PERFORMANCE EVALUATION OF UNCOATED AND MULTI LAYER TiN COATED CARBIDE TOOL IN HARD TURNING

A THESIS SUBMITTED IN PARTIAL FULFILMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

By

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Rourkela

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CERTIFICATE

This is to certify that thesis entitled, **"**PERFORMANCE EVALUATION OF UNCOATED AND MULTI LAYER TiN COATED CARBIDE TOOL IN HARD TURNING**''** submitted by Miss. SUPRIYA SAHU in partial fulfilment of the requirements for the award of Master of Technology in Mechanical Engineering with specialization "Production Engineering" during session 2008-2012 in the Department of Mechanical Engineering, National Institute of Technology, Rourkela.

It is an authentic work carried out by her under our supervision and guidance. To the best of our knowledge, the matter embodied in this thesis has not been submitted to any other University/Institute for award of any Degree or Diploma.

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ABSTRACT

Hard coatings are well known to improve the performance of cutting tools in machining applications, such as high-speed machining and machining of MMC etc. Unfortunately, the development of cutting tool for high-speed machining of hard and difficult-to-cut material has remain a problem for quality and economy of production. The present work studies the performance of multi layer coated tool in machining of hardened steel (AISI 4340 steel) under high speed turning and compared with that of uncoated tool. Also the soft aluminium and soft and abrasive (Al+5% Si) were turned using CNC lathe. The influence of cutting parameters (speed, feed, and depth of cut) on cutting forces, surface finish and tool wear has been analyzed. Under the different cutting conditions, forces were measured both for coated and uncoated tools. For coated tools the forces obtained of resulted in relatively low values. For comparison, uncoated tool was also tested under the similar cutting conditions. The surface roughness of the workpieces were found out using Taylor Hobson (Surtronic 25) Surface Roughness Tester. Tool wear measurements demonstrate the capability of such tools in turning hard materials with reasonable tool life. The wear mechanism at the end of tool life was investigated in detail using scanning electron microscope (SEM). It has also been found that the machining of hard materials at higher speeds and lower feeds is improved by using coated tools as compared to uncoated tools. Turning with coated tool is more economical than the uncoated in terms of energy and power requirements.

CHAPTER 1

INTRODUCTION

1.2. Recent trends in manufacturing by machining

The recent developments in science and technology has put tremendous pressure on manufacturing industries. The manufacturing industries are trying to decrease the cutting costs, increase the quality of the machined parts and machine more difficult materials. Machining efficiency is improved by reducing the machining time with high speed machining. When cutting ferrous and hard to machine materials such as steels, cast iron and super alloys, softening temperature and the chemical stability of the tool material limits the cutting speed.

The productivity enhancement of manufacturing processes imposes the acceleration of the design and evolution of improved cutting tools with respect to the achievement of a superior tribological attainment and wear-resistance. Because of the highly non linear nature of metal cutting and the complex coupling between deformation and temperature fields, a complete understanding of the mechanics of metal cutting is still lacking and is thus the topic of great deal of current research. High speed machining has been the main objective of the Mechanical Engineering through ages. The trend to increase productivity has been the instrumental in invention of newer and newer cutting tools with respect to material and designs. High speed machining is not associated with increased productivity and better surface finish rather associated with a great amount of heat generation. Where the power requirement rises since large amount of cutting force is involved.

Finish hard turning is a new machining process that enables manufacturers to machine hardened materials to their finish part quality without the aid of grinding. Hard turning with multilayer coated carbide tool has several benefits over grinding process such as, reduction of processing costs, increased productivities and improved material properties. This process enables manufacturers to increase product quality and efficiency, while decreasing the cost and processing time. Hard turning is also very attractive to manufacturers because this process is possible without the use of cutting fluid or other lubricants. Dry cutting is beneficial because of the elimination of the cost of the cutting fluid as well as the high cost of fluid disposal. The increasing need to boost productivity, to machine more difficult materials and to improve quality in high volume by the manufacturing industry has been the driving force behind the development of cutting tool materials.

One important aspect that is being vigorously researched and developed is the hard coating for cutting tools. These hard coatings are thin films that range from one layer to hundreds of layers and have thickness that range from few nanometers to few millimeters. These hard coatings have been proven to increase the tool life by as much as 10 folds through slowing down the wear phenomenon of the cutting tools. This increase in tool life allows for less frequent tool changes, therefore increasing the batch sizes that could be manufactured and in turn, not only reducing manufacturing cost, but also reducing the setup time as well as the setup cost. In addition to increasing the tool life, hard coating deposited on cutting tools allows for improved and more consistent surface roughness of the machined work piece. The surface roughness of the machined work piece changes as the geometry of the cutting tool changes due to wear, and slowing down the wear process means more consistency and better surface finish.

Machining efficiency is improved by reducing the machining time with high speed machining. When cutting ferrous and hard to machine materials such as steels, cast iron and super alloys, softening temperature and the chemical stability of the tool material limits the cutting speed. Therefore, it is necessary for tool materials to possess good high-temperature, mechanical properties and sufficient inertness. While many ceramic materials such as TiC, Al2O3 and TiN possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The machining of hard and chemically reactive materials at higher speeds is improved by depositing single and multi layer coatings on conventional tool materials to combine the beneficial properties of ceramics and traditional tool materials. The majority of cutting tools in use today employ chemical vapour deposition (CVD) or physical vapour deposition (PVD) hard coatings. The high hardness, wear resistance and chemical stability of these coatings offer proven benefits in terms of tool life and machining performance. The first technique is the CVD. This method deposits thin films on the cutting tools through various chemical reactions. Most tool coatings were traditionally deposited using the CVD technique until the recent development of PVD. This method deposits thin films on the cutting tools through physical techniques, mainly sputtering and evaporation. Coated hard metals have brought about tremendous increase in productivity since their introduction. Since then coatings have also been applied to high speed steel and especially to HSS drills. Coatings are diffusion barriers ,they prevent the interaction between chip formed during the machining and the cutting material itself. The compounds which make up the coatings used are extremely hard and so they are very abrasion resistant. Typical constituents of coating are Titanium Carbide(TiC), Titanium Nitride (TiN), Titanium Carbonitride (TiCN) and alumina (Al_2O_3).

1.3. Significance of metal cutting

Metal cutting is the removal of metal from work piece in the form of chips in order to obtain a finished product with desired size, shape and surface finish. In virtually all producing sectors for example automobiles, railways, shipbuilding, aircraft manufacture, home appliance , consumer electronics and construction industries etc one finds large shops with many thousands of machining .The cost of machining amounts to more than 15% of to value of the all manufactured products in all industrial countries. Of all the processes used to shape metals, in metal cutting the conditions of operation can be varied to a greater extent to improve the quality and the rate of producing with a reduced cost.

1.4. Theory of metal cutting

Metal cutting process forms the basis of the engineering industry and is involved either directly or indirectly in the manufacture of nearly every product of our modern civilization. The cutting tool is one of the important elements in realizing the full potential out of any metal cutting operation. Over the years the demands of economic competition have motivated a lot of research in the field of metal cutting leading to the evolution of new tool materials of remarkable performance and vast potential for an impressive increase in productivity**.** As manufacturers continually seek and apply new materials for products that are lighter and stronger and therefore more efficient employing that cutting tools must be so developed that can machine new materials at the highest possible productivity.

The main properties which any cutting material must possess in order to carry out its function are:

1. Hardness to overcome wearing action

2. Hot strength to overcome the heat involved

3. Sufficient toughness to withstand vibration

In general, increasing hardness brings with it a reduction in toughness and so those materials in the higher hardness region of the list will fail by breakage if used for heavy cuts, particularly with work pieces which have holes or slots in them which give rise to interruption in the cut.

The properties that a tool material must possess are as follows:

• Capacity to retain form stability at elevated temperatures during high cutting speeds.

• Resistance to diffusion

• High resistance to brittle fracture

• Resistance to thermal and mechanical shock

• Low Cost and ease of fabrication

The cutting tools must be made of materials capable of withstanding

- High stresses (High strength and wear resistant)
- High temperature (high hot hardness)
- Shock generated during chip formation (tough)

In addition to this the material should have the following properties

- Chemical stability
- Anti welding and anti diffusivity
- Thermal conductivity
- Low thermal expansion coefficient
- High Young's modulus
- Easy availability, manufacturability and above all low cost.

1.5. Chronological development of cutting tools

Cutting tools are in continuous stage and have reached a glorious stage to cope of with modern development of science and technology.

A Chronological development of cutting tool materials are given as follows

1. High speed steel
2. Carbides
3. Ceramics
4. UCON
5. Coated Carbides
6. Cubic Boron Nitride (CBN)
7. Diamond

Out of the above materials coated carbides serves as the new generation material material to meet the present needs where must of the research as for used. Carbides which serves almost 60 to 80% of machining needs have taken the market of machining in particular ferrous materials.

1.5. Coatings

Machining efficiency is improved by reducing the machining time with high speed machining. But the softening temperature and the chemical stability of the tool material limits the cutting speed. When cutting ferrous and hard to machine materials such as steels, cast iron and super alloys, softening temperature and the chemical stability of the tool material limits the cutting speed. Therefore, it is necessary for tool materials to possess good high-temperature mechanical properties and sufficient inertness. While many ceramic materials such as TiC, Al2O3 and TiN possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The machining of hard and chemically reactive materials at higher speeds is improved by depositing single and multi layer coatings on conventional tool materials to combine the beneficial properties of ceramics and traditional tool materials.

Coatings are diffusion barriers, they prevent the interaction between chip formed during the machining and the cutting material itself. The compounds which make up the coatings used are extremely hard and so they are very abrasion resistant. Typical constituents of coating are Titanium Carbide(TiC), Titanium Nitride (TiN), Titanium Carbonitride (TiCN) and alumina (Al_2O_3). All these compounds have low solubility in iron and they enable inserts to cut at much higher rate.

Carbide substrates are used because of their

- Higher Productivity by high speed machining
- Improved toughness and crack resistance by optimal dispersion of hard particles.
- Improved plastic deformation resistance and welding resistance for high cutting speed operations.

The effect of coatings are

1. Reduction in friction
2. Reduction in generated heat
3. Reduction in cutting forces.
4. Reduction in the diffusion between the chip and the surface of the tool, especially at higher speeds (the coating acts as a diffusion barrier).
5. Prevention of galling, especially at lower cutting speeds.

In addition to increase the tool life, hard coating is deposited on cutting tools. The majority of cutting tools use chemical vapour deposition (CVD) or physical vapour deposition (PVD) hard coatings, which improves tool life and machining performance.

1.5.1. Types of Coating Technology

Surface coating of tribological applications is associated with deposition temperatures ranging from room temperature to over 1000°C. The coating thickness ranges from microns to several millimeters. Typically, the atomistic methods produce the thinnest coatings. Some methods involve high deposition temperatures that may give undesired phase transformations, softening or shape changes of the coated component. An important benefit of PVD and CVD processes is the high flexibility as to composition and structure of the coatings, and these processes are today successfully utilized to coat a large variety of mechanical components.

1.5.2. CVD (Chemical Vapour Deposition)

CVD method deposits thin films on the cutting tools through various chemical reactions.CVD coated cemented carbides have been a huge success since their introduction in the late 1960's. Since then, chemical vapour deposition technologies have advanced from single layer to multi layer versions combining TiN, TiCN, TiC and Al_2O_3. Modern CVD coatings combine high temperature and medium temperature processes in complex cycles that produce excellent wear resistant coatings with a total thickness of 4-20 μm. However, the high deposition temperature (950-1059°C) during CVD results in diffusion of chemical elements from the carbide substrate to the coating during growth. The main effect is an embrittlement of the coating edge. In addition, the chemistry of the CVD process results in more rapid growth at the cutting edge resulting in an even coating thickness. Therefore, there was a strong driving force to find coatings that could be deposited at lower temperatures in order to allow tools with sharper edges to be coated without any embrittlement effect. The solution is PVD where deposition temperature can be kept at around 500°C.

1.5.3. How does CVD works?

Chemical vapour deposition is a chemical process used to produce high-purity, high-performance solid materials. In a typical CVD process, the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit. Frequently, volatile by-products are also produced, which are removed by gas flow through the reaction chamber. Microfabrication processes widely use CVD to deposit materials in various forms, including: monocrystalline, polycrystalline, amorphous, and epitaxial. These materials include: silicon, carbon fiber, carbon nanofibers, filaments, carbon nanotubes, SiO_2, silicon-germanium, tungsten, silicon carbide, silicon nitride, silicon oxynitride, titanium nitride, and various high-dielectrics. The CVD process is also used to produce synthetic diamond. It is a chemical process used to produce high-purity, high-performance solid materials. The results show that the CVD coating has to be used to improve the production.

1.5.4. PVD (Physical Vapour Deposition)

PVD method deposits thin films on the cutting tools through physical techniques, mainly sputtering and evaporation .PVD coatings, with deposition temperatures of 400-600°C, are gaining greater acceptance in the market place. Over the last decade, they have been successfully applied to carbide metal cutting inserts. They offer performance advantage in applications involving interrupted cuts, those requiring sharp edges, as well as finishing and other applications. Depending on the intended application, different

PVD technologies such as electron beam evaporation, sputtering and arc evaporation are used. Improvements in these technologies such as high ionization magnetron sputtering and new cathodic arc processes have further improved the performance of PVD coated tools. The metal cutting performance of PVD coated tools depend strongly on the composition, microstructure, internal stresses and adhesion of the coating to the substrate as well as the substrate composition and tool geometry. PVD process chain includes pre-PVD processes and post PVD-processes. Pre-treatment processes such as plasma etching and chemical etching influence adhesion, grain growth, stress at substrate surface and coating structure, whereas post-PVD processes influence smoothness of coating surface and better chip flow. PVD coatings attribute excellent cutting performance to cemented carbide inserts. The reason that PVD has more and more taken over with regards to deposition of many coatings is the advantages that lower coating temperatures give with regard to micro-toughness.

1.5.5. Advantages of CVD coated carbides

-A wide range of applications from low to high speed and finishing to roughing.

- Stable Machining is obtained due to high toughness and crack resistant.

- Possible to reduce machining time and maintain good chip control with various chip breakers.

1.6.Types of coating

1.6.1. Single layer coating

The first coating was a single layer of TiC.10 to 12 micrometers thick, which was deposited by a process known as chemical vapour deposition (CVD) onto a substrate of hard metal. During the deposition process some carbon was taken up from the surface of the hard metal as part of coating and this changed the carbon balance at the junction of the coating and the hard metal substrate. This lowering of the carbon balance caused the formation of a brittle compound at the interface between the coating and the substrate and made early coated indexable inserts sensitive to chipping of cutting edge.

The next development was to put down a coating of TiN which prevented any decarburising of the hard metal substrate but the coating which is gold in colour ,did not adhere well to the hard metal base. TiN is an even better diffusion barrier than TiC but TiC has better abrasion resistance.

1.6.2. Multi layer coatings

Although single-layer coatings are finding a range of applications in many sectors of engineering, there are an increasing number of applications where the properties of a single material are not sufficient. One way to surmount this problem is to use a multilayer coating that combines the attractive properties of several materials, each chosen to solve a problem in the application. Multi layer coatings can consist of as many as eight layers with in a total thickness of 10 micrometers or less. Simple examples of this include the use of interfacial bonding layers to promote adhesion, or thin inert coatings on top of wear-resistant layers to reduce the corrosion of cutting tools. There is, however, mounting evidence that the multilayer structure produced when many alternating layers of two materials are deposited can lead to improvements in performance over a mixed coating (by virtue of the introduction of new interfaces) even if the two materials do not have specific functional requirements in the intended application.

1.6.3. Why TiN ?

The majority of inserts presently used in various metal cutting operations are carbide tools coated with nitrides (TiN, CrN, etc.). The TiN deposited as a mono-layer holds a dominant position in the field of hard coatings.

TiN coating is usually used as an outermost layer. As

- it increases the wear resistance
- reduces the sticking of the work material .
- the golden color of the TiN coating helps in wear detection by allowing the operator to distinguish between a used and a new cutting edge corner

1.7. Tool wear

The prediction and control of wear is one of the most essential problems emerging in the design of cutting operations. A useful definition for a worn out tool is: “A tool is considered to be worn out when the replacement cost is less than the cost for not replacing the tool”. Tool failure is said to occur when the tool no longer performs the desired function whereas total failure (ultimate failure) is defined as the complete removal of the cutting edge, a condition obtaining when catastrophic failure occurs. Therefore, in machining operations, tools are considered to be worn out and are changed long before total failures to avoid incurring high costs associated with such catastrophic failures. The tool may experience repeated impact loads during interrupted cuts, and the work piece chips may chemically interact with the tool materials. The useful life of a cutting tool may be limited by a variety of wear processes such as crater wear, flank wear or abrasive wear, built up edge, notching and nose wear.

Flank wear is observed on the flank or clearance face of a metal cutting insert and is caused mainly by abrasion of the flank face by the hard constituents of the workpiece .

Crater wear is observed on the rake face of cutting tools and is caused by chemical interactions between the rake face of a metal cutting insert and the hot metal chip flowing over the tool.

CHAPTER-2

LITRTURE REVIEW

Increasing the productivity and the quality of the machined parts are the main challenges of manufacturing industries. This objective requires better management of the machining system. This literature includes information on hard materials, soft materials, and soft and abrasive materials used in turning, coating materials for cutting tools, wear observed during turning operations and surface finish of the machined work piece. Optimization of cutting parameters is valuable in terms of providing high precision and efficient machining. So an attempt is made to optimize machining parameters using coated tools. The user of the machine tool must know how to choose cutting parameters in order to minimize cutting time, cutting force and produce better surface finish under stable conditions.

The use of coating materials to enhance the performance of cutting tools is not a new concept. Coated hard metals have brought tremendous increase in productivity since their introduction in 1969 and had an immediate impact on the metal cutting industries [3].Due to their significantly higher hardness, carbide-cutting tools are more widely used in the manufacturing industries today than high-speed steels. Coated and uncoated carbides are widely used in the metal working industry and provide the best alternative for most turning operations [4]. Due to their heat resistance, cemented carbides can be used in very hot applications and all types of PVD and CVD processes can be used to deposit coatings [5].The combined substrate-coating properties determine the important properties such as wear, abrasion resistance and adhesion strength of a coating. A hard wear resistant coating can not perform well unless complimented by a hard and tough substrate. Thus, a hard coating deposited on a soft substrate leads to poor properties [1]. Physically and chemically vapour deposited coatings offer today a powerful alternative to improve further the cutting performance of the cutting materials.

It is necessary for tool materials to possess high temperature strength. While many ceramic materials such as TiC, $Al2O3$ and TiN possess high temperature strength, they have lower fracture toughness than that of conventional tool materials such as high-speed steels and cemented tungsten carbides. The machining of hard and chemically reactive materials at higher speeds is improved by depositing single and multi layer coatings on conventional tool materials to combine the beneficial properties of ceramics and traditional tool materials [2].

Machining of metals is a complex process. The cutting tool environment features high-localized temperatures and high stress. The tool may experience repeated impact loads during interrupted cuts, and the work piece chips may chemically interact with the tool materials. The useful life of a cutting tool may be limited by a variety of wear processes such as crater wear, flank wear or abrasive wear, built up edge, depth of cut notching and nose wear. Flank wear is observed on the flank or clearance face of a metal cutting insert and is caused mainly by abrasion of the flank face by the hard constituents of the workpiece.

S. PalDey et al [6] have discussed the wear resistant properties of (Ti,Al)N for various machining applications as compared with coatings such as TiN, Ti(C,N) and (Ti,Zr)N. Tey have found that the high hardness (28_32 GPa), relatively low residual stress (/5GPa), high oxidation resistance, high hot hardness, and low thermal conductivity make (Ti,Al)N coatings most desirable in dry machining and machining of abrasive alloys at high speeds. Multicomponent coatings based on different metallic and nonmetallic elements such as, Cr and Y drastically improve the oxidation resistance, Zr and V improve the wear resistance, whereas, Si increases the hardness, boron improves the abrasive wear behaviour and resistance to chemical reactivity of the film. The presence of a large number of interfaces between individual layers of a multilayered structure results in a drastic increase in hardness and strength. So it is possible to design new wear resistant or functional coatings based on a multilayer or a multi component system to meet the demanding applications of advanced materials.

J.A. Ghani et al [7] investigated the wear mechanism of TiN-coated carbide and uncoated cermets tools at various combinations of cutting speed, feed rate, and depth of cut for hardened AISI H13 tool steel. They have observed that the time taken for the cutting edge of TiN-coated carbide tools to initiate cracking and fracturing is longer than that of uncoated cermets tools, especially at the combinations of high cutting speed, feed rate, and depth of cut and at the combinations of low cutting speed, feed rate, and depth of cut, the uncoated cermets tools show more uniform and gradual wear on the flank face than that of the TiN-coated carbide tools.

Tugrul O zel et al [8] presented the effects of cutting edge preparation geometry, workpiece surface hardness and cutting conditions on the surface roughness and cutting forces in the finish hard turning of AISI H13 steel. They have found that the cutting forces are influenced not only by cutting conditions but also the cutting edge geometry and workpiece surface hardness. The lower workpiece surface hardness and small edge radius resulted in lower tangential and radial forces.

Jeong Suk Kim et al [9] investigated that hard coatings improve the performance of cutting tools in aggressive machining applications, such as high-speed machining. Additionally, the relationship between the machining characteristics and the Si contents were investigated under various high-spindle speeds. It has shown that the tool life was improved up to 50% for the Si content.

J.G. Lima et al [10] have evaluated the machinability of hardened steels at different levels of hardness and using a range of cutting tool materials. They have proved in their result that turning of AISI 4340 steel using low feed rates and depths of cut, the forces were higher when machining the softer steel and that surface roughness of the machined part was improved as cutting speed was elevated and deteriorated with feed rate.

Yong Huang et al [11] have evaluated tool performance in terms of tool life based on the flank wear criterion as a function of cutting conditions, that is, cutting speed, feed, and depth of cut. They found out that cutting speed plays a dominant role in determining the tool performance in terms of tool life, followed by feed and depth of cut, and overall tendencies agree with predictions from the general Taylor tool life equation as well as experimental observations.

J.A. Arsecularatne et al [12] described an experimental investigation on machining of a difficult-to-cut material, AISI D2 steel of hardness 62 HRC with PCBN tools. They have found that most of the tested PCBN tools reached the end of life mainly due to flank wear. The highest acceptable values of tool life and volume of material removal were obtained at the lowest speed tested (70 m/min) but the highest feed used resulted in the highest volume of material removal, lower feeds resulted in higher tool life values.

Ibrahim Ciftci [13] presented the results of experimental work in dry turning of austenitic stainless steels (AISI 304 and AISI 316) using CVD multilayer coated cemented carbide tools. The cutting tools used were TiC/TiCN/TiN and TiCN/TiC/Al2O3 coated cementide carbides. They found out that the cutting speed significantly affects the machined surface roughness values. With increasing cutting speed, the surface roughness values decreased until a minimum value is reached beyond which they increases.

Abhijeet S. Morea et al [14] have proposed that PCBN is the dominant tool material for hard turning applications due to its high hardness, high wear resistance, and high thermal stability. They have presented the result that the flank wear is mainly due to abrasive actions of the martensite present in the hardened AISI 4340 alloy. The crater wear of the cBN–TiN coated inserts is less than that of the PCBN inserts because of the lubricity of TiN capping layer on the cBN–TiN coating.

J. Rech [15] found out that various coatings deposited on a carbide insert has shown the sliding properties of the TiN and (Ti, Al)N+MoS2 coatings, compared to uncoated tools in the context of high-speed dry turning of steels. TiN and (Ti, Al)N+MoS2 coatings reduce the tool–chip contact area, the thickness of the secondary shear zone and the temperature at this interface, which reduce the heat flux transmitted to the cutting tool substrate.

Renato Franc oso de A vila et al [16] tested the performance of uncoated and coated carbide tools (ISO grade K10) with a 3 _m thick monolayer of TiN (produced by PAPVD) when continuous turning AISI 8620 steel. Their results indicate that two distinct crater wear rates are present when machining using coated cutting tools, whereas a higher and single wear rate was identified for the uncoated inserts.

C.H. Che Haron et al [17] investigated the tool life and wear behaviour at various machining parameters. Coated carbide (KC 9125) and uncoated carbide (K 313) were used in turning tool steel AISI D2 bar with hardness of 25 HRC and have found that the wear progression for both type of carbide tools experienced three stages of wear rate, namely; initial, gradual and abrupt stages of wear mechanism. Slow wear rate and uniform flank wear were observed at low feed rate of 0.05 mm/rev. Generally, coated tool performed better as compared to uncoated tool. A good surface finish and longer tool life were achieved using coated tool.

Prabhu U. Arumugam et al [18] have investigated the performance of polished chemical vapor deposited (CVD) diamond tool carbide inserts in comparison with unpolished CVD diamond coated carbide tool inserts in the dry turning of A390 aluminum–silicon hypereutectic alloy. They demonstrated that CVD diamond-coated polished tools generate fewer particles, unlike conventional diamond tools (PCD and unpolished CVD),improve tool life and reduce the cutting forces.

J. Rech [19] found out that coatings exhibit to the best tribological improvements compared to uncoated tools. Four complementary methods were used to qualify the performance of the tribological system with the purpose of reaching a better global understanding of the capability of coatings, chip formation mechanisms, cutting forces, interface temperature. TiN and (Ti,Al)N+MoS2 coatings have shown the best tribological improvements compared to uncoated tools.

A. Devillez et al [20] studied the elementary orthogonal cutting process by taking different coated tools and different cutting conditions. They have used the energy dispersive X-ray analysis and white light interferometer to observe the wear mechanisms and the AlTiN coating was seems to be the best coating. Its good tribological behaviour limits welding and unstable built-up-edge phenomena, abrasive wear is also reduced by its very high hardness due to its ultra-fine crystallinity.

Noordin, M.Y et al [21] introduced hard turning to manufacture parts made from hardened steels. TiAlN coated carbide tool was selected to finish machine hardened steel. Performing hard turning dry at various cutting conditions, that is, cutting speed and feed rate, revealed that satisfactory tool life values and surface finish values that meet the strict range of finish machining were obtained when finish machining hardened steel of 47–48 HRC hardness.

M.Y. Noordin et al [22] presented hard turning of martensitic stainless steel using wiper coated carbide tool at various cutting speeds and feeds. It was found that low cutting speed and low feed produces the longest tool life. The combination of high cutting speed and high feed was found to be unfavourable for hard turning of stainless steel. Wiper coated carbide tool achieved very fine surface finish, much better than the theoretical values and within the strict range of finish machining criteria.

Samir K. Khrais et al [23] did a detailed study on the tribological influences of PVD-applied TiAlN coatings on the wear of cemented carbide inserts and the microstructure wear behaviours of the coated tools under dry and wet machining. They analysed that the micro-structural variations of coatings provide structure-physical alterations as the measures for wear alert of TiAlN coated tool inserts under high speed machining of steels.

Vishal S Sharma et al [24] investigated the machining AISI 52100 steel using a carbide-coated tool. It was found that the cutting force increases with the feed rate and depth of cut. The approach angle has little effect on the cutting force, and increasing the speed causes the cutting force to decrease slightly. The feed force increased with increasing depth of cut and decreased with increasing approach angle, speed, and feed rate.

Reginaldo T. Coelhoa, et al [25] analysed on tool wear when turning hardened AISI 4340 with coated PCBN tools using finishing cutting conditions. They have shown the results of tool wear, cutting force and surface finish obtained from the turning operation on hardened AISI 4340 using PCBN coated and uncoated edges. Due to a combination of high hardness in the cutting temperature range and the presence of an oxidizing layer, TiAlN-nanocoating performed better in terms of tool wear and surface roughness.

CH.R. Vikram Kumar et al [26] studied the comparative performance of TiCN and TiAlN coated tools in machining of AISI 4340 hardened steel under dry, wet and minimum fluid application conditions. Both the tools performed better with minimum fluid application when compared with wet and dry machining. The performance of the TiAlN tool was observed to be better, this is particularly true with reference to wear resistance of the tools and better surface finish on the components.

Recep Yigit et al [27] have done an experimental investigation on the effect of cutting speed in turning nodular cast iron with coated and uncoated cutting tools. The test showed that uncoated WC/Co tool was the worst performing tool with respect to tool wear and the worst with respect to surface finish. The multilayer TiCN+TiC+TiCN+Al2O3 +TiN-coated carbide tool with external TiN layer is the most suitable one for turning nodular cast iron, especially at high cutting speeds.

D.I. Lalwani, N.K. et al [28] investigated the effect of cutting parameters (cutting speed, feed rate and depth of cut) on cutting forces (feed force, thrust force and cutting force) and surface roughness in finish hard turning of MDN250 steel using coated ceramic tool. They have used response surface methodology (RSM) and sequential approach using face centered central composite design. The have shown the result that the cutting forces and surface roughness do not vary much with experimental cutting speed in the range of 55–93 m/min.

R.F. Avila et al [29] analyzed cutting tool life used for cemented carbide tools is the depth of the crater (KT) located on the rake face, given as a function of the feed rate. The result brought a new approach and confirm the importance of the coating to the crater wear resistance, even if the coating has already been delaminated on the rake face.

Tugrul O zel et al [30] investigated the effects of cutting edge geometry, workpiece hardness,feed rate and cutting speed on surface roughness and resultant forces in the finish hard turning of AISI H13 steel. Their results shows that honed edge geometry and lower workpiece surface hardness resulted in better surface roughness. Cutting-edge geometry, workpiece hardness and cutting speed are found to be affecting force components. The lower workpiece surface hardness and honed edge geometry resulted in lower tangential and radial forces.

P. Roy et al [31] studied the compatibility of cutting materials in dry machining of Aluminum and Al–Si alloys. They have shown that chemical inertness of diamond towards aluminium was principally responsible for outperforming an uncoated tool along with other tools coated with hard coatings like TiC, TiN, TiB2, Al2O3, and AlON.

A.K. Chattopadhyay et al [32] studied the wetting characteristics of aluminium towards different cutting tool materials by using uncoated carbide (94%WC+6%Co) and mono or multi-layer coated carbide tools with top coating of TiC, TiN, Al2O3 and diamond. observed that aluminium had a tendency to wet uncoated carbide (94% WC+6%Co) inserts. However, wetting was more pronounced when surface was enriched with cobalt. Coatings like TiC, TiN or Al2O3 could not show pure non-wetting characteristics for aluminium. Turning test with aluminium indicated heavy material built up on uncoated (94%WC+6%Co) tool.

Abhay Bhatt et al [33] presented the results of an experimental investigation on the wear mechanisms of uncoated tungsten carbide(WC) and coated tools (single-layer(TiAlN)PVD, and triple-layer (TiCN/Al2O3/TiN) CVD) in oblique finish turning of Inconel718. It was found that the abrasive and adhesive wear were the most dominant wear mechanisms, controlling the deterioration and final failure of the WC tools and the triple layer CVD coated tools exhibited the highest wear resistance at high cutting speeds and low feeds and the uncoated tools outperformed the single and multi-layer coated tools in the low range of cutting speeds and intermediate feeds.

Kyung-Hee Park et al [34] have analyzed the flank wear on the multi-layer (TiCN/Al2O3/TiCN) coated carbide inserts while turning AISI 1045 steel using advanced microscope and image processing techniques including wavelet transform,they have obtained the flank wear profiles and analyzed the surface roughness and groove sizes on the coating layers. The dominant wear mechanism was found to be the abrasion by the cementite phase in the work material. They concluded that the hardness of the coating is the most important requirement to resist flank wear due to its high wear resistance against abrasion.

M.A. El Hakim et al [35] They have presented the performance of four cutting tool in the machining of medium hardened HSS: polycrystallinec-cBN (c-BN-TiN), TiNcoated polycrystallinec-cBN (c-BN-TiN), ceramic mixed alumina (Al2O3-TiC), and coated tungsten carbide (TiN coated over a multilayer coating (TiC/TiCN/Al2O3)) and have found that the high chemical and thermal stability of Al2O3 tribo-films protects the tool substrate because it prevents the heat generated at the tool/chip interface from entering the tool core.

R. Suresh et al [36] have analyzed the effects of process parameters on machinability aspects by using multilayer hard coatings (TiC/TiCN/Al2O3) on cemented carbide substrate for machining of hardened AISI 4340 and have found that the optimal combination of low feed rate and low depth of cut with high cutting speed is beneficial for reducing machining force. Higher values of feed rates are necessary to minimize the specific cutting force. The machining power and cutting tool wear increases almost linearly with increase in cutting speed and feed rate. The combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness. Abrasion was the principle wear mechanism observed at all the cutting conditions.

2.2. Objective of the present investigation

From the literature it is observed that the potential of TiN coating is well established in machining of ferrous material in soft machining. However a systematic approach in hard turning of such multi layer coated tool is lacking in performance .Under the present investigation of evaluation multi layer TiN coated tool as compare to uncoated tool has been aimed at at a variety of machining conditions under hard turning. A systematic way to evaluate the performance of such tool to find its application in a brooder area including for CNC machining. Keeping the above objective for the work, the experimentation has been planned to carry out .The performance test of uncoated and coated tools both for soft and hard machining. In soft machining materials like Al, soft and abrasive material like Al-Si alloy and hard material like AISI 4340 steel has been planned for the experimental investigation. The primary objective is to evaluate the coated tool in hard machining under extreme conditions of machining to optimize it's parameters.

CHAPTER 3

EXPERIMENTAL INVESTIGATION

The experimental work was divided into three phases: the first phase, turning of AISI 4340 steel was carried out with uncoated and multilayer TiCN+TiC+TiCN+Al2O3 +TiN-coated carbide tool with external TiN layer. In the second phase, turning of soft material (Aluminium) was carried out with uncoated carbide inserts and in the third phase turning of soft and abrasive material (Al+5% Si) was carried out with uncoated carbide inserts.

3.1. Machining of hard material (AISI 4340 Steel)

The present work deals with the turning of hard material such as AISI 4340 steel. It is an important engineering material employed in manufacturing of components in auto and aerospace industries. Since the present trend in the manufacturing industry is high speed dry machining, it was applied to evaluate the performance of coated tools in typical manufacturing processes.

3.1.1.Work material

A solid bar of AISI 4340 steel with 37 mm diameter, 160mm long and of 45 HRC were used as workpiece (Fig3.1).

Fig.3.1.AISI 4340 steel bar

Table.3.1.The chemical composition of AISI 4340 steel in percentage by weight

C	Si	Mn	P	S	Cr	Ni	Mo	Fe
0.382	0.228	0.609	0.026	0.022	0.995	1.514	0.226	95.998

Physical Data of AISI 4340 steel

Density (lb / cu. in.)	0.28
Specific Gravity	7.8
Specific Heat (Btu/lb/Deg F - [32-212 Deg F])	0.116
Melting Point (Deg F)	2600
Thermal Conductivity	21
Mean Coeff Thermal Expansion	6.6
Modulus of Elasticity Tension	33

Mechanical Properties

Density (×1000 kg/m^3)	7.7-8.03
Poisson's Ratio	0.27-0.30
Elastic Modulus (GPa)	190-210
Tensile Strength (Mpa)	744.6
Yield Strength (Mpa)	472.3
Elongation (%)	22.0
Reduction in Area (%)	49.9
Hardness (HB)	217
Impact Strength (J) (Izod)	51.1

3.1.2. Cutting tools

Commercially available uncoated and multilayer TiCN+TiC+TiCN+Al2O3+TiN-coated carbide tool inserts with external TiN layer were employed with geometry of DCMT 11T304-THM and DCMT 11T304-TN 2000 respectively.

Fig.3.2.Uncoated and multilayer coated carbide inserts

Table.3.2.Chemical composition of carbide tools (% wt)

Co	Cr_3C_2	WC
6.0	0.5	93.5

3.1.3. Machine tools

Cutting tests were carried out on a Capstan lathe machine under dry conditions.

Fig.3.3. The capstan lathe

Specification of the Lathe machine

Gottwaldov Capstan lathe, Type R5, Precision Lathe

Manufactured by : Gottwaldov , ZPS , Chekoslovakia

Power of the motor : 7 KW, 5 HP

Centre height : 230 mm

Swing over Bed : 510 mm

Swing over cross slide : 255 mm

Range of spindle speed : 28-1400 rpm.

Turning experiments were carried out at four different cutting speeds which were 82, 105, 130 and 160 m/min and Feed rates were 0.06, 0.09,0.125,0.18 mm/rev (*f*) and depth of cut (*d*) was kept constant at 0.2 mm throughout the experiments. This small depth of cut was used for finish turning. The cutting conditions were kept constant for each of the coated and uncoated tools tested throughout the experiment .The photographic view of the experimental setup is shown in Fig.3.4.

Fig.3.4.The work piece and tool setup

Table.3.3.Conditions for the cutting test

Sl. No.	Cutting Condition	Description
1	Workpiece	AISI 4340 Steel
2	Cutting Inserts	Uncoated Carbide TiN Coated carbide
3	Diameter of w/p	37 mm
4	Length of W/p	160 mm
5	Hardness	45 HRC
6	Cutting Speed	80-160 m/min
7	Feed	0.06- 0.18 mm/rev
8	Depth of cut	0.02 mm
9	Cutting Environment	Dry

3.2. Force measurement

The forces acting on a tool are an important aspect of machining for studying the machinability conditions. Knowledge of the cutting forces is needed to estimate the power requirements and ensure that the machine tool elements, tool-holders, and fixtures are adequately rigid and free from vibrations. Measurements of the tool forces are helpful in optimizing the tool design.

The three components of forces are

Px: axial component of force

Py: radial component of force

Pz: tangential component of force

The cutting forces were measured with a piezoelectric 3-Component Dynamometer (Kistler-9257B) mounted on the lathe. The charge signal generated at the dynamometer was amplified using charge amplifiers (Kistler Type 5814B1)

Fig.3.5.Kistler piezoelectric dynamometer

Dynamometer Specification

Quartz 3-Component Dynamometer(type - 9257B)

Manufactured by – Kistler Instrumente AG, CH-8408 Winterthur, Switzerland

Calibrated partial range for Fx & Fy = 0-500 N, for Fz = 0-1000 N

Fig.3.6.Charge amplifier

Machine specification of Multichannel Charge Amplifier :--

Manufactured by – Kistler Instrumente AG,

CH-8408 Winterthur, Switzerland

Type 5070A having 8 nos. of channel

Forces were measured and recorded for the different cutting conditions both for coated and uncoated tools. The three force components are, the main cutting force (*Fz*), thrust force (*Fx*) and radial force (*Fy*).The measuring signal output was recorded by the N.I. (National Instrument) LAB VIEW data acquisition system (NI 9234) with RS-232C interface between amplifier and the PC allowing all settings and queries to be made in the instrument.(Fig.3.8).Since the analogue signals received from the dynamometer were low, the amplifiers were needed. Three amplifiers were used to amplify analogue signals received from three channels; and supply voltage, input/output signals and deviation values for the desired measurement range were adjusted. These signals (which were the cutting force signals) were converted into digital format in a data acquisition card and were input to the PC.

Fig.3.7.Data acquisition system

The obtained data were analyzed and the results of machining have been presented in the form of graphs. The influence of cutting parameters (v, f, and d) on cutting forces were analyzed.

3.3. Surface roughness measurement

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, high surface finish, high production rate, less tool wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Roughness of the machined surface is an important quality measure in metal cutting, and it is important to monitor and control during the machining operation. If the surface becomes too rough, the cutting tool has to be changed. There are several measurements that describe the roughness of a machined surface. One of the most common is the arithmetic average (AA) value usually known as Ra. So it is needed to measure the surface roughness.

3.3.1.Taylor Hobson (Surtronic 25) surface roughness Tester

The surface roughness was measured by Taylor Hobson (Surtronic 25) Tester(Fig.3.9). The Surtronic 25 tester brings a large display with the simplest of menu structures and the most up-to-date parameters. Its mechanical rigidity and stylus have a firm reputation for giving reliable and repeatable surface finish measurements across a wide range of applications. The Surtronic 25 is battery powered and offers total portability. This instrument can be used either freestanding (on horizontal, vertical or even inverted surfaces) or bench mounted with fixturing for batch measurement and laboratory applications.

Fig.3.8.Taylor Hobson (Surtronic 25) Surface Roughness Tester

The experiments were designed using varying operating parameters like cutting speed, feed rate and depth of cut. These operating parameters are predominantly used in carrying out the experiments. The turning experiment was carried in a capstan lathe. The following cutting conditions were employed for measuring surface roughness: cutting speeds (v) of 80,105,130 and 160 m/min, feed rates (f) of 0.06,0.08,0.12 and 0.18 mm/rev and depths of cut (d) of 0.2,0.3,0.4 and 0.5mm.

3.4. Tool wear measurement

Tool wear is one of the most important aspects that affect tool life and product quality in machining. To study the wear mechanisms on the flank surface, a series of turning tests with AISI 4340 steel was performed at various speed, feed and depth of cut as similar for measurement of surface roughness.To identify the wear mechanisms that can be verified through the experiments, accurate measurement techniques are needed. In this study photographs of tool wear were taken using SEM and an optical microscope.

3.5. Design of experiment

The present experimental investigation deals with the analysis of the experiment by the taguchi methodology, Taguchi analysis consists of the orthogonal arrays. A L_{16} orthogonal array (OA) has been used to determine the importance of the factors or the parameters.

Taguchi's design of experiment with a standard orthogonal array L_{16} was used because of its minimum number of required experimental trials and yet gave a satisfied result. The L_{16} OA has sixteen rows corresponding to sixteen sets of variables setting. Each row of the matrix represents one trial. However, the sequence in which those trials were carried out was random. Sixteen experiments with combination of different cutting parameters were randomly repeated. Four levels of cutting speeds, feed rates and depth of cuts were tested. Factors and levels used in the experiment are shown in Table 3.4.

Table 3.4. Factors and levels used in the experiment

	Level			
Factors	1	2	3	4
Cutting speed (mm/min)	80	105	130	160
Feed rate (mm/rev)	0.06	0.08	0.12	0.16
Depth of cut (mm)	0.2	0.3	0.4	0.5

The table 3.5 given below is the L_{16} OA which is used for the experiments. The sixteen sets of settings were done to analyse the response that is the surface roughness.

Table 3.5. L_{16} OA

Sl No.	Speed (m/min)	Feed (mm/rev)	DOC (mm)
1	80	0.06	0.2
2	80	0.08	0.3
3	80	0.12	0.4
4	80	0.16	0.5
5	105	0.06	0.3
6	105	0.08	0.2
7	105	0.12	0.5
8	105	0.16	0.4
9	130	0.06	0.4
10	130	0.08	0.5
11	130	0.12	0.2
12	130	0.16	0.3
13	160	0.06	0.5
14	160	0.08	0.4

15	160	0.12	0.3
16	160	0.16	0.2

3.6. Machining of soft material (Aluminium)

In this experiment a pure aluminium rod having length of 70mm and diameter 25.4mm was machined in step wise manner in CNC turning machine. The step turning was done at different speeds and feeds keeping the depth of cut constant.

Table.3.6.Cutting condition

No of cut	Speed(rpm)	Feed(mm/min)	Depth of cut(mm)
1	1500	15	0.5
2	1250	35	
3	1000	55	

The CNC program used for machining pure aluminium sample is as given below:

```
N001 G21 G98
        N002 G28 U0 W0
        N003 M06 T0101
        N004 M03 S1500
        N005 G00 X26 Z2
        N006 G01 X24.4
        N007 G01 Z-45 F15
        N008 G00 X26  Z2
        N009 M03 S1250
        N010 G01 X23.4
        N011 G01 Z-30 F35
        N012 G00 X26 Z2
        N013 M03 S1000
        N014 G01 X22.4
        N015 G01 X-15 F55
        N016 G00 X26 Z2
```

N017 G28 U0 W0

N018 M05

N019 M30

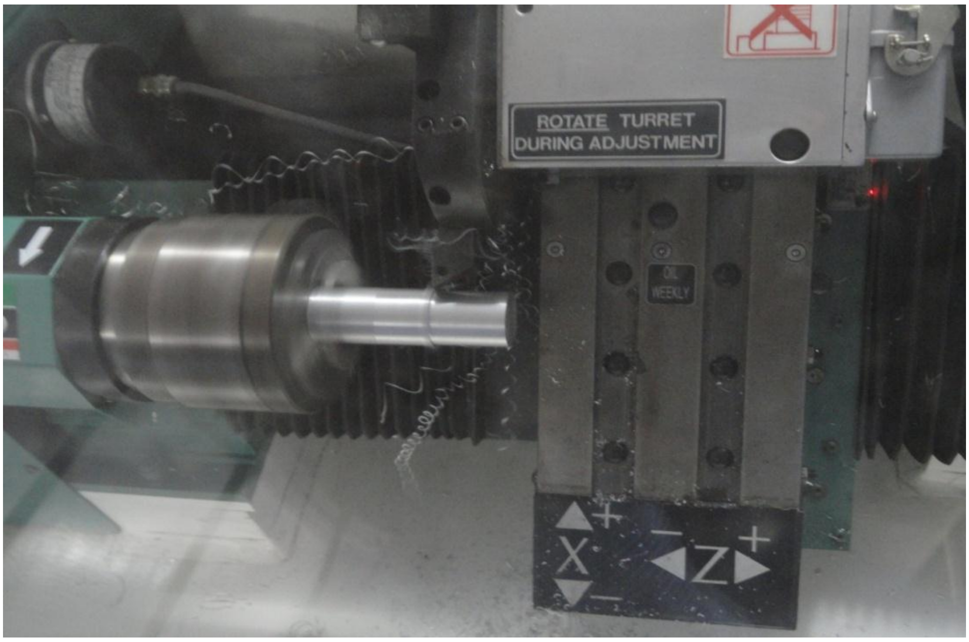


Fig.3.9.CNC Turning of aluminium

3.7. Machining of soft and abrasive material (Al+5%Si)

3.7.1. The casting process

For this experiment the specimen was prepared by sand casting process (Fig.3.11). Small pieces of aluminium of weight 300 gm were melted in an electric arc furnace maintaining the temperature at 877^0 C. Then 5 wt% of silicon powder was added to the molten aluminium and stirred manually by a stirrer. Then it was poured by the crucible through the pouring basin into the mould and casted.

Fig.3.10.The casting process of aluminium-silicon alloy

3.7.2. The CNC turning process

The workpiece was roughly turned in conventional lathe machine and finally machined by CNC lathe keeping depth of constant and varying speed and feed rate as per the machining of aluminium (Table 3.6)The CNC program used in machining of aluminium-silicon alloy is as given below as per the dimensions of the workpiece taken:

N001 G21 G98

N002 G28 U0 W0

N003 M06 T0101

N004 M03 S1500

N005 G00 X25 Z2

N006 G01 X23

N007 G01 Z-45 F40

N008 G00 X25 Z2

N009 G01 X22

N010 G01 Z-45 F40

N011 G00 X25 Z2

N012 G01 X21

N013 G01 Z-45 F15

N014 G00 X25 Z2

N015 M03 S1250

N016 G01 X20

N017 G01 Z-30 F35

N018 G00 X25 Z2

N019 M03 S1000

N020 G01 X19

N021 G01 X-15 F55

N022 G00 X25 Z2

N023 G28 U0 W0

N024 M05

N025 M30

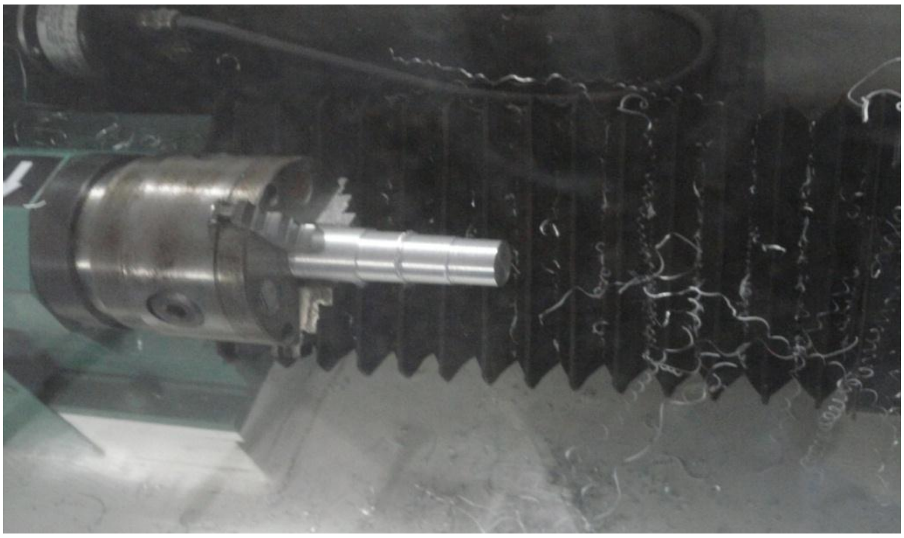


Fig.3.11.Turning in CNC lathe

After turning surface roughness were measured using Surface Roughness Tester

CHAPTER 4

RESULTS AND DISCUSSIONS

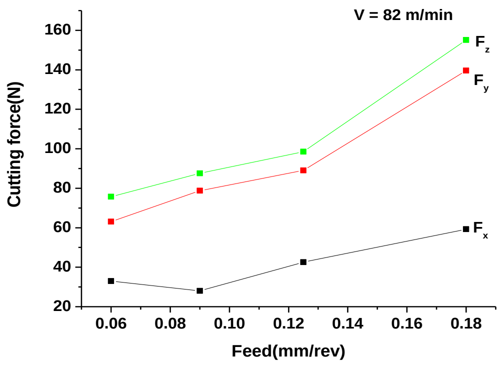
4.1. Hard turning

The result of hard turning has been presented as follows.

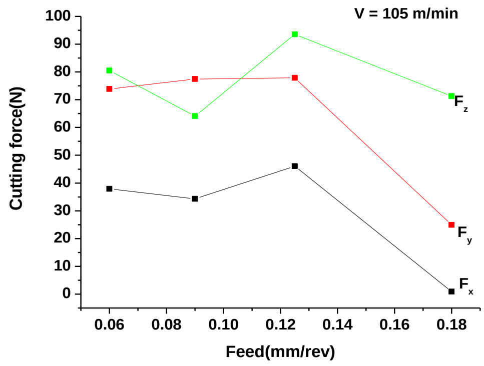
4.1.1. Force measurement

Results of cutting tests are presented in terms of graphs in Fig. 4.1 and Fig.4.2, which shows the variation of different forces with different cutting speed and feed or the uncoated tool .The result for multilayer coated tool are given in Fig 4.3 and Fig 4.4. The results present the variation of cutting forces under feed rates of 0.06, 0.09, 0.125 and 0.18 mm/rev and various cutting speeds such as 82,105,130 to 160 m/min. For the 0.06 mm/rev feed rate and the uncoated tool(fig4.2(a)), the forces decrease with the increase in cutting speed and their values are in the range 20–80 N. For the same feed rate, the forces measured with the coated tools are relatively low in the range 20–65N (Figs.4.3 and 4.4).This indicate the favourable effect of coatings on cutting forces. At higher feed rate and independently of the tested tool, the cutting force values are in the same range, but, the shape of the cutting force curves depends on the cutting tool. However, the variation in the forces for the feed rate of 0.18 mm/rev could be attributed to the process variation or tool morphology at lower medium cutting speed. It is also seen that when cutting speed is increased to 105 m/min from 82 m/min, the cutting forces decrease and then they increase with increase in cutting speed for both cutting tools. These drops in the forces are partly caused by a decrease in contact area and partly by a drop in shear strength in the flow-zone as its temperature rises with increase in speed However, further increase in the cutting speed increases the cutting forces. This is probably due to the increasing heat generated at cutting tool tip and softening of work material at higher speeds. The shape of the cutting forces curves depends on the tool. The differences detected may be surely explained and correlated to the wear mechanisms developed during the tests and observed on the rake and flank faces of the tool[20][27]. For all the coated tools, the cutting forces are lower than the uncoated tool.

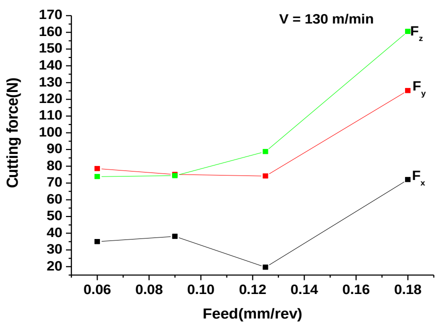
It has been seen that, as cutting speed is increased, the three components of the machining forces (*Fx, Fy, Fz)* are reduced. This reduction in the forces may be attributed to the variation of friction due to the temperature increase in the secondary- shear zone area, which resulted in a reduction in the restricted force. However, further increase in the cutting speed increases the cutting forces. This is probably due to the increasing tool chip interaction at higher speeds. For all the tested tools, the cutting forces for the coated tools yield a lower value. This result is mainly caused by low friction at chip-tool interface due to TiN coating. Coating material affect the coefficient of friction and thermal conductivity. With decrease in coefficient of friction and thermal conductivity of the cutting tool, the average surface roughness of the work material decreses. For the uncoated tool, this minimum value of cutting force is obtained for a cutting speed of about 160 m/min, which corresponds to a limiting value. The higher forces under higher feed rates are due to increased thrust components because of increase in chip cross sectional area. However, the cutting forces for coated tools under similar cutting feeds are lower than that of uncoated tools.



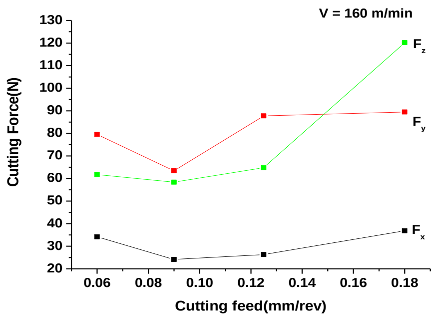
(a)



(b)

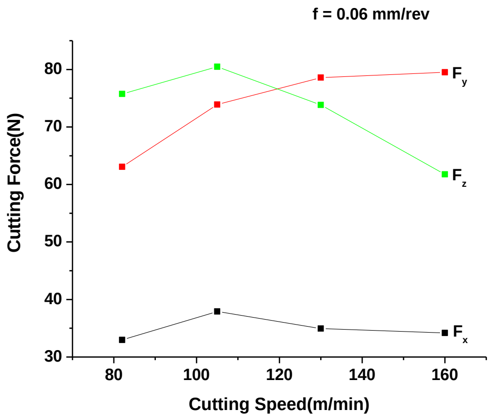


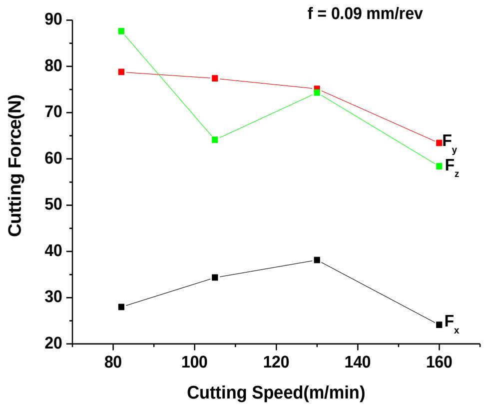
(c)



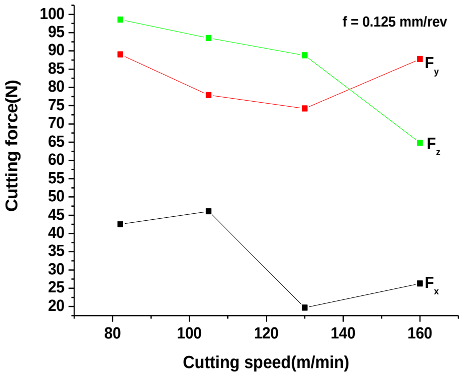
(d)

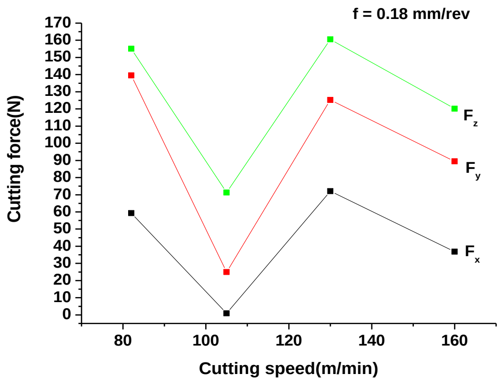
Fig4.1.Effect of speed on different forces for uncoated insert





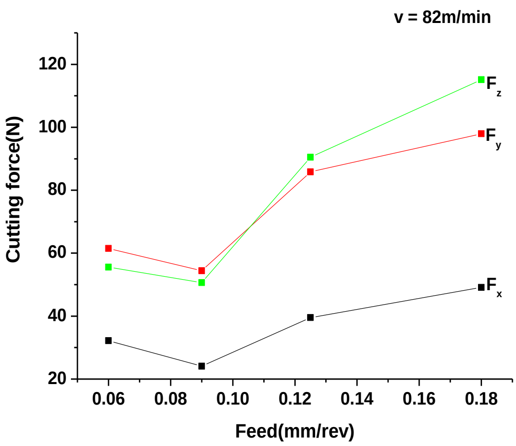
(a) (b)

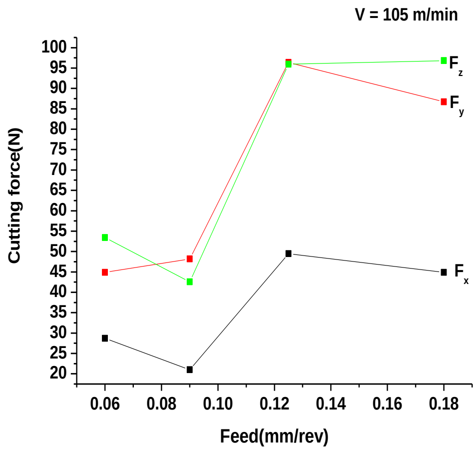




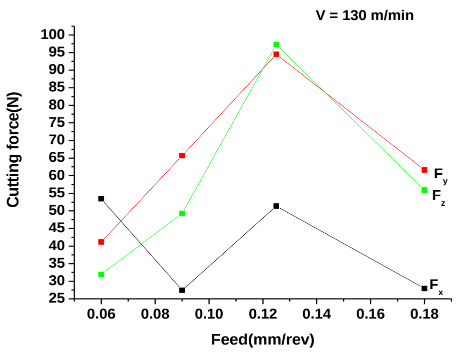
(c) (d)

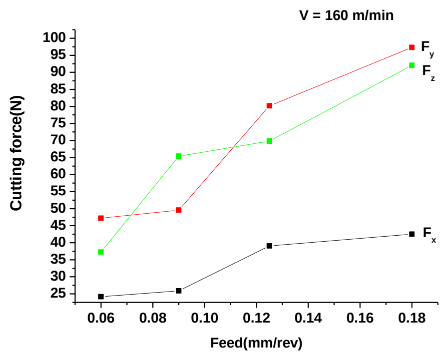
Fig.4.2. Effect of feed on different forces for uncoated insert





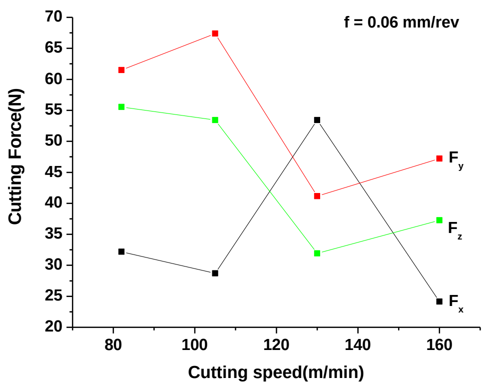
(a) (b)

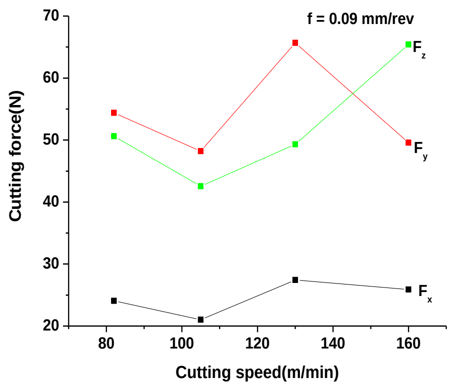




(c) (d)

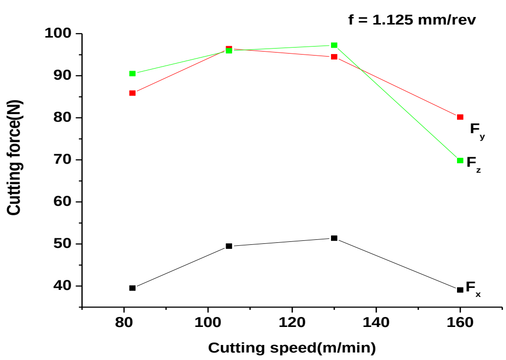
Fig.4.3 Effect of cutting speed on different forces for coated

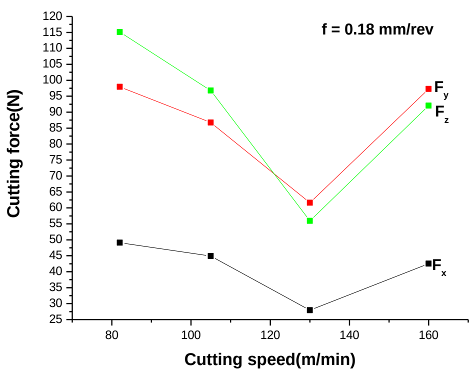




insert

(a) (b)





(c) (d)

Fig.4.4. Effect of feed on different forces for coated insert

4.1.2. Surface roughness measurement

Surface finish in turning has been found to be influenced by a number of factors such as cutting speed, feed rate and depth of cut. The various simple surface roughness parameters used in the industries such as average roughness (Ra), root mean square RMS and maximum peak to valley.

The theoretical arithmetic average surface roughness:

$Ra = 0.032\ f^2/\ R$ (1)

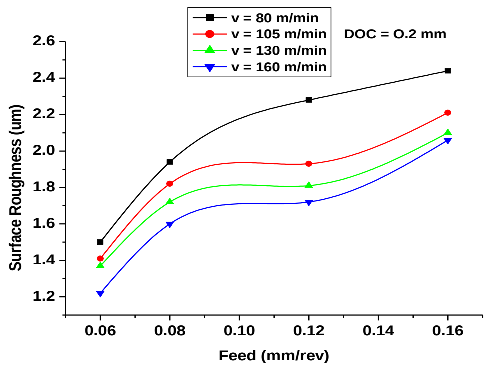
where f= feed rate (mm/rev) and R= tool nose radius (mm). It means that surface roughness increases with increasing feed rate and a large tool nose radius reduce surface roughness of the work piece.

Table.4.1.Experimental data for surface roughness

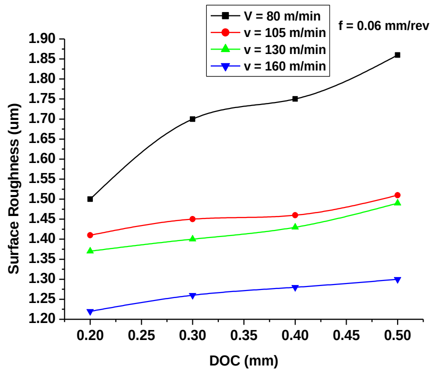
		d = 0.2mm			**d = 0.3 mm**		
V(m/ min)	**f(mm/rev)**	**Ra(μ)**	**Rz(μ)**	**Rt(μ)**	**Ra(μ)**	**Rz(μ)**	**Rt(μ)**
80	0.06	1.5	7.7	8.4	1.7	8.07	9.05
	0.08	1.94	7.8	8.5	1.97	8.17	9.17
	0.12	2.24	9.2	9.9	2.32	9.66	10.66
	0.16	2.44	10.6	11.4	2.5	11.09	12.31
105	0.06	1.41	7.2	8.2	1.45	7.55	8.63
	0.08	1.82	7.4	8.51	1.87	7.78	8.68
	0.12	1.93	8.9	9.2	1.96	9.34	9.93
	0.16	2.21	10.4	11.1	2.23	10.93	11.97
130	0.06	1.37	7.1	7.9	1.40	7.45	8.5
	0.08	1.72	7.3	8.2	1.77	7.64	8.85
	0.12	1.81	8.1	8.7	1.83	8.51	9.40
	0.16	2.1	10.3	10.9	2.51	10.51	11.79
160	0.06	1.22	6.7	7.6	1.26	7	8.2
	0.08	1.6	6.9	7.9	1.66	7.24	8.53
	0.12	1.72	7	8	1.77	7.35	8.62
	0.16	2.06	10.1	10.8	2.12	10.23	11.67

		d = 0.4mm			d = 0.5 mm		
v(m/min)	**f(mm/rev)**	**Ra(μ)**	**Rz(μ)**	**Rt(μ)**	**Ra(μ)**	**Rz(μ)**	**Rt(μ)**
80	0.06	1.75	8.47	9.77	1.86	8.92	10.55
	0.08	2.03	8.58	9.89	2.1	9	10.68
	0.12	2.43	10.12	11.51	2.45	10.62	12.44
	0.16	2.57	11.66	13.27	2.66	12.23	14.36
105	0.06	1.46	7.9	9.5	1.51	8.33	10.26
	0.08	1.93	8.13	9.76	1.98	8.52	10.35
	0.12	2.05	9.78	10.70	2.08	10.29	11.57
	0.16	2.31	11.42	12.91	2.39	12.03	13.94
130	0.06	1.43	7.82	9.23	1.49	8.22	9.92
	0.08	1.81	8.03	9.52	1.83	8.43	10.3
	0.12	1.93	8.92	10.19	1.96	9.37	10.91
	0.16	2.2	11.08	12.71	2.28	11.58	13.7
160	0.06	1.28	7.26	8.33	1.3	7.6	9.52
	0.08	1.65	7.6	9.2	1.71	7.95	9.91
	0.12	1.80	7.7	9.31	1.85	8.06	10.03
	0.16	2.16	11.01	12.59	2.24	11.50	13.52

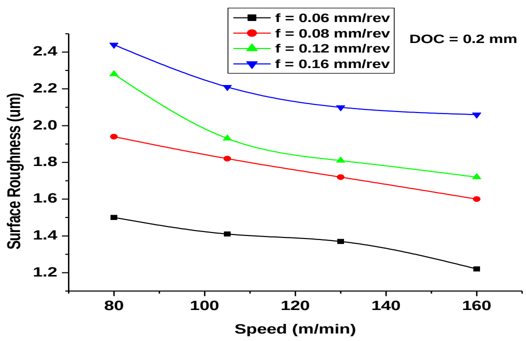
Results of surface roughness tests are presented in Table 4.1 and also in terms of graphs. The Fig.4.5 shows the graphical representation of cutting speed, feed rate and depth of cut Vs surface roughness at cutting speeds of 80, 105, 130 and 160 m/min ,with feed rates of 0.06, 0.08 ,0.12 and 0.16 mm/rev and depth of cut of 0.2,0.3,0.4 and 0.5 mm. The feed rate gave a significant effect on the surface roughness. It was seen that the surface roughness for uncoated carbide tool is decreased with the increase in cutting speed. Surface roughness values for coated carbide tools also decreased with increase in cutting speed for different feed rates. The Ra values of turning AISI 4340 steel measured for coated carbide was in the range of 1.28–2.66 μm. The machined surface roughness decreases with a decrease scratching on the work materials, and a substantial improvement in shiny surface for high speed and low feed rate. The optimum surface roughness in the machining of coated tool was obtained at the cutting speed of 160 m/min and feed rate of 0.06 mm/rev.



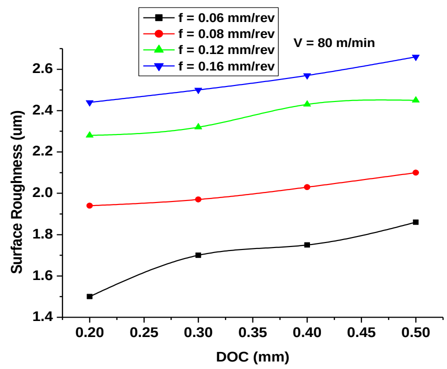
(a)



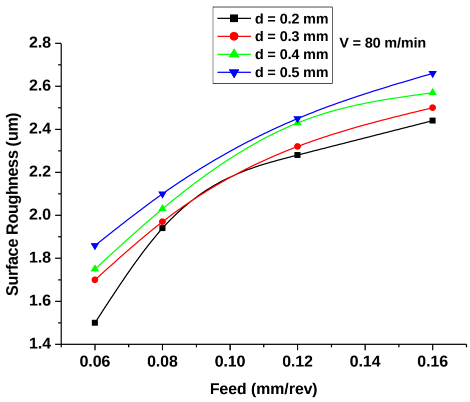
(b)



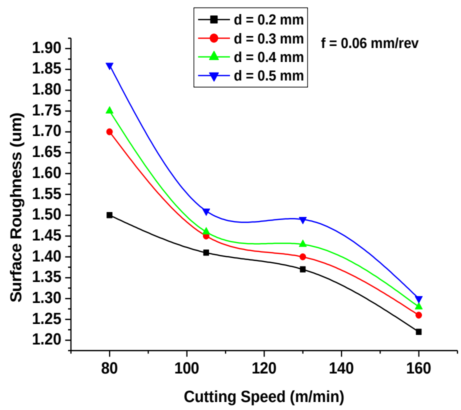
(c)



(d)



(e)



(f)

Fig.4.5.The variation of average surface roughness with cutting speed, feed rate and depth of cut when machining 4340 steel

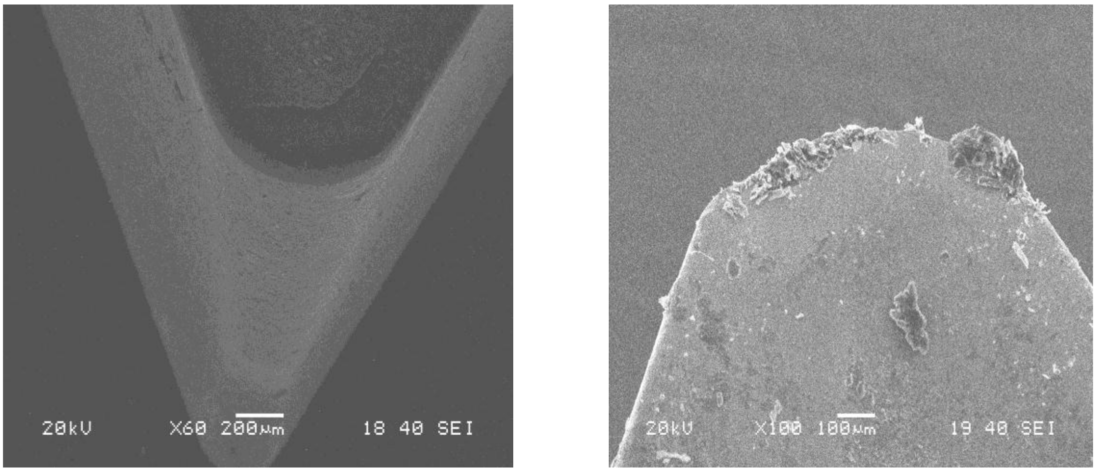
4.1.3. Tool wear measurement

The mechanisms involved in the wear of cutting tools, especially in hard machining, are rather complicated and may include different interacting effects linked together in a complex manner. Primarily, depending on cutting conditions, work material, and tool material, the performance of the tool is limited by flank wear, crater wear, edge chippings, nose wear, or combination of these. Tool wear depends on the tool, work piece material (physical, mechanical and chemical properties), tool geometry, cutting parameters, cutting fluid, etc.

Flank wear was caused by friction between the flank face of the tool and the machined surfaces. Another important wear mechanism for flank wear is adhesion. This type of wear can take place when one solid material is sliding over the counteracting surface. The interaction between two surfaces can be represented by the metallurgical weld or adhesion joint. Adhesive wear takes place when discrete pieces are pulled out from the tool surfaces during sliding. Flank wear attributed to rubbing of the tool with work piece at the interface, causing abrasive and/or adhesive wear and at high temperatures. Abrasion is the main wear mechanism in flank wear.

Crater wear occurs on the rake face of the tool. The crater wear affects the tool geometry. The most important factors influencing crater wear was temperature at the tool tip interface and the chemical affinity between tool and work piece materials.

Fig.4.6 shows the SEM photograph of uncoated carbide inserts. The wear either occurs gradually by abrasive or adhesive wear, through plastic deformation, by more discrete losses of material through discrete fracture mechanism, or by combination of these. Those effects could be due to high mechanical, thermal, and chemical loads generated during hard machining. Capability to predict tool wear during hard turning is necessary to determine the optimum cutting variables. It is also useful to avoid catastrophic tool failure, which can damage the workpiece surface and affect the machine tool performance.



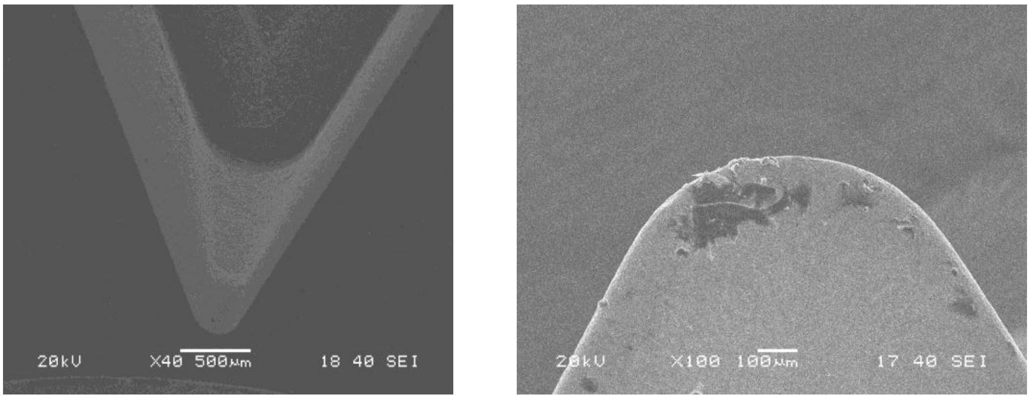
(before machininh) (after machining)

Fig.4.6.SEM images showing the wear of uncoated tools

SEM analysis of the worn surfaces on the coated tools showed significant wear of the multi layer cutting tools due to abrasion from hard particles in the workpiece (Fig.4.7). The coated carbide tool was worn due to progressive wear of the protective coating.

When the surface of the cutting tools was coated with TiN, which had a low friction coefficient and anti-adhering property, the adhesion of steel on the cutting edge can be suppressed therefore decreasing cutting resistance. Reduced formation of built-up edge led to maintaining the sharpness of the edge, and thus to improve the machinability and the quality of the work materials. It was found that the major wear form of the tools were the combination of flank wear and rounding of the nose. For these tools, a removal of coated layer from the substrate were appeared when cutting the harden steel.

Many mechanisms, consistent with those cited in literature, have been considered to identify the wear of TiN coated tools (abrasion, adhesion, diffusion, and tribochemical). In the present study, abrasion and diffusion wear mechanisms have been identified. At the initial stage, the flank wear was observed on the cutting edge and a few layer of coating material was rubbed away due to abrasion between the insert and the work piece. At the gradual stage, the width of flank wear increased and more coated material was removed from the cutting edge and the final stage, the flank wear was increased rapidly until the cutting tool had to be discarded. TiN coating offers a greater degree of protection against chemical wear of the tool. It has been reported that this TiN coating over this kind of cutting tools provided the edge rounding. This edge rounding not only protects the edge during cutting, but also avoids the occurrence of very small chippings on the cutting edge during their cutting test. TiN is characterized by high hardness and wear resistance even at elevated temperatures.



(before machininh) (after machining)

Fig.4.7.SEM images showing the wear of coated tools

At low cutting speed, the contact between work piece and flank of the tool was more and rubbing action continued for more time. The cutting zone temperature increases, this softens and decreases the strength of the BUE. Tool flank wear was strongly influenced by the interactions between cutting tool and work piece in the form of contact stress and cutting temperature. As the cutting speeds and feed rates are increased, the rubbing action also faster and more heat produced even though less contact time exist. The generation of heat at flank side softens the edge and more wear occurred. The increase in cutting speed wears the tool faster and reduces the life of the tool.

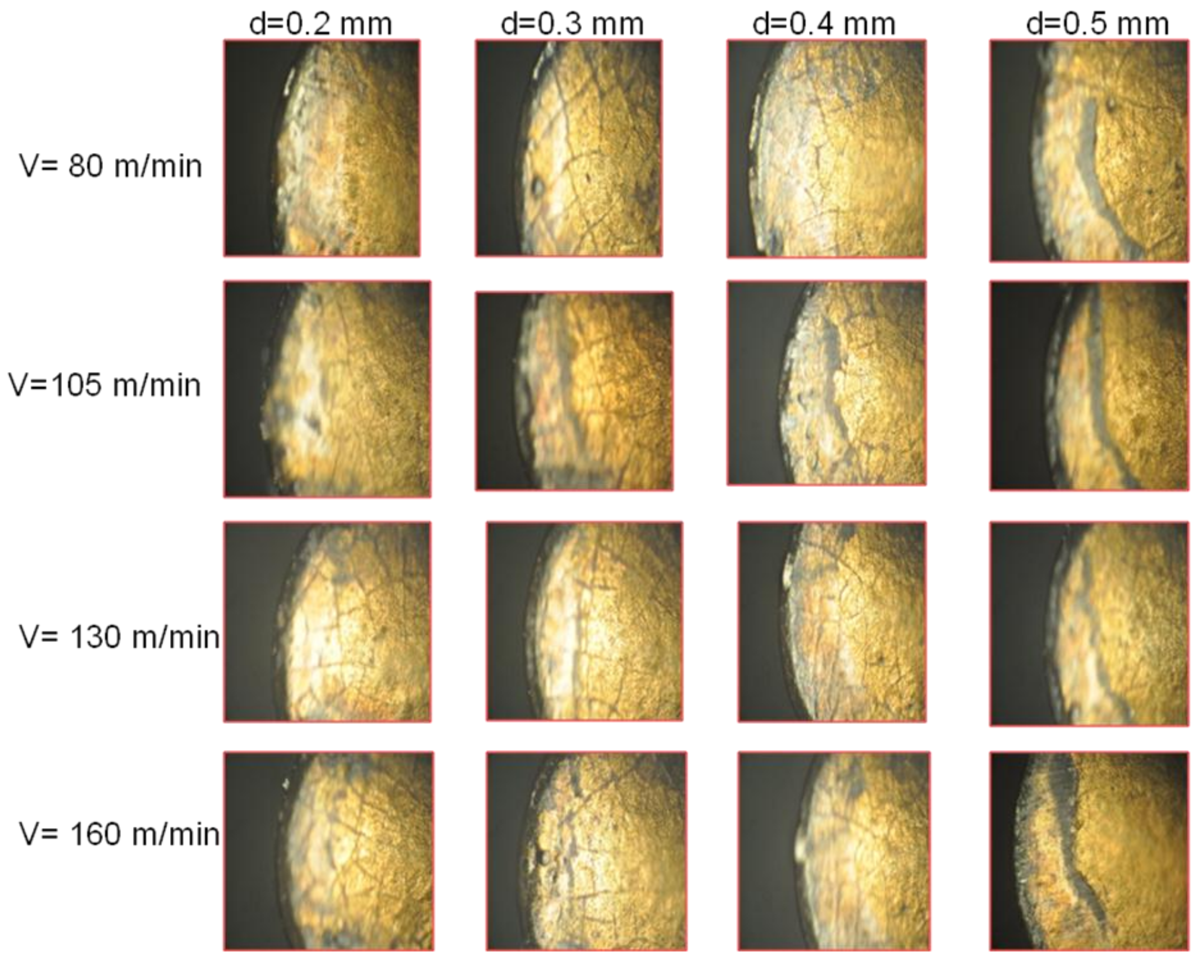


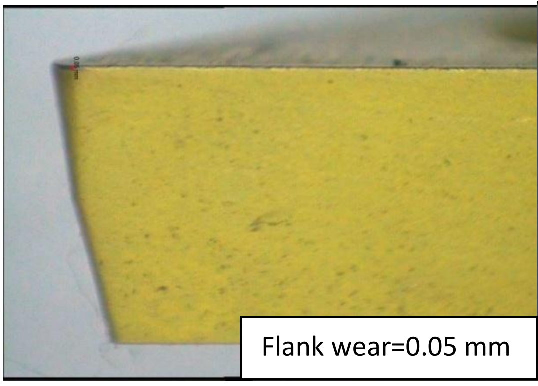
Fig.4.8. Microscopic views of crater wear for multi layer coated carbide tool

First, tool wear at low depth of cut (0.2 mm) and with increasing speed was investigated. Fig.4.9.(a) shows the tool wear for the coated cutting tool at a speed of 80 m/min. Fig.4.9.(b),(c) and (d) illustrates the tool wear at cutting speeds of 105 ,130 and 160 m/min, respectively for the same depth of cut. The flank wear to reach 0.22 mm at cutting speed of 160 m/min and for depth of cut of 0.5 mm was longer than that at cutting speed of 80 m/min,105 m/min and 130 m/min at depth of cuts of 0.2 mm,0.3 mm,0.4 mm respectively. The flank wear was increased with the increase of cutting speed. The gradual wear zones can be easily identified at these elevated cutting speeds. Increase in the cutting speed from 80 to 160 m/min reduced the tool life.

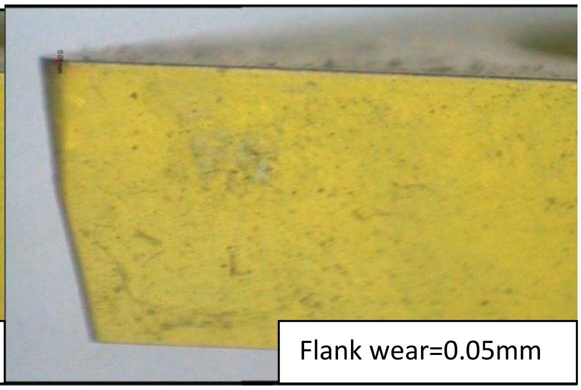
The tool wear results for higher depth of cut of 0.5 mm is very different from those obtained for the depth of cut of 0.2 mm. It shows that the depth of cut has a significant effect on the wear rate. The significant decrease in tool life for coated carbide tools at higher depth of cut can be attributed to the temperature increase.

d = 0.2 mm

V = 80 m/min, V = 105 m/min

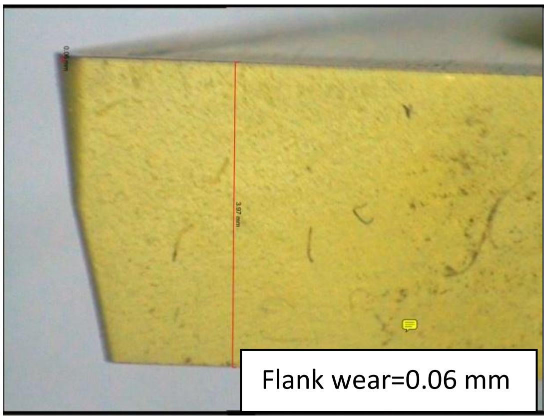


(a)

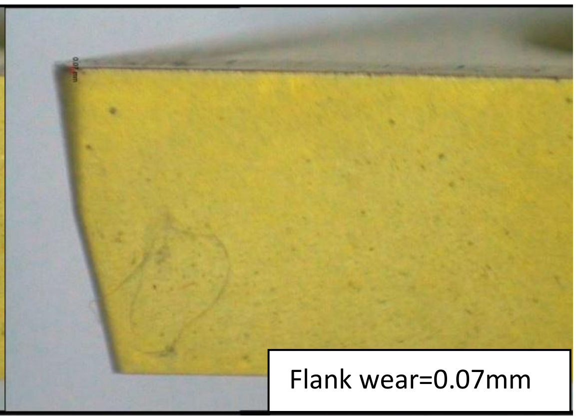


(b)

V = 130 m/min, V = 160 m/min



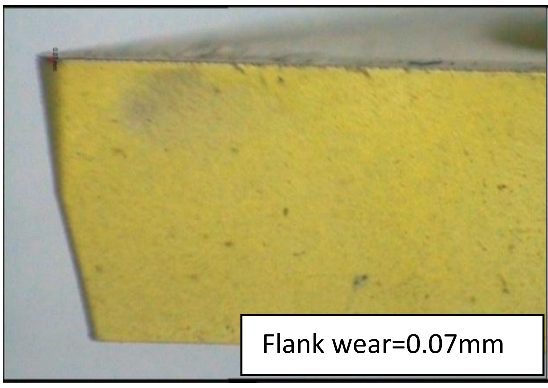
(c)



(d)

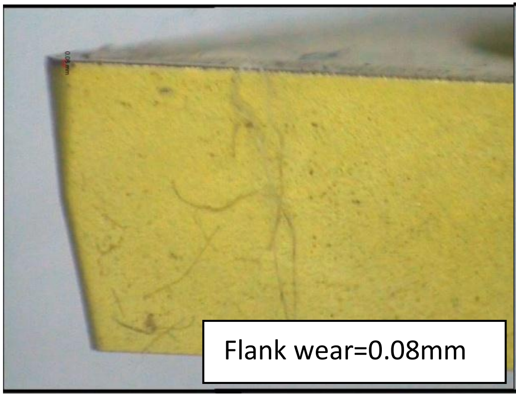
d = 0.3 mm

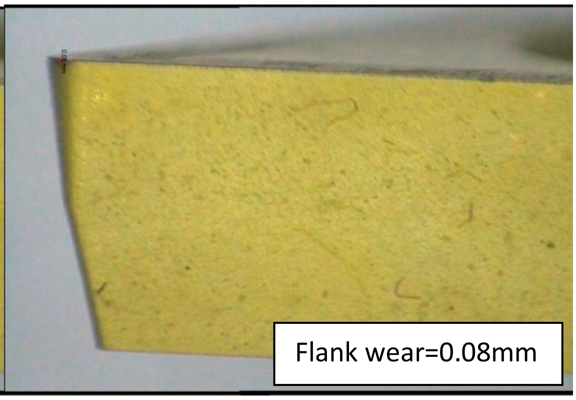
V = 80 m/min V = 105 m/min



(e) (f)

V = 130 m/min V = 160m/min

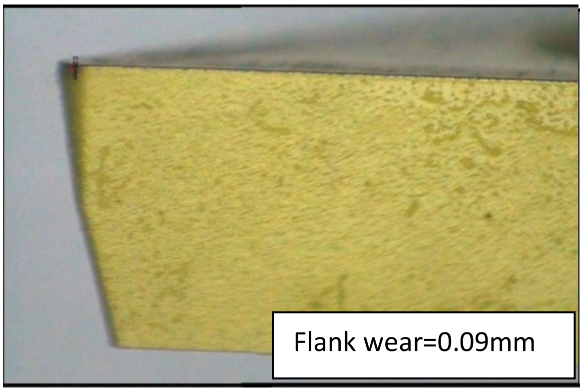


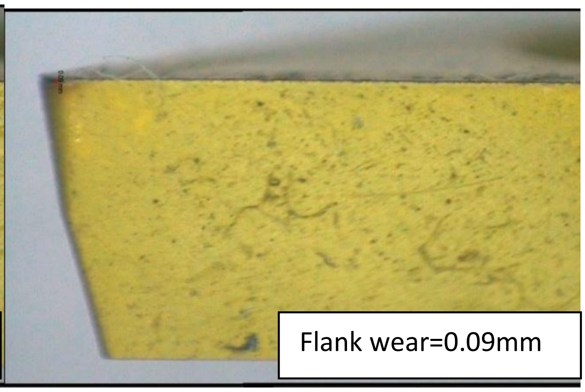


(g) (h)

<u>d = 0.4 mm</u>

V = 80 m/min V = 105 m/min

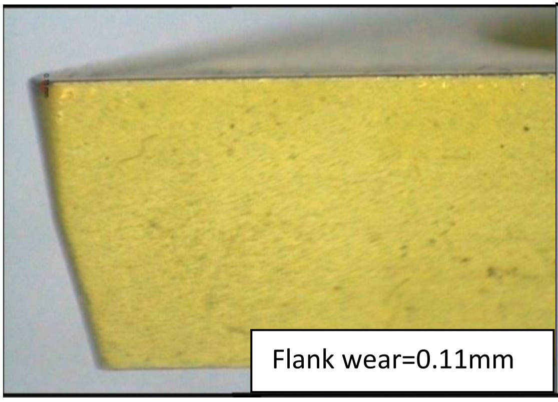




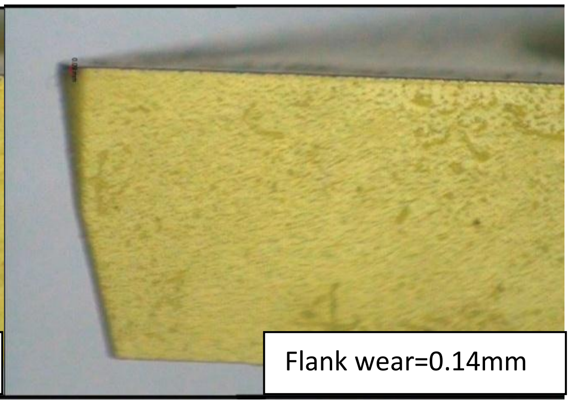
(i) (j)

V = 130 m/min

V = 160m/min



(k)

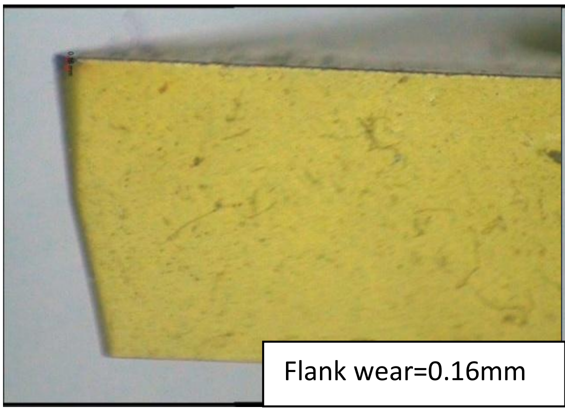


(l)

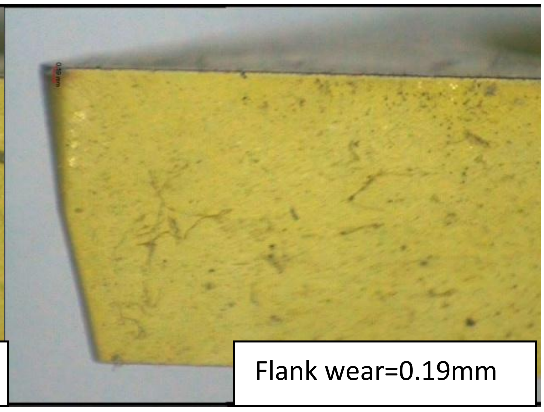
d = 0.5 mm

V = 80 m/min

V = 105 m/min



(m)

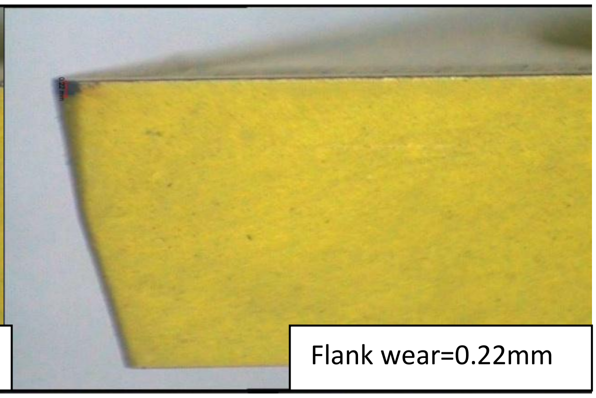


(n)

V = 130 m/min

V = 160m/min

(o)

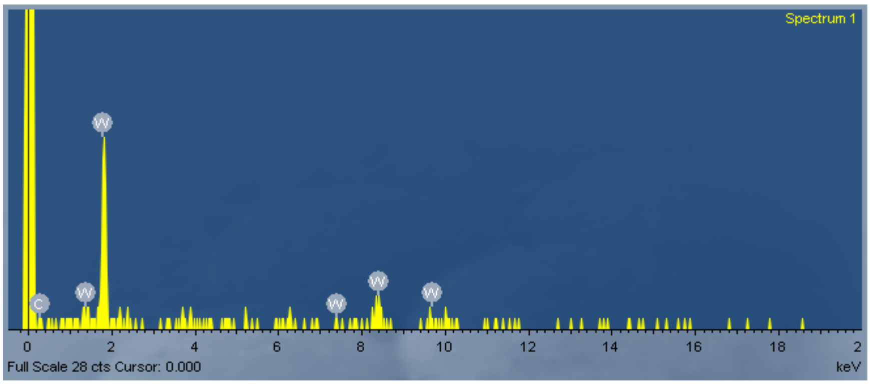


(p)

Fig.4.9. Microscopic views on TiN coated carbide tool for flank wear

4.1.4. Assessment of structure and chemical composition of coated and uncoated tools

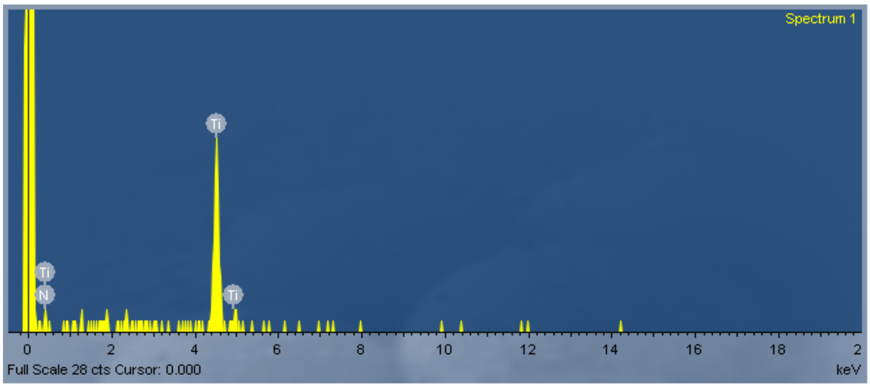
Investigations of the material structure and chemical composition in selected micro-areas of the worn surfaces were performed on a scanning electron microscope equipped with an energy dispersive analyser of X-ray (EDAX).Their weight and atomic percentages are quoted in the relevant EDAX spectrum shown in Fig.4.10(a).The EDAX analysis of uncoated carbide tool confirms the elements associated with the material are 66.85 % W and 33.15% C.



Element	Weight%	Atomic%
C	33.15	88.36
W	66.85	11.64

Fig.4.10(a)..EDAX pattern of uncoated tool

The EDAX analysis in Fig.4.10(b).confirms that elements associated with the coating carbide such as Ti and N predominate and elements associated with the substrate materials are absent.



Element	Weight%	Atomic%
N	10.34	28.28
Ti	89.65	71.71

Fig.4.10(b).EDAX pattern of coated tool

X-ray diffraction was used to evaluate the preferred orientation of the various coatings. Evaluations of the texture of coatings, along with interfacial features of these hard coating, is characterized by X-ray diffraction (XRD). Fig.4.11(a) shows the XRD patterns for uncoated inserts**.** Fig.4.11(b) Shows the TiN films deposited on carbide substrate. (111) peaks are dominant for the specimens, while the other major crystallographic planes of the TiN films are not found, which indicates that the specimens have a strongly (111) preferred orientation. For coated tools (200) and (210) peaks are found for the WC and Co but for uncoated inserts (101) and (210) peaks are found for WC And Co respectively.

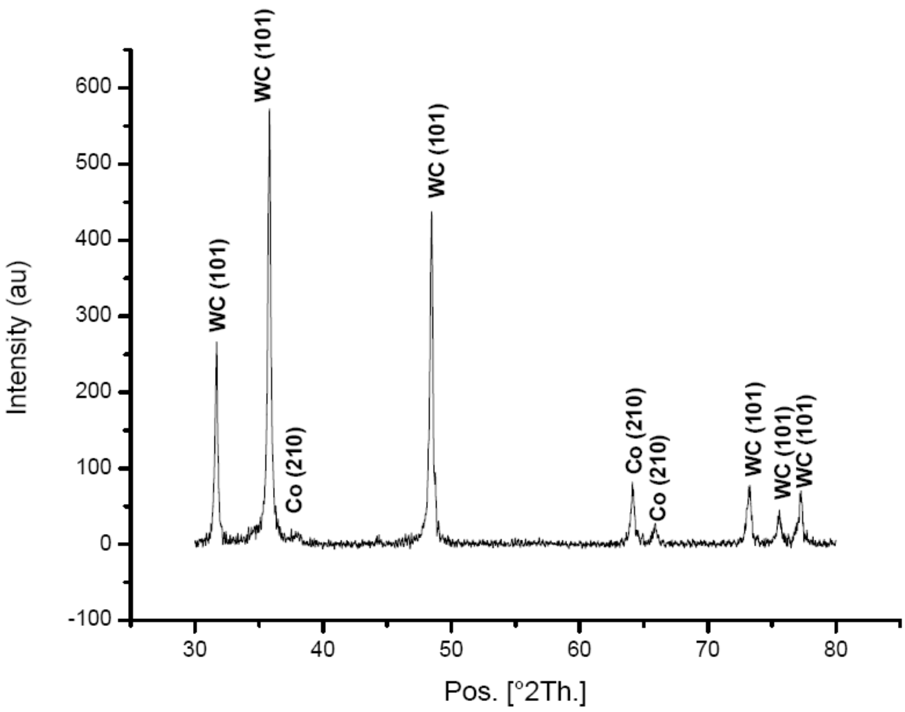


Fig.4.11(a). XRD patterns of uncoated carbide tool

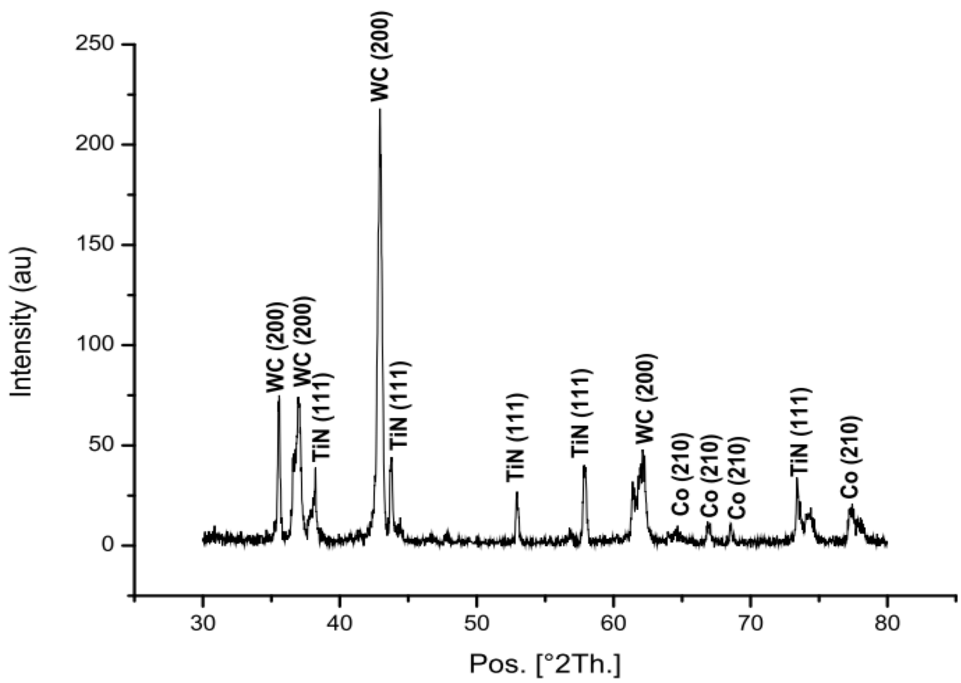


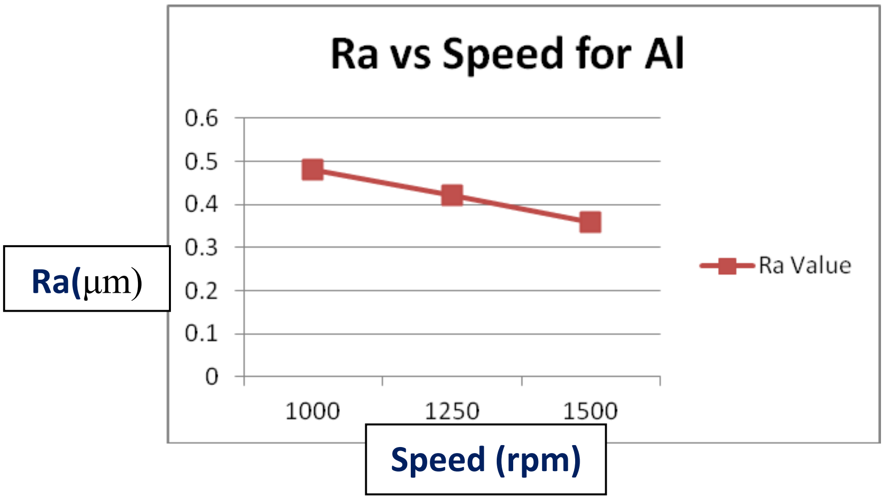
Fig. 4.11(b).XRD patterns of coated carbide tool

4.2. Result of soft (Al) and soft and abrasive(Al+5%Si) turning

Table.4.2. comparison of suface roughness of Al-Si alloy

Sl No.	SPEED (RPM)	FEED (mm/min)	DEPTH OF CUT (mm)	R_a VALUE OF Al (µm)	R_a VALUE OF Al-Si alloy (µm)
1	1000	55	0.5	0.48	2.26
2	1250	35		0.42	2.06
3	1500	15		0.36	1.96

From the above table.5.1 we can see that with the increase in speed and there is decrease in feed value and the surface roughness of both the workpieces are less in value. At the spinde speed of 1500 rpm and feed of 15 mm/min keeping depth of cut constant at 0.5 mm , the average surface roughness Ra was found to be 0.36 µm for aluminium and 1.96 µm for aluminium silicon alloy.



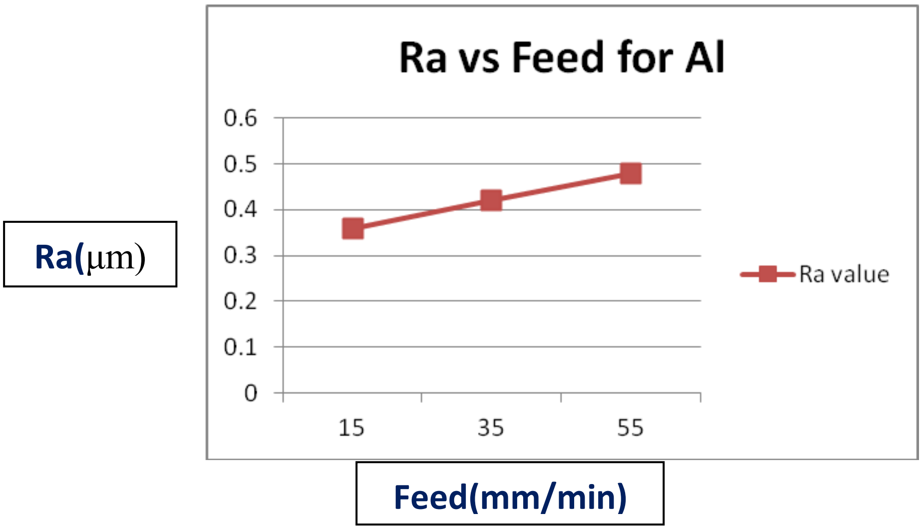
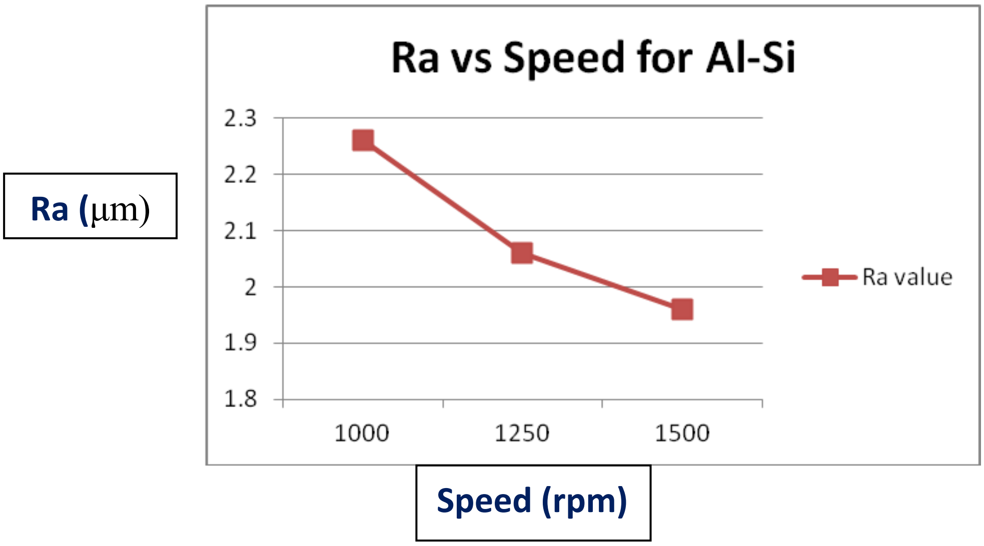


Fig.4.12.The variation of average surface roughness with cutting speed and feed when machining aluminium

From the graphs(Fig.4.12) it has been found that there is a negative relationship between cutting speed and surface roughness. For a lower feed rate of 15 mm/min and higher speed of 1500 rpm, the average surface roughness Ra value was found to be 0.36 µm which is the lower than that at lower speeds and higher feed rates. For a constant depth of cut, at higher speed and at lower feed rate, the surface roughness obtained is very less.



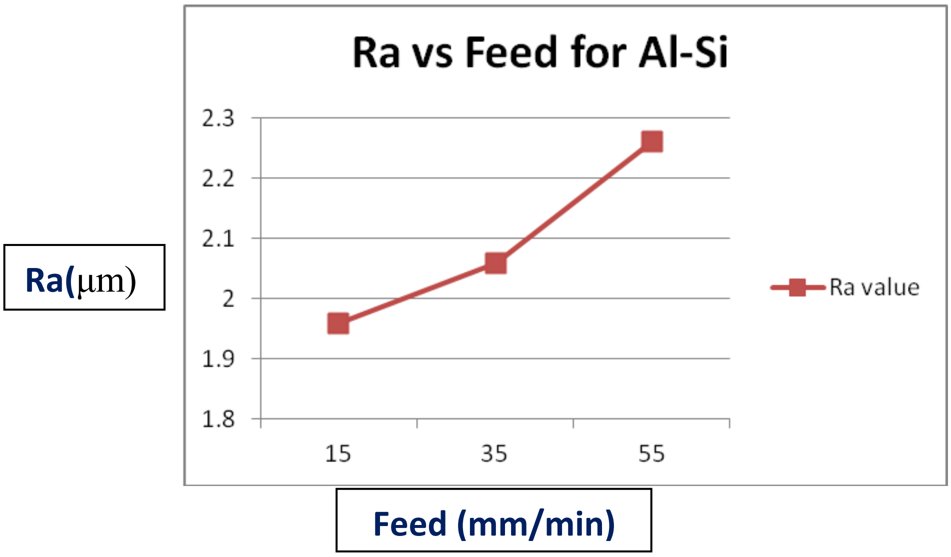


Fig.4.13.The variation of average surface roughness with cutting speed and feed when machining aluminium-silicon alloy

From the graphs (Fig.4.13) it has been found that there is a negative relationship between cutting speed and surface roughness. For a lower feed rate of 15 mm/min and higher speed of 1500 rpm, the average surface roughness Ra value was found to be 1.96 µm which is the lower than that at lower speeds and higher feed rates. For a constant depth of cut, at higher speed and at lower feed rate, the surface roughness obtained is very less.

4.3. Results on Taguchi analysis

Table 4.3. L_{16} OA

Sl No.	Speed (m/min)	Feed (mm/rev)	DOC (mm)	Ra(μ)
1	80	0.06	0.2	1.50
2	80	0.08	0.3	1.97
3	80	0.12	0.4	2.43
4	80	0.16	0.5	2.66
5	105	0.06	0.3	1.45
6	105	0.08	0.2	1.82
7	105	0.12	0.5	2.08
8	105	0.16	0.4	2.31
9	130	0.06	0.4	1.43
10	130	0.08	0.5	1.85
11	130	0.12	0.2	1.81
12	130	0.16	0.3	2.15
13	160	0.06	0.5	1.30
14	160	0.08	0.4	1.65
15	160	0.12	0.3	1.77
16	160	0.16	0.2	2.06

Taguchi Analysis: Surface roughness versus speed, feed and depth of cut

Response Table for Signal to Noise Ratios

Smaller is better

Level	v	f	d
1	-6.405	-3.034	-5.039
2	-5.516	-5.196	-5.181
3	-5.063	-6.047	-5.610
4	-4.466	-7.174	-5.620
Delta	1.939	4.140	0.582
Rank	2	1	3

Response Table for Means

Level	v	f	d
1	2.140	1.420	1.798
2	1.915	1.823	1.835
3	1.810	2.023	1.955
4	1.695	2.295	1.973
Delta	0.445	0.875	0.175
Rank	2	1	3

Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
v	3	8.0138	8.0138	2.6713	23.32	0.001
f	3	36.8024	36.8024	12.2675	107.11	0.000
d	3	1.0625	1.0625	0.3542	3.09	0.111
Residual Error	6	0.6872	0.6872	0.1145		
Total	15	46.5659				

Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj MS	F	P
v	3	0.43020	0.43020	0.143400	20.78	0.001
f	3	1.62815	1.62815	0.542717	78.65	0.000
d	3	0.09045	0.09045	0.030150	4.37	0.059
Residual Error	6	0.04140	0.04140	0.006900		
Total	15	2.19020				

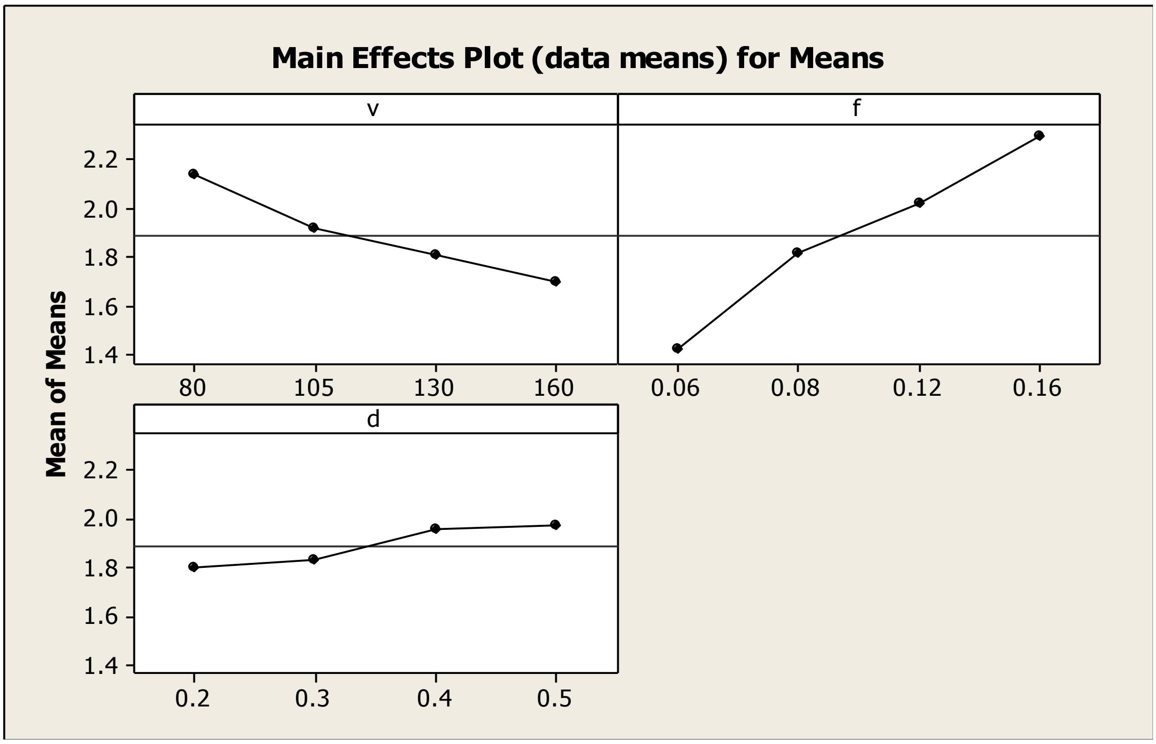


Fig.4.14(a).Main Effect Plot for Mean

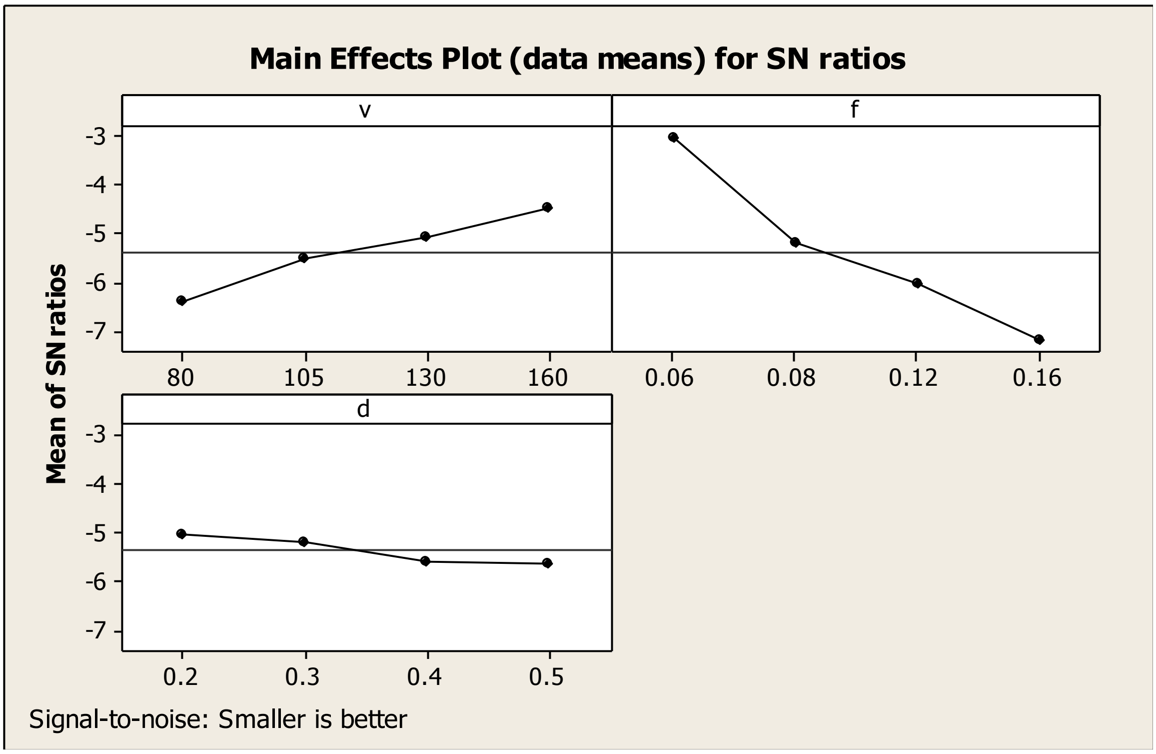


Fig.4.14(b).Main Effect Plot for SN Ratios

From the Taguchi analysis it has been found that the feed is playing as a main parameter for reducing surface roughness, where as depth of cut is having the least affect or does not have significant effect on the surface roughness. If feed value is altered, it will have serious effect on the surface roughness. The speed has medium effect on it. The surface roughness is lowest in case of run 13 and maximum in case of run 4.

CHAPTER 5

Conclusion

Based on the experimental results presented and discussed, the following conclusions are drawn on the effect of cutting speed and feed on the performance of uncoated and multi layer coated carbide tools when turning AISI 4340 steel and performance of uncoated carbide tools when turning aluminium and aluminium-silicon alloy.

1. Coated carbide tools perform better than uncoated carbide tools as far as cutting forces are concerned. For average magnitudes of forces obtained with uncoated carbide tool were higher than those obtained with coated carbide tools under experimental conditions.

2. A cutting speed of 160 m/min has resulted in optimised value of cutting forces in the experimental range. Cutting feed has a direct effect on cutting force. As the feed increases there is a direct increase in the cutting forces.

3. The analysis of the result revealed that, the optimal combination of low feed rate and low depth of cut with high cutting speed is beneficial for reducing machining force.

4. This study concluded that the multilayer TiCN+TiC+TiCN+Al_2O_3+TiN-coated carbide tool with external TiN layer produce better surface roughness with respect to high speed and low feed rate. But the depth of cut has minimum effect on surface roughness. The combination of low feed rate and high cutting speed is necessary for minimizing the surface roughness.

5. Microscopic analysis of the worn surfaces on the cutting tools showed significant wear of the TiN cutting tools due to abrasion . Abrasion was the principal wear mechanism observed at all the cutting conditions. The coated carbide tool was worn due to progressive wear of the protective coating. The cutting toolwear increases almost linearly with increase in cutting speed and feed rate.

6. Results show that, the machining of hard materials at higher speeds is improved by using coated tools. From the experimental investigation it is observed that coated tools give better results as compared to uncoated tools in turning.

7. The uncoated tools have successfully have been employed for machining of soft ductile material like Al and soft and abrasive material like Al-Si alloy. The surfaces obtained under dry machining has been found to be acceptable. However, surfaces produced for Al-Si alloy is not good. Thus better tool and work combination may be used like PCD tools/diamond coated tools.

CHAPTER 6

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