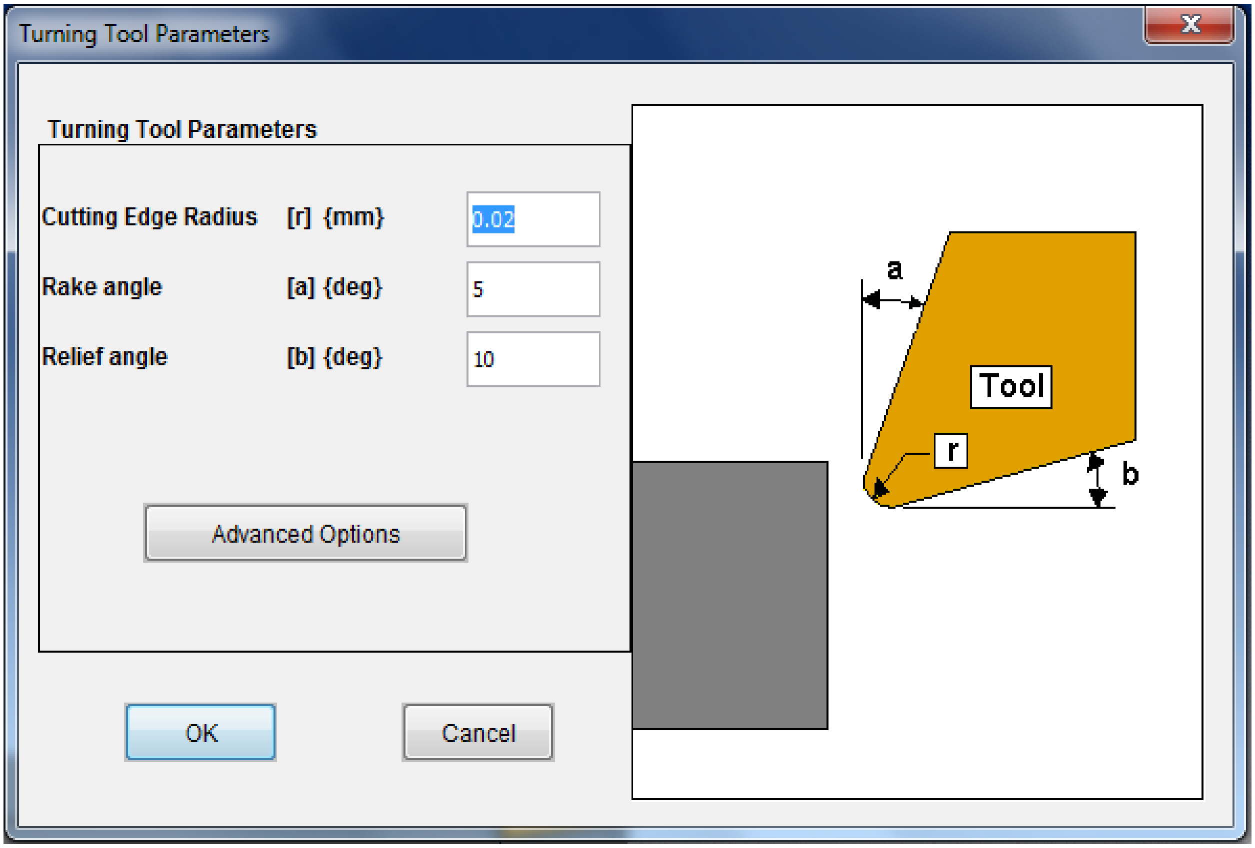
● Standard ○ Custom

Variable Hardness
● Default ○ User Defined
235 Bhn

Figure 3.11: Workpiece material selection

3.8.1(D) Tool geometry

- ❖ Click Tool ► Import Tool ► Tools…
- ❖ Select turning tool parameters and click OK
- ❖ Select Tool ► ToolMaterial…
- ❖ Select the Carbide–Grade-K material, and click OK


Turning Tool Parameters

Turning Tool Parameters

Cutting Edge Radius [r] {mm}: 0.02

Rake angle [a] {deg}: 5

Relief angle [b] {deg}: 10

Figure 3.12: Turning tool parameters setup

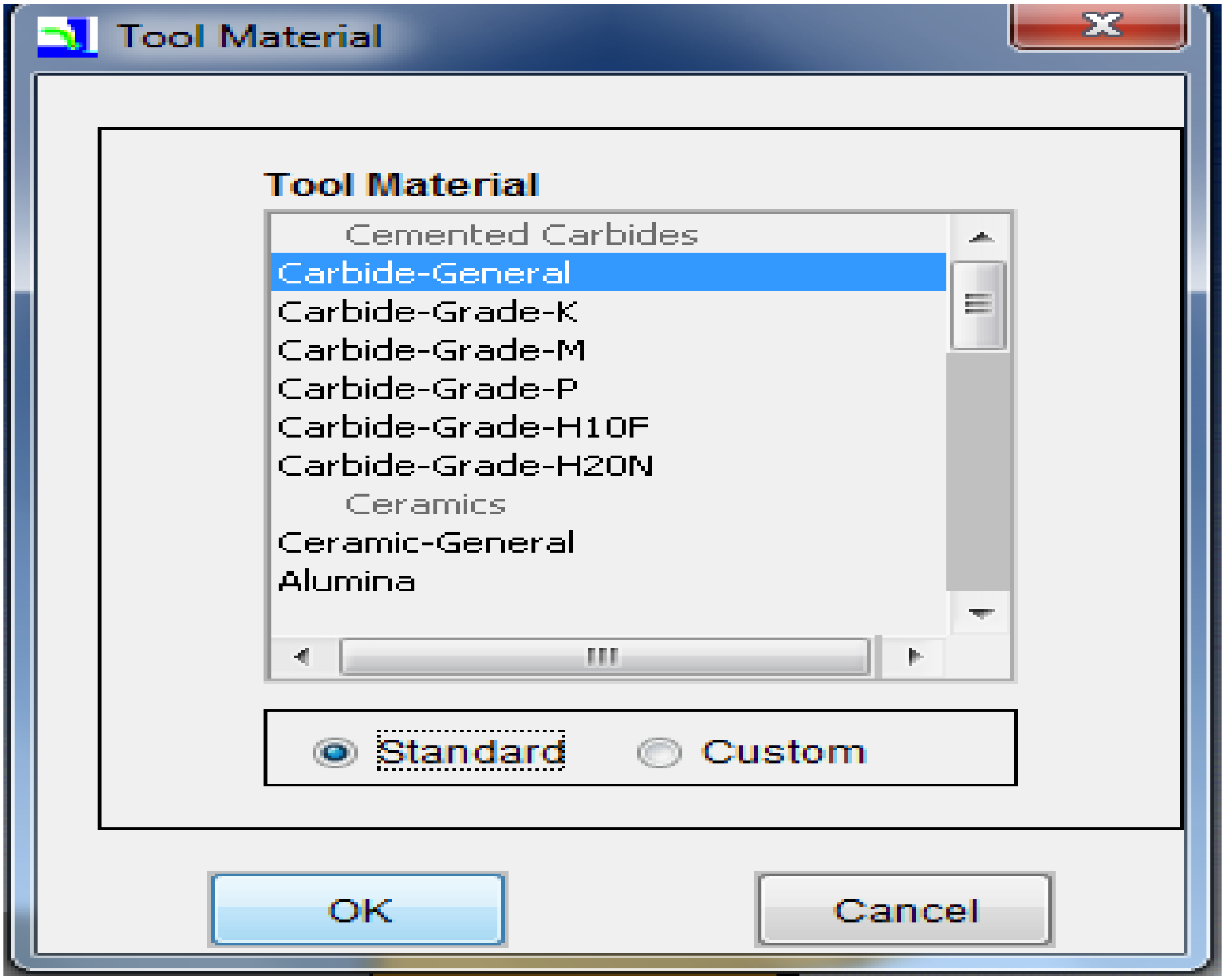
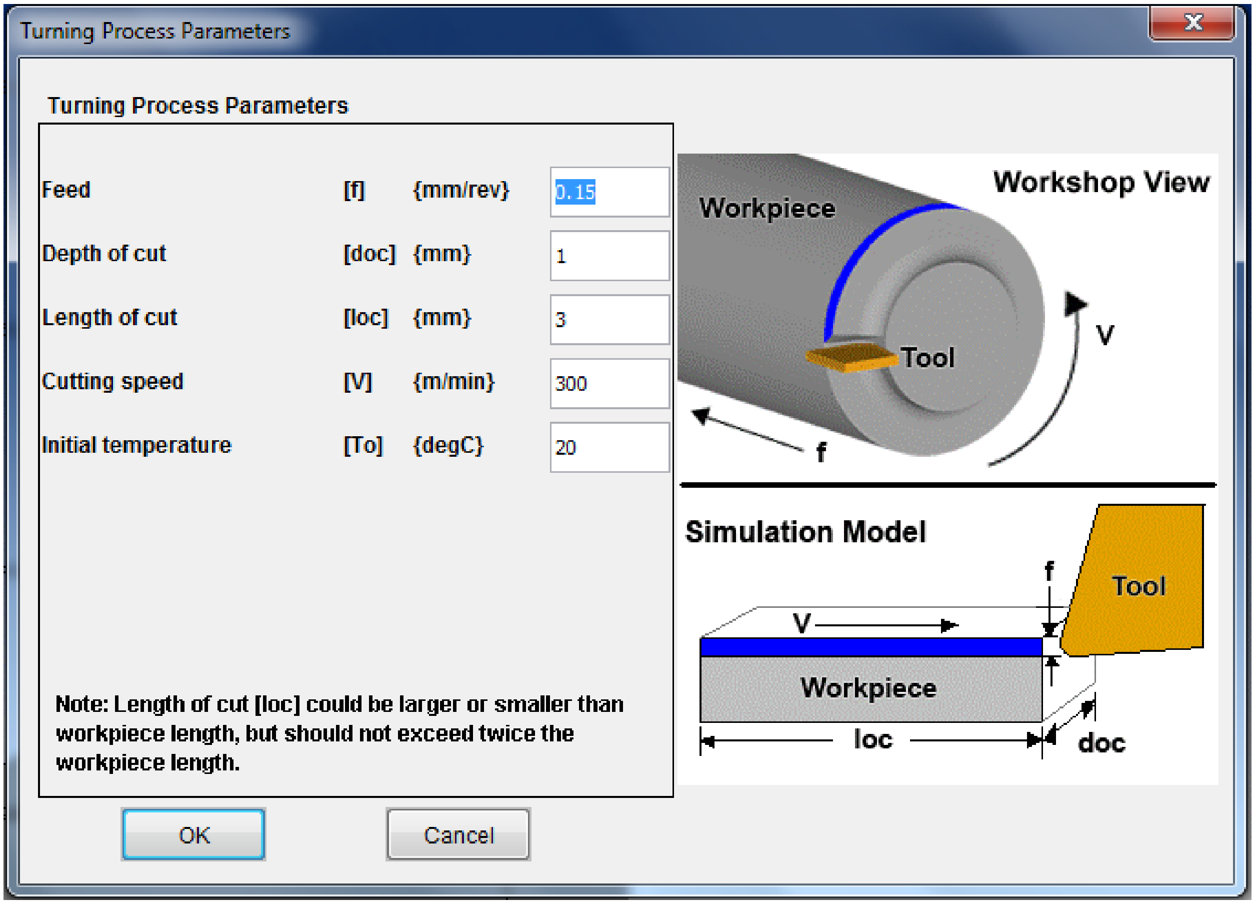


Figure 3.13: Tool material selection

3.8.1(E) Process Parameters

- Select Process ► Process Parameters...
- Within the Turning Process Parameters window, enter the process parameters shown below, and then click OK



Turning Process Parameters

Feed	[f]	{mm/rev}	0.15
Depth of cut	[doc]	{mm}	1
Length of cut	[loc]	{mm}	3
Cutting speed	[V]	{m/min}	300
Initial temperature	[To]	{degC}	20

Note: Length of cut [loc] could be larger or smaller than workpiece length, but should not exceed twice the workpiece length.

Figure 3.14: Turning process parameters setup

3.8.1(F) Simulation Output Customization

- Select Simulation ► Simulation Options and access the General Tab
- Select Rapid for the simulation mode

Note: Rapid mode is being used in this example to find a fast result for demonstration purposes. Generally, standard mode is recommended as it utilizes a more refined mesh to provide more reliable and accurate results.

3.8.1(G) Submitting the Project

- ❖ Select Project ▶ Save As
- ❖ Name the project example.twp, and click Save
- ❖ Select Simulation ▶ Submit ▶ Submit Current Job, and then click OK

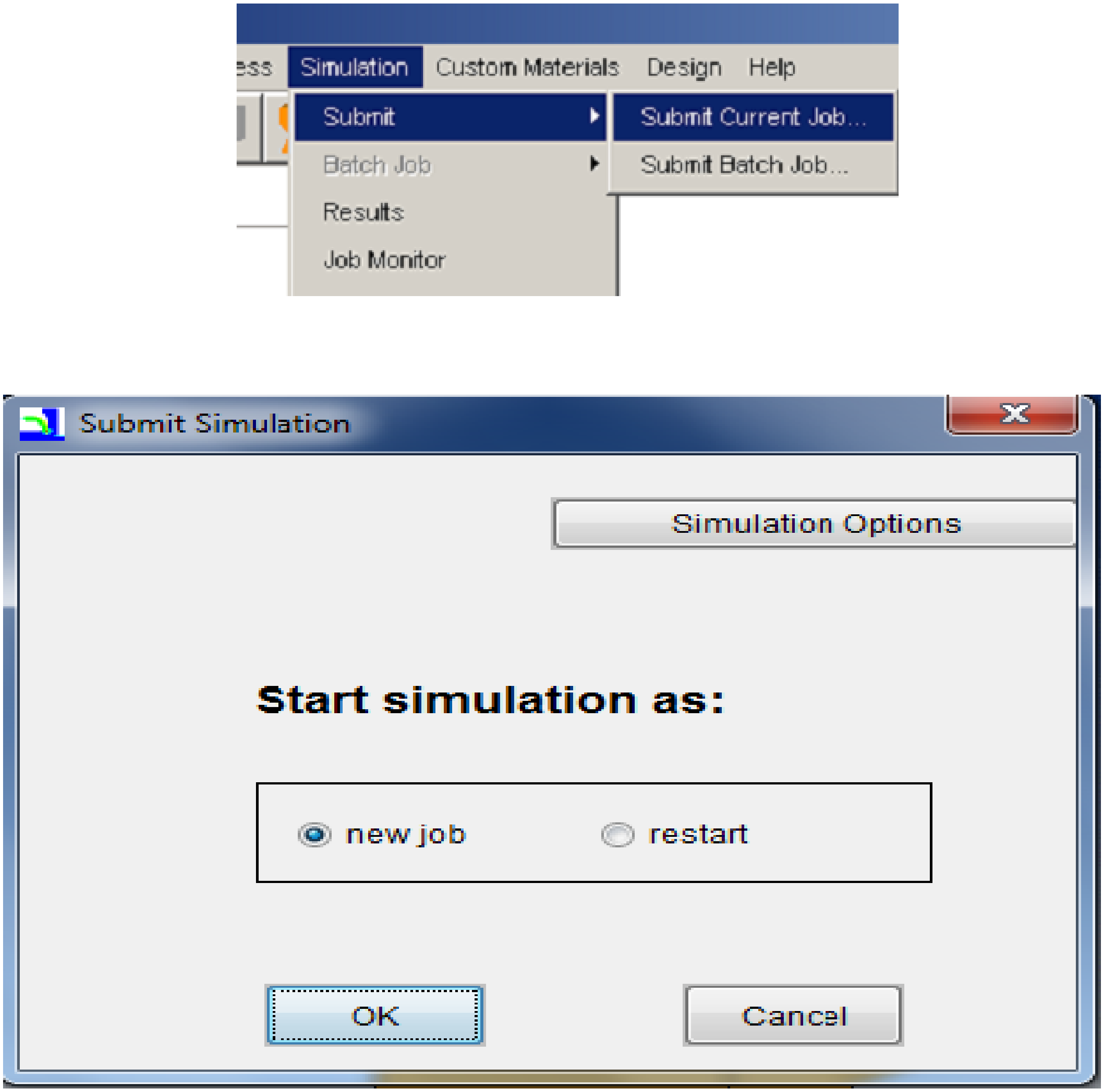
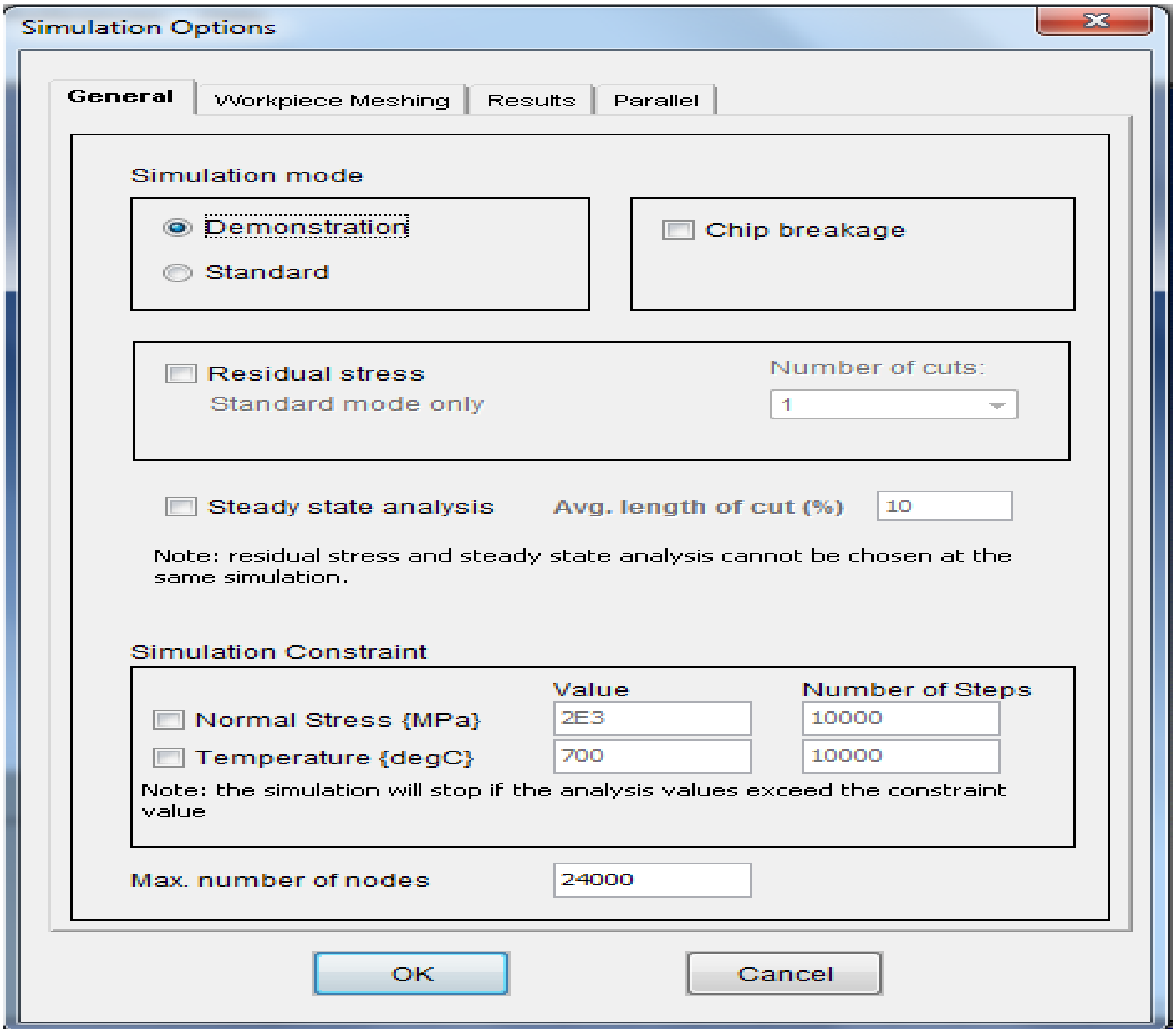


Figure 3.15: Submission of the project in the software



Simulation mode

● Demonstration

○ Standard

☐ Chip breakage

☐ Residual stress
Standard mode only

Number of cuts: 1

☐ Steady state analysis Avg. length of cut (%) 10

Note: residual stress and steady state analysis cannot be chosen at the same simulation.

Simulation Constraint

	Value	Number of Steps
☐ Normal Stress {MPa}	2E3	10000
☐ Temperature {degC}	700	10000

Note: the simulation will stop if the analysis values exceed the constraint value

Max. number of nodes 24000

Figure 3.16: Submission of the project in the software in detail view

3.8.1(H) Viewing the Results

- Select Simulation ► Results
- Tecplot will now open and you will be able to view the results of the simulation thus far.

Note: In order to see the most recent results, Tecplot must be closed and then re-opened. This will update the results to the point at which the simulation has currently run.

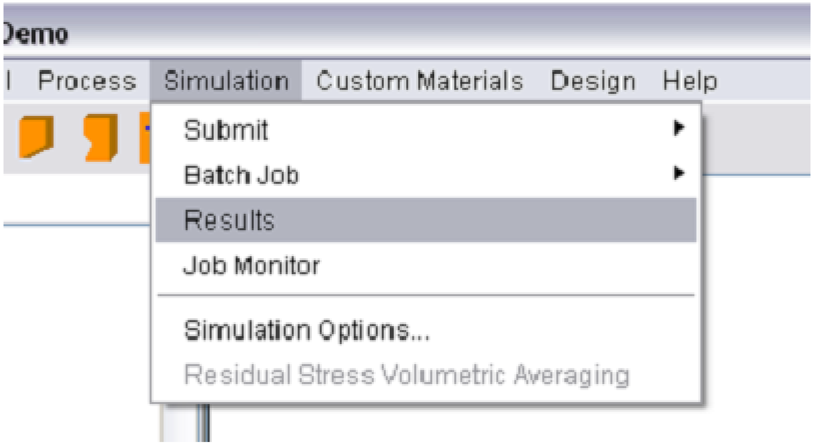


Figure 3.17: Viewing the result in the software

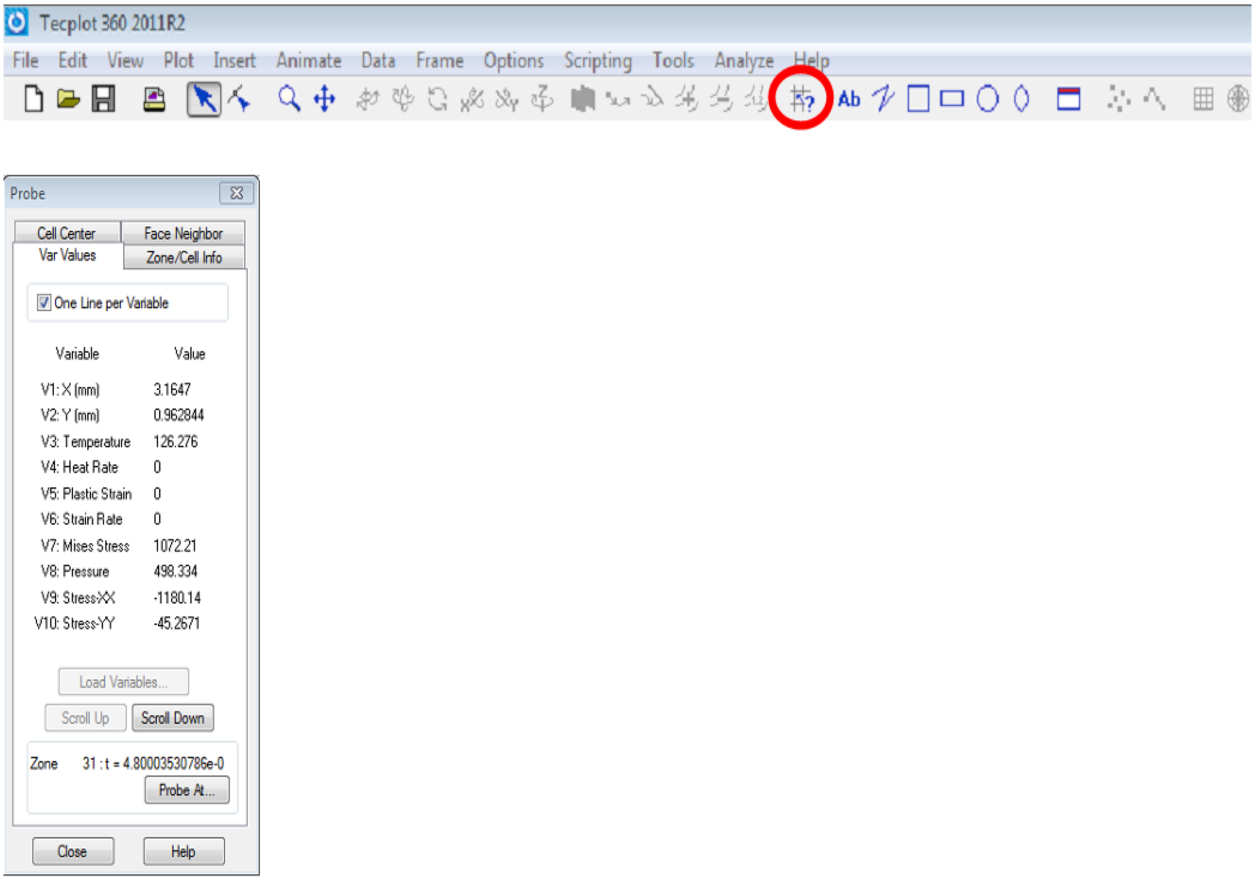
3.8.1(I) Using Tecplot

Zooming and Panning

- Click and hold the middle mouse button and zoom in and out by moving the mouse up and down.
- Pan around the results by clicking and dragging with the right mouse button.

Probing for Data

- Click the Tool to Probe Data button from the group of icons on the left side of Tecplot.
- Using the Probe tool, click on the simulation results to see information about that specific point.



☑ One Line per Variable

Variable	Value
V1: X (mm)	3.1647
V2: Y (mm)	0.962844
V3: Temperature	126.276
V4: Heat Rate	0
V5: Plastic Strain	0
V6: Strain Rate	0
V7: Mises Stress	1072.21
V8: Pressure	498.334
V9: Stress-XX	-1180.14
V10: Stress-YY	-45.2671

Zone 31 : t = 4.80003530786e-0

Figure 3.18: Use of Tecplot in the software

Quick Analysis Dialog

- Select Tools ► AdvantEdge Quick Analysis
- Explore the different functions available in each of the different tabs. Contour relates to the top half of the results, and Time History relates to the bottom half.

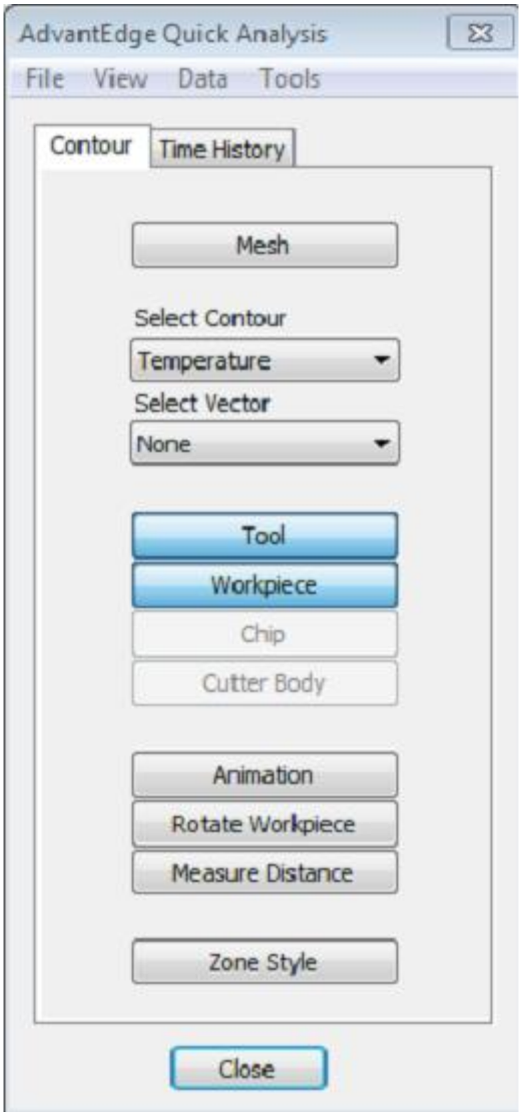
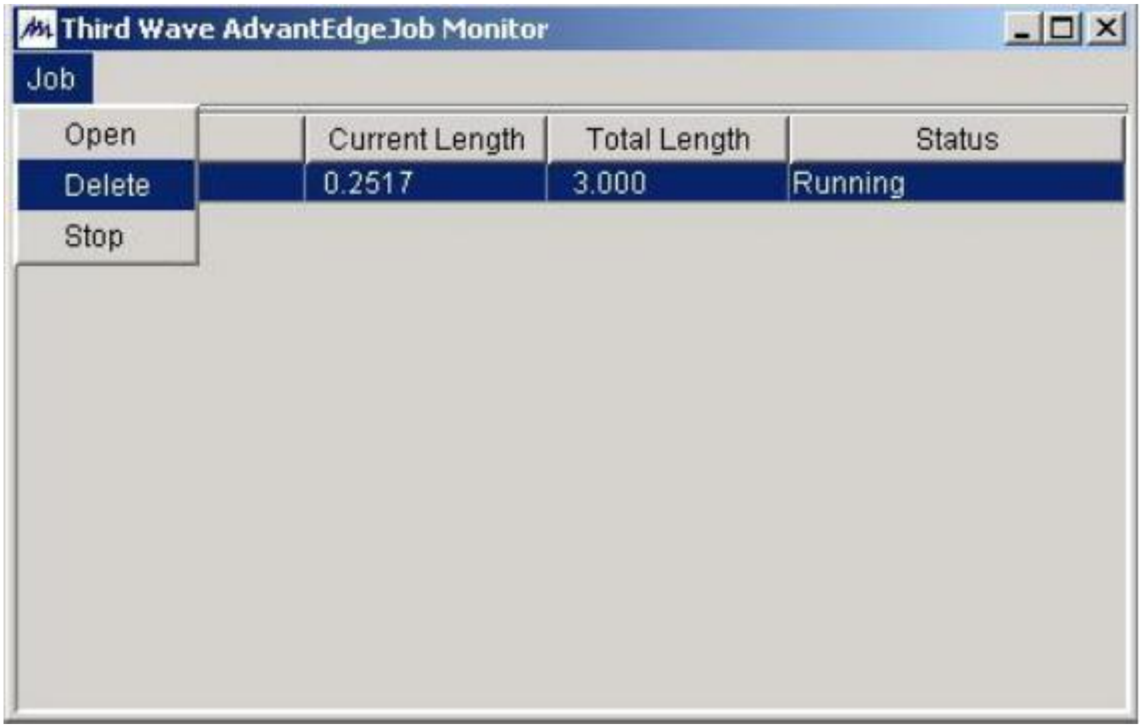


Figure 3.19: Quick Analysis Dialog

3.8.1(J) Deleting the Project

Before moving on, it is necessary to stop the job that is currently running (if it has not finished yet).

- Select Job ► Delete. The analysis will be stopped and removed from the AdvantEdge Job Monitor list.



	Current Length	Total Length	Status
	0.2517	3.000	Running

Figure 3.20: Deleting the Project

3.9 Conclusion

AdvantEdge FEM use to decrease the need for trial and error testing.The structure of the AdvantEdge FEMcan be obtained with the help of pre-processor module, simulation module and postprocessor module, Table 1. The pre-processor module isdeparture support. It contains data input for the models and also the simulation controls. The simulation module is the module where the actual simulation takes place. Once the necessary data for the modelling and simulation have been entered, the solver makes calculations using the finite element method. These computations are hidden from user. After the calculations are made, in the postprocessor module, the results are processed and displayed in various forms, such as graphs and images. Among the results obtained, we can enumerate: chip formation, chip and tool temperature, stresses, strains, cutting forces, tool wear, damage etc.Actually AdvantEdge FEM contains:

- An extensive standard tools library, but also gives user the possibility of creating, within the program, new tool geometries and also importing them from CAD files;
- An extensive material library, but also gives to the user the possibility of introducing new materials, based on known material properties.

Chapter 4

RESULT:

4.1 Introduction

Simulations were performed with Third Wave Systems AdvantEdge finite element based modeling software, which integrates advanced finite element numerics and material modeling for customize for machining applications. And the experimental work of our study has been done in the machine lab of Islamic University of Technology. The main aim of our study is to Study and determine the influence of process parameters (feed rate, cutting speed, rake angle, depth of cut and length of cut) upon cutting force, temperature and chip breakage. And Compare between simulation and experimental results to indicate the results are consistent or inconsistent.

4.2 Experimental design

We have done five experiments to study the effect of cutting speed and feed rate on the cutting forces and chip breakage in turning process. Actually we do simulation work with the help of AdvantEdge FEM software and experimental work in the machine lab with the help of turning machine. The experimental design of our study is given bellow with the help of a table.

Table 4.1: **Experimental design**

Experiment No	Parameter Values			
	Cutting Speed (m/min)	Rake Angle (^{0})	DOC (mm)	Feed (mm/rev)
01	23	-5	2	0.15
02	47	-5	2	0.15
03	70	-5	2	0.15
04	40	-5	1	0.20
05	68	-5	1	0.20

4.3 AdvantEdge and Experiment result

AdvantEdge FEM uses the continuous remeshing in order to separate the chip. During metal, cutting the workpiece material flows around the cutting edge of the tool and the remeshing takes place whenever the elements from the cutting edge area change their initial shape. Due to automatic remeshing, these programs allow also the modelling and simulation of complex geometry workpieces. we get the simulation result with the help of AdvantEdge FEM software. And the experimental result from the machine lab by doing work by with the help of turning machine.

4.3.1 Simulation Result

Before starting the simulation, the user must know that in AdvantEdge FEM 2D the material behaviour law can be also introduced. The Johnson-Cook material behaviour model is widely used in finite element modelling but in this case it cannot predict the phenomena responsible for the appearance of the segmented chips, also known as saw-tooth chips. Calamaz et al.developed a new material law which considers the strain rate, the temperature and also the strain softening effect when analyzing the chip formation and shear localization during machining.

The simulation result that we have got from the AdvantEdge FEM software directly for different experiments are given bellow with the help figure.

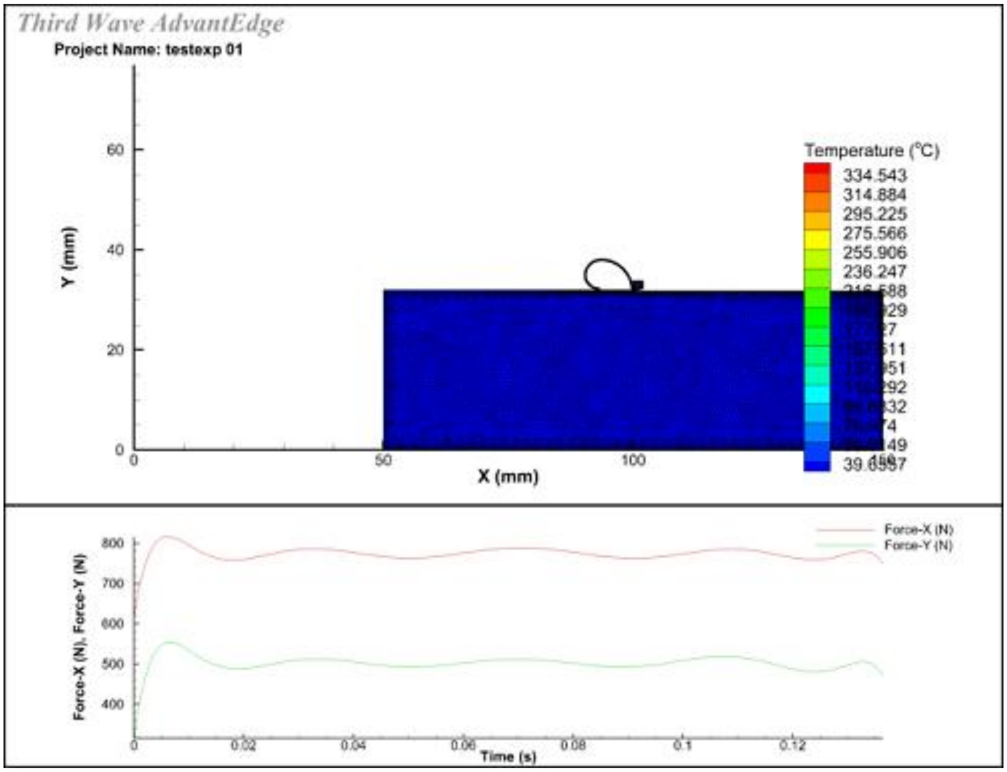


Figure4.1:Result of simulation for experiment 01 using AdvantEdge FEM software

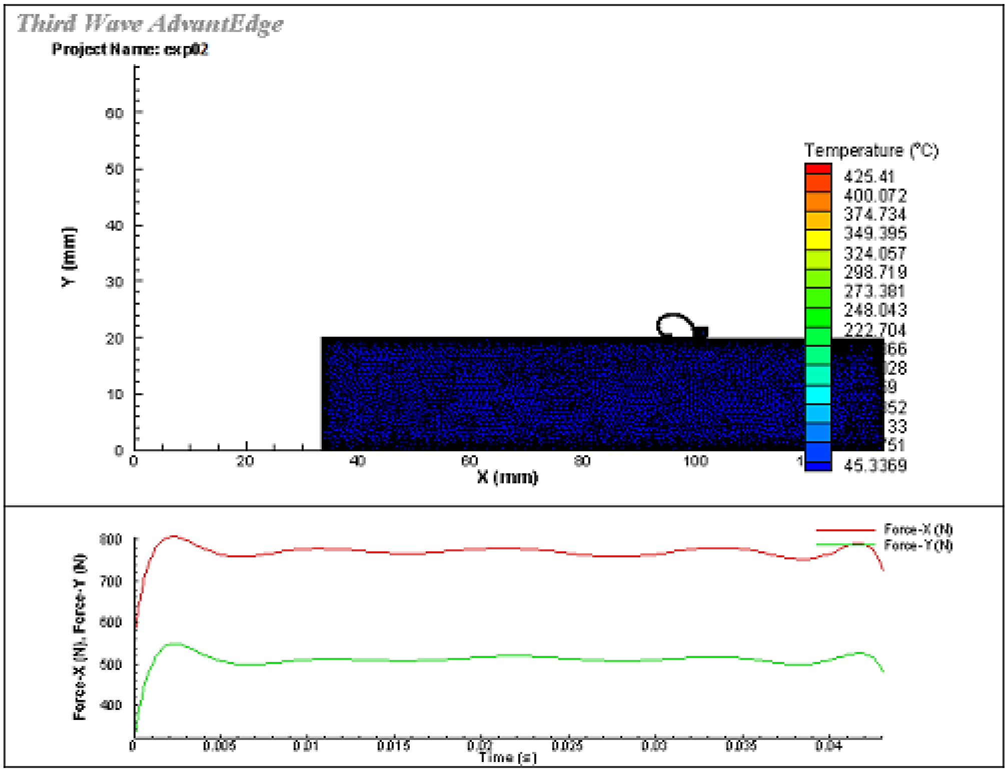


Figure4.2:Result of simulation for experiment 02 using AdvantEdge FEM software

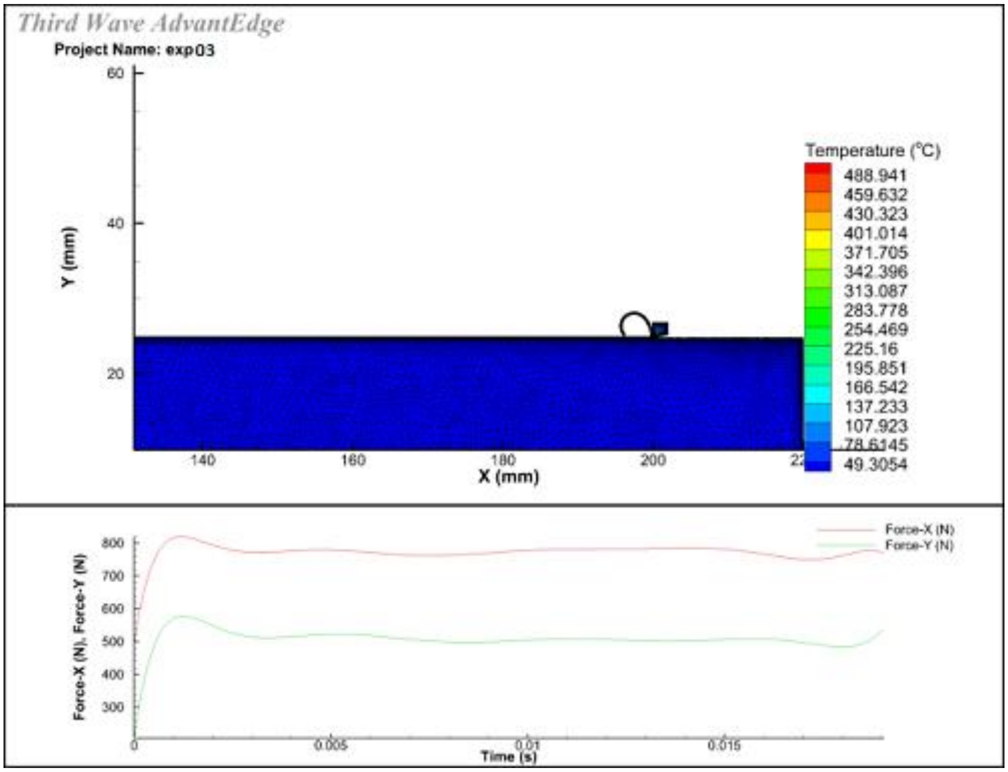


Figure4.3:Result of simulation for experiment 03 using AdvantEdge FEM software

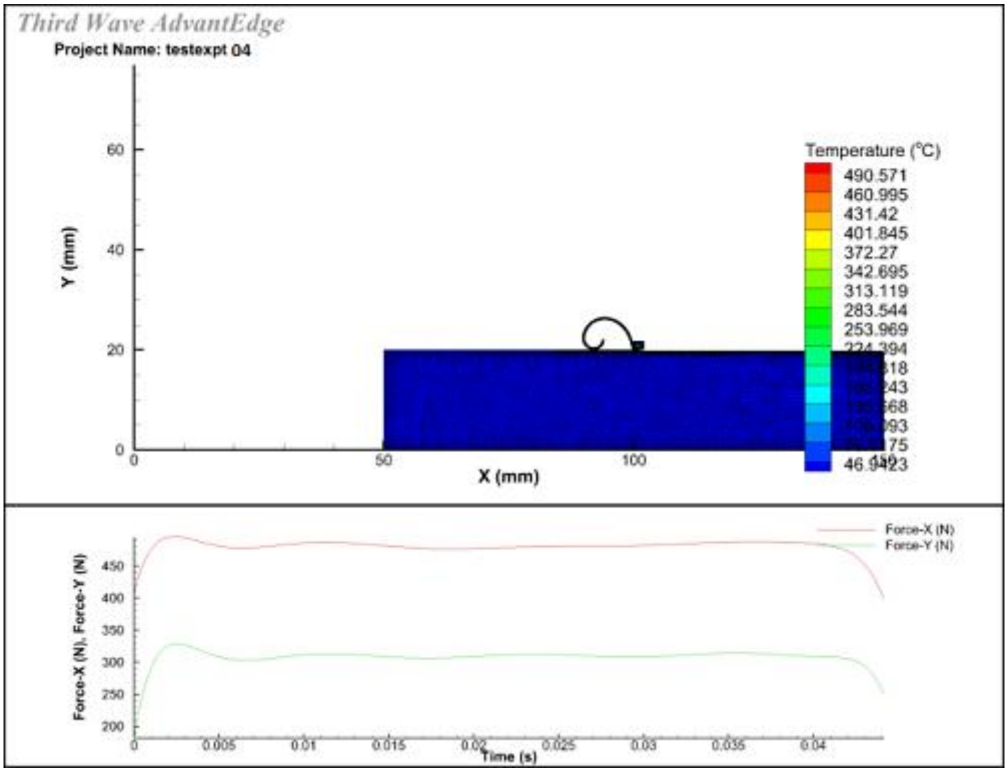


Figure4.4:Result of simulation for experiment 04 using AdvantEdge FEM software

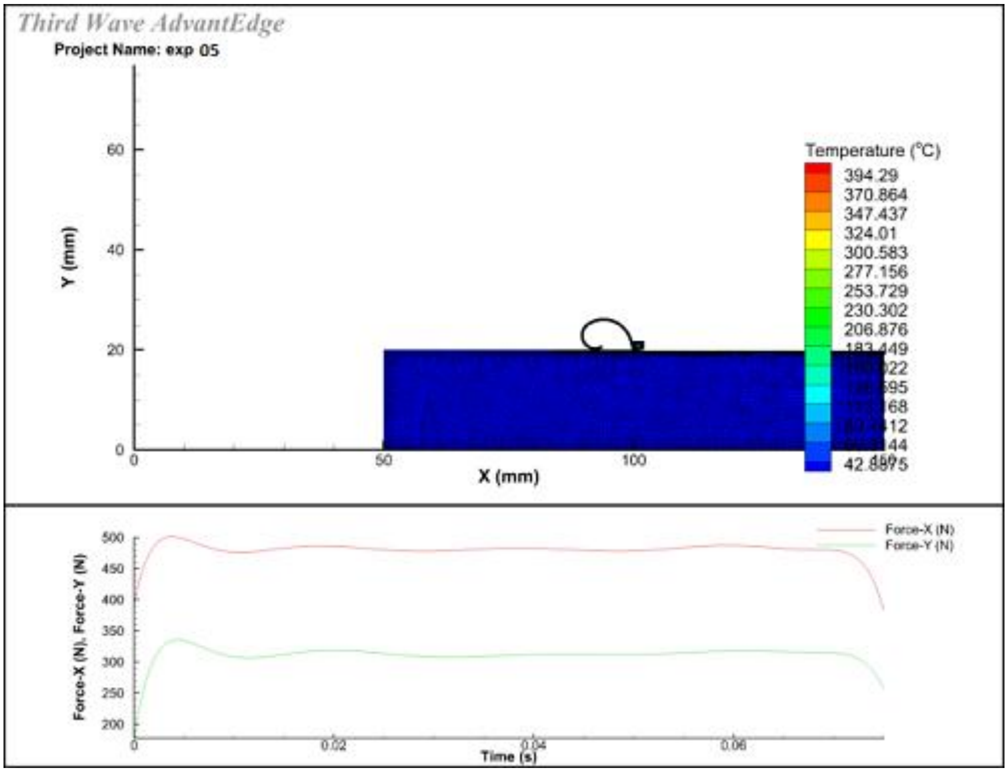


Figure4.5:Result of simulation for experiment 05 using AdvantEdge FEM software

4.3.2 Result Analysis of Cutting Force and Temperature with respect to Time

For Experiment 01, 02, 03 (where cutting speed is 23, 47, 70m/min respectively and feed rate is same for this three experiments which is 0.15mm). Actually for experiment 03 we take the highest cutting speed as 70m/min. And for this reason experiment 03 takes short time to complete the simulation than the experiment 01 & 02. The following figure shows the effect of cutting speed.

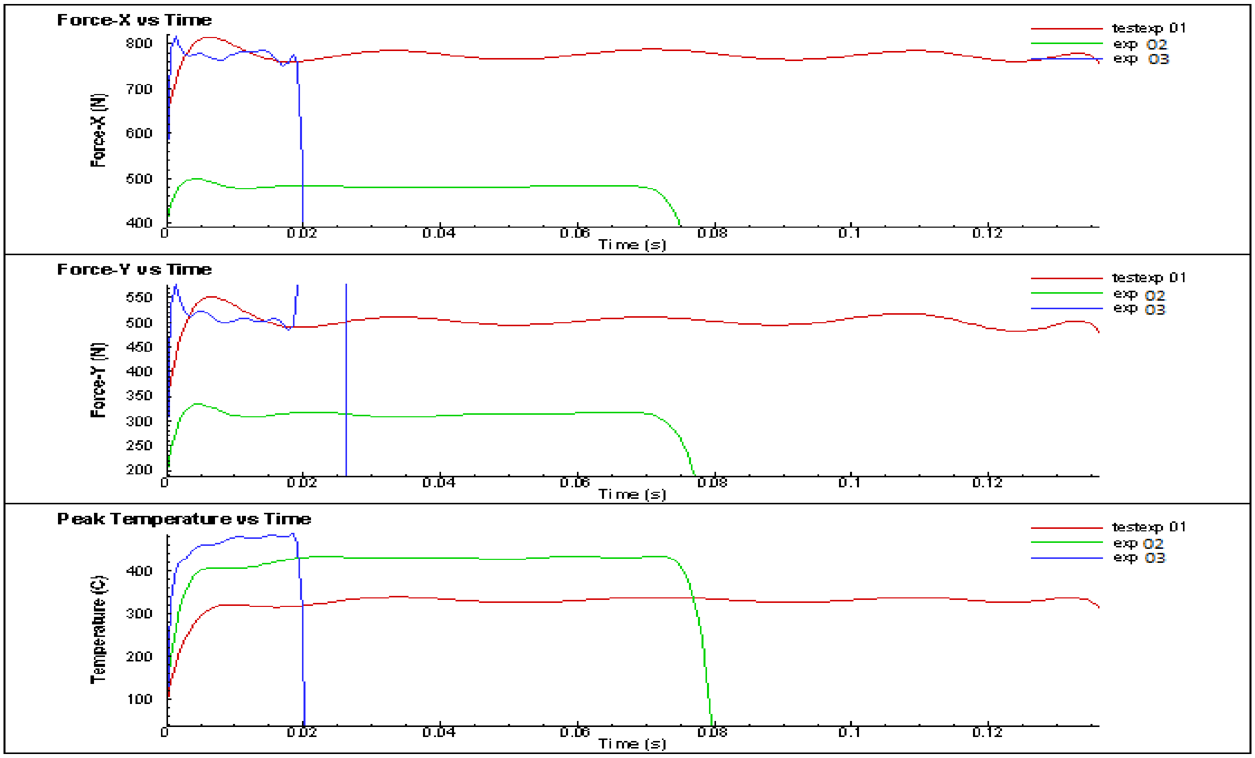


Figure4.6: Result Analysis of Cutting Force and Temperature with respect to Time using AdvantEdge FEM software for experiment 01, 02 & 03

Again for Experiment 04, 05 (where cutting speed is 40,68m/min respectively and feed rate is same for this two experiments which is 0.20mm). Actually for experiment 05 we take the highest cutting speed as 68m/min. And for this reason experiment 05 takes short time to complete the simulation than the experiment 04. The following figure shows the effect of cutting speed.

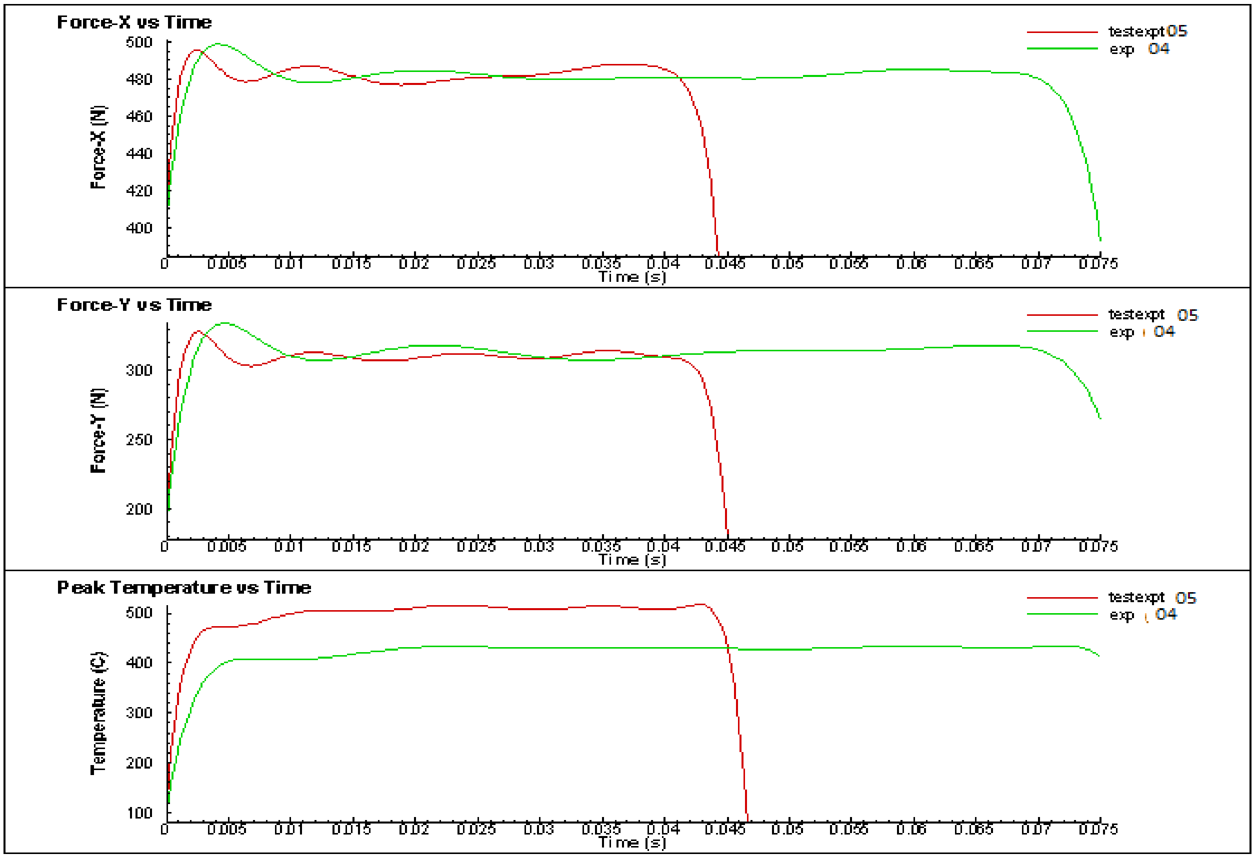


Figure4.7: Result Analysis of Cutting Force and Temperature with respect to Time using AdvantEdge FEM software for experiment 04 & 05

4.3.3 Measurement of Chip Thickness from Simulation

Actually from the AdvantEdge FEM software we can measure the thickness of the chip by using measurement bar of the software. The following figure shows the way how we measure the thickness of the chip using AdvantEdge FEM software.

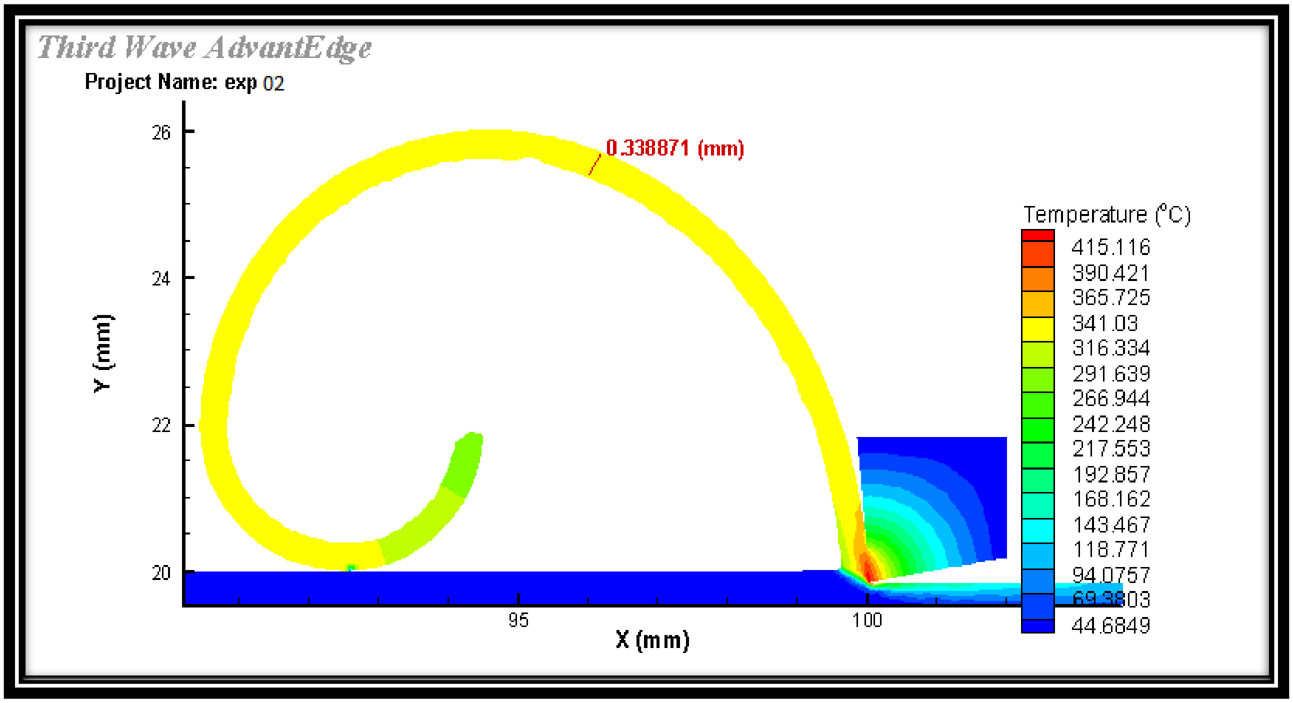


Figure4.8: Measurement of Chip Thickness from Simulation using AdvantEdge FEM software for experiment 02 (where cutting speed is 47m/min and feed rate is 0.15mm)

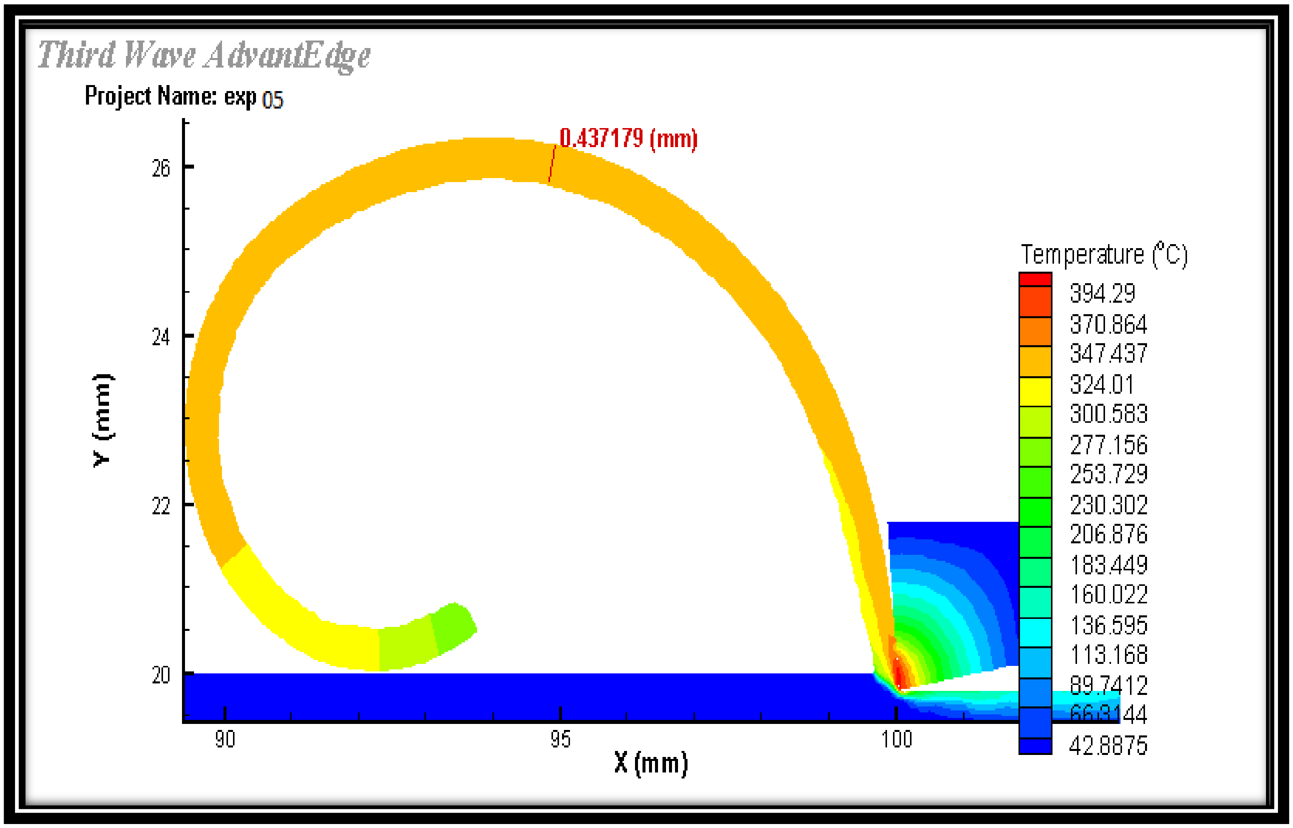


Figure4.9: Measurement of Chip Thickness from Simulation using AdvantEdge FEM software for experiment 05 (where cutting speed is 68m/min and feed rate is 0.20mm)

The above figure shows the example of the measurement of the thickness of the chip using AdvantEdge FEM software. We have done the same thing that is shown in the above figure to measure the thickness of the chip for experiment 01, 03 & 04. The results we get from the simulation are:

- For Experiment no 01, thickness of the chip is 0.34mm
- For Experiment no 02, thickness of the chip is 0.34mm
- For Experiment no 03, thickness of the chip is 0.35mm
- For Experiment no 04, thickness of the chip is 0.45mm
- For Experiment no 05, thickness of the chip is 0.44mm

4.3.4 Measurement of Chip Thickness from Experiment

Kobayashi et.al.(1960) observed continuous chip morphologies for the conditions investigated. We measure thickness of the chip with the help of slide caliper in the machine lab.The figures of chip that we found from the experiment are given bellow:

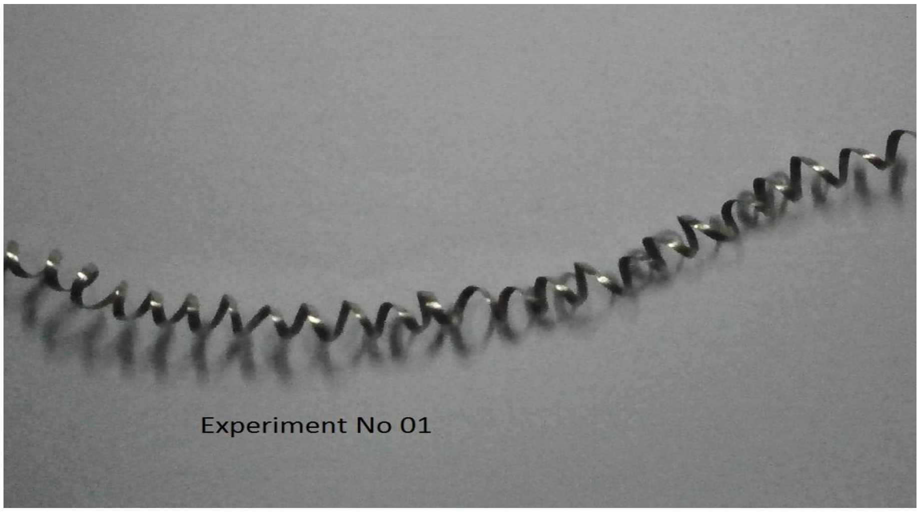


Figure4.10: Chip that we found from the experiment 01

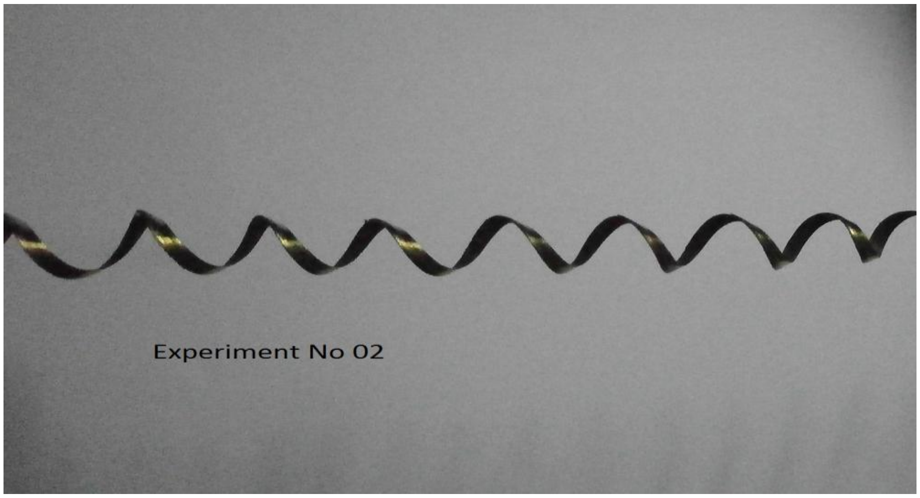


Figure4.11: Chip that we found from the experiment 02

Figure4.12: Chip that we found from the experiment 03

Figure4.13: Chip that we found from the experiment 04

Figure4.14: Chip that we found from the experiment 05

Now the results we get from the experiment are:

- For Experiment no 01, thickness of the chip is 0.30mm
- For Experiment no 02, thickness of the chip is 0.35mm
- For Experiment no 03, thickness of the chip is 0.28mm
- For Experiment no 04, thickness of the chip is 0.55mm
- For Experiment no 05, thickness of the chip is 0.45mm

4.3.5 Chip thickness comparison

Chip thickness provides an estimation of friction conditions. The simulated and experimented chip thicknesses are compared for 304-stainless-steel in Fig.4.11.

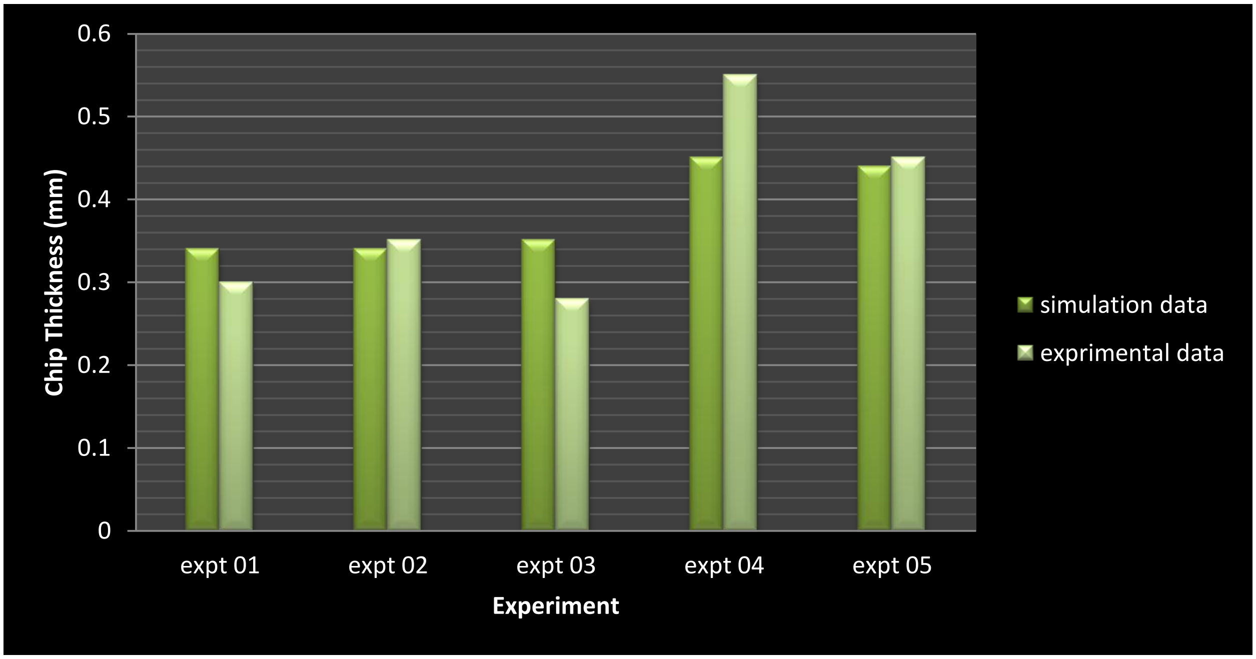


Figure4.15: Chip thickness comparison

As we see, there is a small difference between the simulation and experimental result of chip thickness. The reasons behind this variation are as follows:

- Machine used for the experiment was not up to date.
- Errors may be occurred when process parameter was set up manually.
- Thickness of the chips being very small, errors may be occurred in measurement of thickness with slide calipers.

Chapter 5

DISCUSSION AND CONCLUSION:

5.1 Introduction

In this paper, an attempt has been made to study the effect of cutting speed and feed rate on the cutting forces and chip breakage in turning process. Metal cutting modeling provides an alternative way for better understanding of machining processes under different cutting conditions. Using the capabilities of finite element models, it has recently become possible to deal with complicated conditions in metal cutting. Finite element modeling makes it possible to model several factors that are present during the chip formation .As simulation tool for the purpose of this study; the FEM software used is AdvantEdge FEM.Actually this paper presents the advantage of using software for simulation of cutting process and study of stainless steel turning. To complete our research wok we use 2D Finite Element Model (F.E.M.) of chip formation process, proposed in the software named AdvantEdge FEM with an experimental set up in the laboratory.

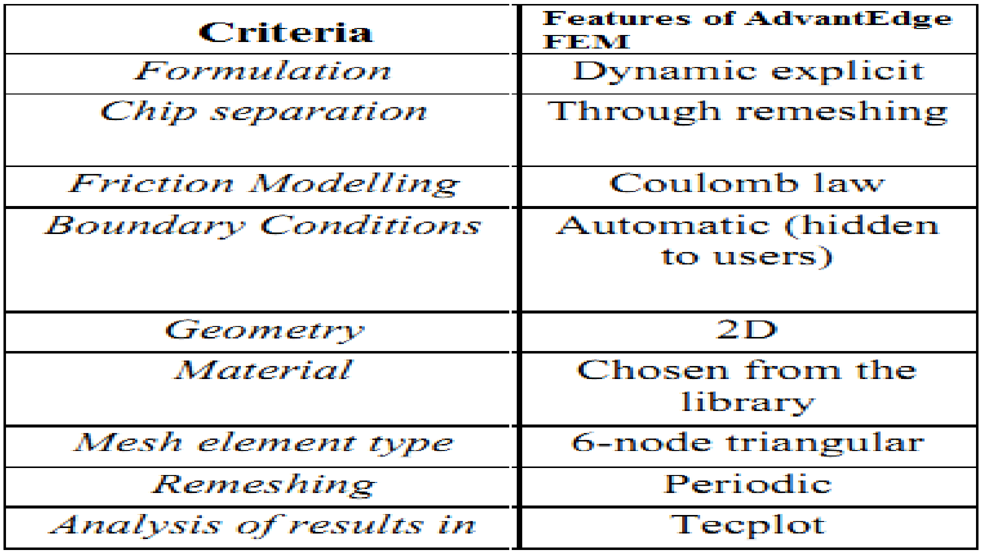
5.1 Discussion

Based on the review, the following things have been observed:

- Increased cutting speeds (VC) resulted in decreased cutting tool forces and machined surface temperatures.
- Tool wear resulted in increased cutting tool forces and machined surface temperature.
- Force has been found to be an important variable in the generation of surface temperature.

- Thus, it is possible to increase machine utilization and decrease production cost in an automated Manufacturing environment.
- Increasing the rake angle in positive section caused the decrease of the cutting force. On the other hand, increasing the rake angle in negative section increases the cutting force.
- The AdvantEdge FEM software used for this study has some features. They are given bellow with the help of a table:

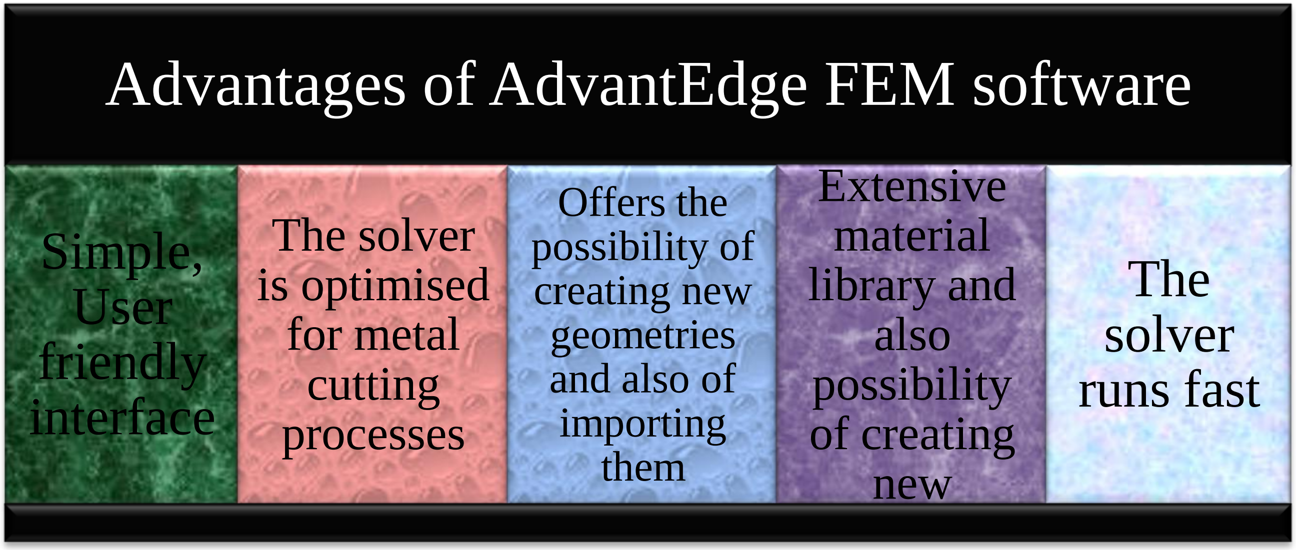
Table5.1: Features of AdvantEdge FEM software



Criteria	**Features of AdvantEdge FEM**
Formulation	Dynamic explicit
Chip separation	Through remeshing
Friction Modelling	Coulomb law
Boundary Conditions	Automatic (hidden to users)
Geometry	2D
Material	Chosen from the library
Mesh element type	6-node triangular
Remeshing	Periodic
Analysis of results in	Tecplot

- The AdvantEdge FEM software has some advantages. They are given bellow with the help of a table:

Table5.2: Advantages of AdvantEdge FEM software



Advantages of AdvantEdge FEM software

- Simple, User friendly interface
- The solver is optimised for metal cutting processes
- Offers the possibility of creating new geometries and also of importing them
- Extensive material library and also possibility of creating new
- The solver runs fast

5.3 Conclusion:

A finite element model was utilized to study the effect of cutting speed and feed rate on the cutting forces and chip breakage in turning process in 304-stainless steel. The AdvantEdge FEM software used for this study because, AdvantEdge FEM decrease the need for trial and error testing. The simulation results on cutting forces and chip thicknesses are compared with experimental data in order to indicate the consistency and accuracy of the results when conducting the comparison. The experimental validation showed a good qualitative agreement. Thus, FEM of cutting process can be considered as a promising and reliable tool for machining development within the near future.

5.4 Future Scope

Turning Process is a important machining process in which a single-point cutting tool and cutting inserts removes material from the surface of a rotating cylindrical work piece, so by the finite element analysis on turning process helps to determine problems were occur in tool and workpiece like plastic deformation, mechanical breakage, cutting edge blunting, brittle fracture and tool wear can reduce and by the considering optimized parameter. We can find minimum surface roughness and high surface finish. Also we can increases tool life.

LIST OF TABLES

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