ANALYSIS OF TOOL WEAR IN TURNING OPERATION OF EN38 STEEL

A
Thesis Report

submitted in partial fulfilment of the requirement for the award of degree of

MASTER OF ENGINEERING
IN
CAD/CAM & ROBOTICS

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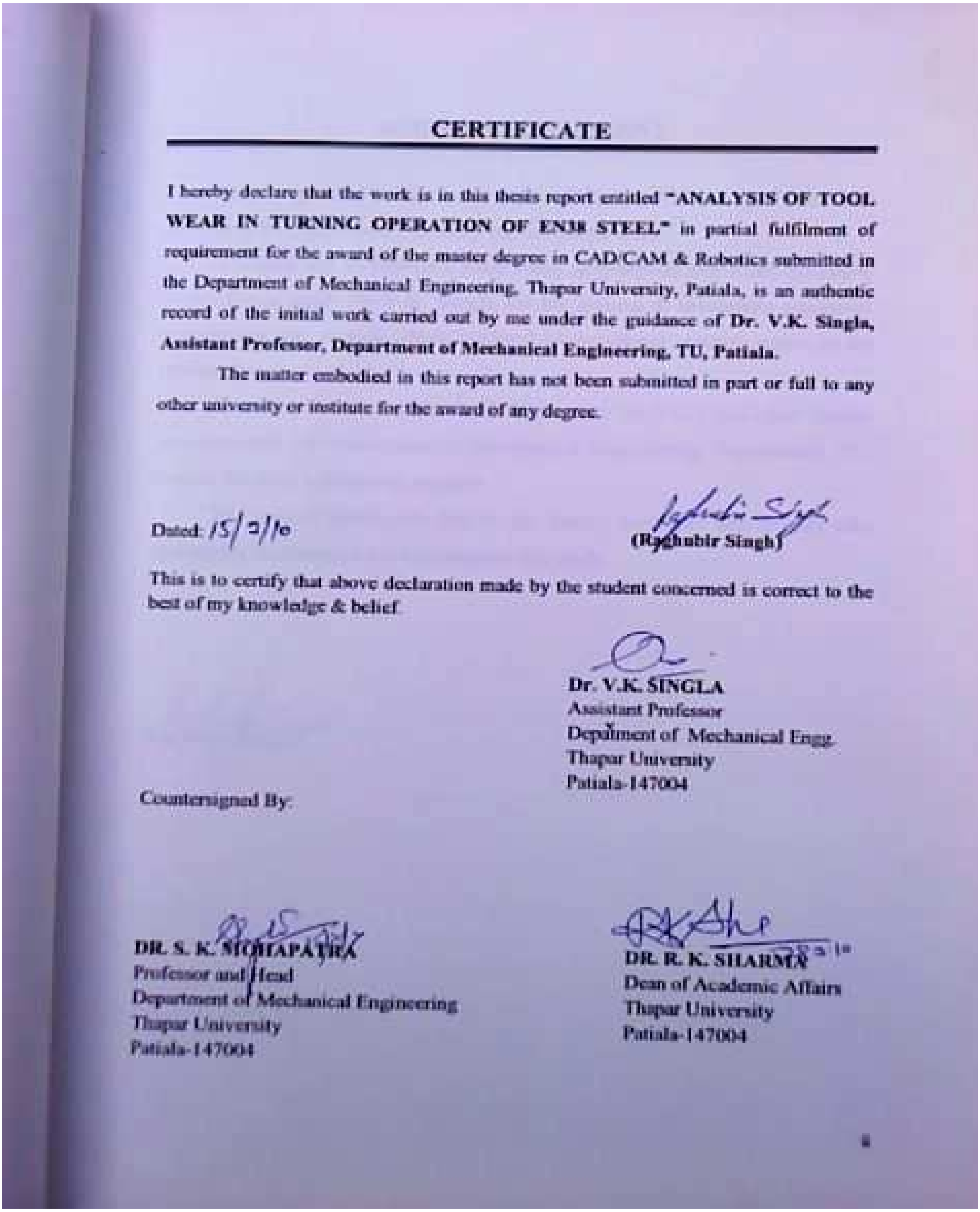

CERTIFICATE

I hereby declare that the work is in this thesis report entitled **"ANALYSIS OF TOOL WEAR IN TURNING OPERATION OF EN38 STEEL"** in partial fulfilment of requirement for the award of the master degree in CAD/CAM & Robotics submitted in the Department of Mechanical Engineering, Thapar University, Patiala, is an authentic record of the initial work carried out by me under the guidance of **Dr. V.K. Singla, Assistant Professor, Department of Mechanical Engineering, TU, Patiala.**

The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Dated: 15/3/10

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This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

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ABSTRACT

The objective of this thesis work is to analyze the tool wear of the single point cutting tool used in the turning operation of EN38 steel. The single point cutting tool is used for machining cylindrical shape specimen of EN38 steel. A number of tests are performed with different cutting speed and feed rates. Cutting forces and tool wear is measured from these experiments. This data helped in analyzing the cutting process.

The carbide tool is used for the experimental work. Total sixteen experiments are carried out and the results are plotted in the form of graphs. These graphs show the variation of cutting forces and flank wear w.r.t. cutting speed and the various conclusions are drawn from these graphs. SEM tests are conducted to observe the tool wear surface of the carbide tool.

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CHAPTER 1
INTRODUCTION

1.1 LATHE TURNING The machine tool that performs turning operations in which unwanted material is removed from a work piece rotated against a cutting tool. The lathe is one of the oldest and most important machine tools. Wood lathes were in use in France as early as 1569. During the Industrial Revolution in England the machine was adapted for metal cutting. The rotating horizontal spindle to which the work holding device is attached is usually power driven at speeds that can be varied. On a speed lathe the cutting tool is supported on a tool rest and manipulated by hand. On an engine lathe the tool is clamped onto a cross slide that is power driven on straight paths parallel or perpendicular to the work axis. On a screw cutting lathe the motion of the cutting tool is accurately related to the rotation of the spindle by means of a lead screw that drives the carriage on which the cutting tool is mounted.

1.1.1 CLASIFICATION OF LATHE

1. **Engine Lathe** It is the most common form of lathe, motor driven and comes in large variety of sizes and shapes.
2. **Bench Lathe** A bench top model usually of low power used to make precision machine small work pieces.
3. **Tracer Lathe** A lathe that has the ability to follow a template to copy a shape or contour.
4. **Automatic Lathe** A lathe in which the work piece is automatically fed and removed without use of an operator. Cutting operations are automatically controlled by a sequencer of some form.
5. **Turret Lathe** The lathe which have multiple tools mounted on turret either attached to the tailstock or the cross-slide, which allows for quick changes in tooling and cutting operations.
6. **Computer Controlled Lathe** It is a highly automated lathe, where cutting, loading, tool changing, and part unloading are automatically controlled by computer coding.

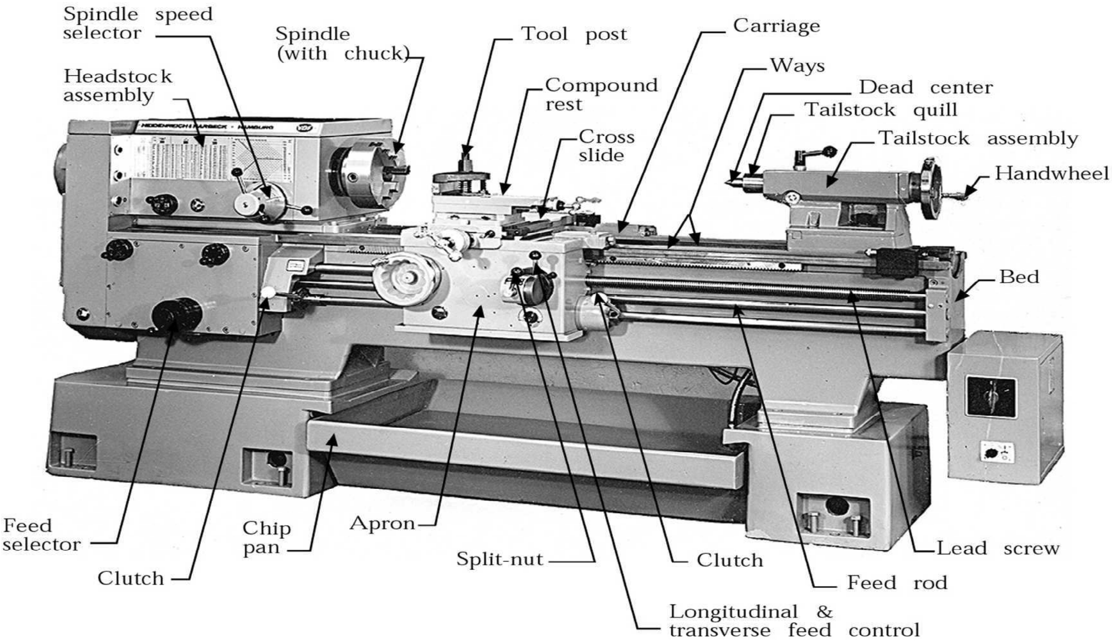
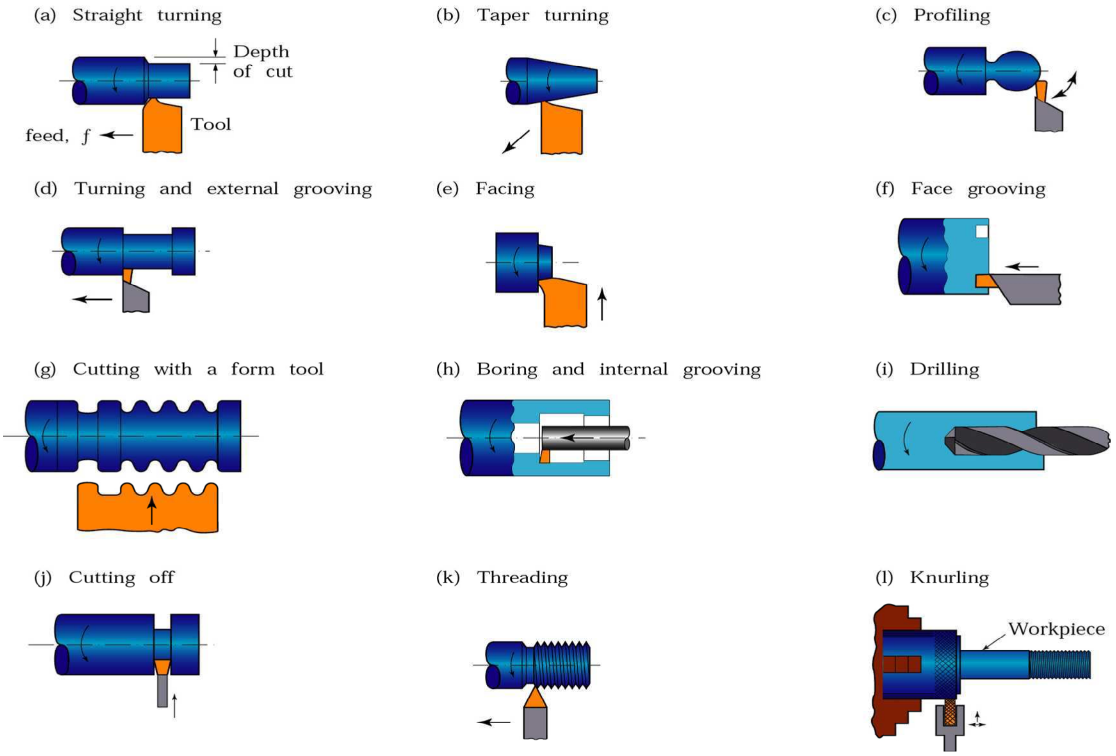


FIG. 1.1 Component Description of Lathe

1.1.2 LATHE OPERATIONS

1. **Turning** It produces straight, conical, curved, or grooved workpieces.
2. **Facing** To produce a flat surface at the end of the part or for making face grooves.
3. **Boring** To enlarge a hole or cylindrical cavity made by a previous process or to produce circular internal grooves.
4. **Drilling** To produce a hole by fixing a drill in the tailstock.
5. **Threading** To produce external or internal threads.
6. **Knurling** To produce a regularly shaped roughness on cylindrical surfaces.



(a) Straight turning (b) Taper turning (c) Profiling (d) Turning and external grooving (e) Facing (f) Face grooving (g) Cutting with a form tool (h) Boring and internal grooving (i) Drilling (j) Cutting off (k) Threading (l) Knurling

FIG. 1.2 Lathe Operations

1.2 LATHE HOLDING DEVICE (CHUCK) It is used to hold workpiece and sometimes tool also as in case of drilling a hole it holds drill tool. These are of several types as discussed below.

1. **Three jaw Chuck** For holding cylindrical stock centered.
2. **Four jaw Chuck** This is independent chuck generally has four jaws, which are adjusted individually on the chuck face by means of adjusting screws.
3. **Collet Chuck** Collet chuck is used to hold small workpieces.
4. **Magnetic Chuck** Thin jobs can be held by means of magnetic chucks.

1.3 CUTTING TOOL In lathe turning operation generally single point cutting tool is used. The material of cutting tool differs for machining different kind of work materials. The cutting speed and feed rate are also taken into account while selecting a particular cutting tool. The description of cutting tool is given in fig. 1.3.

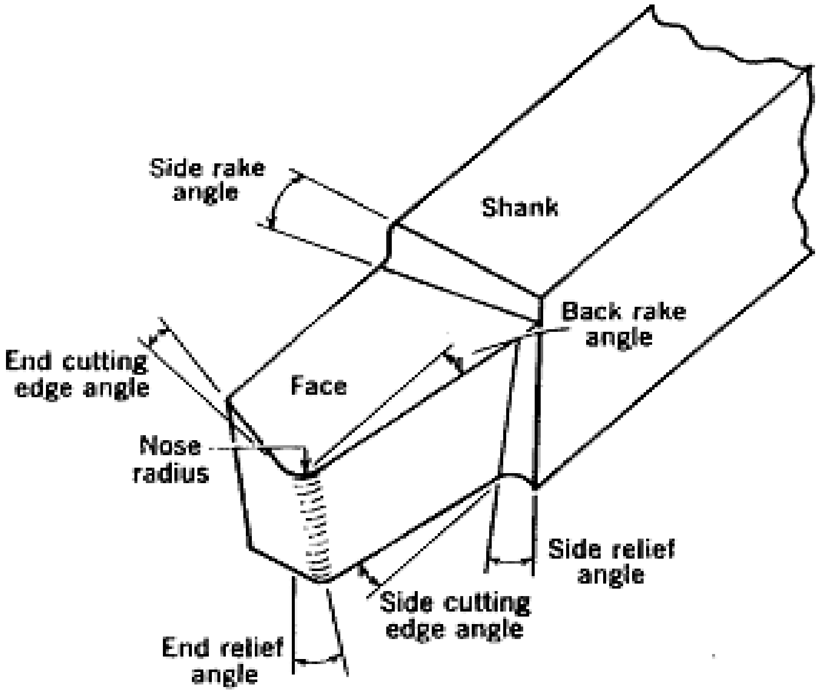


Fig.1.3 Cutting Tool Description

Terminology for the lathe tool is described in the fig 1.4.

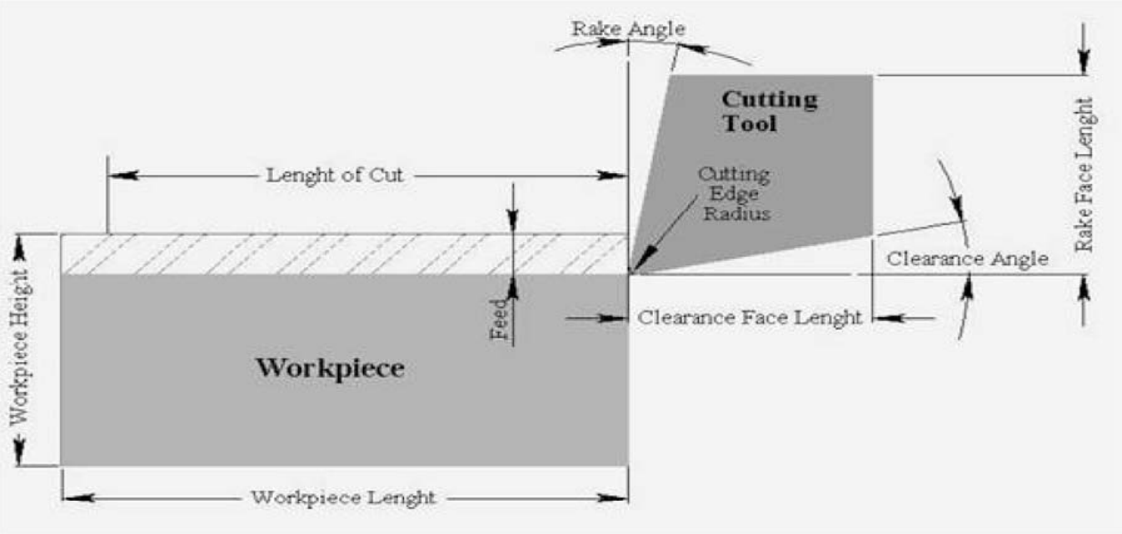


Fig. 1.4 Cutting Tool Terminology

CHAPTER 2
LITERATURE REVIEW

2.1 REVIEW OF LITERATURE

Thamizhmanii S. et al. [1] found that the surface roughness from various tests shows a decrease in value at higher cutting speed and feed rate. The cutting tool has produced micro chipping and has not affected the surface finish Micro cracks were obtained from the edge of micro chipping. The notch wear might have been caused due to hard particles and other impurities present in the material. There is no formation of built- up- edge that is usually occurring during machining cast iron at lower cutting speed. Further work can be carried in the direction of measuring the residual stresses by turning and formation of built- up edge under high speed machining.

Ozel Tugrul et al. [2] studied that tool nose design affects the surface finish and productivity in finish hard turning processes. Surface finishing and tool flank wear have been investigated in finish turning of AISI D2 steels (60 HRC) using ceramic inserts. Multiple linear regression models and neural network models are developed for predicting surface roughness and tool flank wear. In neural network modelling, measured forces, power and specific forces are utilized in training algorithm. Experimental results indicate that surface roughness *R*a values as low as 0.18–0.20 μm are attainable with wiper tools. Tool flank wear reaches to a tool life criterion value of VBC = 0.15mm before or around 15 min of cutting time at high cutting speeds due to elevated temperatures. Neural network based predictions of surface roughness and tool flank wear are carried out and compared with a non-training experimental data. These results show that neural network models are suitable to predict tool wear and surface roughness patterns for a range of cutting conditions.

Omar B. Bin et al. [3] observed that wear pattern depend on the CBN tools used, work piece material composition, and cutting conditions. They also concluded that generally, adhesion, abrasion and diffusion are considered to be main tool wear mechanisms in CBN hard turning: however, the individual effect of each mechanism depends on the combinations of the CBN tool and work materials, cutting conditions, tool geometry etc. A few basic mechanisms dominate cutting tool wear are: 1. Diffusion wear affected by chemical loading on the tool and cutting material 2. Oxidation wear - causes gaps to occur in coated film and results in a loss of the coating at elevated temperature, 3. Fatigue wear - is a thermo-mechanical effect and leads to the break down of the edges of the cutting tool, 4. Adhesive wear occurs at low machining temperatures on the chip face of the tool and leads to the formation of a built up edge, and the continual break down of the built up edge and the tool edge itself, 5. Abrasive wear affected by hardness of the work material and is controlled by content of the cutting material.

Lin H.M. et al. [4] found that tool life rises with the increase of cutting speed until a maximum is reached where it starts to decrease. In low speed cutting, abrasion is the main form of wear. When cutting speed is increased, a sticking layer is formed and remained on the tool face which protects tool face from wearing. At high cutting speed, the chip is transformed from continuous type to saw-tooth type. Friction force is increased accordingly, and the layer on tool face is abraded gradually. Since diffusion between work and tool materials becomes more severe at high cutting speed, the bond between the hard particles is weakened, and wear on the rake face is increased drastically. Together with the increase of crater wear, flank wear is increased.

Kamarudin K. et al. [5] observed that Flank wear in the ceramic cutting tools is mechanically activated wear usually by the abrasive action of the hard work piece material with the ceramic tools. The flank wear is characterized by the abrasive groove and ridges on the flank face. The flank wear of cutting tool has a significant effect on the quality of the machined surface. Flank wear has a detrimental effect on surface finish, residual stress and micro structural changes, shape of tool, cutting conditions. The high temperature generated between the cutting face and work piece causes abrasive and or adhesive wear. These types of wear affect the tool materials properties as well as work piece surface. The reasons for increase in flank wear were due to increase in temperature at the cutting edge due to more contact time between tool and work piece. The temperature may influence to lose its hardness and wear. When the cutting speed was lower, the flank wear was lower and as these parameters are increased, the flank wear also increased.

Mahfoudi Farouk et al. [6] studied that most of the known wear mechanisms are activated during machining of hard materials with PCBN tool such as mechanical, thermal or chemical damage. Mechanical damage like fracture is related to the brittleness and toughness of the hard material CBN and its weakness to resist under shear solicitation. Tool failure is often a consequence of other tool damage mechanisms. Mechanical abrasive wear is always practically mentioned when hard turning is performed at cutting speeds ranging typically from 100 to 250 m/min. Abrasive wear is considered to be caused by hard elements of martensite present in the work material. When abrasive wear dominates, scars on flank face and rake face are observed. Chemical and diffusion wears were more discussed in the literature. For a long time, PCBN was considered as a material having a poor chemical affinity with the other materials and chemical and diffusion wears were often forgotten by the studies, especially on crater wear. But, more and more, it is concluded that chemical wear plays an important role for the damage mechanisms of CBN inserts.

Arsecularatne J.A. et al. [7] investigated that in turning; catastrophic tool failure is to be avoided since it can damage the component, the tool and/or the machine tool and thus interrupt the machining process substantially. Instead, the useful life of a tool can be defined in terms of the progressive wear that occurs on the tool rake face (crater wear) and/or clearance face (flank wear). Of these two, flank wear is often used to define the end of effective tool life. This is also physically more meaningful as the flank wear land width has, once a certain level is reached, a major negative influence on dimensional accuracy and surface finish of the component as well as the stability of the machining process.

Huang Yong et al. [8] predicted that abrasive wear is damage to a surface, which arises because of the relative motion of either harder asperities or perhaps hard particles trapped at the interface. Hardened steel has a two-phase microstructure, consisting of body-centered cubic ferrite and small particles of cementite. Cementite particles in hardened steel are not as closely constrained by the ferrite matrix phase as the cementite lamella in the pearlite structure. Free cementite particles are easily generated in hard turning along the tool rake face and flank face. These hard particles are forced against the tool surfaces, causing three-body abrasive wear. Based on the above discussion, three-body abrasive wear is considered the dominant abrasive wear mechanism in hard turning.

Xie L. J. et al. [9] studied that the main tool failures, which take place in turning operation, include progressive wear (flank wear and crater wear), chipping, partial fracture, plastic deformation, thermal crack, etc. At present, experimental and analytical methods are still the main ways to investigate every type of tool wear. However, with the continuous development of more and more powerful computers and numerical methods and their ever-widening application in manufacturing, phenomena in metal machining, such as cutting force, temperature, and even progressive tool wear are gradually studied using numerical methods mainly including finite differential method and finite element method . It is expected that in the future will become an effective tool for the tool wear study and partly take the place of time- and cost-consuming experimental methods.

Lorentzon J. et al. [10] has estimated that for the high stress at the tool–chip interface, the work hardening, and the high temperature involved in the machining of nickel alloys all contribute to tool wear. It is therefore important to understand the wear process in order to predict wear rates and improve tool life. In the past, experimentation has been the main method used for investigating wear. However, continuous development of numerical methods such as the finite element method together with more powerful computers enables simulation of complicated contact problems such as the cutting processes. Finite element method has proved to be an effective technique for analyzing the chip formation process and predicting process variables such as temperatures, forces, stresses, etc. Therefore, the use of simulations has increased considerably over the past decade, and coupled thermo-mechanical simulation of the chip formation process has been used by many researchers.

However, this approach for simulation of tool wear in machining nickel-based super alloys has shown considerable discrepancy between simulated and measured geometry, especially in the region around the tool tip. Consequently, more work is required to enable accurate tool wear simulations. To do this properly, it is necessary to simultaneously work with modeling wear and friction at the tool–chip interface, as these phenomena are strongly related.

Wang Xiaoyu et al. [11] had studied Hard turning with cubic boron nitride (CBN) tools. It is found that the cutting edge of a tool insert in machining is subject to a combination of high stresses, high temperatures, and perhaps chemical reactions which cause the tool wear due to one or several mechanisms. These mechanisms depend on the tool and work piece material combination, cutting geometry, environment, and mechanical and thermal loadings encountered. Different classifications of tool wear processes have been addressed in the literature. Basically, five wear mechanisms or any combinations of them are involved in the tool wear progression. They are abrasion, adhesion, fatigue, dissolution/ diffusion, and tribochemical process. It is well accepted that the tool wear mechanisms in machining involve more than one wear mechanism and it is difficult to predict the relative importance of any one of them. Crater and flank wear are most reported wear patterns in machining including hard turning. Crater wear is mainly caused by physical, chemical, and/or thermo mechanical interactions between the rake face of the insert and the hot metal chip, and flank wear occurs primarily when the flank face rubs against the work piece surface.

Mamalis A. G. et al. [12] had worked on finite element method modeling of high speed hard turning. Simulations of various machining operations using the finite element method have been reported over the last three decades. The first models that appeared in the 1970s used the Eulerian formulation for modelling orthogonal cutting. In this approach the finite element mesh is spatially fixed and the material flows through it, in order to simulate the chip formation. The computational time in such models is reduced, due to the few elements required for modeling the workpiece and the chip, and it is mainly used for simulating the steady state condition of the cutting process. The elements do not undergo severe distortion, since the mesh is a priori known, but this formulation requires complex programming. Furthermore, experimental data must be on hand prior to the construction of the model in order to determine the chip geometry. Although this formulation is still utilized by some researchers, the updated Lagrangian formulation has been proposed and is more widely used today. In this approach, the elements are attached to the material and the undeformed tool is advanced towards the work piece. For the formation of the chip, a chip separation criterion in front of the tool edge is applied. There are many criteria proposed so far which can be geometric or physical and may involve for example a critical distance between the tool and the work piece; when the tool reaches this critical distance from the workpiece the elements ahead of the tool edge are divided and thus the chip is formed. Other separation criteria pertain to critical values of e.g., stress or strain in order to initiate the chip formation and even crack propagation criteria have been reported for this procedure. A disadvantage of this method is connected to the large mesh deformation observed during the simulation; due to the attachment of the mesh on the workpiece material, the mesh is distorted because of the plastic deformation in the cutting zone. In order to overcome this disadvantage continuous remeshing and adaptive meshing are usually applied, increasing considerably the required calculation time. Nevertheless, the advances in computers have made it possible to reduce the time needed for such an analysis to acceptable levels. Note that an arbitrary Lagrangian-Eulerian formulation has also been proposed with the aim of combining the advantages of the two methods, but it is not as widely used.

Bouzid Sai W. et al. [13] has studied that the flank wear was measured in connection to cutting time. This is to determine the tool life defined as the usable time that has elapsed before the flank wear has reached the criterion value. It is shown that an increase in cutting speed causes a higher decrease of the time of the second gradual stage of the wear process. This is due to the thin coat layer which is rapidly peeled off when high-speed turning. The investigation included the realization of a wear model in relation to time and to cutting speed. An empirical model has also been developed for tool life determination in connection with cutting speed. On the basis of the results obtained it is possible to set optimal cutting speed to achieve the maximum tool life.

Sharma Vishal S.et al. [14] had estimated that the most crucial and determining factor for successful maximization of the manufacturing process and its automation in any typical metal cutting process is tool wear. Thus monitoring of tool wear is an important requirement for realizing automated manufacturing. Due to its nonlinear and stochastic nature, predicting or monitoring tool wear is a difficult task. Initial efforts to develop tool condition monitoring systems focused mainly on the development of mathematical models of the cutting process which were dependent upon large amounts of experimental data. These methods did not take into account the complex and diverse nature of the metal cutting operations. The lack of an accurate model for wear prediction led researchers to resort to other methods of sensor integration. The quest for such methods was based on the requirement that these systems to operate without human assistance and/or interruption. These systems should recognize and estimate most or all forms of the tool wear in metal cutting.

Astakhov Viktor P. et al. [15] studied that the nature of tool wear, unfortunately, is not yet clear enough, in spite of numerous investigations. Although various theories have been introduced hitherto to explain the wear mechanism, the complexity of the processes in the cutting zone hampers the formulation of a sound theory of cutting tool wear. Cutting tool wear is a result of complicated physical, chemical, and thermomechanical phenomena. Because different "simple" mechanisms of wear (adhesion, abrasion, diffusion, oxidation, etc.) act simultaneously with predominant influence of one or more of them in different situations, identification of the dominant mechanism is far from simple, and most interpretations are subject to controversy . These interpretations are highly subjective and are based on the evaluation of the cutting conditions, possible temperature and contact stress levels, relative velocities, and many other process parameters and factors. As a result, experimental, or post-process methods, are still dominant in the known studies of tool wear and only topological or, simply, geometrical parameters of tool wear are selected and, thus, reported on in tool wear and tool life studies.

For given combination of the tool and workpiece materials, there is the cutting temperature, referred to as the optimal cutting temperature θopt, at which the combination of minimum tool wear rate, minimum stabilized cutting force, and highest quality of the machined surface is achieved. This temperature is invariant to the way it has been achieved (whether the workpiece was cooled, pre-heated, etc).

When the depth of cut increases and the uncut chip thickness is kept the same, the specific contact stresses at the tool chip interfaces, the chip compression ratio (defined as the radio of the chip and the uncut chip thicknesses), and the average contact temperature remain unchanged. Therefore, an increase in the depth of cut should not change the tool wear rate if the machining is carried out at the optimum cutting regime.

Maranhao C. et al. [16] found that AISI 316 is not easy to machine, even with specific coated tools. Stainless steels contain chromium addition, in general, between 12 and 25 wt% Cr which is responsible for corrosion resistance and levels as high as 25 wt% Ni to produce an austenitic structure, which leads to extreme high work-hardening rates. Acid resistance can be obtained with the addition of molybdenum. AISI 316 is widely used to produce critical structural components in chemical industries and nuclear power stations because they provide a unique combination of high mechanical properties and corrosion resistance. Stainless steels are considered difficult to machine due to their high tensile strength, high ductility, high work-hardening rate, low thermal conductivity and abrasive behaviour. These properties often lead to high cutting forces and high cutting temperature, fast tool wear rates, high susceptibility to notch wear, difficulties with chip breakability, BUE formation and poor surface finish. Because of these reasons, a coated tool with a chip breaker was used to perform the cut. Work hardening can occur which leads to unstable chip formation and vibrations (which induces to mechanical modifications and behaviour heterogeneity on the machined surface). Due to their low thermal conductivity, heat conduction is difficult at the tool tip and heat concentrated areas may appear in the working material. These aspects affect the integrity of the piece and lead to residual stressed affected layers. Having that said, it is fundamental to study residual stresses when machining these types of materials. The energy that is used to plastically deform the workpiece material during a turning operation is transformed into heat. The developed temperatures that appear during the machining operation are mainly related with the contact between the tool and chip, the level of cutting forces and the friction between tool and chip. A portion of the heat that occurs is transferred to the cutting tool and workpiece while the majority it is dissipated through the chip. The shear zone is subject of the majority of heat therefore; the contact length between the chip and tool influences the cutting forces, cutting conditions of the tool, the tool performance and tool life.

Coelho Reginaldo T. et al. [17] had studied that wear minimization has been pursued by different means, beginning with tool steels and heat treatments, going later to new tool materials and, more recently, to coatings. The first great improvement happened with HSS, but its use in metal cutting has been strongly reduced, given place to sintered carbides, since the middle of the last century. Recent developments to improve carbide performance are with submicron and ultra-fine grains, with grain size as low as 0.2 mm. PCD and PCBN appeared during the second half of last century. Although PCD proved to be suitable only for nonferrous materials, PCBN, however, can be applied to cut steels in their hardened state, competing with the latest improvements in ceramic materials and also grinding processes. Ceramic in contrast, have been employed in metal cutting since the beginning of the last century, but its reliability is always dubious as cutting insert. Additionally, ceramics, PCBN and PCD are still expensive, compared to carbide, and their application must be carefully analyzed when costs are the main concern. An ideal cutting material has to combine high hardness and wear resistance with good toughness and chemical stability, but no material has ever shown all these properties together at their best combination. As an alternative, tools can be coated with materials more suitable to withstand cutting conditions at the interface tool chip. Accordingly, better properties are added on the surface, combined with an adequate substrate. Coating materials usually offer higher hardness at high temperature, good chemical stability, lubricant properties, good thermal properties, etc.

Li Xiaoli et al. [18] had worked on Real-time tool wear condition monitoring in turning. It has been recognized widely that tool life can be divided into three phases characterized by three different flank wear processes: (i) break-in, (ii) normal wear and (iii) abnormal or catastrophic wear. The sudden rise in wear rate observed during the abnormal tool wear phase (phase iii) is an indication of the need for tool replacement. Because many factors affect tool wear, the wear curve usually fluctuates and is not smooth. Cutting force is one important characteristic variable to be monitored during the cutting processes. Research results show that tool breakage, tool wear and workpiece deflection are strongly related to cutting force. Commercial dynamometers have been used to measure cutting force accurately. Although different types of dynamometers are available for different cutting applications, however, the reduced stiffness of machine tools, leading to chatter and dimensional error, lack of overload protection and high cost limit their application.

Arrazola P.J et al. [19] stated that Finite Element Modeling of chip formation has proved great sensitivity to tool/chip friction coefficient. This parameter cannot be adequately identified through conventional tests, because thermal and mechanical loadings during these tests are far from those encountered during machining. Friction parameters at the tool–chip contact are hard to identify. Only few methods are available and, in all cases, experiments are not conducted in similar conditions to those encountered in the cutting process.

Baker Martin et al. [20] studied that a finite element model of a two-dimensional, orthogonal metal-cutting process is used to study the influence of the cutting speed on the cutting force and the chip formation process. The model uses a generic flow stress law. Friction is neglected as its speed dependence is only poorly known. It is shown that the experimentally observed decrease of the cutting force with the cutting speed and the plateau at high cutting speeds are reproduced by the simulation. The decrease is mainly caused by a change in the shear angle due to thermal softening. At large cutting speeds, segmented chips are produced. It is also shown by an analytical calculation that segmented chips at large cutting speeds are energetically more favourable than continuous chips.

Shi Guoqin et al. [21] found that despite the great progress that has been achieved in modeling metal cutting processes, there are still several fundamental issues that remain open and deserve detailed analysis. One of these issues is the frictional behavior along the tool–chip interface and its effect on thermomechanical quantities involved in metal cutting. Another issue is the understanding of tool wear and its correlation, if any, with thermomechanical quantities in metal cutting. This is a complicated issue and its understanding depends on many factors. It appears that so far research effort has been focused on the physics of wear and no attempt has been made to quantify wear and tool life by combining experimental observations with numerical simulation solutions of thermomechanical quantities in metal cutting.

Umbrello D. et al. [22] stated that in machining, as in any other process in which heavy deformations are imposed to the material, a large quantity of heat is generated. The validity of the latter statement is enforced by the development of tool materials and machines, which allow to reach very high cutting speeds. Rotation speeds of the mandrel higher than 18,000 rpm and cutting speeds of several hundreds of m/min are to be considered as usual values today. Furthermore, the use of lubricants and coolants is nowadays dissuaded due to the relevant impact on the environment (pollution) and to the heavy influence on the industrial costs. It is well known that a large part of the generated heat is due to the deformation work occurring on the shear plane (primary shear zone), according to many of the traditional models concerning chip formation theory. In addition, a secondary source of heat generation is located on the rake face, where the mechanism responsible for heat generation is friction between the workpiece surface and the tool.

2.2 PROBLEM DESCRIPTION

The turning operation is one of the main operations used in machining of different parts. Mainly single point cutting tool is used in the turning operation. For this purpose, variety of cutting tools available in the market. These tools have different geometry and different materials to machine a variety of steels and alloys. EN38 steel is mainly used for making dies and other heavy duty machine parts as it is very hard steel. Machining EN38 steel requires special cutting tool materials. The study of tool wear in this case is very important for economical machining and good surface finish.

The objective of this thesis work is to analyze the tool wear of the single point cutting tool used in the turning operation of EN38 steel. The single point cutting tool is used for machining cylindrical shape specimen of EN38 steel. A number of tests are performed with different cutting speed and feed rates. Cutting forces and tool wear is measured from these experiments. This data will be helpful in analyzing the cutting process.

Different graphs of cutting forces Vs cutting speed and tool wear Vs cutting speed are plotted and these graphs shows the variation of tool wear and cutting forces. Further SEM tests are conducted to observe the tool wear surface of the carbide tool.

CHAPTER 3
TOOL WEAR

Tool wear monitoring/sensing should be one of the primary objectives in order to produce the required end products in an automated industry so that a new tool may be introduced at the instant at which the existing tool has worn out, thus preventing any hazards occurring to the machine or deterioration of the surface finish. Cutting tools may fail due to the plastic deformation, mechanical breakage, cutting edge blunting, and tool brittle fracture or due to the rise in the interface temperatures.

Throughout the world today, there is a continuous struggle for cheaper production with better quality. This can be achieved only through optimal utilization of both material and human resources. Machining operations comprise a substantial portion of the world's manufacturing infrastructure. They create about 15% of the value of all mechanical components manufactured worldwide. Because of its great economic and technical importance, a large amount of research has been carried out in order to optimize cutting process in terms of improving quality, increasing productivity and lowering cost [24].

Tool wear influences cutting power, machining quality, tool life and machining cost. When tool wear reaches a certain value, increasing cutting force, vibration and cutting temperature cause surface integrity deteriorated and dimension error greater than tolerance. The life of the cutting tool comes to an end. Then the cutting tool must be replaced or ground and the cutting process is interrupted. The cost and time for tool replacement and adjusting machine tool increases cost and decreases the productivity. Hence tool wear relates to the economic of machining and prediction of tool wear is of great significance for the optimization of cutting process.

3.1 TOOL WEAR

Cutting tools are subjected to an extremely severe rubbing process. They are in metal-to-metal contact, between the chip and work piece, under conditions of very high stress at high temperature. The situation is further aggravated due to the existence of extreme stress and temperature gradients near the surface of the tool. During cutting, cutting tools remove the material from the component to achieve the required shape, dimension and finish. However, wears are occurring during the cutting action, and it will result in the failure of the cutting tool. When the tool wear reach certain extent, the tool or edge change has to be replaced to guarantee the ordinary cutting action.

3.1.1 TOOL WEAR METHODOLOGY

Under high temperature, high pressure, high sliding velocity and mechanical or thermal shock in cutting area, cutting tool has normally complex wear appearance, which consists of some basic wear types such as crater wear, flank wear, thermal crack, brittle crack, fatigue crack, insert breakage, plastic deformation and build-up edge. The dominating basic wear types vary with the change of cutting conditions.

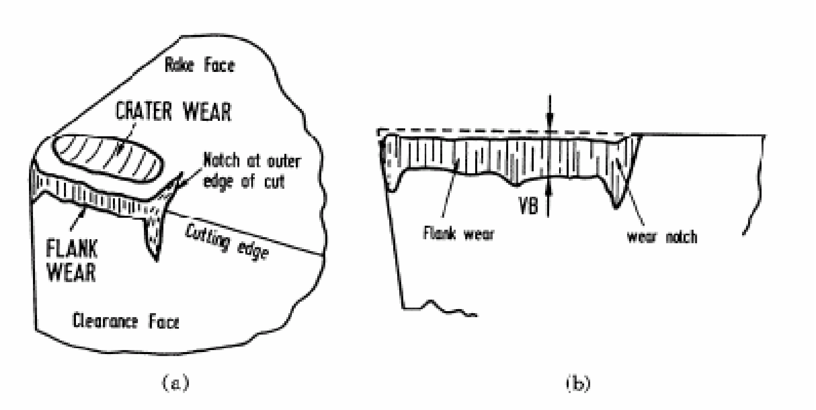


Fig. 3.1 Types of Tool Wear [24]

Crater wear In continuous cutting, for example in turning operation, crater wear normally forms on rake face. It conforms to the shape of the chip underside and reaches the maximum depth at a distance away from the cutting edge where highest temperature occurs. At high cutting speed, crater wear is often the factor that determines the life of the cutting tool, because the tool edge is weakened by the severe cratering and eventually fractures. Crater wear is improved by selecting suitable cutting parameters and using coated tool or ultra-hard material tool.

Flank wear Flank wear is caused by the friction between the newly machined work piece surface and the tool flank face. It is responsible for a poor surface finish, a decrease in the dimension accuracy of the tool and an increase in cutting force, temperature and vibration. Hence the width of the flank wear land “VB” is usually taken as a measure of the amount of wear and a threshold value of the width is defined as tool reshape criterion.

3.1.2 WEAR MECHANISM

In order to find out suitable way to slow down the wear process, many research works are carried out to analyze the wear mechanism in metal cutting. It is found that tool wear is not formed by a unique tool wear mechanism but a combination of several tool wear mechanisms.

Tool wear mechanisms in metal cutting include abrasive wear, adhesive wear, delamination wear, solution wear, diffusion wear, oxidation wear, electrochemical wear, etc. Among them, abrasive wear, adhesive wear, diffusion wear and oxidation wear are very important.

Abrasive wear Abrasive wear is mainly caused by the impurities within the workpiece material, such as carbon, nitride and oxide compounds, as well as the built-up fragments. This is a mechanical wear, and it is the main cause of the tool wear at low cutting speed.

Adhesive wear The simple mechanism of friction and wear proposed by Bowden and Tabor is based on the concept of the formation of welded junctions and subsequent destruction of these. Due to the high pressure and temperature, welding occurs between the fresh surface of the chip and rake face because of the chip flowing on the rake face results in chemically clean surface.

Severe wear is characterized by considerable welding and tearing of the softer rubbing surface at high wear rate, and the formation of relatively large wear particles. Adhesion wear occurs mainly at low machining temperatures on tool rake face, such built up edge (BUE).Under mild wear conditions, the surface finish of the sliding surfaces improves.

Diffusion wear Wear is a process of atomic transfer at contacting asperities. A number of workers have considered that the mechanism of tool wear must involve chemical action and diffusion. They have demonstrated welding and preferred chemical attack of (W) tungsten carbide in (W-Ti) tungsten-titanium carbides. There are several ways in which the wear may be dependent on the diffusion mechanism.

(i) Gross softening of the tool: Diffusion of carbon in a relatively deep surface layer of the tool may cause softening and subsequent plastic flow of the tool. This flow may produce major changes in the tool geometry, which result in high forces and a sudden complete failure of the tool.

(ii) Diffusion of major tool constituents into the work (Chemical element loss): The tool matrix or a major strengthening constituent may be dissolved into the work and chip surfaces as they pass the tool. In cast alloy, carbide or ceramic tools, this may be the prime wear phenomenon. With HSS tools, iron diffusion is possible, but it seems unlikely to be the predominant wear process. Diamond tool – cutting iron and steel is the typical example of diffusion wear.

(iii) Diffusion of a work-material component into the tool: A constituent of the work material diffusing into the tool may alter the physical properties of a surface layer of the tool. For example, the diffusion of lead into the tool may produce a thin brittle surface layer, this thin layer can be removed by fracture or chipping.

Oxidation wear High temperatures and the presence of air mean oxidation for most metals. A slight oxidation of tool face is helpful to reduce the tool wear. It reduces adhesion, diffusion and current by isolating the tool and the workpiece. But at high temperature soft oxide layers, for example WO3, TiO2, are formed rapidly, and then taken away by the chip and the workpiece. This results in a rapid tool material loss, which is oxidation wear.

Chemical wear Corrosive wear (due to chemical attack of a surface)

Fatigue wear Fatigue wear is often a thermo-mechanical combination. Temperature fluctuations and the loading and unloading of cutting forces can lead to cutting edge cracking and breaking. Intermittent cutting action leads to continual generation of heat and cooling as well as shocks of cutting edge engagement.

Under different cutting conditions dominating wear mechanisms are different. For a certain combination of cutting tool and workpiece, the dominating wear mechanisms vary with cutting temperature. According to the temperature distribution on the tool face, it is assumed that crater wear is mainly caused by abrasive wear, diffusion wear and oxidation wear, but flank wear mainly dominated by abrasive wear due to hard second phase in the workpiece material.

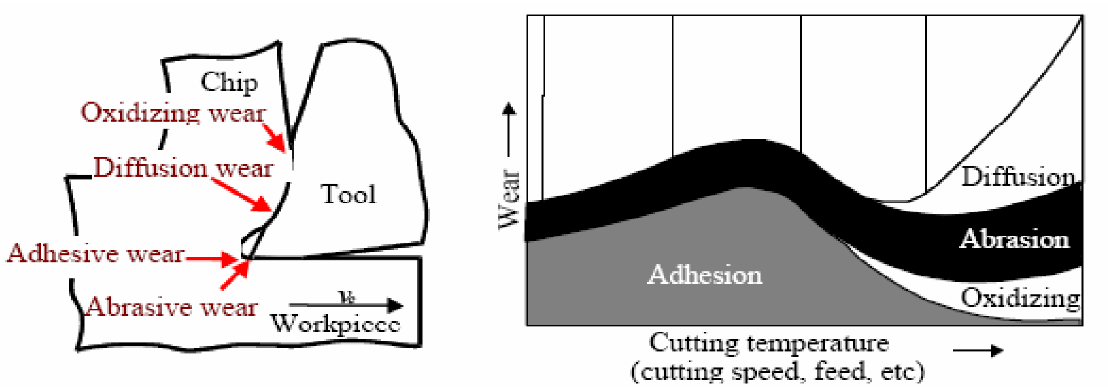


Fig. 3.2 Wear mechanisms [24]

3.1.3 PREDICTION OF TOOL WEAR

Prediction of tool wear is complex because of the complexity of machining system. Tool wear in cutting process is produced by the contact and relative sliding between the cutting tool and the work piece and between the cutting tool and the chip under the extreme conditions of cutting area; temperature at the cutting edge can exceed 530°C and pressure is greater than 13.79 N/mm2. Any element changing contact conditions in cutting area affects tool wear**.** Figure 3.3 shows influencing elements of the tool wear. These elements come from the whole machining system comprising workpiece, tool, interface and machine tool.

Workpiece It includes the workpiece material and its physical properties (mechanical and thermal properties, microstructure, hardness, etc), which determine cutting force and energy for the applied cutting conditions.

Tool The tool material, tool coatings and tool geometric design (edge preparation, rake angle, etc) need to be appropriately chosen for different operations (roughing, semiroughing, or finishing). The optimal performance of a cutting tool requires a right combination of the above tool parameters and cutting conditions (cutting speed, feed rate, depth of cut)

Fig. 3.3 Influencing elements of tool wear [24]

Interface It involves the interface conditions. In 80% of the industrial cutting applications, coolants are used to decrease cutting temperatures and likely reduce tool wear. Increasingly new technologies, such as the minimum liquid lubrication, have been developed to reduce the cost of coolant that makes up to 16% of the total machining costs.

Dynamic The dynamic characteristic of the machine tool, affected by the machine tool structure and all the components taking part in the cutting process, plays an important role for a successful cutting. Instable cutting processes with large vibrations (chatters) result in a fluctuating overload on the cutting tool and often lead to the premature failure of the cutting edge by tool chipping and excessive tool wear.

The problem of tool wear monitoring in machining operation has been active area of research. This is because tool change strategies, product quality, tooling costs, and productivity are all influenced by tool wear. Reduction in production cost and increase in productivity can be realized by making the most use of a tool's life and therefore increasing the time between tool changes.

3.2 EFFECT OF TOOL WEAR ON TECHNOLOGICAL PERFORMANCE

3. 2.1 CONSEQUENCES OF TOOL WEAR

- Decrease the dimension accuracy;
- Increase the surface roughness;
- Increase the cutting force;
- Increase the temperature;
- Likely cause vibration;
- Lower the production efficiency, component quality;
- Increase the cost.

Influence on cutting forces Flank wear (or wear-land formation) and chipping of the cutting edge affect the performance of the cutting tool in various ways. The cutting forces are normally increased by wear of the tool. Crater wear may, however, under certain circumstances, reduce forces by effectively increasing the rake angle of the tool. Clearance-face (flank or wear-land) wear and chipping almost invariably increase the cutting forces due to increased rubbing forces.

Surface finish (roughness) The surface finish produced in a machining operation usually deteriorates as the tool wears. This is particularly true of a tool worn by chipping and generally the case for a tool with flank-land wear although there are circumstances in which a wear land may burnish (polish) the workpiece and produces a good finish.

Dimension accuracy Flank wear influences the plan geometry of a tool this may affect the dimensions of the component produced in a machine with set cutting tool position or it may influence the shape of the components produced in an operation utilizing a form tool.

Vibration or chatter The vibration is another aspect of the cutting process which may be influenced by flank wear. A wear land increases the tendency of a tool to dynamic instability. A cutting operation which is quite free of vibration when the tool is sharp may be subjected to an unacceptable chatter mode when the tool wears. [24]

3.2.2 CHARACTERISTICS OF TOOL WEAR

- Huge contact stress at the rake and flank surface
- High temperature (800-1000 °C for carbide and steel combination)

Hence, generalized wear theory cannot be directly used for accurate study of the tool wear.

CHPATER - 4
INSTRUMENTATION AND EXPERIMENTATION

4.1 INSTRUMENTATION

The various instruments used for experimentation are discussed here in this section.

Table 4.1 List of Equipments

HMT LT 20 Lathe Machine
Scanning Electron Microscope JEOL JSM-6510LV
Olympus Tool Maker’s Microscope STM 6
Kistler Force Measurement Dynamometer Multi channel charge amplifier Type-5070 And data acquisition system

4.1.1 FORCE MEASUREMENT

A force measurement actually involves the measurement of a deflection, caused by that force, with a suitable calibration between the force and the deflection it produces. For measuring small deflections, various devices have been used. Some of them are listed below:

1. The dial indicator.
2. Pneumatic devices.
3. Optical devices.
4. Piezoelectric crystals.
5. Strain Gauges.

Out of these, most widely used dynamometer is of strain gauge type. In this category, bounded- wire strain gauges have commonly been used. Usually these bonded wire gauges have been specified by the resistance and the gauge factor (F). The gauge factor is a measure of sensitivity of gauge and is defined as:

$F= (\Delta R/R)/ (\Delta l/l) = \Delta R/\varepsilon R$

Where, ε is the normal strain and can be calculated as: $\varepsilon = \Delta l/l$

In our case, bonded wire strain gauge of resistance 120+ and gauge factor 2, have been used. In order to measure the strains of the order of 1+, the changes of the resistance of the same order of magnitude need to be measured. This can be made by means of Wheatstone bridge as shown in figure 4.1. No current will flow through the galvanometer (G) if the four resistances satisfy the equation

R1/R4=R2/R3

For the sake of simplicity, the lathe operation is frequently taken as a orthogonal cutting process. In this case, the resultant force will act in a known plane and only two force components are required to analyze the cutting process. In the present case, the axial cutting force, Fc, and the tangential cutting force, Ff, have been used.

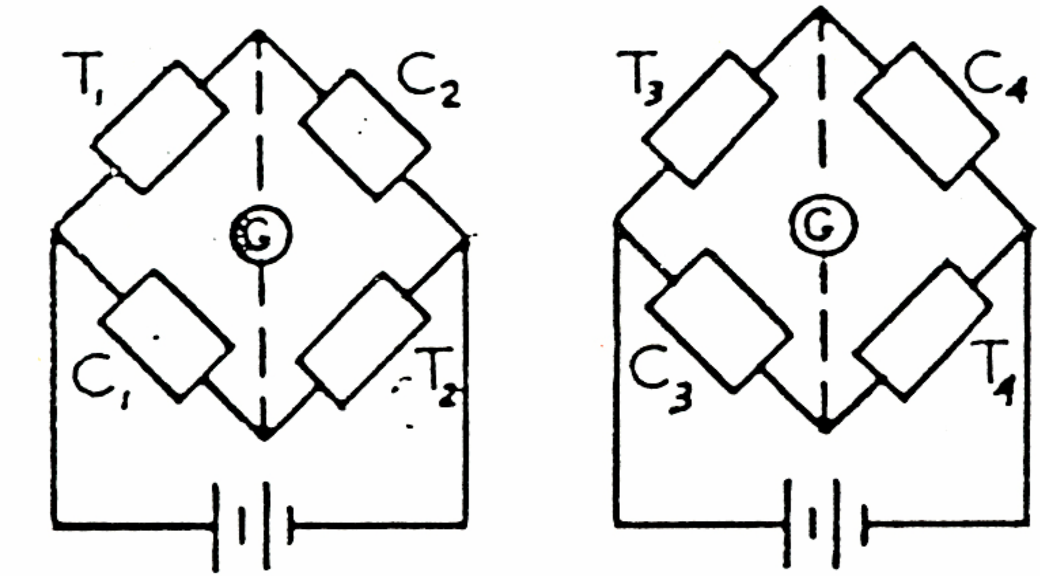


Fig. 4.1 Wheatstone bridge

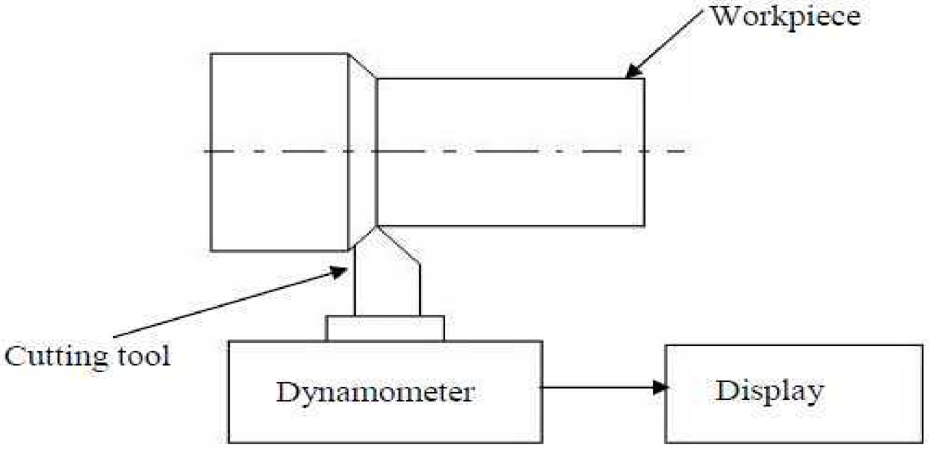


Fig. 4.2 Schematic diagram of the lathe and equipment setup

A two component cutting force dynamometer of cantilever type is used in the present work. The dynamometer structure is made of aluminum. The action of the forces is to bend the structure. The axial cutting force, Fc, bends the structure about the one axis and the tangential feed force, Ff, bends the structure about another axis. Strain gauges have been used to measure these distortions (moments), and the recordings are calibrated to give a measure of the forces applied.

4.1.2 SCANNING ELECTRON MICROSCOPE (SEM)

For present work JEOL JSM-6510LV type SEM used. The JSM-6510LV low vacuum SEM is a high-performance scanning electron microscope for fast characterization and imaging of fine structures. JSM-6510LV enables observation of specimens up to 150mm in diameter. With a high resolution of 3.0 nm at 30kV, the JSM-6510LV delivers good clarity of the finest structures. Specifications of SEM are given in appendix-B.

Operation of the SEM is very simple through an intuitive GUI interface. Multiple users will find it easy to save customized workspaces accessible by login. A unique optional Stage Navigation System coupled with the optional stage automation makes it easy to locate the minute area of interest on the large sample without losing overall position. Standard automated features include auto focus/auto stigmator, auto gun (saturation, bias and alignment), and automatic contrast and brightness.

Fig. 4.3 JSM-6510LV Scanning Electron Microscope

4.2 EXPERIMENTATION

Experiments were carried out on a turning lathe. A carbide tip turning tool was clamped in a two component strain gauge dynamometer using a tool holder. For the experimentation, EN 38 steel workpiece of 150mm length was held in a three – jaw chuck. Tool height and tool overhang was set to the required level with the help of gauges. A rough turning pass was made initially to eliminate the runout of the workpiece. The output flank wear was measured with the help of a Tool Maker's Microscope.

4.2.1 PLANNING OF EXPERIMENT

A scientific approach to planning of experiments must be incorporated in order to perform an experiment most effectively. Statistical design of experiments is the process of planning the experiments so that the appropriate data could be collected which may be analyzed by statistical method resulting in valid and objective conclusions. Planning of experiments was employed in order to fulfill the following requirements:

- To get the data uniformity distributed over the whole range of controllable factors to be investigated.
- To reduce the total number of experiments.
- To establish a relationship between different input variables and the output accurately in the selected range of investigation.

4.2.2 EXPERIMENTAL PROCEDURE

The experiments were made on the HMT LT-20 lathe using a bar turning process under dry conditions. For the range of range of cutting conditions (cutting speed, feed, and depth of cut) it was required to measure the three force components Ft, Fa and Fr, and flank wear. A total of sixteen experiments were carried out, all with the same basic configuration and carbide inserts were replaced after performing a single test. The depth of cut is kept same in all experiments.

Work material: The EN 38 Steel was chosen for the present investigation with a diameter of 55 mm and 150 mm length. The composition of EN38 is:

C: 0.35-0.4%

Si: 0.05-0.35%

Mg: 0.6-0.9%

Sulphur: 0.5%

Phosphorous: 0.5%

Tool material: The tool material used should be capable of high speed machining with dry cutting conditions. In present investigation carbide inserts were used for performing the experiments.

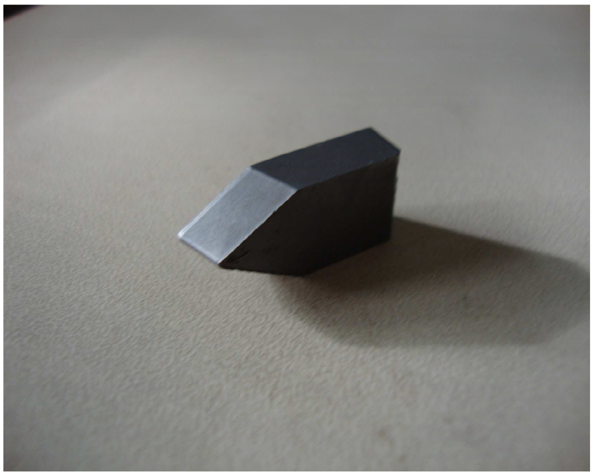


Fig. 4.4 Cutting Tool

Tool geometries:

a) Tool length: 16.02mm

b) Tool width: 8.02 mm

c) Nose radius: 0.4 mm

4.2.3 EXPERIMENT METHODOLOGY

A HMT LT 20 make lathe was used for turning experiment whose specifications have been given in appendix -A. Fig. 4.2 shows the schematic diagram of the machine and equipment setup. The dynamometer is mounted on tool post with the help of a holder specially designed for this experimental work.

Then the actual experiments have been carried out with the different input cutting conditions for different experiments for constant volume of material removal in each case. The experiments carried out are summarized as:

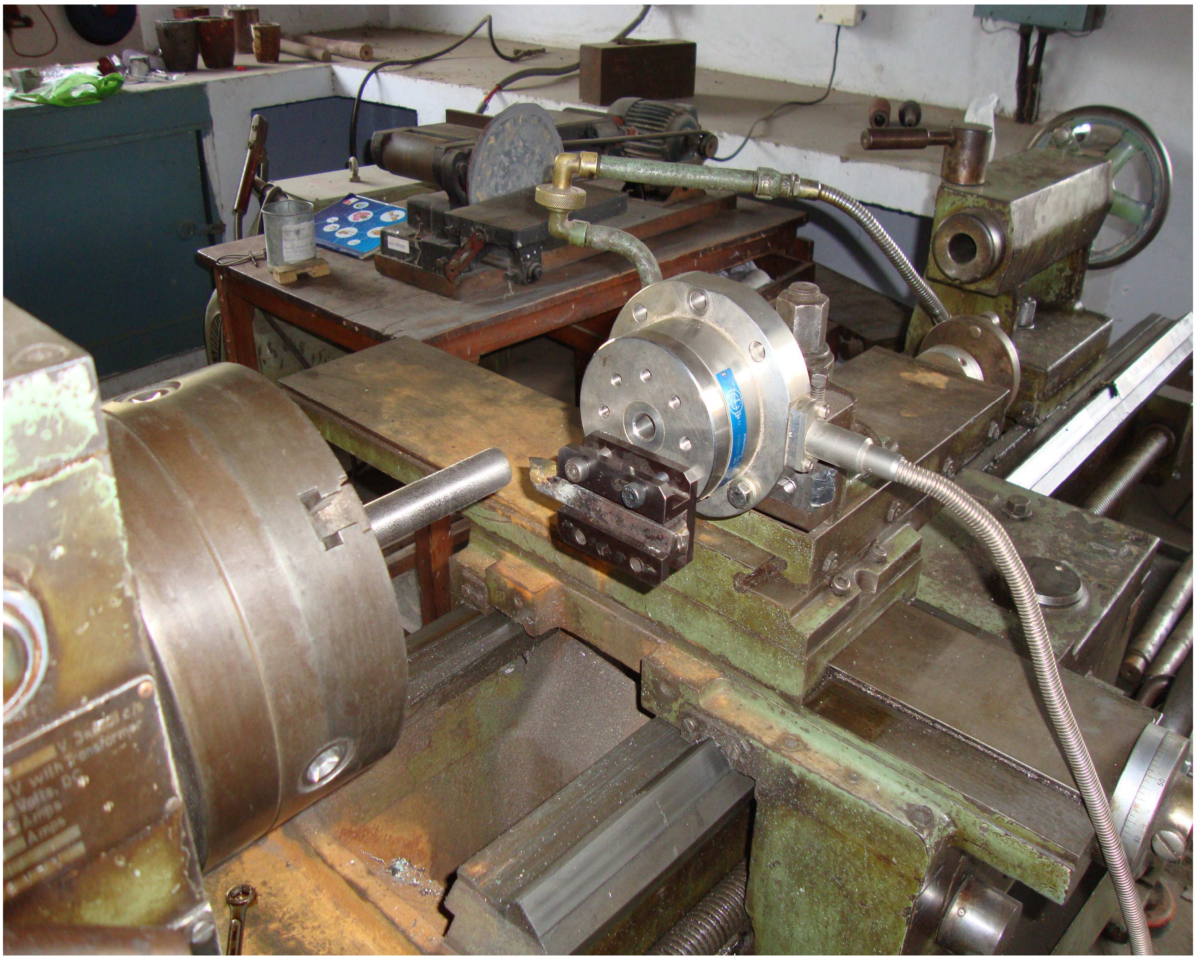


Fig. 4.5 Machine Setup

1. Carry out experiment on lathe machine using EN 38 as work piece and commercial available Carbide Tool of triangular shape.
2. Machining is done with different sets of Cutting speed, depth of cut, & feed rates.
3. Measuring the cutting forces with dynamometer.
4. Measuring the flank wear of the carbide insert with microscope.
6. Observing the wear trends in SEM.

Fig. 4.6 Data receiving from the Dynamometer

The flank wear is measured and value of cutting forces is given by dynamometer. These values of flank wear and cutting forces are plotted against cutting speed to obtain the wear trends.

CHAPTER 5
RESULTS AND DISCUSSION

In the present chapter the results for the present problem that is Analysis of tool wear in turning operation of EN38 steel have been developed in accordance with the previously developed models for tool wear [1], [3] and [5]. The number of experiments has been conducted to find out the cutting forces and flank wear of the tool, made of tungsten carbide, at varying machining parameters, which are cutting speed (v), cutting feed (f) and keeping depth of cut (d) constant. Using this data various graphs are plotted and analyzed. Also cutting tool wear behavior is observed using SEM after various cuts.

5.1 MACHINING PARAMETERS USED FOR EXPERIMENTATION

Table 5.1: Cutting parameters

Cutting speed v (rpm) (Range)	Feed f (mm/rev) (Range)	Depth of cut d (mm) (Range)
88,150,250,420	0.05,0.11,0.22,0.45	0.35(constant)

The table 5.1 shows the numerical values of the various machining parameters (cutting speed, feed and the depth of cut), that have been selected for experimentation, for the measurement of cutting forces and flank wear. The EN38 steel workpiece material has been used for experimentation, and its specifications have been shown in appendix C**.** The cutting material used is Tungsten Carbide.

The table 5.2 shows the experimental values of wear, and cutting forces for different speed, feed and depth of cuts for the different set of experiments conducted on the carbide cutting tool. Total 16 experiments were conducted and depth of cut is kept constant in all the experiments.

To eliminate the effect of wear on the experiments, the tools have been replaced after every cut of constant volume of workpiece material. In total 16 carbide bits have been used for all the different set of experiments to be conducted. Tool edge has been made straight or parallel to the chuck to have an orthogonal cut. The experiments were conducted for constant volume. Constant volume signifies that equal amount of material was removed in all the different sets of experiment conducted. This has been done so that all the measurements should be taken correctly at the same operating conditions to have a good accuracy in results with minimum possible error.

Table 5.2: Experimental Results of measured parameters against parameters V, f and d

S.No.	Cutting Speed v (rpm)	Feed f (mm/rev)	Depth of cut d (mm)	Fx (N)	Fy (N)	Fz (N)	Flank Wear(μm)
1	88	0.05	0.35	18	22	14	0
2	88	0.11	0.35	22	14	18	46
3	88	0.22	0.35	30	8	26	0
4	88	0.45	0.35	11	5	7	125
5	150	0.05	0.35	37	45	17	33.4
6	150	0.11	0.35	118	90	42	92.5
7	150	0.22	0.35	65	73	46	15.5
8	150	0.45	0.35	33	82	58	76.4
9	250	0.05	0.35	28	9	6	55.2
10	250	0.11	0.35	12	31	19	75
11	250	0.22	0.35	12	7	15	37
12	250	0.45	0.35	48	87	71	95
13	420	0.05	0.35	33	26	21	76
14	420	0.11	0.35	17	54	33	53
15	420	0.22	0.35	54	78	62	112
16	420	0.45	0.35	42	94	50	65

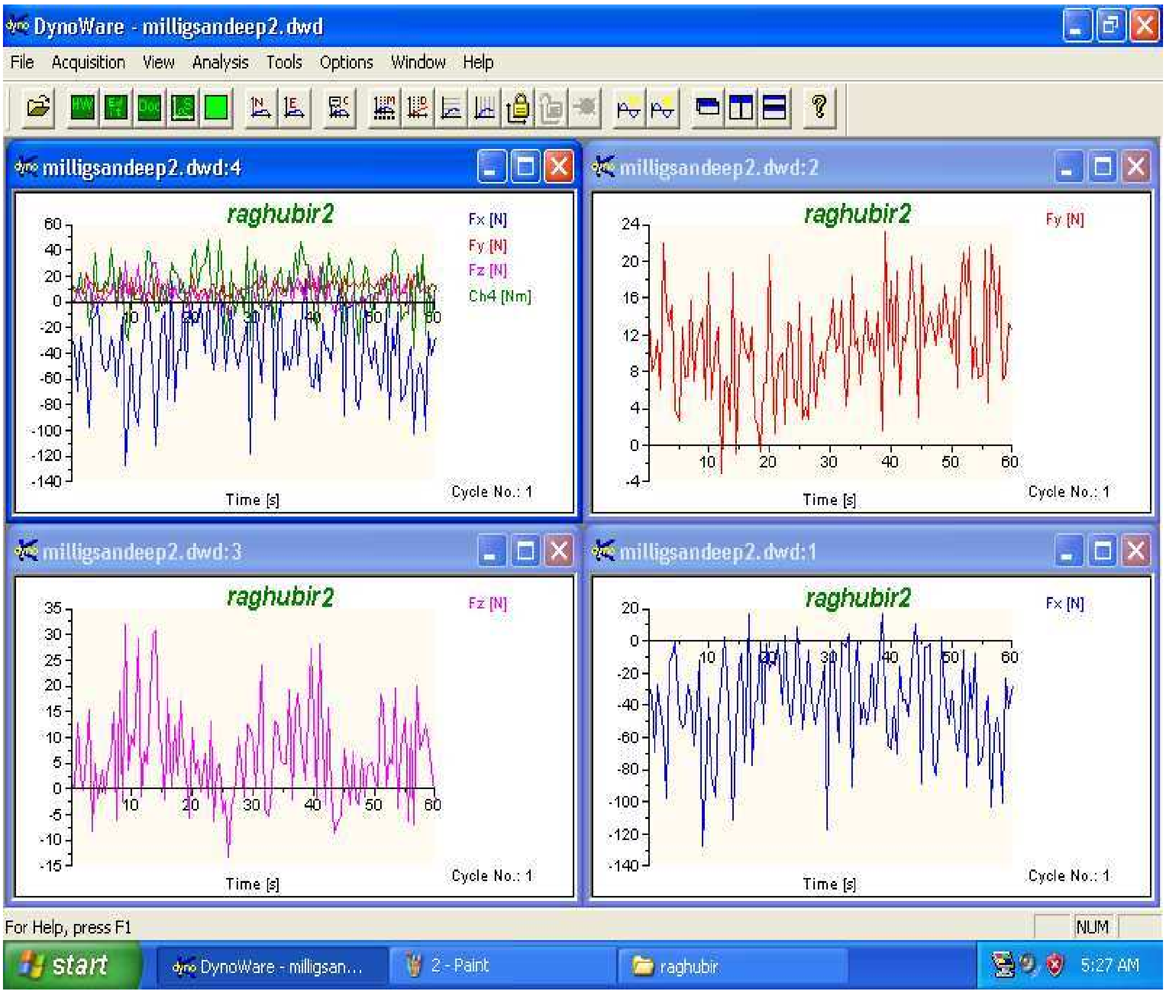


Fig. 5.1 Data recording by Dynamometer

5.2 VALIDATION OF RESULTS

In order to check the validity of the results various graphs are plotted between Cutting Speed and Force components (Fx, Fy and Fz) and between Cutting Speed and Flank Wear. These plots are compared with the results given by Thamizhmanii S. [1], for checking the validity of results. The results from the reference are well in accordance with the results of the present work.

5.2.1 VARIATION OF VARIOUS FORCES WITH CUTTING SPEED

Fig. 5.2 to 5.5 shows the variation of forces with cutting speed.

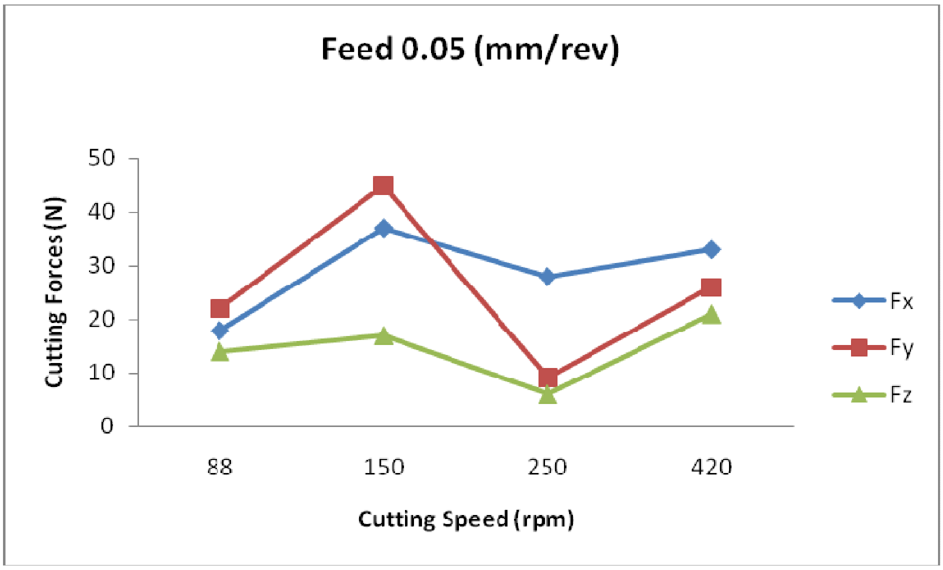


Fig. 5.2 Cutting Speed Vs Forces at 0.05 Feed

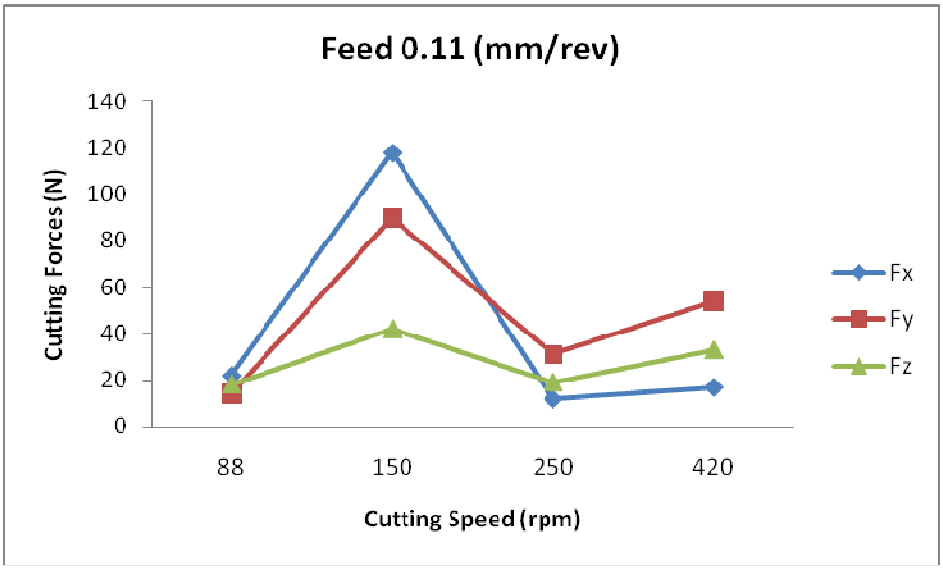


Fig. 5.3 Cutting Speed Vs Forces at 0.11 Feed

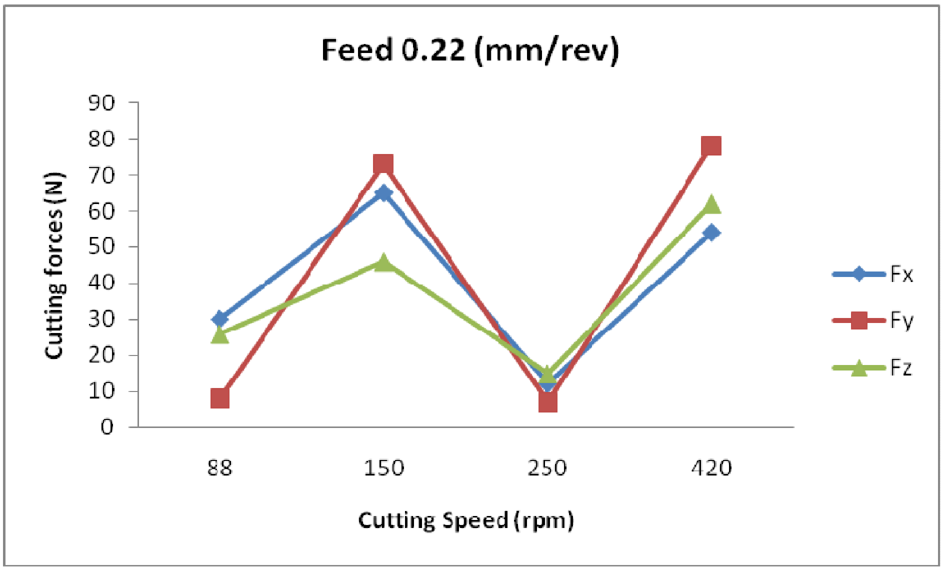


Fig. 5.4 Cutting Speed Vs Forces at 0.22 Feed

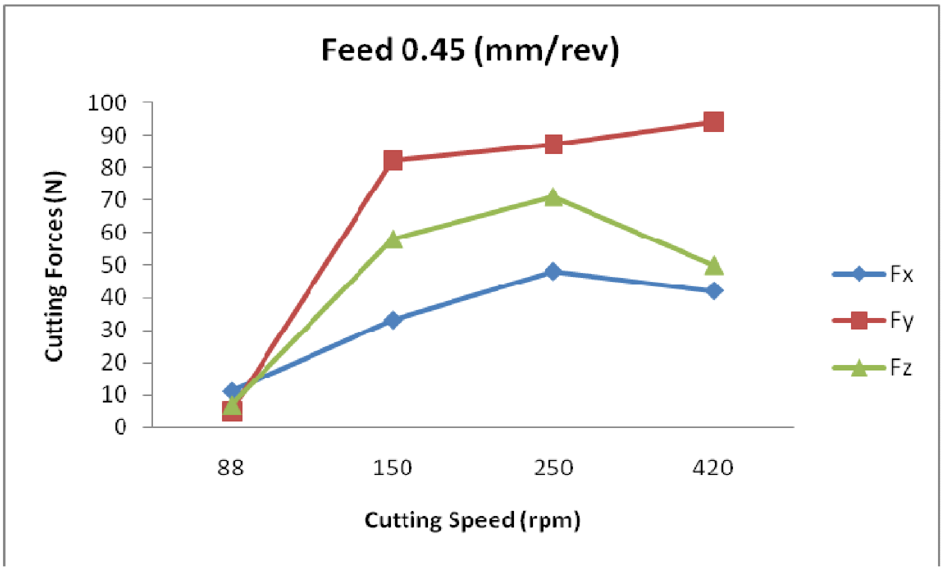


Fig. 5.5 Cutting Speed Vs Forces at 0.45 Feed

5.2.2 VARIATION OF FLANK WEAR WITH CUTTING SPEED

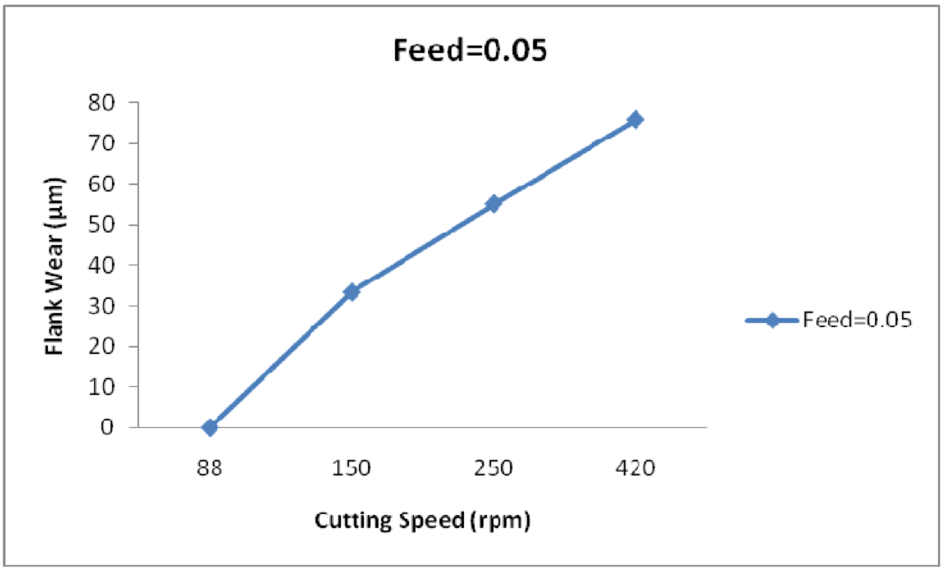


Fig. 5.6 Cutting Speed Vs Flank Wear at 0.05 Feed

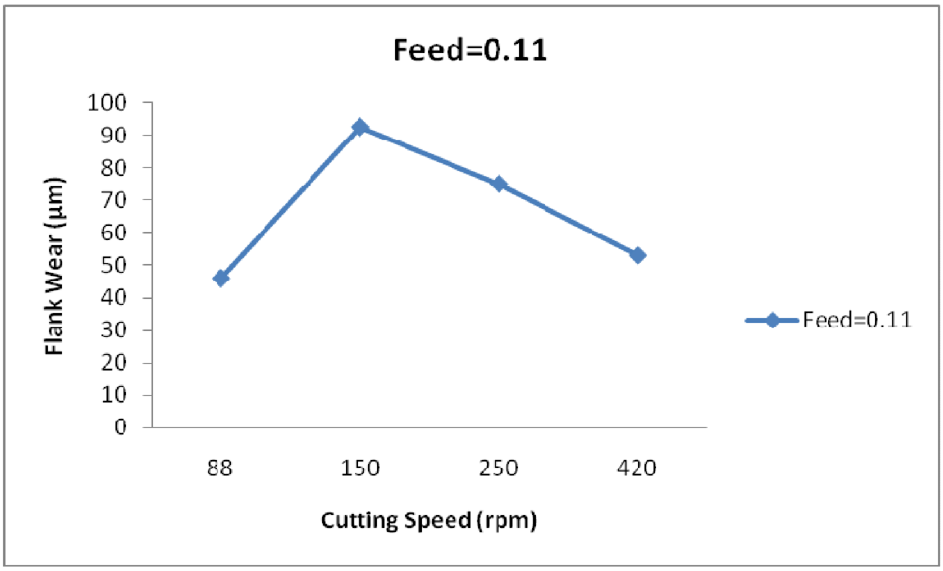


Fig. 5.7 Cutting Speed Vs Flank Wear at 0.11 Feed

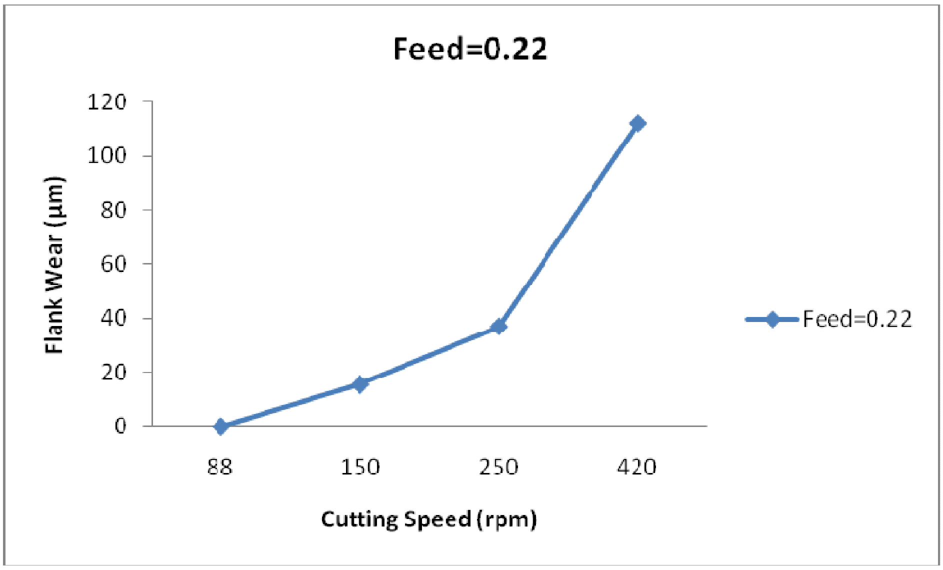


Fig. 5.8 Cutting Speed Vs Flank Wear at 0.22 Feed

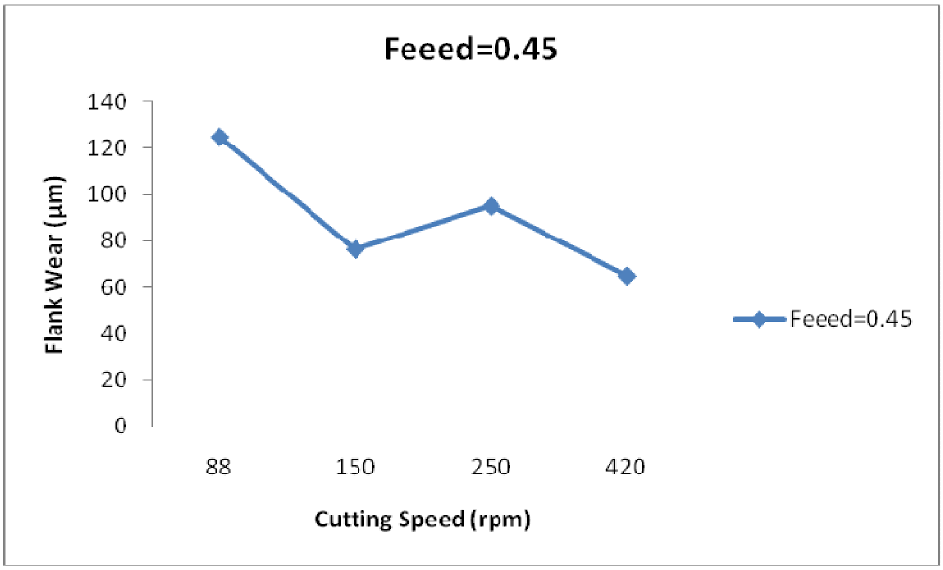


Fig. 5.9 Cutting Speed Vs Flank Wear at 0.45 Feed

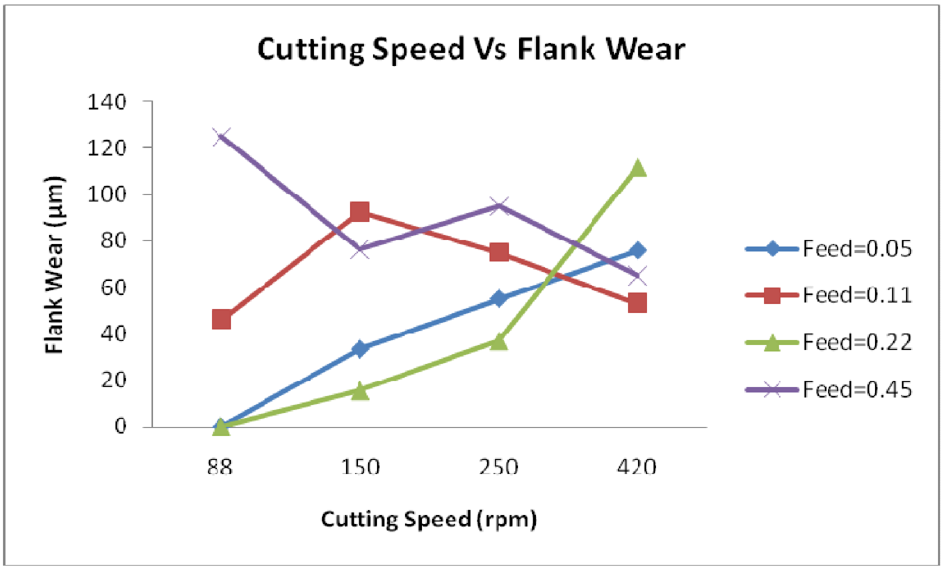


Fig. 5.10 Variation of Flank Wear with Cutting Speed

5.3 RESULTS AND DISCUSSIONS

1. Cutting Forces

There are three cutting forces which are acting on a single point tool (Fx,Fy and Fz)**.** The Fx is the feed force which is acting on the X direction, the Fy is cutting force acting of on Y direction and Fz is the radial force acting on the Z direction. The cutting forces were measured using 3 component dynamometer (Kistler, multi channel charge amplifier type 5070 and a data acquisition system). The figures 5.2-5.5 show the various cutting forces measured during turning. The radial force Fz was low when cutting at feed of 0.05 and 0.11 where as the cutting force Fy low at the start and increased when the cutting speed increased. The cutting force Fy was almost equal to Fx and Fz and gives better results at higher cutting speed. These are shown in the figure 5.4. During machining at 0.45 mm / rev cutting force Fx was high and shows increasing trend.

2. Tool Wear(Flank Wear)

The flank wear is a widely used criterion for evaluating tool life because of its importance in most applications. The figure 5.6-5.10 shows cutting speed Vs flank wear. Flank wear is produced mainly by the abrasion of carbides, sand inclusions and harder chilled skins.

The flank wear in this experiment was not present when machining at 88 rpm cutting speed and at 0.05 mm / rev feed, then increased to 76µm at 420 rpm speed having same feed rate. But flank wear 125 µm observed at speed 88 rpm having feed of 0.45 mm /rev. In other experiments, the flank wear was less than 125 µm. Fig. 5.11 show flank wear at 150 rpm and 0.22 mm/rev feed and fig. 5.12 shows nose wear at 88 rpm and 0.45 mm/rev feed. The micro cracks are shown in the figure Fig. 5.13 at 250 rpm and 0.22 mm/rev feed. The two main effects are responsible for tool wear are oxidation of the tool and interdiffusion of the constituting elements between tool and workpiece. Fig. 5.14 shows flank wear surface at 150 rpm and 0.45 mm/rev feed and fig. 5.15 shows Built up Edge (BUE) formation at cutting speed of 420 rpm and 0.11 mm/rev feed. Hard particles plough grooves into the cutting tool material. Excessive notch wear affects surface finish and weakens the cutting edge. Fig. 5.15 shows notch wear at 250 rpm and 0.05 mm/rev feed rate.

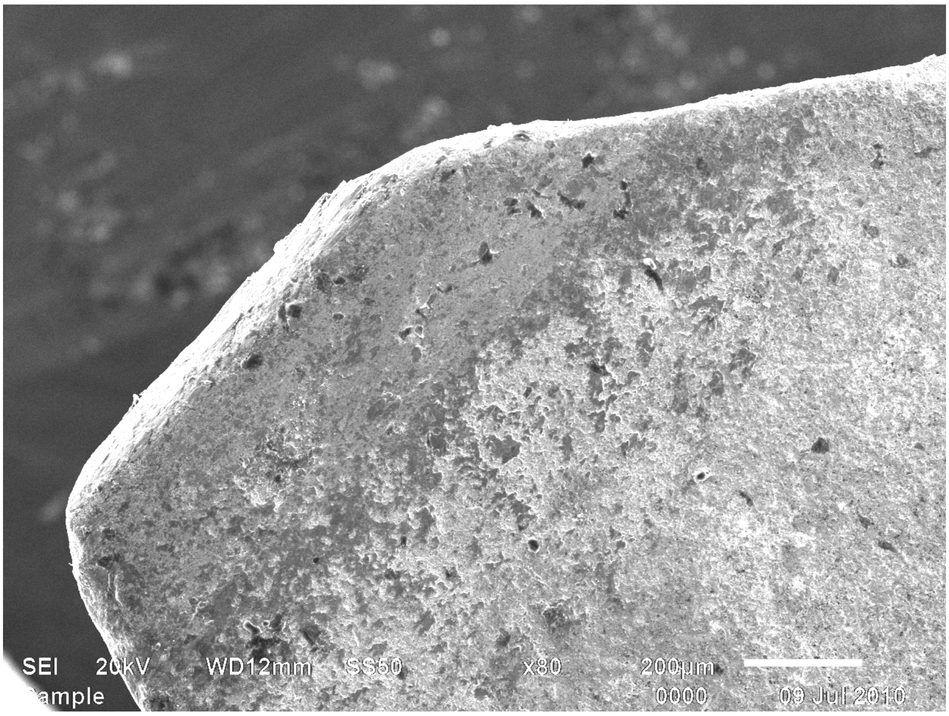


Fig. 5.11 SEM Micrograph shows Flank Wear at 150 rpm and 0.22 mm/rev feed

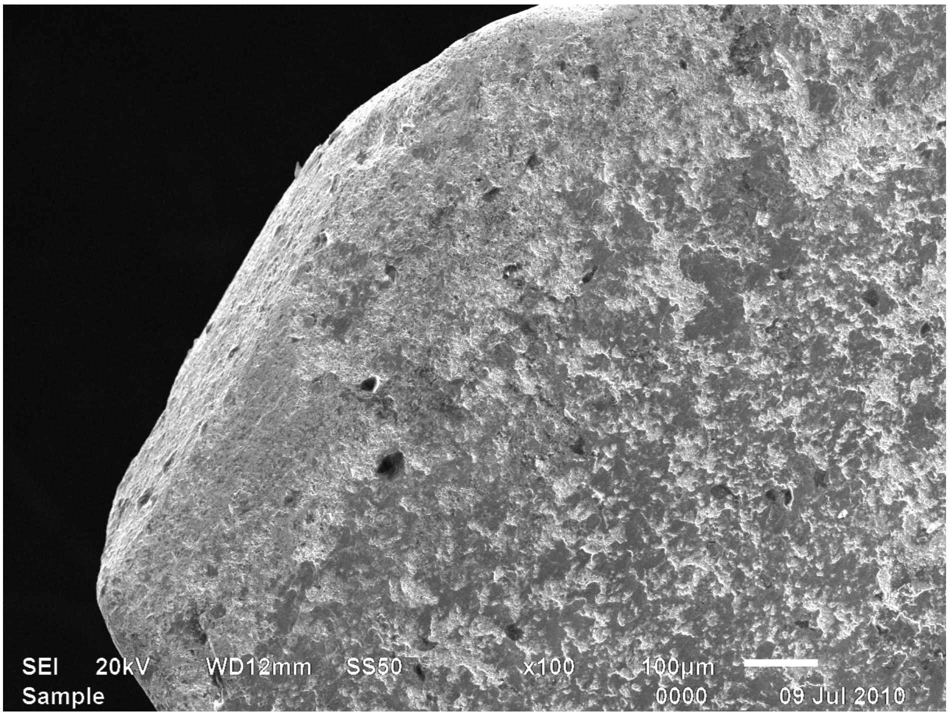


Fig. 5.12 SEM Micrograph shows Nose Wear at 88 rpm and 0.45 mm/rev feed

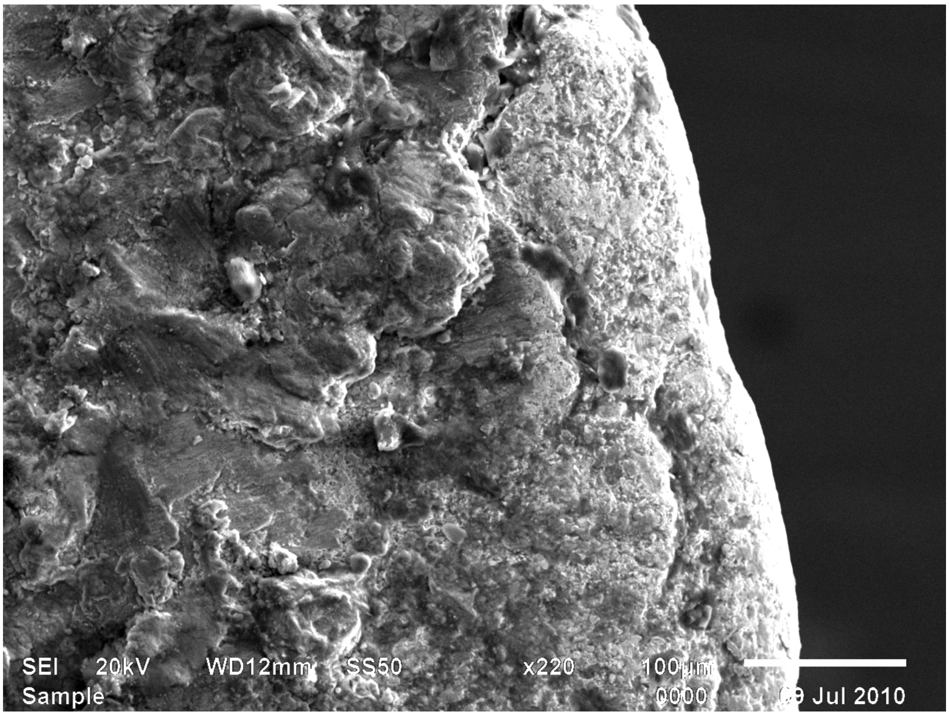


Fig. 5.13 SEM Micrograph shows micro crack formation at 250 rpm and 0.22 mm/rev feed

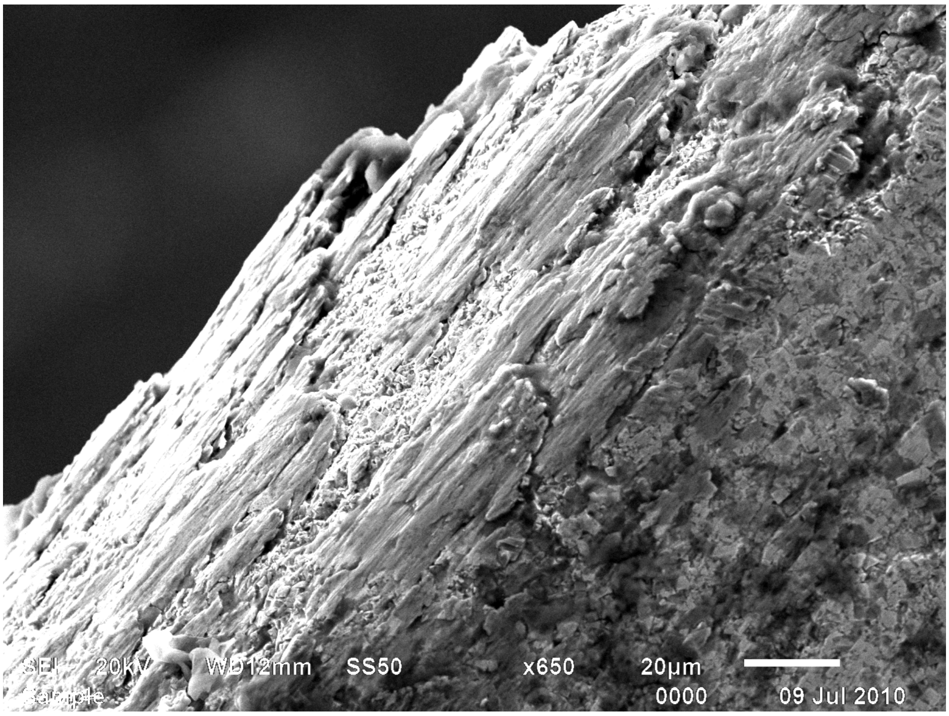


Fig. 5.14 SEM Micrograph shows flank wear surface at 150 rpm and 0.45 mm/rev feed

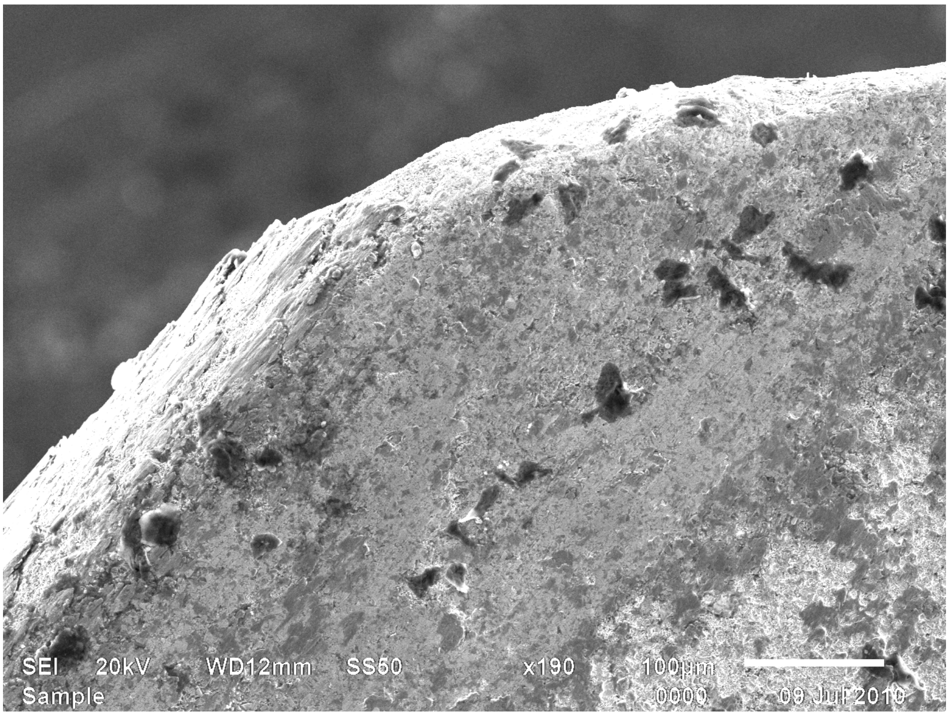


Fig. 5.15 SEM Micrograph shows BUE at 420 rpm and 0.11 mm/rev feed rate

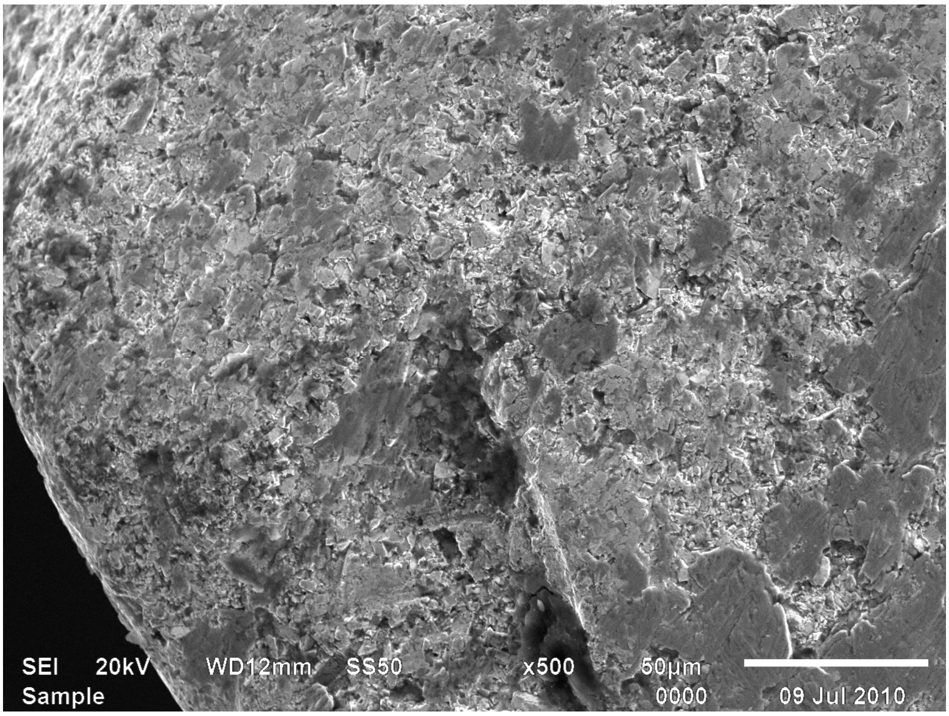


Fig. 5.16 SEM Micrograph shows notch wear at 250 rpm and 0.05 mm/rev feed rate

5.4 CONCLUSIONS

Based on the results presented in previous sections, the following conclusions have been observed:

1. The cutting forces have significantly less value at the cutting speed of 88 rpm and 250 rpm for all feed rates except the feed rate of 0.45 mm/rev.
2. The radial force Fz was almost equal to Fx and Fy and at higher cutting speeds.
3. During machining at 0.45 mm / rev cutting force Fy was high and shows increasing trend.
4. Maximum flank wear 125 μm observed at speed 88 rpm having feed rate of 0.45 mm /rev.
5. The flank wear occurred at low cutting speed with high feed rate.
6. Built up Edge(BUE) is formed at cutting speed of 420 rpm and 0.11 mm/rev feed rate.
7. Notch wear is observed at cutting speed of 250 rpm and 0.05 mm/rev feed rate.

5.5 SCOPE FOR FURTHER WORK

With increasing competitiveness as observed in the recent times, manufacturing systems in the industry are being driven more and more aggressively. So there is always need for perpetual improvements. Thus for getting still more accurate results we can take into account few more parameters as given below:

1. CNC machines can be used for the experimentation to have the better control of the process variables and also parameters can be set to the desired accuracy.
2. The other combinations of machine, cutting tool and work material can be studied.
3. The study can also be extended on other hard tool materials e.g. CBN etc.
4. The range of different machining parameters can be studied.
5. The experiments can be conducted for constant time period instead of constant volume.
6. Further research can be extended on temperature measurements.

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APPENDIX – A

SPECIFICATIONS OF THE CENTRE LATHE

Center Height	200 mm
Center Distance	1000 mm
Swing	
Over Bed	420 mm dia
Over Cross slide	220 mm dia
In Gap	550 mm dia
Gap Width 155 mm dia	
Transverse	
Of Cross slide	225 mm
Of Top	125 mm
Of Tailstock Spindle	150 mm
Spindle Bore	53 mm dia
Spindle Bore Taper	Metric Short No. 7
Spindle Speed	32-1200 rpm
Spindle Speed Ratio	1.69
Tool Shank Size	25x25, 20x20 mm
Feed	
Longitudinal Feeds	0.05-2.7 mm/rev
Cross Feed	0.01-0.54 mm/rev
Main Motor	2.2KW/3 HP
Weight of Machine	1250 Kg
Height of the Spindle Center above Floor	1035 mm
Floor Space	915x2725 mm
3 Phases, 415 V, 50 Hz, AC Supply	

APPENDIX –B

SEM SPECIFICATIONS

MAKE: JOEL JSM-6510LV

Resolution	High Vacuum mode: 3.0 nm (30kV) Low Vacuum mode: 4.0 nm (30kV)
Accelerating voltage	0.5 to 30 kV
Magnification	x5 to 300,000 (printed as a 128mm x 96mm micrograph)
Filament	Pre-centered W hairpin filament (with continuous auto bias)
Objective lens	Super conical lens
Objective lens apertures	Three position, controllable in X/Y directions
Maximum specimen size:	
GS Type stage	32mm full coverage
LGS Type stage	125mm dia. full coverage (152.4mm dia. loadable)
Specimen stage**:	
GS Type stage	Eucentric goniometer X=20mm, Y=10mm, Z=5mm-48mm R=360° (endless) Tilt -10/+90°
LGS Type stage	Eucentric goniometer X=80mm, Y=40mm, Z=5mm-48mm R=360° (endless) Tilt -10/+90° (Computer controlled 2, 3 or 5 axis motor drive: option)

APPENDIX –C

WORKPIECE SPECIFICATIONS

Work piece material : EN 38 steel

Work piece combination :

C: 0.35-0.4%

Si: 0.05-0.35%

Mg: 0.6-0.9%

Sulphur: 0.5%

Phosphorous: 0.5%

- Cutting tool material : K10 CARBIDE INSERT
- Hardness : 1500 BHN