A Dissertation on

"Comparison of Different Coatings on High Speed Steel Tool"

Submitted In the Partial Fulfillment of the Requirement for the Award of the Degree

Master of Technology

IN

Computational Design

Submitted By

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DECLARATION

This is to certify that the work presented in this dissertation entitled **"Comparison Of Different Coatings On High Speed Steel Tool"** towards the partial fulfillment of the requirements for the award of the degree of **Master of Engineering** with specialization in **Computational Design**, from Delhi Technological University, Delhi is an authentic record of my own work carried out under the supervision of **Mrs. Navriti Gupta**, assistant professor, Department of Mechanical Engineering at Delhi Technological University, Delhi.

To the best of my knowledge, the content of this dissertation report has not been submitted by me for the award of any previous degree to anyone else.

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This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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CERTIFICATE OF APPROVAL

It is certified that the contents and form of the project entitled **“Comparison Of Different Coatings On High Speed Steel Tool ”** submitted by **Abhishek Kumar (2K13/CDN/20)** is hereby approved as a creditable study of research topic and has been submitted in a satisfactory manner for its acceptance as prerequisite to the degree for which it has been submitted.

It is understood that by this approval, the under signed do not necessarily endorse any conclusion drawn or opinion expressed there, but approve the Submission for the purpose for which it is submitted.

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Abstract

At present, high speed machining is the most promising approach to increase both efficiency and precision of metal cutting process. There are different types of cutting tools in use for machining various materials for the multiple operations in order to produce components. The manufacturers of these components expect to improve their productivity, quality of the components and longer life of the cutting tools. Quality and productivity play a vital role in present's manufacturing market. Therefore, every manufacturing or production unit should concern about the quality of the product. Apart from quality, there exists another criterion, called productivity which is directly related to the profit level and also goodwill of the organization. The study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity with special emphasis on reduction of cutting tool flank wear. Because reduction in flank wear ensures increase in tool life. Traditional hard coatings, such as TiN, TiAlN, WC, TiC, Cermets etc played an important role in the development stage of new generation cutting tools in an attempt to improve the wear resistance of cutting and forming tools. The tool manufacturers also aims at producing quality tools to with stand for higher cutting forces, thermal resistivity with more wear resistance and to give longer life of the tool, to produce better surface finish product and maintain desired dimensional accuracies of the product. For the past several years the materials of the cutting tools are the same, but due to continuous improvements in enhancing the life of the cutting tools, different methods process are in progress for producing the tools. The cutting tool manufacturers with their rich R&D experience and continuous innovations, carrying on their production activity to meet the challenges of the market demand and it has been investigated by various researcher for improving their productivity, quality of the components and longer life of the cutting tools.

In this project a new coating i.e. carbon nanotubes(CNT) coating deposited on HSS tool by Chemical vapor deposition (CVD) method and compared the results with as CNT coated HSS tool and non coated HSS tool at different cutting parameters such as depth of cut and feed rate on lathe machine with dynamometer.

The changes in the microstructure, elemental composition and crystallographic phases of non coated and deposited coated tools pre-turning and post turning were examined using Scanning electron microscopy and e-dax test and comparative analysis of imparted forces such as Cutting force, feed force and axial thrust force has been done by the use Origin 2015 software.

The results during dry turning of EN8 grade medium carbon steel with various cutting parameters with coated and non coated tools revealed that reduction in cutting force upto 32.315 % was observed.

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INTRODUCTION

1.1 Background

In the present competitive market of producing goods to meet the rapidly increasing demand of products having high tolerance, the manufacturing or production units continuously making great effort for increasing qualitative products and for decreasing cost of machining. Cutting tool materials has been developed for producing qualitative products, for machining difficult and complex materials and enhance the productivity. For metal cutting, carbon steel material was produced a century ago, now various and different cutting tools of different materials are being developed continuously to meet the demand of production industries.

In a comparative study of coatings of TiN, TiAlN and Diamond researcher reported that the hard coatings of TiAIN are of higher oxidation resistance than TiN. It was found that for TiN at 500°C severe oxidation occurred but did not occur on TiAIN until the temperature reached 750°C [1,2]. On the basis of research made in the area for developing ternary nitride coatings with nano structured, It was observed that coatings deposited with nano grain structure shows higher hardness in comparison to the coatings based on coarser grain size, but during machining high temperature developed on cutting tool due to which grain growth takes place, which results in reduction in hardness of coatings. It is therefore of their interest to investigate a way that at elevated temperature nano structured ternary nitride coatings would be structurally. In the study of coating based on at temperature up to 1000°C, its hardness was evaluated and compared with another coating materials [3-9].

Generally, Covalent or metallic bonds are formed when we add aluminum to the TiN phase which results a polar inter phase between them. After Studying it was obesved thatcoatings with TiAlN gives higher performance as compared to TiN coatings, due to its outstanding properties it is now being used for forming and cutting tools for high speed machining. It is used as insulating barriers deposited on aluminum in integrated circuits due to its impressible properties suxh as high resistance to oxidation at low thermal conductivity and high temperature deposited. There are various method to produce these coatings such ad sputtering, ionic implantation and reactive electric arc evaporation. The phenomenon of these coatings includes that when surface is heated adhesion of Al_2O_3 at high level form a protective layer to covered surface due to which oxygen diffused into the covered surface of material. It was also observed that films of TiAlN structure mainly based on amount of aluminum added, coatings seems dark gray in color if greater amounts of aluminum are present and with the less amount of aluminum coating becomes golden in colour [10-17]

Various research has been done in nanotechnology due to outstanding properties of carbon naonotubes (CNTs) such as thermal, mechanical and electrical property. Major applications of CNTs due to its impressible properties are scanning probe microscopy tips, microelectronic device, intramolecular gene delivery devices, composite materials, electrochemical probes, hydrogen and energy storage etc. [18] and the aim of this project is to meet the applications in mechanical tool industries for enhancing mechanical properties of tool , increase the tool life and ultimately cost of machining by preparing a CNT coating on HSS tool and analyzing its properties.

1.2 High Speed Machining

Machining with high speeds (HSM) is one of the growing and advanced technologies as compared to conventional cutting. HSM led to increase efficiency, accuracy and impart quality to work materials and ultimately reduce the machining time and machining coat at some cuttimg parameters. There is a various definition of HSM, and in 1931 Sir Carl Soloman has given its first definition. According to their study temperature at tool chip interface begins decreasing when machining with high speed carried out such as 5 to 10 times greater than that conventional machining. (Fig. 1)

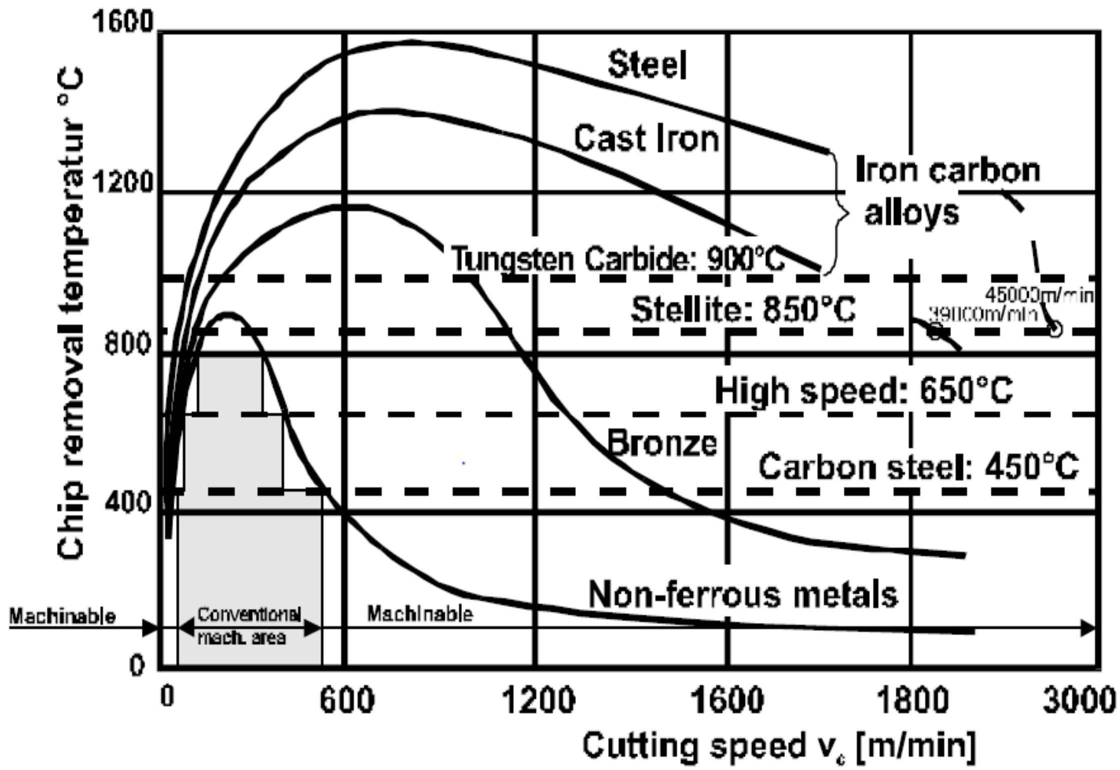


Fig 1. Temperature v/s cutting speed

Source: Pasko, R. - Przybylski, L. & Slodki, B., High Speed Machining- The Effective Way of Modern Cutting, 2010 (19)

It is impossible to verify this theory completely based on existing and recent investigated results. For different materials, at cutting edge temperature start decreasing at some cutting speed relatively. HSM can be defined in various ways depends on some factors as given as follows [19]

- Machining with high cutting speed,
- Machining with high speed and feed,
- Machining with high rotational speed ,
- Machining with high feed machining ,
- Machining with high productive machining.

Practically, it is said that HSM is not a shows high cutting speed only, but HSM can be defined as it is a process in which the machining are performed with advanced methods and at different highly efficient production machines and equipment [19].

Major applications of HSM is machining and finishing of hardened steels performed at both high speeds and feeds. The HSM processes are increasingly and widely used in present manufacturing. However, such processes responsible for discontinuous chip formation which is highly correlated with increase in tool wear, disintegration of the work piece surface finish, and lack of accuracy in the machined part. The variations of cutting force components are depends on of chip load and cutting speed. The variations in cutting force produces severe self excited and forced vibrations which cause degradation of the tool life, work piece geometry, finish and lastly machine tool itself.

Some parameters for HSM are given as

1.2.1 True Cutting Speed

As cutting speed is dependent on both spindle speed and tools diameter, HSM can be defined as true cutting speed above a certain level. The cutting speed and the feed rate are linearly dependent which results in high feeds with high speeds.

1.2.2. Material Removal Rate

The material removal rate, Q is consequently and considerably smaller than in conventional machining with the exception when machining in aluminum other non ferrous materials and in finishing and super finishing operations in all types of materials.

1.2.3. Surface Finish

Like in conventional machining the surface finish in HSM is dependent on different conditions like the geometry of cutting tool, wear conditions of the cutting tool, coating of the cutting tool, lubrication, cutting strategy are determined on the CAM system, work piece material, cutting tool extension etc. Considering all these parameters are controlled, the expected surface finish may be calculated through the different techniques.

1.2.4. Tool Cost And Machining Cost

In HSM, cost of cutting tools will increase substantially. The benefit of HSM is can be shown by a reduction of processing time and cost, reduction of finishing work, better surface finish, higher accuracy etc. For this purpose cutting tool cost can only be seen as an integral part of the overall cost accounting. Machining cost will be less than the conventional machining process due to reduction of process time and elimination of process steps.

1.3 Requirement Of High Speed Machining

High Speed Machining enables manufacturers to shorten machining times and to achieve a higher surface quality**.**HSM is a powerful machining method that combines high feed rates with high spindle speeds, specific tool motion and specific tools.

- To survive in the competitive market, it is desirable to use HSM in order to reduce time of machining and hence production cost.
- The new emerging materials like composite materials, stainless steel alloys and heat resistant, bimetals, hardened tool steels, compact graphite iron, aluminum alloys etc., needs this new machining such as HSM.
- HSM provides high quality of products by not taking into account manual finishing of moulds or dies with a complex 3-D geometry, aluminum component machining etc.
- HSM avoids the number of setups of components and allows the easy flow of material, which can reduce substantially the manufacturing throughout time.
- HSM technique is one of the main technique in rapid product development.

Here the HSM mostly applied in all machining operations and thereby reduction of two process steps. Normal reduction in time compared to the process A is approximately equal to 30-50%. The other benefits include material handling cost reduction, increased productivity, lower residual stress, machining of very thin walls possibility, enhanced tolerance of damage, reduced delivery times, coolant elimination and increase in cutting efficiency etc.

1.4 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 shape, size and surface finish. Virtually all producing units for example automobiles, railways, aircraft manufacture, shipbuilding, home appliance , consumer electronics and construction industries etc required large shops with many thousands of machining .The machining cost amounts to more than 15% of the value of the all manufactured products in all industrial countries. Of all the processes used to shape and size the metals in metal cutting process the conditions of operation can be varied to a high extent to improve the quality and the rate of producing parts with a reduced cost.

1.5 Theory of metal cutting

Metal cutting process is the basic tool of the engineering industry and is related either directly or indirectly in the manufacturing of every product of our modern civilization. The cutting tool is one of the important component in realizing the full prospective out of any metal cutting process. From last many years the need and demands of economic competition have increased widely research in the field of metal cutting which leads to the progression of new tool materials of desirable performance and vast capacity for increase in productivity up to greater extent**.** As manufacturers continually seek and apply new emerging materials for products that are lighter, stronger and more efficient suggesting that cutting tools must be developed that can machine new materials at the highest productivity and accuracy.

The main properties of any cutting material must have in order perform its function accurately are:

1. Hardness to overcome wearing action.
2. Hot strength to overcome the heat involved
3. Sufficient toughness to withstand vibration

In general for using heavy cuts, increasing hardness results it reduction in toughness and so those materials in the higher hardness region of the list will fail by breakage, especially with work pieces or jobs which have holes or slots in them which give imparts interruption in the cut.

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

• Capacity to retain form stability at elevated temperatures during high cutting speeds.
• Resistance to diffusion
• Resistance to mechanical and thermal shock.
• High resistance to brittle fracture.
• Low Cost and ease of fabrication.

The cutting tools must be made of type of materials to withstand :

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

In addition to these 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.

1.6 Cutting Tools

The cutting tools are especially designed for high metal removal rate to suit HSM . All the costs such as cutting and holding tools used in HSM are to be designed for the specific and desired purpose of machining. The tools are generally designed cutting edges with either zero or negative rake angles. One of important design feature of the cutting tool is having thick core to withstand maximum bending. The increase in run-out error in the tool or tool holder reduces the tool life to a great extent. A method is come into existence to change the length tool length, so that the most stable region falls at the high speed of the spindle. Various different designs of tool and tool holder interface are developed for reducing the instability. Stability of the interface can be improved by using shrink fit tooling and shortening of the overhang portion. High spindle speed limits the use of conventional cutting tools with taper interface provided. A modification has developed in conventional taper design for achieving more stiffness through face contact. The high development of cutting tool materials and holding devices has increased the Use of HSM. The development of super hard cutting materials such as Cubic Boron Nitride (CBN), Poly Crystalline Cubic Boron Nitride for machining hard steel has created various newer applications for HSM. Also the development of machining with various coating technologies is able to withstand the high temperature produced in HSM. In HSM the super hard materials and cutting edges which resist the high temperatures is the way to provide maximum performance for different types of materials.

Among the cutting tools which is used for machining and alloy of steels carbide is the most common widely used tool material. Carbide tools have a greater degree of toughness but poor hardness as compared to advanced emerging materials such as cubic boron nitrite (CBN) and ceramics. To improve the hardness and surface conditions carbide tools are coated with hard coatings such as titanium nitride (TiN), Titanium carbonitride (TiCN) and titanium aluminum nitride (TiAlN).

1.7 Needs And Development Of Cutting Tool Materials

- With the progress of the industrial world it has been needed to continuously develop and improve the cutting tool materials and geometry.
- To meet the increasing demands for high quality, productivity and economy of machining.
- For rapidly increasing demand of micro and nano machining.
- To get high accuracy and effective machining of the super hard materials that are coming up with the fast and vast progress of science, research and technology.
- For precision and ultra-precision machining.

Performance of cutting tools depends upon:

- The cutting tool materials.
- The cutting tool geometry.
- Proper selection and use of those tools.
- The machining conditions and the environments.

1.8 Different Cutting Tool Materials

1.8.1 High Speed Steel (HSS)

HSS come into existence in around 1905 made a revolution at that time in the history of cutting tool materials though got later lagged by various other novel tool materials such as cemented carbides and ceramics which could machine much faster than the HSS tools.

The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe. Such tools made up of HSS could machine mild steel workpiece at speed only upto 20 to 30 m/min but HSS is still used as cutting tool material where;

- The tool geometry and mechanics of chip formation are complex, such as helical twist drills, reamers, gear shaping cutters, hobs, form tools, broaches etc.
- Brittle tools which are not suitable under shock loading like carbides, ceramics etc.
- The small scale industries cannot afford costlier tools
- The old or low powered small machine tools cannot accept high speed and feed.
- The tool is to be used number of times by resharpening.

The effectiveness and efficiency of HSS tools and their application were gradually improved by enhancing its properties and surface condition through:

- Refinement of microstructure
- Addition of large amount of cobalt and Vanadium to increase hot hardness and wear
- resistance respectively.
- Manufacture by powder metallurgical process.
- Surface coating with heat and wear resistive materials like TiC, TiN, etc by Chemical Vapour Deposition (CVD) or Physical Vapour Deposition (PVD).

1.8.2 Stellite

Satellite is a cast alloy of Cobalt (40 to 50%), Chromium (27 to 32%), tungsten (14 to 19%) and Carbon (2%). Stellite have higher toughness and more heat and wear resistance than the basic HSS (18 – 4 – 1) But such stellite as cutting tool material omitted due to its poor grindability and specially after emerging cemented carbides.

1.8.3 Sintered Tungsten carbides

The advent of sintered carbides made another breakthrough in the history of cutting tool materials.

- **Straight or single carbide**

  The straight or single carbide tools or inserts were produced by powder metallurgical process such as mixing, compacting and sintering 90-95% WC powder with cobalt. The hot, hard and wear resistant WC grains are held by the binder Co which provides the necessary strength and toughness. Such tools are suitable for machining brittle materials such as grey cast iron, brass, bronze etc. which produce discontinuous chips at cutting velocities two to three times of HSS tools.

- **Composite carbides**

  The single carbide is not used for machining steels due rapid growth of wear, particularly crater wear, by diffusion of Co and carbon from the tool to the chip under the high stress and temperature results bulk contact between the continuous chip and the tool surfaces. For machining steels subsequently, another type of material composite carbide have been developed by adding (8 to 20%) a gamma phase to WC and Co mix. The gamma phase is a mix of TiC, TiN, TaC, NiC etc. which have high diffusion resistant than WC due to their high stability and less wettability by steel.

- **Mixed carbides**

  Titanium carbide (TiC) is stable as well as much harder than WC. So for machining ferritic steels causing high diffusion and adhesion wear a large quantity (5 to 25%) of TiC is added with WC and Co to form another grade material called Mixed carbide. But increase in TiC content reduces the toughness of the tools. So, for finishing with light cut but high speed, the harder grades containing upto 25% TiC are used and for heavy rough work material at lower speeds lesser amount (5 to 10%) of TiC is suitable.

1.8.4 Plain ceramics

Ceramics have high compressive strength, chemical stability and hot hardness results to powder metallurgical production of indexable ceramic tool inserts since 1950. Alumina (Al_2O_3) is preferred to silicon nitride (Si_3N_4) for higher hardness and chemical stability. Si_3N_4 having hig toughness but more difficult to process. The nature of plain ceramic tools are brittle caused limited applications. Plain ceramics tools are generally used with high cutting speeds for finish machining of ferrous alloys or cast iron work-pieces, they are also used for machining of very hard materials of hardness upto HRC 63 but at low to medium range cutting velocity and at very rigid machinery.

Advantages

- Very high hardness
- Very high hot hardness
- Chemical stability
- Antiwelding
- Less diffusivity
- High abrasion resistance
- High melting point
- Very low thermal conductivity
- Very low thermal expansion coefficient

Shortcomings

- Poor toughness
- Poor tensile strength
- Low thermal conductivity
- Less density

The plain ceramic have greater properties than existing tool materials in some application areas like high speed machining of softer steels mainly for higher hot hardness as indicated in figure 2.

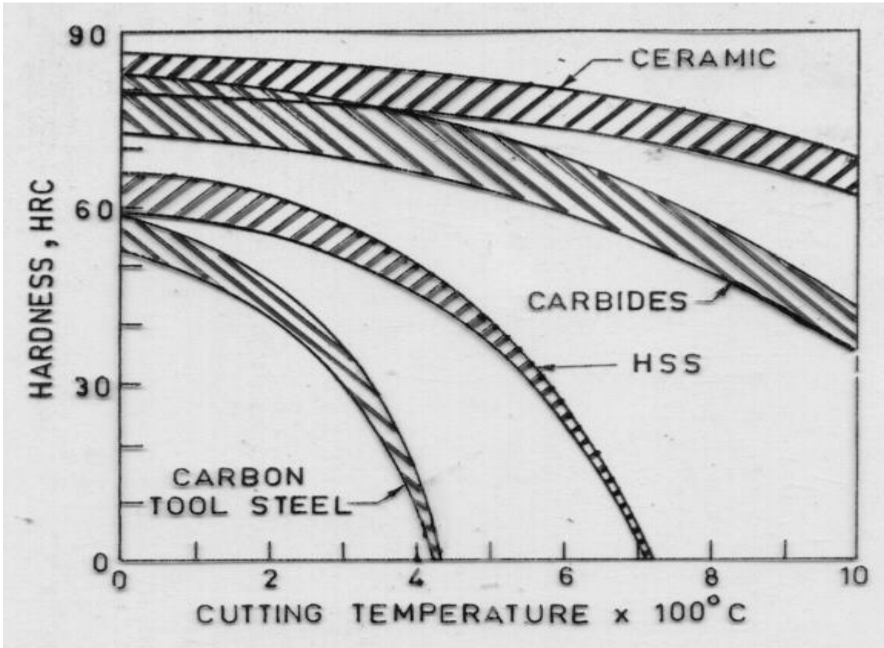


Fig 2. Hot hardness of the different commonly used tool materials.

Source: S.K. Choudhary, P. Srinivas, "Tool wear prediction in turning", Material Processing and Technology, 2004, v. 153, pp. 276-280.[20]

Though the use of brittle plain ceramic tools upto strength and toughness could be substantially improved since 1970, gradually decreased for being restricted to

- Uninterrupted machining of soft cast irons and steels only
- Relatively high cutting velocity but only in a narrow range (200 to 300 m/min)
- Requiring very rigid machine tools

1.9 Tool 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. During machining ferrous and hard to machine materials like steels, cast iron and super alloys. Temperature at which it gets soft and the chemical stability of the tool material binds the cutting speed. Therefore, it is required for tool materials to exhibit sufficient inertness and good high-temperature mechanical properties. However, various ceramic materials like TiC, Al2O3 and TiN exhibit high temperature strength and it has lower fracture toughness than that of conventional tool materials like high speed steels(HSS) and cemented tungsten carbides. By depositing single or multi layer coatings on conventional tool materials the machining of chemically reactive and hard materials at higher speeds in addition to the effective and beneficial properties of ceramics and traditional tool materials.

Coatings are dispersal obstruction which prevents the interaction between chip formed during the machining and the cutting material itself. The material compounds which formed as coatings used are highly hard and ultimately abrasion resistant. Such constituents of coatings are Titanium Carbide(TiC), Titanium Carbonitride (TiCN) ,alumina (Al2O3), Titanium Nitride (TiN), Carbon nano tubes(CNT).

1.10 Need of Coatings

During high speed machining heat is generated from plastic deformation energy of the workpiece in the primary shear zone and at chip or tool interfaces in secondary shear zone, some amount of heat content is also generated at machined tertiary shear zone as shown in figure. This large amount of heat generation leads to deformation of the cutting edges, thus the surface of the tools demands high hardness, abrasion resistant, chemically inert, low thermal conductivity, and having low coefficient of friction whereas bulk should be tough having high thermal conductivity to avoid deformation of tool form and geometry. This combination of the material properties can be achieved with the help of coating. Coatings act as a chemical and thermal barrier between the tool and workpiece which prevent chemical reactions between the tool and work material, increase the wear resistance of tool, reduce built-up edge formation, prevent deformation of the cutting edge due to excessive heating and decrease friction between the tool and chip**.** Thus, Coatings improves the performance of the cutting tools in comparison to uncoated tools during the machining operations.

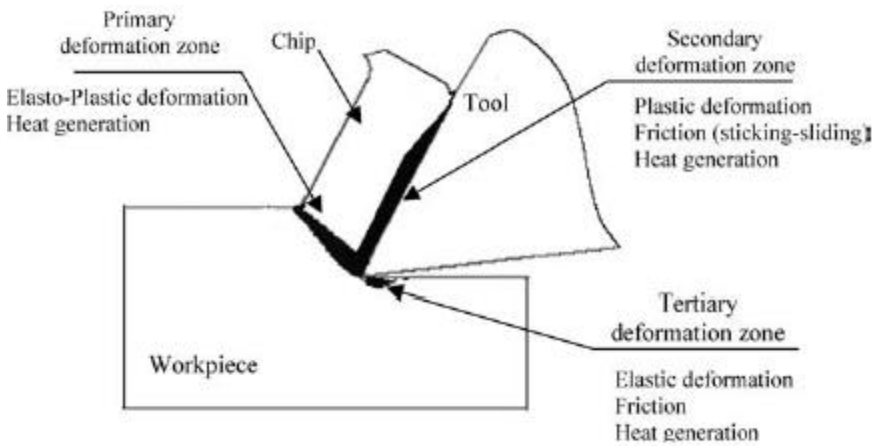


Fig 3. Primary and secondary shear zones during plastic deformation of material

Source: N.A. Abukhshim, P.T. Mativenga, M.A. Sheikh, "Heat generation and temperature prediction in metal cutting: A review and implications for high speed machining", 2005, v. 20, pp. 1-19 [21]

Hard coating deposited to cutting tools can effectively alter the properties of the cutting tools. Less heat will be generated on tool during the cutting operations due to low coefficients of frictions and low tendency to adhesion of the coating to the work piece material. The low thermal conductivities of the coating will produce a thermal barrier on the tool surface.

In addition to high thermal stability, hot hardness and oxidation resistance. Resistances will reduce the wear of the tool and less amount of heat will be transferred to the tool and thus a major part of the generated heat will be transported away from the cutting areas with the chips.

1.11 Types Of Coated Tools

1.11.1 Coated carbides

The properties and performance of carbide tools can be significantly improved by

- Refining microstructure
- Manufacturing by casting are expensive and uncommon
- Surface coating are made remarkable contribution.

Hard and thin coating of single or multilayers of more stable, heat and wear resistive materials such as TiC, TiCN, TiOCN, TiN, Al_2O_3 etc on carbide substrates having high toughness by processes like chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) etc at controlled pressure and temperature enhanced metal removal rate and overall machining cost,

- Reduction of cutting forces and power consumption
- Increase in tool life by 200 to 500% for same cutting velocity or increase in cutting velocity by 50 to 150% for Same tool life
- Improvement in product quality
- Effective and efficient machining of wide range of work materials
- Pollution control by less or no use of cutting fluid through :

    - Reduction of abrasion, adhesion and diffusion wear
    - Reduction of friction and BUE formation
    - Heat resistance and reduction of thermal cracking and plastic deformation

1.11.2 Cermets

These sintered hard inserts are formed by combining 'cer' from ceramics such as TiC, TiN or TiCN and 'met' from metal binder like Ni, Ni-Co, Fe etc. The modern cermets has been giving much better performance since around 1970s and they are being made by TiCN which has more wear resistant, less porous and easier to fabricate.

The characteristic features of such cermets, in comparison to sintered tungsten carbides are :

- The grains are made of TiCN in place of WC and Ni or Ni-Co and Fe as binder in place of Co.
- Harder, more chemically stable and hence more wear resistant
- More brittle and less thermal shock resistant
- Wt% of binder metal varies from 10 to 20%
- Cutting edge sharpness is retained unlike in coated carbide inserts
- It can machine steels at higher cutting velocity than that used for tungsten carbide, even coated carbides in case of light cuts.

1.10.3 Coronite

The properties and performance of HSS tools could have been improved efficiently by refinement of microstructure, powder metallurgical process of making and surface coating as it is already mentioned earlier. Recently a unique tool material named Coronite has been came into existence for making the tools such as small and medium size drills and milling cutters etc. which were earlier generally made of HSS. Basically Coronite is made by combining HSS for strength and toughness and tungsten carbides for heat and wear resistance. Micro-fine TiCN particles are uniformly dispersed into the matrix.

The coronite based tool is made of three layers in contrast with carbides;

- the central HSS or spring steel core
- a layer of coronite of thickness around 15% of the tool diameter
- a thin 2 to 5 μm PVD coating of TiCN.

Such tools more productive as well as provides higher product quality. The coronite tools fabricated by hot extrusion process followed by PVD coating of TiN, TiCN or HSS tools in respect to cutting forces, tool life and surface finish.

1.11.4 Cubic Boron Nitride

Cubic boron nitride is the hardest material presently available next to diamond. CBN as compacts has been introduced as cutting tools in 1970 and onwards. It is produced by bonding a 0.5 to 1 mm layer of polycrystalline cubic boron nitride to cobalt based carbide substrate at very high temperature and pressure. It is inert and pertain greater hardness and fracture toughness at elevated machining speeds. It gives tremendous performance in grinding of material having high hardness and strength. Due to high hardness, toughness, chemical and thermal stability and wear resistance CBN cutting tool inserts come into existence for high material removal rate (MRR) as well as precision machining provides excellent surface conditions of the products, thus these tools are used in machining effectively for wide range of work materials having high carbon content and alloy steels, non-ferrous metals and alloys, exotic metals like Ni-hard, Inconel, Nimonic etc and many non-metallic materials which are difficult to machine with conventional machining tools. It is stable at temperatures upto 1400^o C. While machining grey cast iron the operative range of speed for CBN is 300 to 400 m/min.

Speed ranges for some other materials are given as :

• Hard cast iron (> 400 BHN) : 80 – 300 m/min
• Superalloys (> 35 R_C) : 80 – 140 m/min
• Hardened steels (> 45 R_C) : 100 – 300 m/min

Preparation of cutting edge is the most important factor that affects performance of cBN inserts in addition to speed.CBN tools used effectively with a honed or chamfered edge preparation, especially for interrupted cuts. Such as ceramics, CBN tools are also available only in the form of indexable inserts. The only limitation of it is its high cost.

1.11.5 Diamond Tools

Single stone, natural or synthetic, diamond crystals are used as tip or edge of cutting tools. Natural single stone crystal is used for various applications, where high accuracy and precision are required due to its extreme hardness and sharp edges.

Some important uses are:

- Single point cutting tool tips and small drills for high speed machining of non-ferrous metals, ceramics, plastics, composites, etc. and effective machining of difficult-to-machine materials
- Drill bits for mining, oil exploration, etc.
- Tool for cutting and drilling in glasses, stones, ceramics, FRPs etc.
- Wire drawing and extrusion dies
- Super abrasive wheels for critical grinding.

Natural diamond requires a more reliable source of diamond due to Limited supply, increasing demand, high cost and easy cleavage. It caused to the manufacturing of artificial diamond grits by ultra high temperature and pressure synthesis process, which gives manufacturing of diamond in large scale with shape and friability of the diamond grits as desired for various applications and some control over size.

1.11.5.1 Polycrystalline Diamond (PCD)

The polycrystalline diamond (PCD) tools consist of a layer (0.5 to 1.5 mm) of fine grain size, randomly oriented diamond particles sintered with a suitable binder such as cobalt and then bonded to a desired substrate such as cemented carbide or Si_3N_4 inserts. PCD exhibits excellent wear resistance, hold sharp edge, generates little friction in the cut, provide high fracture strength, and had good thermal conductivity. These properties plays an important role to PCD tool long life in conventional and high speed machining of soft, non-ferrous materials such as aluminium, magnesium, copper etc, super advanced composites and metal-matrix composites, superalloys, and non-metallic materials. PCD is generally well suited for abrasive materials such as drilling and reaming metal matrix composites where use of PCD gives 100 times more than life of carbides. PCD is not suitable for ferrous metals due to its high solubility of carbon in these materials at elevated temperature. but PCD tools can be used to machine some of specific materials under special conditions i.e. light cuts can be successfully machined in grey cast iron. The major benefit of such PCD tool is higher toughness due to fine grain structure with reduced cleavage and random orientation of the grains.

But use of PCD have some limitations like :

- High tool cost
- Presence of binder, cobalt, which reduces wear resistance and thermal stability
- Complex tool shapes like in-built chip breaker cannot be made
- Size restriction, particularly in making very small diameter tools

1.11.5.2 Diamond coated carbide tools

Due to the fact that the formation of low pressure synthesis of diamond from gaseous phase, lots of effort has been made to use thin film diamond as cutting tool . They are generally used as thin less than 50 µm or thick greater than 200 µm films of diamond produced by CVD method for cutting tools, dies, wear surfaces and also abrasives for Abrasive Jet Machining (AJM) and grinding. Thin film is directly deposited on the tool surface. Thick film greater than 500 µm is grown on an primary substrate after that brazed to the actual tool substrate and the primary substrate is removed by dissolving it or by other method. Thick film diamond having applications in making inserts, drills, reamers, end mills, routers. PCD coating has been more popular than single diamond crystal coating due to the fact that it is Free from binder and having higher hardness, resistance to heat and properties close to natural diamond

- Highly pure, dense and free from single crystal cleavage
- Allows wider range of size and shape of tools and it can be coated on any shape of the tool including rotary tools
- Relatively less expensive

However, to get improved and reliable performance of thin film CVD diamond coated tools such as carbide, nitride, ceramic, sic etc in terms of greater tool life, dimensional accuracy and surface finish of jobs essentially need :

- Good bonding of the diamond layer.
- Adequate properties of the film, e.g. Wear resistance, micro-hardness, edge coverage, edge sharpness and thickness uniformity
- Ability to provide work surface finish required for specific applications.

While CBN tools are used for high speed machining of hard and strong steels and similar materials, Diamond tools are widely useful for machining stones, slates, glass, ceramics, composites, FRPs and non ferrous metals specially which are sticky and BUE former such as pure aluminum and its alloys.

1.12 Carbon Nanotubes

A CNT is comprised of one or many graphitic sheets, rolled up into a cylinder. Carbon can exist in many forms and take on varying chemical and physical properties. Carbon atoms have six total electrons, occupying the 1s2, 2s2, and 2p2 orbitals. The bond strength between the valence electrons in the outer two orbitals is weaker than that in the 1s2 orbital, thus allowing a mixing or hybridization of the electrons. This mixing is made possible by the small energy difference between the 2s and 2p energy levels. The three possible hybridizations in carbon are sp, sp2 and sp3 and three respective example materials include acetylene, polyacetylene, and methane.

CNTs can be grouped into two classifications based upon the number of layers of graphitic carbon that comprise their sidewalls:

- Singlewalled CNTs (SWNTs)
- Multiwall CNTs (MWNTs)

1.12.1 Singlewalled Nanotubes

Tubes consisting of one single layer are called singlewalled nanotubes. Single-walled nanotubes (SWNTs) can be viewed as seamless cylinders rolled up from a piece of grapheme. The structure and conductivity of the nanotube is determined by the chirality of the nanotube.

1.11.2 Multiwalled Nanotubes

Those having more than one layer of carbon are referred to as multiwall CNTs (MWNTs). Multiwalled nanotubes (MWNTs) can be thought of as concentric singlewalled nanotubes of increasing diameter arranged in a nested, Russian doll type fashion. The material properties of MWNTs are mostly dependent upon the perfection and orientation of the graphitic planes comprising the MWNT[25]. Depending upon the structuring of the concentric nanotubes and the presence of slight imperfections, a multiwalled nanotube can exhibit a number of structural formations including herringbone and bamboo type. Herringbone MWNTs exhibit graphitic planes, also called graphines, at an angle to the central nanotube axis.

1.12.3 Properties Of Nanotubes

The impressive properties of CNTs in three aspects, mechanical, electrical and biological or chemical can be presented as:

1.12.3.1 Mechanical

- SWNTs are strong and stiff.
- The Young's modulus of nanotubes is 1TPa, is five times higher than that of steel [22]
- Theoretically predicted tensile strength, the maximum tensile stress one material can sustain before failure, is 130GPa [23]

These mechanical properties, combined with electrical conductivity, also led the interest in people to couple SWNTs into nano-electromechanical systems. For example, an electrically actuated tunable oscillator using SWNTs has been demonstrated [24]

1.12.3.2 Chemical or Biological

- SWNTs are chemically inert, especially when no defects are present. This makes them chemically stable and biologically compatible. Studies have shown that SWNT FETs can operate in aqueous solutions [25; 26]

- SWNTs are ideal materials to make detectors that are capable to reach single-molecule level sensitivity [26; 30].

- Potential applications are not limited to sensors. On top of being chemically stable, SWNTs have large surface to volume ratio and are becoming an interesting material as electrodes in electrochemistry researches. SWNTs can be used as electrodes [27] or nucleate sites for nanoparticle growth [28].

1.12.3.3 Electrical

- SWNTs are made of graphene; graphene has high intrinsic electron mobility [29] due to its lack of lattice defects as compared to most other semiconductor materials and its unique linear dispersion relation.

- The diameters of SWNTs are so small that the electron wave vectors along the circumferences are quantized. This produces a series of sub-bands in a nanotube.

- SWNTs have tremendous electrical performances. High quality SWNTs can have mobility greater than 10,000 $cm^2/(V.s)$ and it also have mean free path greater than 1 mm. Not only its extraordinary conductance, but also it can have minimum capacitance coupling with gates when these tiny SWNTs made into FETs. These two factors lead to small RC time constant. People are using SWNT FETs which is operating at up to 50GHz [28]

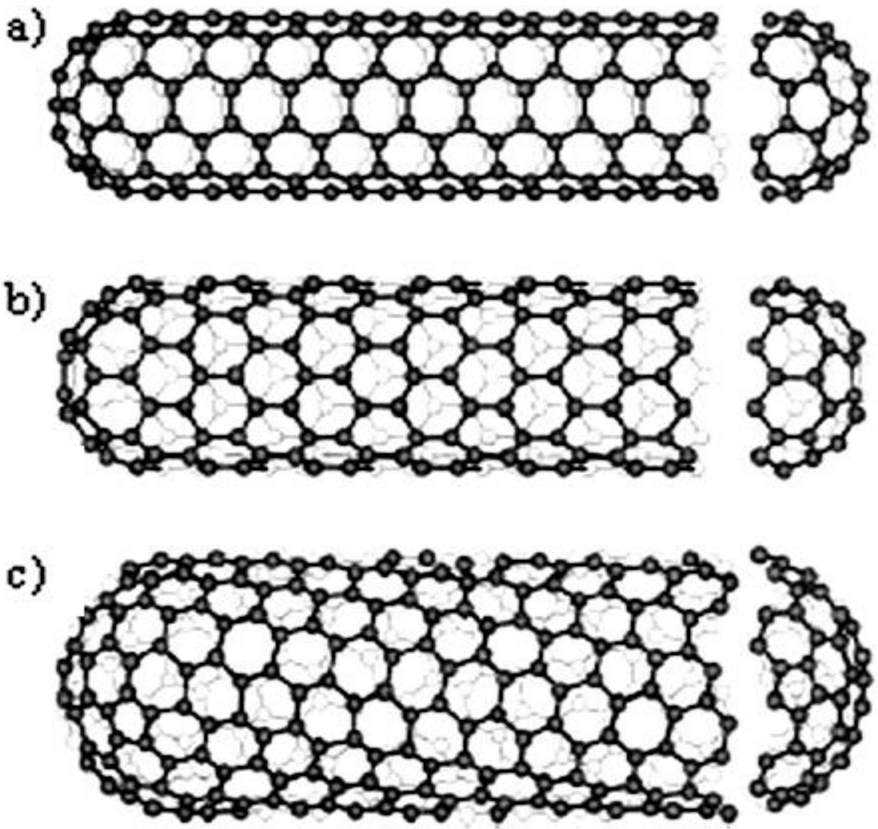


Figure 4. Three types of CNTs consisting a) zigzag, b) armchair and c) chiral

Source: M. S. Dresselhaus, G. Dresselhaus, and P. C. Eklund, Science of Fullerines and Carbon Nanotubes: Academic, 1995 [31]

1.13. Types of coatings

Different types of coatings are used on cutting tools for enhancing their performance during machining operations. On the basis of composition, structure and nature these coatings can be classified are as follows:

(1) Conventional hard coatings

(2) Multicomponent alloy coatings

(3) Multilayer coatings

(4) Composite coatings

(5) Soft coatings

(6) Super lattice coatings

(7) Super hard coatings

S.NO.	**Coatings**	**Examples**
1	Conventional hard coatings	TiC, TiN, TiCN, Al2O3, HfC ,HfN
2	Multicomponent alloy coatings	TiAIN, TiCrN, TiVN
3	Multilayer coatings	TiC/TiCN/TiN,TiC/TiN/Al2O3, TiC/TiCN/TiN/Al2O3
4	Composite coatings	Ti + MoS2, TiN + MoS2
5	Soft coatings	MoS2, WS2
6	Superlattice coatings	TiN/NbN, TiN/VN
7	Superhard coatings	Diamond and CBN

Table 1. Classification of various types of coating with their examples

1.14 Coating processes

Coatings can be deposited on the tool substrate by different vapour deposition techniques. These techniques helps to achieve the desired degree of accuracy in terms of uniformity of coating material over the substrate and coating thickness. The various types of processes that are used for depositing the tool coatings are as follows:

(1) Chemical vapour deposition process (CVD)

(2) Physical vapour deposition process (PVD)

1.14.1 Chemical Vapour Deposition (CVD)

CVD technique deposits thin films of coating material on the cutting tools through various chemical reactions. Coating of cemented carbides by CVD method, became more popular because it was introduce in the late 1960's. Due to the fact that chemical vapour deposition technologies became advanced from single layer to multi layer versions combining TiN, TiCN, TiC and Al2O3. Recent CVD coatings combine high temperature and medium temperature processes that produce excellent wear resistant coatings with a total thickness of 4-20 µm, with the high deposition temperature (950-1059°C) during CVD results in diffusion of chemical elements from the carbide substrate to the coating during growth. Embrittlement of the coating edge is the main effect of CVD process. In addition to the chemistry of the CVD process gives greater rapid growth at the cutting edge which results in an even coating thickness. So a strong driving force are there to find coatings that could be deposited at lower temperatures in order to allow tools with sharper edges to be coated and omit the embrittlement effect. The solution of this problem is PVD where deposition temperature can be kept at around 500°C.

1.14.2. Working Of CVD

Chemical vapour deposition is a chemical process which is used to produce highly pure and high performance solid materials. In a typical CVD process, substrate is exposed to one or more evaporative precursors, which react and decompose on the substrate surface to produce the desired and suitable coating. Often, volatile by-products are also formed, which are removed by gas flow through the reaction chamber. There are various applications of CVD process such as in microfabrication processes CVD is widely used to deposit materials in different forms i.e. monocrystalline, amorphous, epitaxial and polycrystalline. These materials consists silicon, filaments, carbon fiber, carbon nanofibers, carbon nanotubes, SiO2, tungsten, silicon-germanium, silicon carbide, silicon nitride, silicon oxynitride, titanium nitride, and different high dielectrics. The CVD process is also used to produce synthetic diamond.The results shows that the CVD coating is used to improve the production.

1.14.3. Physical Vapour Deposition (PVD)

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 industrial market. From last so many years, PVD have been successfully applied to carbide metal cutting inserts. It gives advantage in various applications such as interrupted cuts, those requiring sharp edges, as well as finishing.

Fig.5 Different stages of PVD coating technique

Various kinds of PVD process that are used for depositing the thin films are as follows:

(1) Cathodic arc evaporation

(2) Electron beam deposition

(3) Pulsed laser deposition

(4) Sputter deposition

The main reasons for depositing the PVD coatings are they pertains improved hardness and wear resistance, improved oxidation and reduced friction. But due to its high capital cost involvement and low deposition rates makes them unfit for use where there is restriction in terms of time and money.

1.15 Tool Wear

Tool wear can be termed as the gradual failure of cutting tools due to regular and continuous machining operations. Tool wear can be in various forms which includes crater wear, flank wear edge wear, plastic deformation, mechanical breakage and nose wear. There are various reasons which cause the tool wears. Rapidly, thermal forces that could cause the wear and mechanical breakage can also be caused by excessive force that causes immediate failure. The machining parameters of the operation are known to be one of the most common factors that cause tool wear. From a study on surface finish and flank wear using multiple regression models and neural network models done using turning as the machining operation, it is recommended that the best tool life was obtained in the combination of lowest feed rate and lowest cutting speed.(32)

1.15.1 Crater Wear

The most common tool wear in machining operation is crater wear and flank wear. In the study of Boothroyd and Knight(33), under very high speed cutting conditions, crater wear is of the factor that finds the life of the cutting tool; crater wear becomes so severe that the tool edge is weakened and at the end fractures but when tools are used under some economical conditions, the wear of the tool on its flank, which is the flank wear, is usually the controlling factor. Crater wear occurs on the rake face of the tool as shown in figure . It is a crater like wear occurred on the surface parallel to the cutting edge. Kalpakjian and Schrnid (34) suggested that the most significant factors that influence crater wear are temperature at the tool-chip interface and the chemical affinity between the tool and work piece.

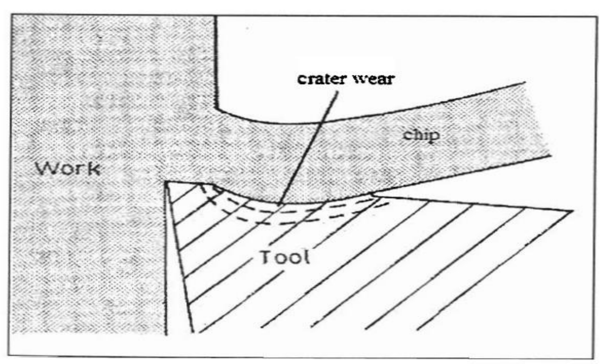


Figure 6: Crater wear

Source :Serope Kapakjian, Steven Schmid, Manufacturing Engineering And Technology,2001 (34)

In the research of crater wear mechanisms of TiCN-Ni-WC cermets during dry machining concluded that with the increase in speed and feed rate, cutting becomes steady with the reduction in the cutting force consequently.

1.15.2 Flank Wear

Flank wear occurs on the relief face of the tool and it is generally occured by the rubbing of the tool along the machined surface as shown in figure 19 that causes adhesive and/or abrasive wear or from machining at very high temperature that affects the tool material properties as well as the surface of work piece. (34).

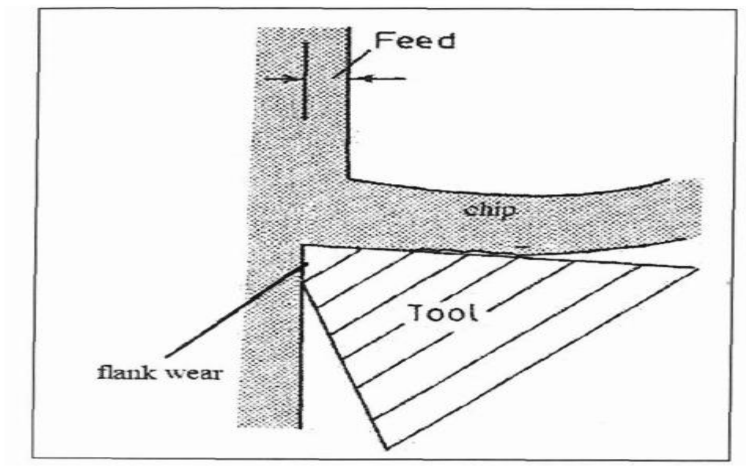


Figure 7: Flank wear

Source :Serope Kapakjian, Steven Schmid, Manufacturing Engineering And Technology,2001 (34)

From a study on tool wear prediction in turning by Choudhury and Srinivas (35), it is suggested that the cutting velocity and the index of diffusion coefficient have the most significant effect, followed by the feed rate and the depth of cut.

CHAPTER-2
LITERATURE REVIEW

2.1 Introduction

In this section our main aim to study all the past research, which have already done in the field of our area of interest. The literature review consists of different research papers related to area of interest i.e. too decrease the tool wear for machining and improve the tool life. After reviewing all research paper we are capable to identify the research gap and problem formulation. After analysing all the technical factor and economic factor, we can define our objective, which is basically an outcome come of literature review. So with respect to research work this is the most important section or area of study.

2.2 Scope of Literature Review

The review help us to decide what has already done in the past and what we have to do further for improvement in existing technology. The review also helps us to find out problems in present research work and to analyse different economic and environmental factor on which system is working. The detailed study of review creates a mind setup about our area of research and provides a direction to our study, which helps us to reach our objective and to decide a methodology to achieve this objective or goal. The literature review is the basic building block of every research work.

2.3 Significant Contribution in Proposed Area of Research

This section includes all the previous research work related to performance and behavior of coated and non coated tool for machining which has already done in the past and it will be combination of theoretical and experimental study work and results outcome of these past research study are described.

2.3.1 Analysis of Tool-wear and Cutting Force Components in Dry, Preheated, and Cryogenic Machining

Source: Y. Kaynak, H.E. Karaca, R.D. Noebe, I.S. Jawahir, Analysis of Tool-wear and Cutting Force Components in Dry, Preheated, and Cryogenic Machining of *NiTi* Shape Memory Alloys; 2013, v.8, pp.498-503 [(36]

This research work describes the ways to reduce the notch wear at higher cutting speed in comparison with machining under dry and preheated conditions. On experimental findings in this research, cryogenic machining is considered a promising approach for improving machining performance of NiTi shape memory alloys.

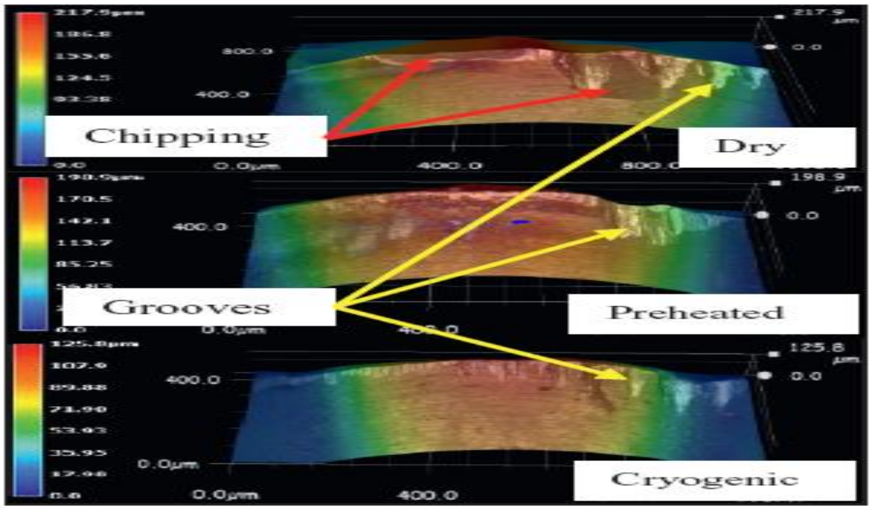


Fig. 8. Wear patterns observed on the flank face of cutting tools under different conditions at 50 m/min

Source: Y. Kaynak, H.E. Karaca, R.D. Noebe, I.S. Jawahir, Analysis of Tool-wear and Cutting Force Components in Dry, Preheated, and Cryogenic Machining of *NiTi* Shape Memory Alloys; 2013, v.8, pp. 98-503 (36)

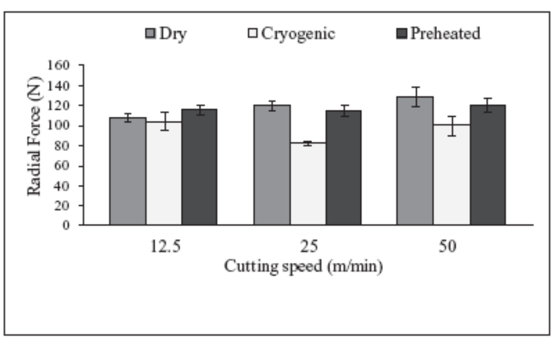


Fig 9. Variation of radial force with cutting speeds and cooling/preheated conditions (f = 0.1 mm/rev; d = 0.5 mm) [3]

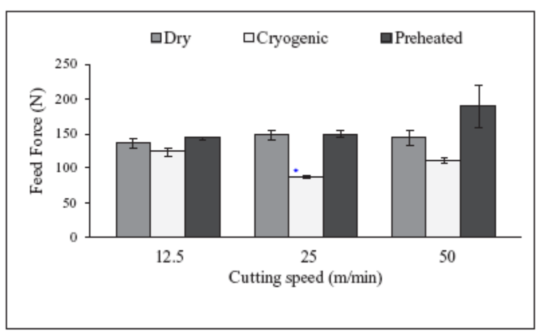


Fig. 10. Variation of feed force with cutting speeds and cooling/preheated conditions (f = 0.1 mm/rev; d = 0.5 mm)

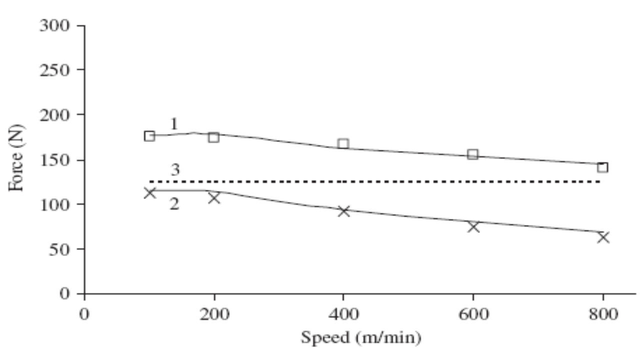
Source: Y. Kaynak, H.E. Karaca, R.D. Noebe, I.S. Jawahir, Analysis of Tool-wear and Cutting Force Components in Dry, Preheated, and Cryogenic Machining of *NiTi* Shape Memory Alloys; 2013, v.8, pp. 498-503 (36))

In addition to machining parameters and conditions, solid-state phase transformation has a significant effect on machining performance measures such as tool-wear rate and cutting forces in machining of NiTi shape memory alloys. Therefore, it is proposed that through modeling and simulation of the machining process, supported by validation, reduced tool-wear and cutting forces can be achieved.

2.3.2 Prediction of cutting forces in machining of metal matrix composites

Source: A. Pramanik, L.C. Zhang_, J.A. Arsecularatne, Prediction of cutting forces in machining of metal matrix composites; 2006, v. 46, pp. 95-1803 [(37)]

This paper describes Prediction of cutting forces in machining of metal matrix composites. Mechanics model for predicting the forces of cutting aluminum-based SiC or Al2O3 particle reinforced MMCs. The predictions shows that, the force due to chip formation is much higher than those due to ploughing and particle fracture. A comparison between predicted and experimental force results showed excellent. The force generation mechanism was considered to be due to three factors i.e. the chip formation force, the ploughing force, and the particle fracture force and the calculations of these force components were based on Merchant's shear plane analysis, Griffith theory and slip line field theory, respectively.



	Experimental symbol	Predicted lines for model	
		Present	Ref.[24]
Cutting force	□	1	3
Thrust force	×	2	Unable to predict

Fig.11. Comparison of predicted and experimental forces with varying cutting speed

Source: A. Pramanik, L.C. Zhang_, J.A. Arsecularatne, Prediction of cutting forces in machining of metal matrix composites; 2006, v. 46, pp.

2.3.3 Micro structural analysis of wear micro mechanisms of WC–6Co cutting tools during high speed dry machining

Source: T. Kagnaya, C. Boher, L. Lambert, M. Lazard, T. Cutard, Microstructural analysis of wear micro-mechanisms of WC–6Co cutting tools during high speed dry machining; 2014, v. 42, pp. 151-162 [38]

This research Micro structural analysis of wear micro mechanisms of WC–6Co cutting tools during high speed dry machining. The damages of WC–6Co uncoated carbide tools during dry turning of AISI 1045 steel at mean and high speeds found by different techniques. After studying , investigations revealed that that at conventional cutting speed Vc ≤ 250 m/min, normal cutting tool wear types such as adhesion, abrasion and built up edge are clearly observed. However, for cutting speed Vc N 250 m/min a severe wear is observed because the behavior of the WC–6Co grade completely changes due to a severe thermo mechanical loading. From the chemical analyses carried out in the zone of strong adhesion, it was not obvious to conclude that there is diffusion of the tool elements in the adhesion layer i.e the chip and vice-versa. However, the diffusion wear phenomenon perhaps takes place in the thin adhesion layer at tool–chip interface and consequently requires other techniques than those used in their investigations.

2.3.4 Effects of cutting fluid application on tool wear in machining and Interactions with tool-coatings and tool surface features

Source: Anshu D. Jayal, A.K. Balaji, Effects of cutting fluid application on tool wear in machining:Interactions with tool-coatings and tool surface features; 2009, v. 267, pp. 1723–1730[39]

This research focused to provide insight into the mechanisms of tool wear not only in the presence of CFs, but also the influence of chip-breaking geometric features, and tool-coating systems, on CF conditions. An experimental study into the effects of different CF application methods on tool wear during machining of AISI 1045 steel using flat-faced and grooved, coated carbide cutting tools has been made. The wear mode was analysed by thermal considerations, not through any other CF application methods based on capability of friction, and due to forced lubrication action were not favouring tool life under few conditions. There was no lubrication was found under CF, *MQL*, or any other application condition, but due to forced lubrications to reduce friction by using CFs along with EP additives was one of the reason to enhanced tool wear by chemical attack when the substrate of tool was exposed, and attainable to the CF. The influence of different methods of CF application on tool wear while machining of AISI 1045 steel under different machining conditions were found to have the presence or absence of chip breaking grooves and an interaction with the tool coating material system. Grooves of chip-breaking on the tool surface allowed the applied cutting fluids to influence the cutting process more subsequently by providing them few degree of access to the chip underside. This study suggested that with all the conditions which was employed, lowest wear were given by flood application of CF. Due to reduction in tool temperatures in the case of single-layer PVD coated tools there was delayed the onset of crater wear, but while using the multi-layer CVD coated tools the plastic deformation of the tool can be occurred, and due to lower tool body temperatures reduction in bulging of the flank surface was observed.

2.3.5 Cutting performance and wear characteristics of Al2O3/TiC ceramic cutting tools with WS2/Zr soft-coatings and nano-textures in dry cutting

Source: Youqiang Xing, Jianxin Deng , Shipeng Li, Hongzhi Yue, Rong Meng, Peng Gao, Cutting performance and wear characteristics of Al2O3/TiC ceramic cutting tools with WS2/Zr soft-coatings and nano-textures in dry cutting; 2014, v.318, pp. 12-26 [(40).]

This paper consists development of novel Al2O3/TiC cutting tools with coating and laser technologies such as the WS2/Zr coated Al2O3/TiC ceramic cutting gool and nano-textured Al2O3/TiC ceramic cutting tools deposited with WS2/Zr composite soft-coatings to reduce the tool wear and improve the cutting performance . The cutting force, friction coefficient, cutting temperature, and tool wear were experimentally found. The results revealed that use of the WS2/Zr coated Al2O3/TiC cutting tools with and without nano-textures subsequently enhance the lubrication property at the tool-chip interface, the cutting temperature, cutting force , friction coefficient and tool wear were reduced in comparison to conventional available tools; it was more beneficial and affective to use the nano-textured tools with deposition of WS2/Zr composite soft-coatings. Simultaneously, the nano-textures geometry has a impressible effect on the lubricity, in the area of nano-textures use of WS2/Zr coated cutting tool is the most impactful for reducing the tool wear and improving the cutting performance. The adhesion, abrasive wear, and chipping are the predominant characteristics of wear on the surface of conventional tools.

2.3.6 Evaluation of wear resistance of AlSiTiN and AlSiCrN nano composite coatings for cutting tools

Source : L. Settineri , M.G. Faga , G. Gautier , M. Perucca, Evaluation of wear resistance of AlSiTiN and AlSiCrN nano composite and coatings for cutting tools, 2000, v.57, pp. 575-578 (41)

This paper presents Some functional and mechanical properties, as well as the wear resistance of nanocomposite AlSiTiN and AlSiCrN coatings produced via Cathodic Arc PVD, with multilayer and gradient microstructure, were analysed and compared to those of commercial AlTiN and AlCrN films. Investigation via SEM-EDS of the wear mechanisms shown how temperature affects the involved phenomena: at room temperature abrasion is the main responsible, whereas at high temperature wear is mainly due to oxidation phenomena, leading to surface modifications. Under these last conditions, formation of an oxidised protective layer of alumina and alumina–silica was proposed for AlTiN- and Ti-based nanocomposites coatings, inducing an increase of wear resistance with respect to AlCrN coating, for which similar phenomena were not evident. The proposed wear mechanism can be a guideline to forecast the behaviour at different temperature conditions. It can be supposed, in fact, a better performance of Cr-based coatings in operations in which no temperature driven surface modification occurs, like tapping or similar operation. When higher temperatures are involved, other coatings appear more suitable, due to the formation of a protective oxide layer.

2.3.7 CBN tool wear in hard turning: a survey on research progresses

Source: Yong Huang; Chou, Y. Kevin, Liang, Steven Y, CBN tool wear in hard turning: a survey on research progresses; 2007, v. 35, pp.443-443 (42)

This research is based on a survey to analyse the wear of CBN tool during hard turning .wear patterns depend on the CBN tools used, cutting conditions and material composition of workpiece. The factor which is generally used as the tool life criterion is the flank wear land width and another measure such as crater wear depth should also be taken in consideration. In general adhesion, abrasion and diffusion are taken into consideration as the main tool wear mechanisms in hard turning with CBN; however, the effect of each mechanism of wear depends on the combinations of the workpiece material, CBN tool and geometry of tool, cutting conditions. Characteristics of CBN tool i.e. CBN grain size, the binder phase and CBN content etc. Basically abrasion, adhesion, and diffusion are considered during modeling of crater and flank wear rates in hard turning and some already available and proposed models can be used for predicting the flank and crater wear rates and analyse the relative importance and behaviour of each wear phenomenon. For achieving complete understanding of CBN tool wear, cutting parameters, stresses, cutting temperatures, and physical and chemical properties of the tool material and the workpiece should be taken into consideration in combination for each hard turning application.

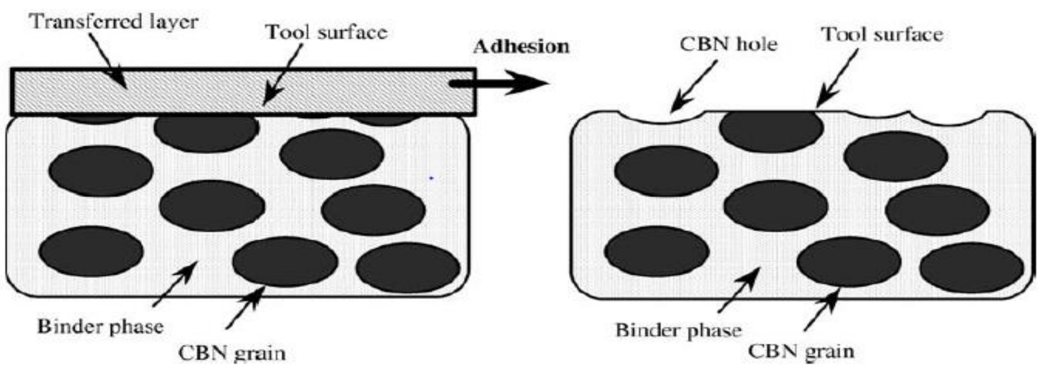


Fig. 11 A simple model of adhesive wear process with the
Interaction of a transferred layer

Source: Yong Huang; Chou, Y. Kevin, Liang, Steven Y, CBN tool wear in hard turning: a survey on research progresses; 2007, v. 35, pp.443-443 (42)

2.3.8 Wear behavior of some cutting tool materials in hard turning of HSS

Source: M.A. El Hakim, M.D.Abad, M.M.Abdul hameed, M.A.Shalaby, S.C.Veldhuis, Wear behavior of some cutting tool materials in hard turning of HSS; 2011, v. 44, pp.1174-1181 (43)

This research aimed to comparative anlayse the tool life and wear mechanism of various coated tools. Machining experiments of the HSS were performed with four numbers of cutting tools. when machining on selected work piece material, ceramic coated carbide tool and mixed alumina shows longer tool life as compared to CBN tools. HSS and CBN both tools shown poor performance at high cutting speeds. SEM is used to analyse the chips produced during machining but no conclusion could be made for their morphology. After investigating chip compression ratio, it is found that at high speeds there is decrease in the CCRs ratio with the Al_2O_3+TiC cutting tool. It is also found that the CCRs for chips produced from mixed alumina tools and the coated carbide tools lower than that for CBN tools. At high cutting speeds mixed alumina tool gives the lowest CCR values. Wear of the cBN cutting tools due to abrasion from hard particles of the workpiece are shown by EDX and SEM. The coated carbide tool was worn due to progressive wear of the protective coating are found. Analysis of the mixed ceramic tool was done by using Raman spectroscopy and the formation of different oxides was found such as iron oxides, aluminum and titanium. SEM image described the presence of Al_2O_3 in the region of flank wear.

2.3.9 Cutting Characteristics of PVD and CVD - Coated Ceramic Tool Inserts

Source : M. Sokovic ,J. Kopac , L.A. Dobrzanski, J. Mikula, K. Golombek, D. Pakula ,Cutting Characteristics of PVD and CVD - Coated Ceramic Tool Insert, 2006, v. 28, pp.1-2 (44)

This paper focused on research to investigate the results of cutting characteristics of the modern sintered ceramic tool inserts coated with PVD and CVD coatings techniques. After studying It was revealed that at different cutting conditions, the thin wear resistant coating on ceramic tool inserts increases their wear resistance due to abrasion, which plays a impressible effect for improving tool life. Deposition of the hard anti wear coatings onto the sintered ceramic tool inserts with the physical deposition technique (PVD) is one of the most important achievements in the improvement of the properties of ceramic cutting tools. It is found that improvement of tool life as well as the quality of the machined surfaces, elimination of cutting fluids used and reduction of machining costs can be possible by using the anti-wear coatings of the gradient and multi TiN+ (Ti,Al,Si)N+ TiN types on ceramic tool.

2.3.10 A note on the comparison of microstructure and coating characteristics of hard metal inserts

Source: Fazal A. Khalid, A note on the comparison of microstructure and coating characteristics of hard metal inserts; 1994, v.37, pp. 212-223 (45)

This research work highlights the role of coating characteristics that are difficult to optimise the cutting parameters of hard metal indexable inserts. With the use of scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) a comparison and characteristics of coating structure and matrix found in the hard metal inserts which is used for cutting tools. Using line scan micro analysis, variation of the elements found in the single as well as multi-layered coating was investigated. Analyses of micro structural coating shows that multi-layered coated insert specimen have better performance as compared to single-layered coated specimens. The thickness and hardness of coating were also observed to be higher in Multi-layered TiN/Al2O3 coated specimen as compared with single-layered TiN coated specimen which could be related to processing condition and the coating morphology.

2.3.11 High temperature behaviour of magnetron sputtered Nano crystalline titanium aluminum nitride coatings

Source: W. Y. Yeung, R. Wuhre and D.J. Attard, High Temperature Behaviour Of Magnetron Sputtered Nanocrystalline Titanium Aluminium Nitride Coatings; 118(2006), pp.299-304 (46)

This research examined the thermal stability of nano crystalline ternary nitride coatings at elevated temperatures. It was found that an unexpected grain refinement occurred in the coatings deposited at a nitrogen pressure of 0.4 m Torr after the heat treatment. Heat treatment was applied to the coatings at temperatures up to 1000°C A stronger development of TiN or TiAIN (200) component was also evident at temperatures above 800°C. With a finer and densified grain structure, the hardness of the coatings increased substantially from -1700 to 2300 HV.

	As-deposited		Heat-treated (to 1000^0C)	
Nitrogen Pressure (mTorr)	**0.4**	**0.65**	**0.4**	**0.65**
Average Roughness (nm)	5.3	5.0	11.2	18.8
Mean Grain Height (nm)	20.0	20.7	39.3	77.6
Grain Diameter (nm)	130	168	90	220
Hardness (HV)	1688	1173	2329	1228

Table 2 Comparison of grain diameter, surface roughness and hardness of the titanium ternary nitride coatings prior to and after heat treatments

Source: Yong Huang; Chou, Y. Kevin, Liang, Steven Y, CBN tool wear in hard turning: a survey on research progresses; 2007, v. 35, pp.443-443 (42)

2.3.12 New coating developments for high performance cutting tools

Source : E. Uhlmann, E.Wiemann, S. Yang, J. Krumeich, A. Layyous, New coating developments for high performance cutting tools; 2014, v. 01, pp.151-151 [43]

This paper describes the results of interrupted turning and milling experiments with Cr-based multilayer nitride hard coatings, with incorporated Ti, V, Y, Al Mo, V, and Al, with the use of elementary metal targets and unbalanced magnetron sputtering, started from the presently available TiAlN coatings as reference, the project investigate new Cr-based coating, TiAlN films enhanced by alternative alloying elements, and special ceramic coatings. After carrying out preliminary turning experiments, a number of model wear experiments, including abrasion, adhesion, cavitations, oxidation and scratch-tests, observed the main wear mechanisms of the new coatings. Subsequently, milling experiments were carried out with the most promising tools.. Some new and innovative ceramic tool coatings are also presented. The highest improvement compared to a TiAlN reference coating was accomplished in the machining of a chrome-cobalt alloy, where the measured wear could be reduced by more than 60 %.,A new special ceramic coating was developed and tested. During the machining of nickel-base alloy, hardened steel, and alloy steel it has capacity to withstand the very complex cutting conditions even at the early era of development. In the machining of the latter two workpiece materials, it was found that the wear was lower than the wear of the presently available reference coating.

2.3.13 Improving mechanical characteristics of an aluminum cutting tool by depositing multilayer amorphous carbon with assistance of plasma immersion ion implantation

Source : Noriaki Ikenaga, Yoichi Kishi, Zenjiro Yajima, Noriyuki Sakudo, Improving mechanical characteristics of an aluminum cutting tool by depositing multilayer amorphous carbon with assistance of plasma immersion ion implantation; 2012, v.272, pp.361- 364 [44]

This research work emphasized to improve the machining process for aluminum a cutting tool has been tried to be coated with such a carbonic deposition. They developed a multilayer a-C:H film which consists of three layers of different hardness. The multi layers are formed simply by switching gas flows and changing RF power. The hardness and the friction of multilayer a-C:H films are close to those of a- C:H single layer. Thus, the mechanical properties are determined mainly by the surface of multilayer film. However, multi layer coated tools show higher durability in processing aluminum work than those coated with a single layer. The experiment shows that high durability i.e. tool life comes from the hardness of the second layer. The durability i.e. is determined by the time when some scratch due to aluminum adhesion on the tool blade starts to appear on the processed surface. Therefore, the hardness of second layer affects on the aluminum adhesion to tool surface. It is indicated that the aluminum adhesion is not determined only by the friction of surface. As a result, the second-layer hardness enhances the characteristics of the multilayer film for processing aluminum work while the surface friction being kept low.

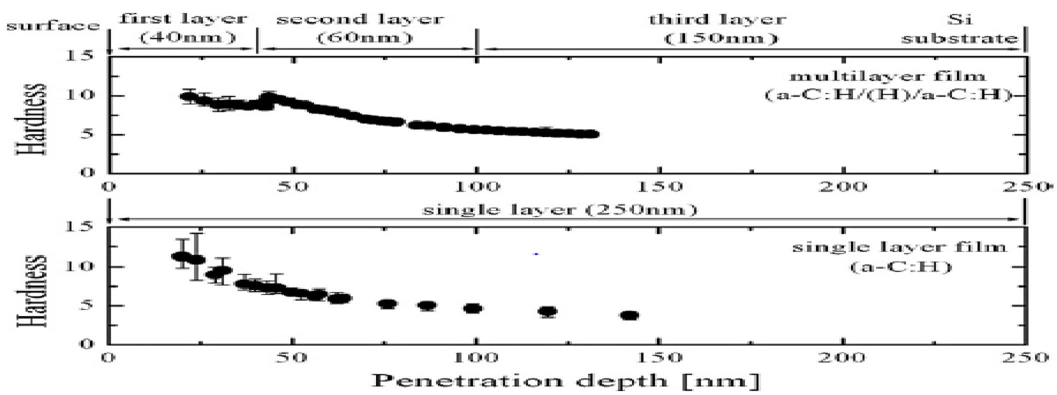


Fig. 12 Relationship between the penetration depth of indenter and the hardness for single layer film and multilayer film structure

Source : Noriaki Ikenaga, Yoichi Kishi, Zenjiro Yajima, Noriyuki Sakudo, Improving mechanical characteristics of an aluminum cutting tool by depositing multilayer amorphous carbon with assistance of plasma immersion ion implantation; 2012, v.272, pp.361- 364 [44]

2.3.14 Carbon based coatings for high temperature cutting tool applications

Source: D. Grimanelis , S. Yang , O. Bohme, E. Roman, A. Alberdi, D.G. Teer, J.M. Albella, Carbon based coatings for high temperature cutting tool applications; 2202, v. 11, pp.176-184 [45]

In this research Carbon based composite coatings with Ti, Cr, N and B, additions have been developed by using unbalanced magnetron sputtering method and it is found that the coatings have very good adhesion about 60 N critical load and high hardness of 2000 HV. Due to metal incorporated such as metal nitrides, borides and carbides is the reason to increase their adhesion to the substrate and reduce the internal stress of the carbon films. It has been observed in gear machining without any lubricant, Coated tools with the duplex CrTiBCN+C/CrTiB layers permits to machine at higher feed rates and cutting speeds as compared to TiN based coated tool. These results verified the use of new coatings in cutting operations where high temperatures may develop during machining of hard materials. It was observed a protective Cr_2O_3 surface film formed which behave as a oxygen diffusion barrier when chromium diffusion takes place at temperatures above 200 ^{0}C gives and ultimately at higher temperature it prevents the wear of the outer carbon layer.

2.3.15 Wear and tool life of tungsten carbide, PCBN and PCD cutting tools

Source: J.A. Arsecularatne, L.C. Zhang, C. Montross, Wear and tool life of tungsten carbide, PCBN and PCD cutting tools; 2006, v. 46, pp.482-491(46)

This paper based on Wear and tool life of PCD, PCBN and tungsten carbide cutting tools.
The wear mechanisms of cutting tools made of PCBN, PCD and tungsten-carbide (WC), were examined on the basis of temperature and the tool life results available in the literature. It is found that tool wear was greatly influenced by the temperature for the combination of tool and worpiece such as PCBN/hardened-steel and WC/steel. It was revealed that the most likely dominant tool wear phenomenon for for PCBN is chemical wear and that for WC is diffusion. For PCD, more investigation, results and further research is needed to find the dominant wear mechanism.

2.3.16 Tool materials rapid selection based on initial wear

Source : Yuan Yuefeng, Chen Wuyi, Gao Liansheng, Tool Materials Rapid Selection Based on Initial Wear; 2010, v. 23(3), pp. 60232-6 (47)

In this research the tool materials rapid selection method based on the initial wear can be used to primarily select tool materials for reducing cost and selection time. From results it is found wear rate during initial wear period (WRIWP) and wear rate in uniform wear period (WRUWP) to certain extent shows a qualitative relationship. Suitable tool materials for machining titanium alloy are selected based on qualitative relationship of wears, The experimental results shows that this method is useful and effective. Thus , to select suitable cutting tool materials quickly, the new tool materials rapid selection may be used before performing any systematic machinability tests. This technology can be applied for initial selection of cutting tool materials in not only the machinability research but also for the workshop production.

2.3.17 Hard AlTiN, AlCrN PVD coatings for machining of austenitic stainless steel

Source: J.L. Endrino, G.S. Fox-Rabinovich, C. Gey, Hard AlTiN, AlCrN PVD coatings for machining of austenitic stainless steel; 2009, v. 204(3), pp.252-262[48]

This research investigated that the machine-ability of austenitic stainless steels can be improved due to application of coated cutting tools. It is observed that hard PVD coating with improved surface finish and low thermal conductivity should be used in this case. Result showed that improvement of frictional characteristics at the tool and workpiece interface as well as chip evacuation process. In this research the stainless steel plates were machined with cemented carbide finishing end mills with four high aluminum containing PVD coatings such as AlCrNbN, AlCrN, nano-crystalline (nc) AlTiN and fine grained AlTiN. Both AlCrN and AlTiN based coatings have high oxidation resistances by the formation of aluminum oxide surface layers. In the investigation of deposition treatment was done by using the Abbot-Firestone ratio curves the coating surface texture before and after post-deposition treatment was analysed. Minimal intensity of wear after length of cut 150 m was found for cutting tools with the nc-AlTiN coating.

CHAPTER-3

RESEARCH GAP

After study about past research in the field of reducing tool wear by lesser amount of force imparted on coated tool than non coated tool I found that tool life is mainly depends on the wear rate of tool shank which is ultimately depends on three forces i.e. cutting force, thrust force and axial force involved. So it has been found that the coating material, coating characteristics that is used to reduce tool wear at different cutting parameters such as depth of cut and feed rate plays an important role to make the tool as well as machining more effective and After going through the literature reviews, It can be summarized that lots of the work has been done in hard coatings on HSS cutting tools. Many researchers worked on the various coatings on HSS tools such as Coated carbides, Cermets, Coronite, Cubic Boron Nitride(CBN), Diamond tools, composites , Nano composites, DLC, WC, TiC, TiAlN etc and its wear and performance analysis using FEM but Coating of carbon nanotubes (CNTs) on HSS cutting tools and its performance has not been investigated by any researcher.

By studying and reviewing the past research, it has been seen that conventional coated and non coated tool can experience much forces, which in turn limits the tool life. Therefore application of coating of tools comes in to existence due to great mechanical, thermal, optical etc properties of coating material in order to improve tool life.

CHAPTER-4

SHORTCOMINGS ENCOUNTERED

The detailed study of literature review helps us to evaluate the outcome of the review which associated with some problems also. This section describes the all problems associated with the machining of EN8 carbon steel rod on lathe with CNT coated and non coated HSS tool and measurement of forces incurred during machining.

Some problems arise in all previous research study is as discussed below:

1. Cost of CNT coating setup , which is used as coated tool while machining and also the centre lathe with dynamometer that accounts maximum cost in overall cost of machining and production of parts.
2. Structural characterization techniques of carbon nanotubes coated HSS tool are necessary to find crystal structure and particle dimensions such as XRD, SEM and TEM. All these characterization techniques account big cost in the research work.
3. While machining errors in measurement of forces incurred on tool using dynamometer problems come in to account.
4. Improper centering of work material in jaw chuck also creates hindrance in machining.
5. Giving Improper axial feed to tool and depth of cut is also one of the problem for accurate results.
6. For microscopic structure analysis of wear on tool surface using SEM technique, it is required to cut the tool insert from tool but it is too difficult to cut the HSS tool insert due to its high hardness it needs diamond tool.

CHAPTER-5

OBJECTIVE OF THE STUDY

After going through all the past research and challenges comes in the path of our research I decided about the complete objective of my project work study i.e. Comparison of different coatings on HSS tool.

a. Coating used on tool for turning operation in project work is carbon nanotubes(CNT)
b. Dynamometer is used for measuring forces incurred on tool while machining.
c. Centre lathe machine is used for turning of EN8 carbon steel rod.

Some important objectives related to project work are as follows:

- To get the carbon nanotubes coating on single point HSS cutting tool using chemical vopour deposition technique.
- A systematic way to evaluate the performance of such CNT coated tool and uncoated tool to find its application in a brooder area.

Keeping the above objective for the work, the experimentation has been planned to carry out. The performance tests of uncoated and coated tools for simple turning. The primary objective is to evaluate the coated tool in hard machining under extreme conditions of machining to optimize it's parameters.

CHAPTER 6
EXPERIMENTAL SET-UP AND EQUIPMENTS

6.1 Introduction

The experimental work is divided into two phases: First phase is to turning of EN8 carbon steel rod with uncoated HSS tool at different speed and different cutting parameters such as depth of cut and feed rate. Second phase is to turning of EN8 medium carbon steel rod with CNT coated HSS tool at different speed and different cutting parameters such as depth of cut and feed rate.

6.2 Machining of hard material (EN8 medium carbon steel)

The present work deals with the turning of hard material such as EN8 medium carbon steel rod. EN8 is widely used for many general engineering applications. Typical applications include shafts, studs, bolts, connecting rods, screws, rollers. 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.

6.3.Work material

A solid rod of EN8 medium carbon steel with 30 mm diameter, 500 mm long and of 50 HRC were used as workpiece (Fig. 14).

Fig.13 EN8 Carbon steel rod

6.3.1. Chemical composition of EN8 steel

S.No.	Chemical Compositions	Amount (%)
1.	Carbon	0.36-0.44%
2.	Silicon	0.10-0.40%
3.	Manganese	0.60-1.00%
4.	Sulphur	0.050 Max
5	Phosphorus	0.050 Max
6.	Iron	Balance

Table.3.The chemical composition of EN8 carbon steel in percentage by weight

6.3.2 Mechanical properties of EN8 steel

Condition	Yield stress x 106 Pa	Tensile stress MPa	Elongation %
Normalized	280	550	16
Cold drawn(thin)	530	660	07

Table 4. Mechanical properties of EN8 carbon steel

6.4 Cutting tools

Commercially available uncoated HSS single point cutting tool and deposit the multiwalled carbon nanotubes(MWCNT) coating on HSS tool.

Fig.14 Uncoated HSS tool and CNT coated HSS tool

Tungsten(W)	Chrom(Cr)	Vanadium(V)	Carbon (C)	Iron (Fe)
18	4	1	0.7	Balance

Table.5 Chemical composition of HSS tools (% wt)

6.5.Machine tools

Turning operations were performed on a 12” swing Centre lathe machine under dry conditions. Generally, the metal cutting lathe or centre lathe is used to machine the metal into cylindrical shapes. The work material which rotates the operator can be gripped securely in jaw chuck, bolted to face or setup between two centers. The cutting tool mounted on tool post on the top of carriage can be moved along the bed or at right angles to it. The lengthwise movement or transverse movement of tool produces a circular surface on workpiece and cross transverse produces flat surface.

Fig.15 The Centre Lathe

Source: Metal Cutting Lab, Mechanical Engg Workshop, DTU

6.5.1 Specification of the Lathe machine

Harrison centre lathe, Type 12” Swing, Precision Lathe

Manufactured by : Harrison

Power of the motor : 15 KW, 10 HP

Distance between centre : 1500 mm

Swing over Bed : 420 mm

Swing over cross slide : 255 mm

Range of spindle speed : 45-1000 rpm.

Turning operations were performed at two different cutting speeds i.e. 439 and 639 rpm and depth of cut (*d*) were 0.3175, 0.635, 0.9525, 1.27, 1.5878, 1.905, 2.225, 2.54, 2.8575, 3.175 mm and Feed rates were 0.074 and 0.1168 mm/rev (*f*) throughout the experiments. The turning parameters were kept constant for both of the coated and uncoated tools tested throughout the experiment.

Fig.16 Tool setup with workpiece

Source: Metal Cutting Lab, Mechanical Engg Workshop, DTU

6.5.2 Turning conditions

S.No.	Cutting conditions	Description
1.	Workpiece	EN8 medium carbon steel
2.	Cutting inserts	Uncoated HSS CNT Coated HSS
3.	Diameter of Workpiece	30 mm
4.	Length of Workpiece	400 mm
5	Hardness	50 HRC
6.	Cutting speed	156 rpm to 639 rpm
7.	Feed	0.074mm to 0.1168mm
8.	Depth of cut	0.3175mm to 3.175mm
9.	Cutting environment	Dry

Table 6. Turning conditions

6.6 Force measurement

The forces acting on a tool are an important factor of machining to study and anlayse the machinability of cutting tool. To ensure the power requirements knowledge of the cutting forces is needed and ensure that the machine tool-holders, tool elements, and fixtures are subsequently rigid and free from vibrations. For optimizing the tool design measurements of the tool forces are very much helpful.

The three components of forces are

F_x: axial component of force

F_y: radial component of force

F_z: tangential component of force

Forces acting on the cutting tool were measured by lathe tool dynamometer Testmaster (Dial-B2B) with tool holder mounted on lathe machine.

Fig.17 Lathe Tool Dynamometer

Source: Metal Cutting Lab, Mechanical Engg Workshop, DTU

Specification of Dynamometer

X,Y,Z Forces Capacity : 500 kg

Excitation: 10V DC

Linearity : 10%

Accuracy : 2%

Cross sensitivity: 2%

Maximum overload: 150%

Cutting forces were measured with different cutting conditions for both coated and uncoated tool. Three components of forces were measured i.e. Cutting force (F_x), Feed forec (F_y) and axial thrust (F_z). Sensor is rigidly mounted on the tool post, and the cutting tool can be fixed to the sensor directly which gives the facility to measure the forces accurately without lose of the force. The sensor used with dynamometer is made of single element with three different wheat stones strain gauge bridge.

CHAPTER-7

EXPERIMENTATION AND DATA COLLECTION

7.1 Introduction

This section deals with experimental readings or data of all forces i.e. cutting force, feed force and axial thrust force acting on CNT coated and uncoated HSS tool at different cutting parameters such as depth of cut, feed rate and cutting speed while turning EN8 carbon steel rod on centre lathe machine. Further this area include coating characterization techniques for multiwalled carbon nano tubes (MWCNT).

7.2 Structural characterization techniques

There are many type of structural characterization techniques used to obtain the information regarding the structure of MWCNT. This section deals with the important structural techniques like Scanning Electron Microscopy (SEM), Energy dispersive X-ray Spectroscopy (EDX), Transmission Electron Microscopy(TEM) that the effect of proximity of indentation to the free surface is eliminated.

7.2.1 Scanning Electron Microscopy (SEM)

In this technique high energy electron are used to produce image of solid surfaces and also provide the necessary information about structural arrangement and geometrical features of carbon nano tubes. In this method a topographical image of carbon nano tubes formed due to the generation of secondary electron, when primary electron beam is used to scan the surface of carbon nanotubes. SEM image for MWCNT are shown in figure 18 which is provided by physics department Delhi technological university.

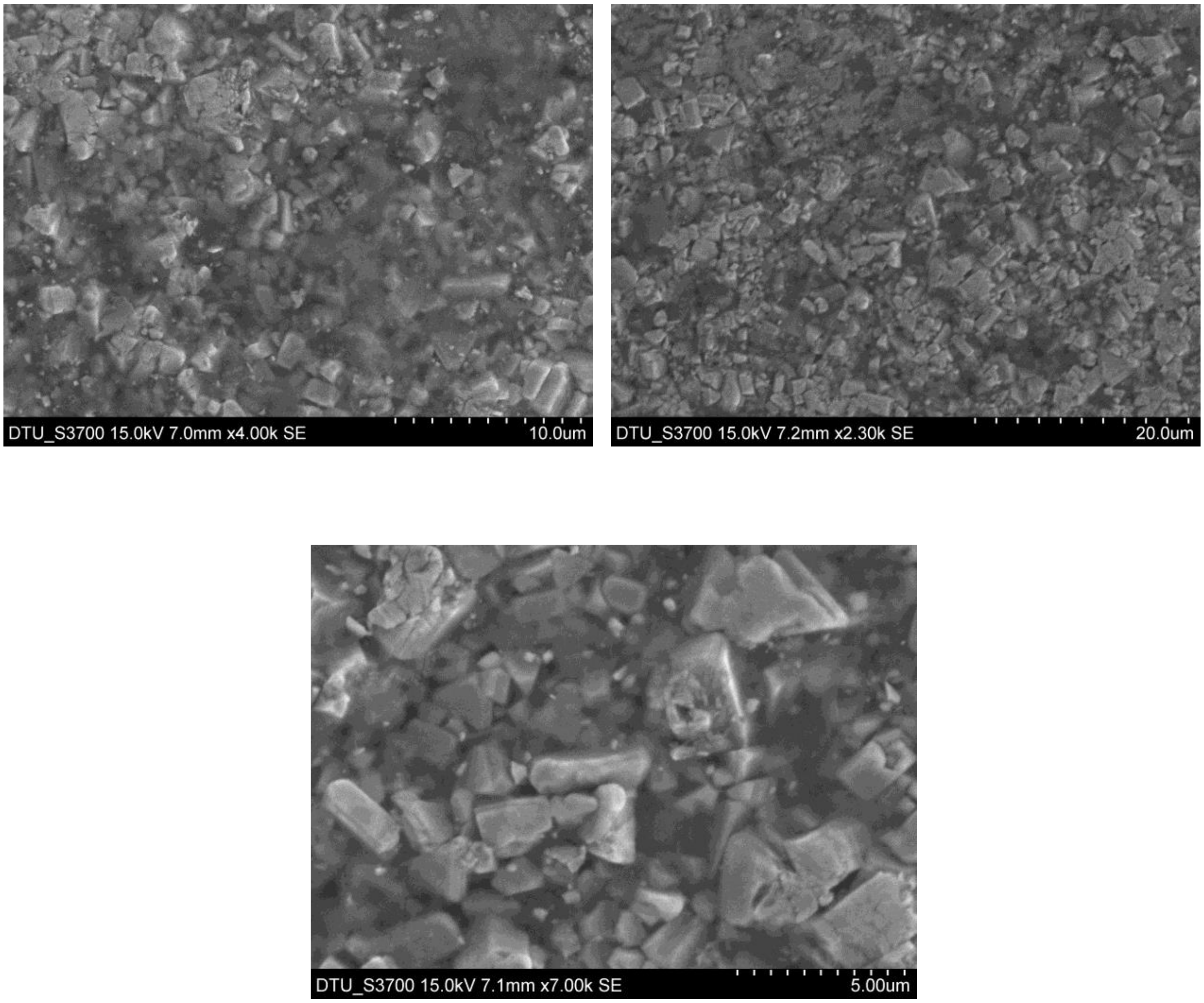


Fig.18 SEM image of HSS cutting tool insert

Source: Nano Science and Technology Department, DTU

7.2.2 Energy dispersive X-ray Spectroscopy (EDX)

EDX is an analytical technique for chemical characterization of a sample. In this technique a beam of x-ray is focused into the sample. Energy dispersive spectrometer measured the number of energy of X-rays emitted from the sample specimen. EDX shows the element composition of specimen by difference in energy between two shells and atomic structure of emitting element. Elemental composition of HSS cutting tool insert is shown in figure 19, which is provided Physics department of Delhi technological university.

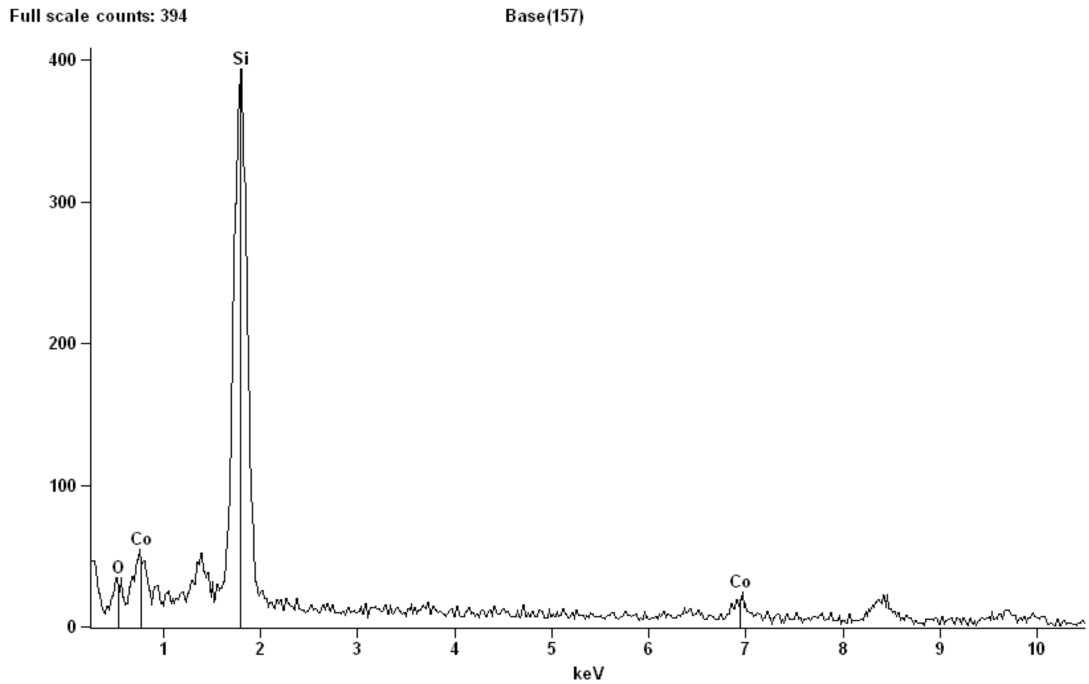


Fig.19 Elemental composition of HSS cutting tool inserts

Source: Nano Science and Technology Department, DTU

Acc.Voltage: 15.0 kV Take Off Angle: 74.9 deg.

Element Line	*Net Counts*	*Int. Cps/nA*	*Weight %*	*Weight % Error*	*Atom %*	*Atom % Error*	*Formula*	*Standard Name*
O K	427	---	14.84	+/- 1.70	26.19	+/- 3.01	O	
Si K	4546	---	62.68	+/- 1.48	63.03	+/- 1.48	Si	
Si L	0	---	---	---	---	---		
Co K	215	---	22.49	+/- 3.66	10.78	+/- 1.75	Co	
Co L	561	---	---	---	---	---		
Total			100.00		100.00			

Table 7. Quantitative composition of HSS tool inserts

7.3 Experimental Data and Readings

This section includes the reading and data of experimental work. Forces i.e. Cutting force, feed force, axial thrust force acting on CNT coated and uncoated HSS tool are measured using lathe tool dynamometer while turning EN8 carbon steel rod at different cutting parameters such as depth of cut, feed rate and cutting speed to comparative analyse the performance of Coated and uncoated tool.

7.3.1 Readings for Uncoated tool

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	3	1	8	0.074	409
2.	0.635	6	3	14		
3.	0.9525	8	4	26		
4.	1.27	10	5	22		
5.	1.5875	12	6	18		
6.	1.905	14	7	14		
7.	2.225	16	8	10		
8.	2.54	18	9	6		
9.	2.8575	20	10	2		
10.	3.175	22	11	-2		

Table 8 .Variation of forces acting on uncoated tool with depth of cut at feed=0.074 mm/rev and speed=409 rpm

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	5	3	1	0.1168	409
2.	0.635	9	5	1		
3.	0.9525	12	7	9		
4.	1.27	15	9	10		
5.	1.5875	18	11	11		
6.	1.905	21	13	12		
7.	2.225	24	15	13		
8.	2.54	27	17	14		
9.	2.8575	30	19	15		
10.	3.175	33	21	16		

Table 9. Variation of forces acting on uncoated tool with depth of cut at feed=0.1168 mm/rev and speed=409 rpm

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	3	1	5	0.074	639
2.	0.635	6	4	7		
3.	0.9525	9	6	8		
4.	1.27	10	8	10		
5.	1.5875	11	10	12		
6.	1.905	12	12	14		
7.	2.225	13	14	16		
8.	2.54	14	16	18		
9.	2.8575	15	18	20		
10.	3.175	16	20	22		

Table 10. Variation of forces acting on uncoated tool with depth of cut at feed=0.074 mm/rev and speed=639 rpm

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	4	2	5	0.1168	639
2.	0.635	9	5	5		
3.	0.9525	15	12	18		
4.	1.27	18	20	27		
5.	1.5875	21	28	36		
6.	1.905	24	36	45		
7.	2.225	27	44	54		
8.	2.54	30	52	63		
9.	2.8575	33	60	72		
10.	3.175	36	68	81		

Table 11. Variation of forces acting on uncoated tool with depth of cut at feed=0.1168 mm/rev and speed=639 rpm

7.5.2 Readings for Coated tool

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	2	2	4	0.074	409
2.	0.635	4	2	2		
3.	0.9525	6	3	1		
4.	1.27	8	4	2		
5.	1.5875	10	5	3		
6.	1.905	12	6	4		
7.	2.225	14	7	5		
8.	2.54	16	8	6		
9.	2.8575	18	9	7		
10.	3.175	20	10	8		

Table 12. Variation of forces acting on coated tool with depth of cut at feed=0.074 mm/rev and speed=409 rpm

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	2	7	1	0.1168	409
2.	0.635	3	1	3		
3.	0.9525	5	2	4		
4.	1.27	8	4	3		
5.	1.5875	11	6	2		
6.	1.905	14	8	1		
7.	2.225	17	10	0		
8.	2.54	20	12	-1		
9.	2.8575	23	14	-2		
10.	3.175	26	16	-3		

Table 13. Variation of forces acting on coated tool with depth of cut at feed=0.1168 mm/rev and speed=409 rpm

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	3	2	8	0.074	639
2.	0.635	5	3	4		
3.	0.9525	6	4	1		
4.	1.27	8	5	1		
5.	1.5875	10	6	1		
6.	1.905	12	7	1		
7.	2.225	14	8	1		
8.	2.54	16	9	1		
9.	2.8575	18	10	1		
10.	3.175	20	11	1		

Table 14. Variation of forces acting on coated tool with depth of cut at feed=0.074 mm/rev and speed=639 rpm

S.No.	Depth of cut (mm)	Cutting force (Kg)	Feed force (Kg)	Axial thrust (Kg)	Feed (mm/rev)	Speed (RPM)
1.	0.3175	2	1	4	0.1168	639
2.	0.635	6	3	4		
3.	0.9525	8	5	6		
4.	1.27	12	8	3		
5.	1.5875	16	11	0		
6.	1.905	20	14	-3		
7.	2.225	24	17	-6		
8.	2.54	28	20	-9		
9.	2.8575	32	23	-12		
10.	3.175	36	26	-15		

Table 15. Variation of forces acting on coated tool with depth of cut at feed=0.1168 mm/rev and speed=639 rpm

Chapter-8

Results and Discussions

8.1 Introduction

This is the important section of the experimental work because this section deals with the performance evaluation CNT coated and Uncoated HSS tool and it includes graphical representation of results outcomes of the forces acting on CNT coated and uncoated HSS tool for turning EN8 carbon steel workpiece at different cutting parameters such as depth of cut and feed rate on centre lathe with dry conditions.

8.2 Results of turning operation with uncoated HSS tool at 0.074 mm/rev feed and 409 rpm speed

Figure 20 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust acting on uncoated HSS tool at 0.074 mm/rev feed and 409 rpm speed with different depth of cut.

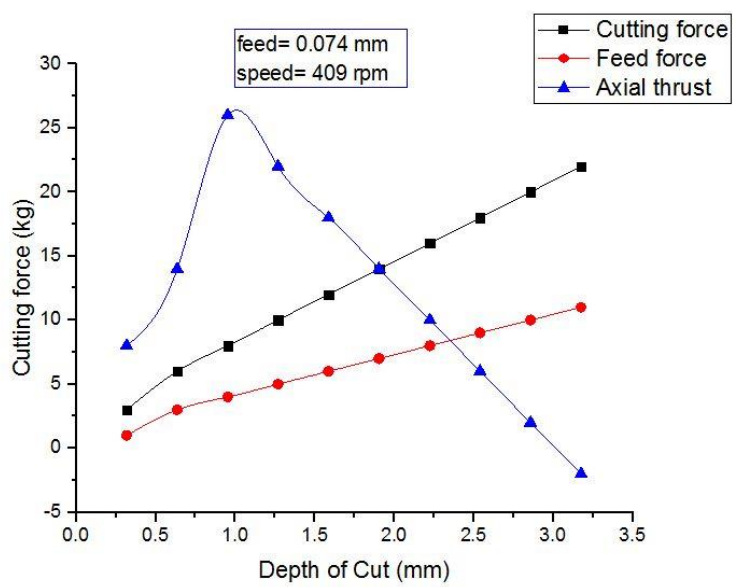


Fig.20 Results of turning operation with uncoated HSS tool at 0.074 mm/rev feed and 409 rpm speed

Experimental readings of forces acting on uncoated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.074 mm/rev feed and 409 rpm speed and graph was plotted using Origin 2015 software which shows cutting force and feed force acting on uncoated tool varies from 3-22 kg and 1-11 kg respectively and increases with increase in depth of cut but with increase in depth of cut axial thrust force first increases to some value then start decreasing and its varies from 8 to -2 kg.

8.3 Results of turning operation with uncoated HSS tool at 0.1168 mm/rev feed and 409 rpm speed

Figure 21 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust acting on uncoated HSS tool at 0.1168 mm/rev feed and 409 rpm speed with different depth of cut.

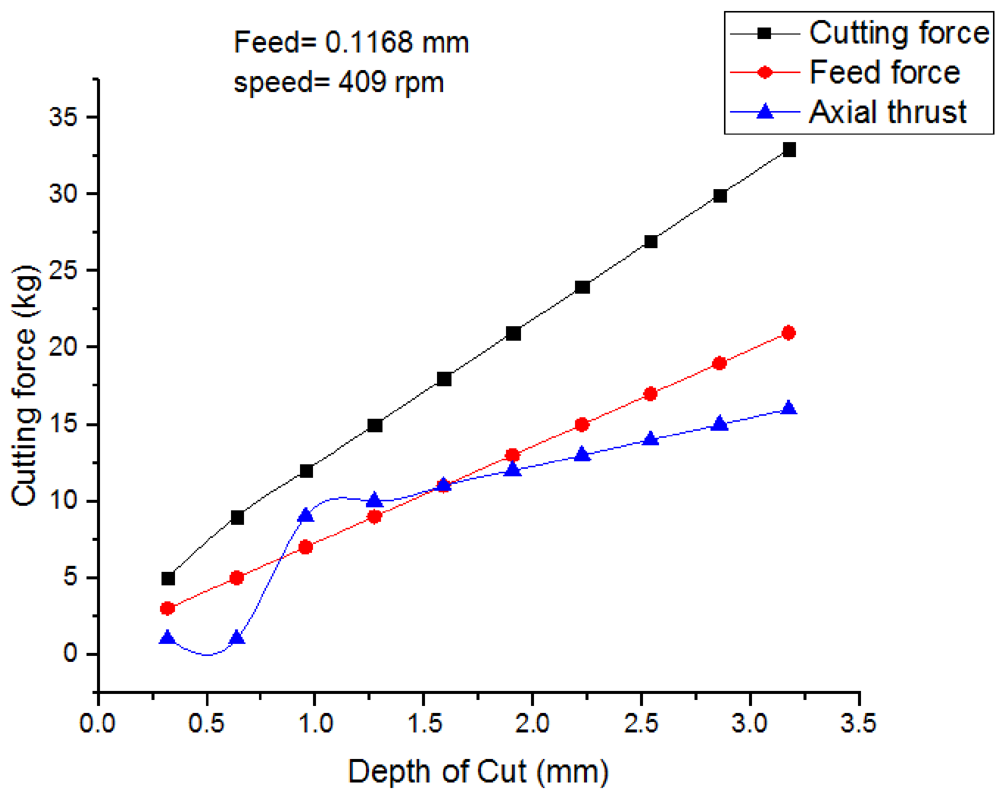


Fig.21 Results of turning operation with uncoated HSS tool at 0.1168 mm/rev feed and 409 rpm speed

Experimental readings of forces acting on uncoated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.11684 mm/rev feed and 409 rpm speed and graph was plotted using Origin 2015 software which shows cutting force, feed force and axial thrust force acting on uncoated tool varies from 5-33 kg, 3-21 kg and 1-16 kg respectively and these forces increases with increase in depth of cut.

8.4 Results of turning operation with uncoated HSS tool at 0.074 mm/rev feed and 639 rpm speed

Figure 22 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust acting on uncoated HSS tool at 0.074 mm/rev feed and 639 rpm speed with different depth of cut.

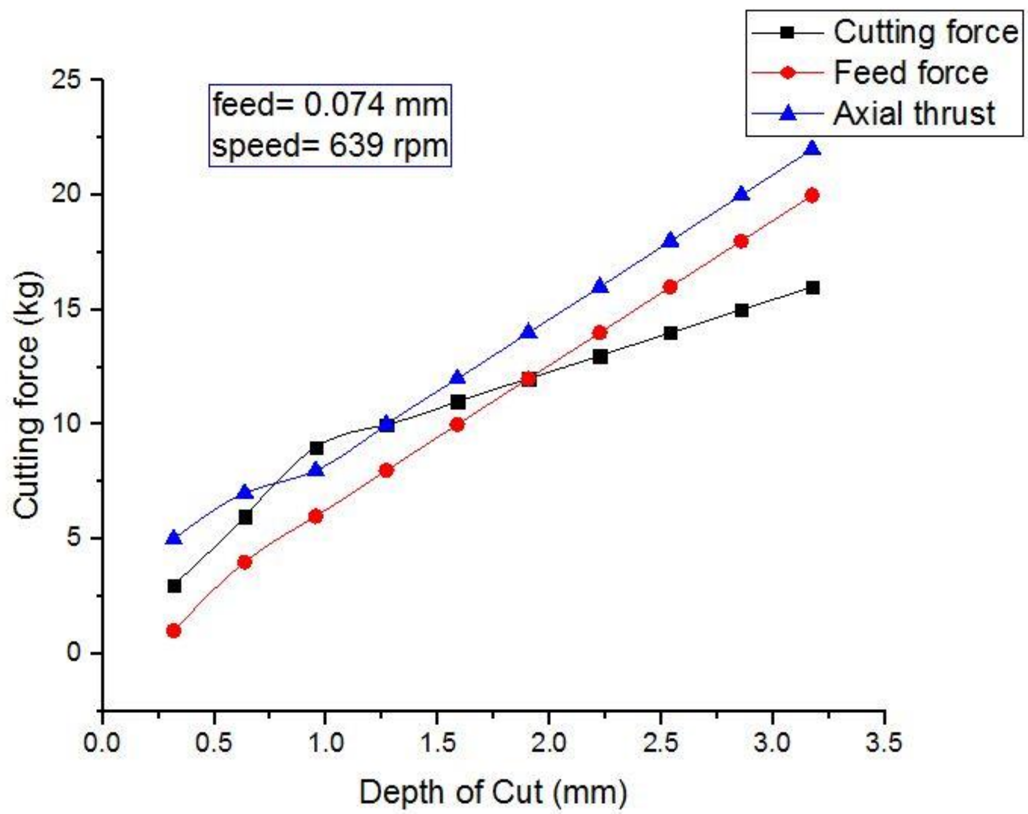


Fig.22 Results of turning operation with uncoated HSS tool at 0.074 mm/rev feed and 639 rpm speed

Experimental readings of forces acting on uncoated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.074 mm/rev feed and 639 rpm speed and graph was plotted using Origin 2015 software which shows cutting force, feed force and axial thrust force acting on uncoated tool varies from 3-16 kg, 1-20 kg and 5-22 kg respectively and these forces increases with increase in depth of cut.

8.5 Results of turning operation with uncoated HSS tool at 0.1168mm/rev feed and 639 rpm speed

Figure 23 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust acting on uncoated HSS tool at 0.1168 mm/rev feed and 639 rpm speed with different depth of cut.

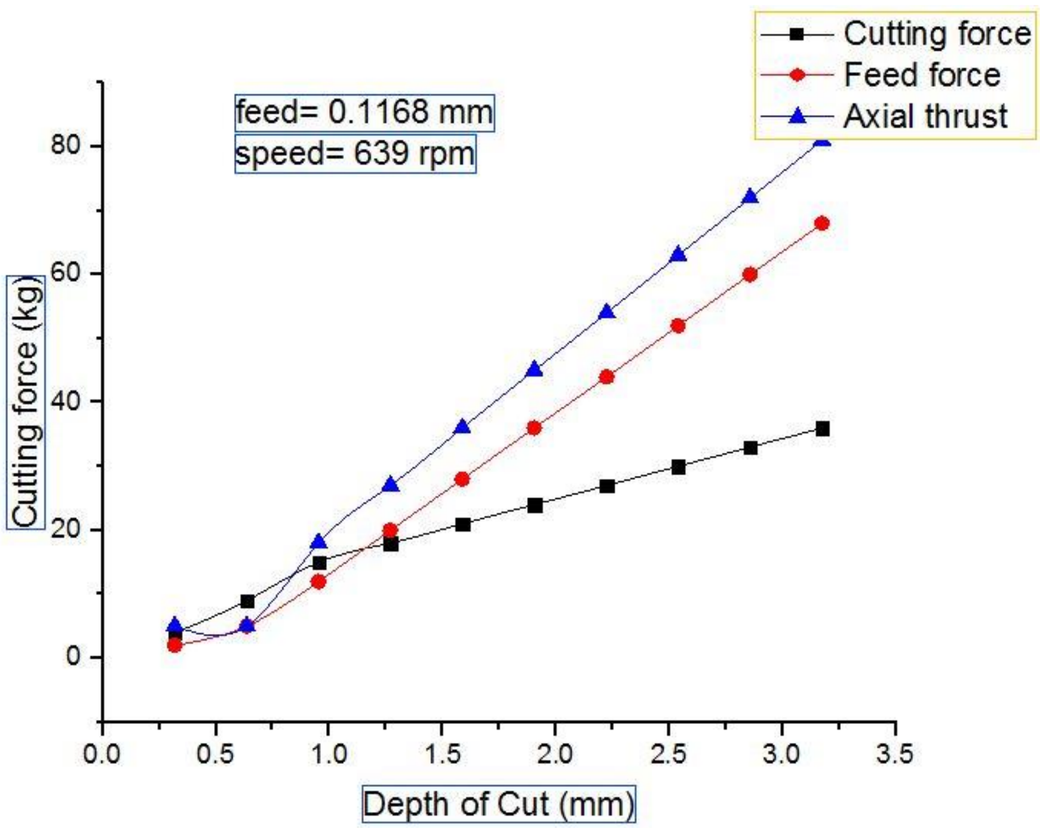


Fig.23 Results of turning operation with uncoated HSS tool at 0.1168 mm/rev feed and 639 rpm speed

Experimental readings of forces acting on uncoated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.1168 mm/rev feed and 639 rpm speed and graph was plotted using Origin 2015 software which shows cutting force, feed force and axial thrust force acting on uncoated tool varies from 4-36 kg, 2-68 kg and 5-81 kg respectively and these forces increases with increase in depth of cut.

8.6 Results of turning operation with CNT coated HSS tool at 0.074 mm/rev feed and 409 rpm speed

Figure 24 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust acting on CNT coated HSS tool at 0.074 mm/rev feed and 409 rpm speed with different depth of cut.

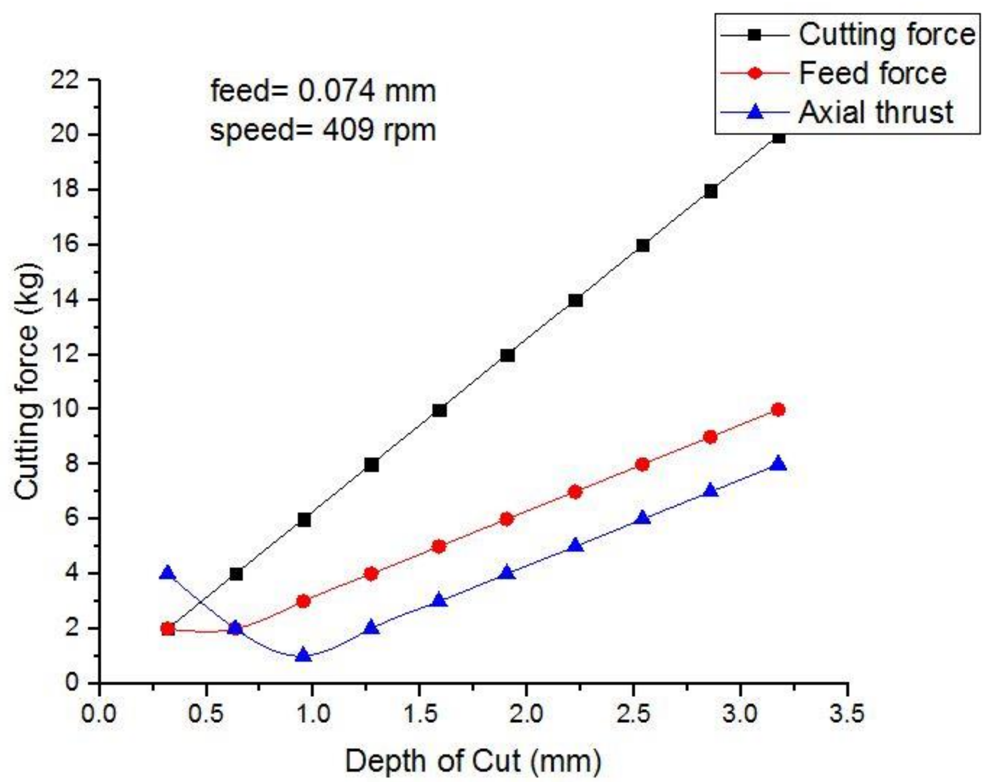


Fig. 24 Results of turning operation with CNT coated HSS tool at 0.074 mm/rev feed and 409 rpm speed

Experimental readings of forces acting on CNT coated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.074 mm/rev feed and 409 rpm speed and graph was plotted using Origin 2015 software which shows cutting force and feed force acting on CNT coated tool varies from 2-20 kg and 2-10 kg respectively and increases with increase in depth of cut but with increase in depth of cut axial thrust force first increases to some value then start decreasing and its varies from 4-8 kg. All the three forces are slightly lesser than forces acting on uncoated at the same cutting condition which is in favour of CNT coated tool.

8.7 Results of turning operation with CNT coated HSS tool at 0.1168 mm/rev feed and 409 rpm speed

Figure 25 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust force acting on CNT coated HSS tool at 0.1168 mm/rev feed and 409 rpm speed with different depth of cut.

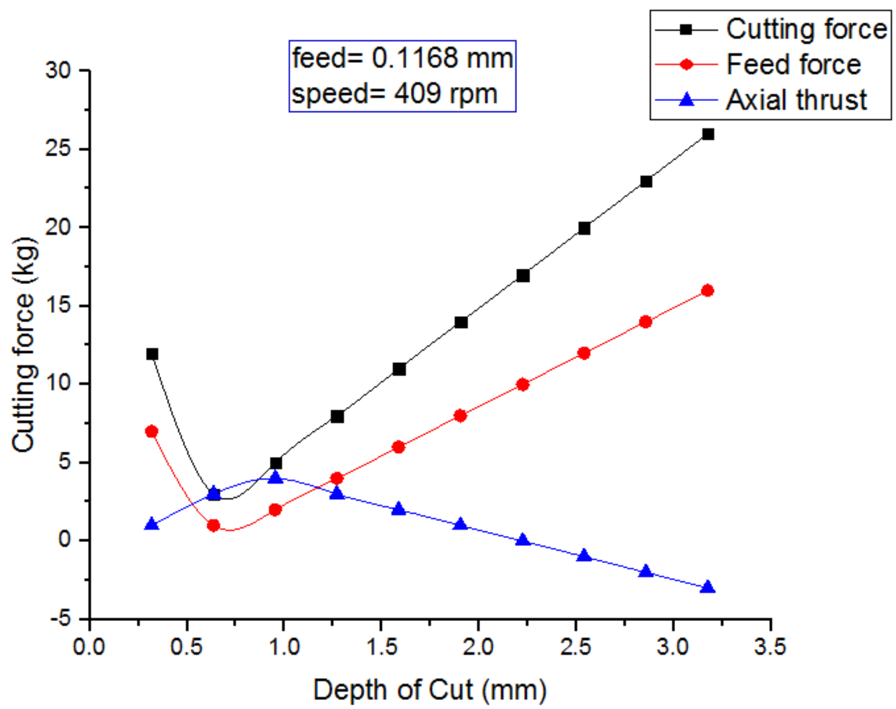


Fig.25 Results of turning operation with CNT coated HSS tool at 0.1168 mm/rev feed and 409 rpm speed

Experimental readings of forces acting on CNT coated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.1168 mm/rev feed and 409 rpm speed and graph was plotted using Origin 2015 software which shows cutting force, feed force and axial thrust force acting on CNT coated tool varies from 3-20 kg, 2-11 kg and 8-1 kg respectively and with increase in depth of cut all forces first increases to some value then start decreasing. All the three forces are slightly lesser than forces acting on uncoated at the same cutting condition which is in favour of CNT coated tool.

8.8 Results of turning operation with CNT coated HSS tool at 0.074 mm/rev feed and 639 rpm speed

Figure 26 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust force acting on CNT coated HSS tool at 0.074 mm/rev feed and 639 rpm speed with different depth of cut.

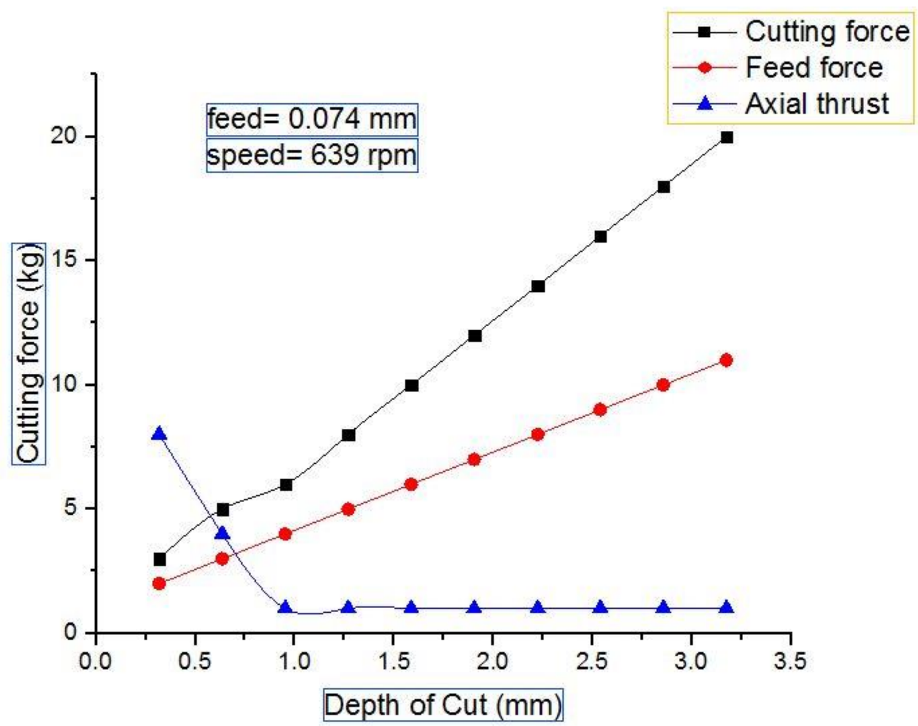


Fig.26 Results of turning operation with CNT coated HSS tool at 0.074 mm/rev feed and 639 rpm speed

Experimental readings of forces acting on CNT coated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.074 mm/rev feed and 639 rpm speed and graph was plotted using Origin 2015 software which shows cutting force and feed force acting on CNT coated tool varies from 2-36 kg and 1-26 kg respectively and increases with increase in depth of cut but with increase in depth of cut axial thrust force first increases to some value then becomes constant and its varies from 4 to -15 kg. All the three forces are slightly lesser than forces acting on uncoated at the same cutting condition which is in favour of CNT coated tool.

8.9 Results of turning operation with CNT coated HSS tool at 0.1168 mm/rev feed and 639 rpm speed

Figure 27 shows the complete graphical representation of variation of forces such as cutting force, feed force and axial thrust force acting on CNT coated HSS tool at 0.168 mm/rev feed and 639 rpm speed with different depth of cut.

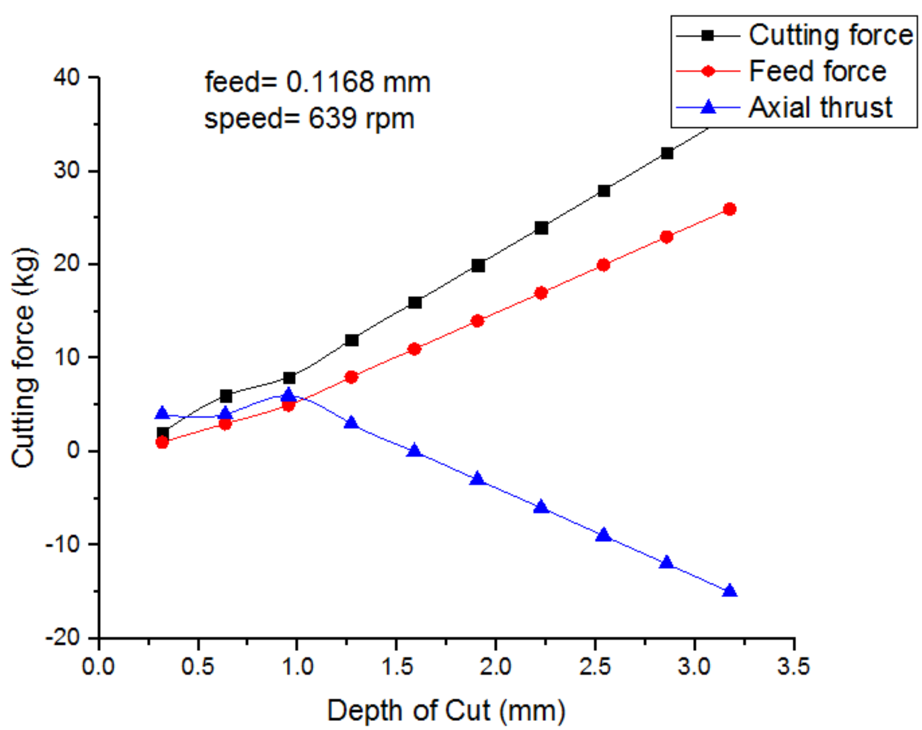


Fig.27 Results of turning operation with CNT coated HSS tool at 0.1168 mm/rev feed and 639 rpm speed

Experimental readings of forces acting on CNT coated tool with ten numbers of different depth of cut i.e. 0.3175 to 3.175 mm is taken using lathe tool dynamometer at 0.1168 mm/rev feed and 639 rpm speed and graph was plotted using Origin 2015 software which shows cutting force and feed force acting on CNT coated tool varies from 2-36 kg and 1-26 kg respectively and increases with increase in depth of cut but with increase in depth of cut axial thrust force first increases to some value then start decreasing and its varies from 4 to -15 kg. All the three forces are slightly lesser than forces acting on uncoated at the same cutting condition which is in favour of CNT coated tool.

8.10 Statistics of forces acting on uncoated and coated tools

Statistics includes mean, standard deviation and mode of forces i.e. cutting force, feed force and axial thrust force are computed using Origin 15 software to compare the mean and S.D of forces acting on uncoated and coated tool and analyzing their performance.

8.10.1 For forces acting on uncoated and coated tool at 0.074 mm/rev feed and 409 rpm speed

A) Cutting force:

Statistics on Columns (7/1/2015 01:02:27)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!A1"Cuting Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Uncoated tool	10	12.9	6.22629	129	3	13	22

Statistics on Columns (7/1/2015 01:10:09)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!D1"Cuting Force on Coated Tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Coated Tool	10	11	6.0553	110	2	11	20

Table 16. Statistics of cutting force acting on uncoated and coated tool 0.074 mm/rev feed and 409 rpm

From above computations of mean, median and S.D of cutting force acting on coated and uncoated at 0.074 mm/rev feed and 409 rpm, we can see that there is 17.327% of cutting force reduction on coated tool, which is in favour of using CNT coated tool.

B) Feed force

Statistics on Columns (7/1/2015 01:07:46)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!C1"Feed Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Uncoated tool	10	6.4	3.20416	64	1	6.5	11

Statistics on Columns (7/1/2015 01:11:06)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!F1"Feed Force on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Coated tool	10	5.6	2.87518	56	2	5.5	10

Table 17 Statistics of feed force acting on uncoated and coated tool 0.074 mm/rev feed and 409 rpm

From above computations of mean, median and S.D of feed force acting on coated and uncoated at 0.074 mm/rev feed and 409 rpm, it has been observed that there is 14.28% of feed force reduction on coated tool, which is also in favour of using CNT coated tool.

C) Axial Thrust

Statistics on Columns (7/1/2015 01:09:05)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!E1"Axial Thrust on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Uncoated tool	10	11.8	8.7661	118	-2	12	26

Statistics on Columns (7/1/2015 01:14:08)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!B"Axial Thrust on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Coated tool	10	4.2	2.29976	42	1	4	8

Table 18. Statistics of axial thrust force acting on uncoated and coated tool 0.074 mm/rev feed and 409 rpm

From above computations of mean, median and S.D of axial thrust force acting on coated and uncoated at 0.074 mm/rev feed and 409 rpm, it has been observed that there is drastic reduction in axial thrust of 64.4% on coated tool, which is also in favour of using CNT coated tool.

8.10.2 For forces acting on uncoated and coated tool at 0.1168 mm/rev feed and 409 rpm speed

A) Cutting Force

Statistics on Columns (7/1/2015 01:16:44)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!A1"Cuting Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Uncoated tool	10	19.4	9.25203	194	5	19.5	33

Statistics on Columns (7/1/2015 01:21:01)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!D1"Cuting Force on Coated Tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Coated Tool	10	12.9	8.49117	129	2	12.5	26

Table 19. Statistics of feed force acting on uncoated and coated tool at 0.1168 mm/rev feed and 409 rpm

From above computations of mean, median and S.D of cutting force acting on coated and uncoated at 0.1168 mm/rev feed and 409 rpm, we can see that there is 50.38% of cutting force reduction on coated tool, which is in favour of using CNT coated tool.

B) Feed Force

Statistics on Columns (7/1/2015 01:17:59)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!C1"Feed Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Uncoated tool	10	12	6.0553	120	3	12	21

Statistics on Columns (7/1/2015 01:22:17)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!F1"Feed Force on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Coated tool	10	8	5.0111	80	1	7.5	16

Table 20. Statistics of feed force acting on uncoated and coated tool at 0.1168 mm/rev feed and 409 rpm

From above computations of mean, median and S.D of feed force acting on coated and uncoated at 0.1168 mm/rev feed and 409 rpm, it has been observed that there is 50% of feed force reduction on coated tool, which is also in favour of using CNT coated tool.

C) Axial Thrust

Statistics on Columns (7/1/2015 01:19:32)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!E1"Axial Thrust on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Uncoated tool	10	10.2	5.30827	102	1	11.5	16

Statistics on Columns (7/1/2015 01:23:20)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!B"Axial Thrust on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Coated tool	10	0.8	2.29976	8	-3	1	4

Table 21. Statistics of axial thrust force acting on uncoated and coated tool at 0.1168 mm/rev feed and 409 rpm

From above computations of mean, median and S.D of axial thrust force acting on coated and uncoated at 0.1168 mm/rev feed and 409 rpm, it has been observed that there is drastic reduction in axial thrust of 92.15% on coated tool, which is also in favour of using CNT coated tool.

8.10.3 For forces acting on uncoated and coated tool at 0.074 mm/rev feed and 639 rpm speed

A) Cutting Force

Statistics on Columns (7/1/2015 01:45:32)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!A1"Cuting Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Uncoated tool	10	10.9	4.06749	109	3	11.5	16

Statistics on Columns (7/1/2015 01:50:58)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!D1"Cuting Force on Coated Tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Coated Tool	10	11.2	5.76965	112	3	11	20

Table 22. Statistics of cutting force acting on uncoated and coated tool 0.074 mm/rev feed and 639 rpm

From above computations of mean, median and S.D of cutting force acting on coated and uncoated at 0.074 mm/rev feed and 639 rpm, it has been observed that there is 2.67% of increment in cutting force on coated tool, which limits the use of coated tool at this feed and speed.

B) Feed force

Statistics on Columns (7/1/2015 01:48:10)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!C1"Feed Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Uncoated tool	10	10.9	6.22629	109	1	11	20

Statistics on Columns (7/1/2015 01:52:23)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!F1"Feed Force on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Coated tool	10	6.5	3.02765	65	2	6.5	11

Table 23. Statistics of feed force acting on uncoated and coated tool 0.074 mm/rev feed and 639 rpm

From above computations of mean, median and S.D of feed force acting on coated and uncoated at 0.074mm/rev feed and 639 rpm, it has been observed that there is 67.68% of feed force reduction on coated tool, which is also in favour of using CNT coated tool.

C) Axial thrust

Statistics on Columns (7/1/2015 01:49:33)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!E1"Axial Thrust on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Uncoated tool	10	13.2	5.76965	132	5	13	22

Statistics on Columns (7/1/2015 01:53:36)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!B"Axial Thrust on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Coated tool	10	2	2.3094	20	1	1	8

Table 24. Statistics of axial thrust force acting on uncoated and coated tool 0.074 mm/rev feed and 639 rpm

From above computations of mean, median and S.D of axial thrust force acting on coated and uncoated at 0.074 mm/rev feed and 639 rpm, it has been observed that there is drastic reduction in axial thrust of 84.84% on coated tool, which is also in favour of using CNT coated tool.

8.10.4 For forces acting on uncoated and coated tool at 0.1168 mm/rev feed and 639 rpm speed

A) Cutting Force

Statistics on Columns (7/1/2015 01:25:20)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!A1"Cuting Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Uncoated tool	10	21.7	10.37144	217	4	22.5	36

Statistics on Columns (7/1/2015 01:37:09)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!D1"Cuting Force on Coated Tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Cuting Force on Coated Tool	10	18.4	11.5393	184	2	18	36

Table 25 Statistics of cutting force acting on uncoated and coated tool 0.074 mm/rev feed and 639 rpm

From above computations of mean, median and S.D of cutting force acting on coated and uncoated at 0.1168 mm/rev feed and 639 rpm, it has been observed that there is 17.93% of reduction in cutting force on coated tool, which favours the use of coated tool at this feed and speed.

B) Feed force

Statistics on Columns (7/1/2015 01:34:10)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!C1"Feed Force on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Uncoated tool	10	32.7	23.15191	327	2	32	68

Statistics on Columns (7/1/2015 01:38:48)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!F1"Feed Force on Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Feed Force on Coated tool	10	12.8	8.63842	128	1	12.5	26

Table 26 Statistics of feed force acting on uncoated and coated tool 0.074 mm/rev feed and 639 rpm

From above computations of mean, median and S.D of feed force acting on coated and uncoated at 0.1168 mm/rev feed and 639 rpm, it has been observed that there is 60.85% of feed force reduction on coated tool, which is also in favour of using CNT coated tool.

C) Axial thrust

Statistics on Columns (7/1/2015 01:26:45)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!E1"Axial Thrust on Uncoated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Uncoated tool	10	40.6	27.01933	406	5	40.5	81

Statistics on Columns (7/1/2015 01:42:10)

Notes

Input Data

	Data	Range
Data	[Book1]Sheet1!B"Axial Thrust o n Coated tool"	[1*:10*]

Descriptive Statistics

	N total	Mean	Standard Deviation	Sum	Minimum	Median	Maximum
Axial Thrust on Coated tool	10	-2.8	7.4057	-28	-15	-1.5	6

Table 27. Statistics of axial thrust force acting on uncoated and coated tool 0.074 mm/rev feed and 639 rpm

From above computations of mean, median and S.D of axial thrust force acting on coated and uncoated at 0.1168 mm/rev feed and 639 rpm, it has been observed that there is drastic reduction in axial thrust of 93.10% on coated tool, which is also in favour of using CNT coated tool.

8.11 Tool wear measurement

Tool wear can be termed as the gradual failure of cutting tools due to regular and continuous machining operations. Tool wear can be in various forms which includes crater wear, flank wear edge wear, plastic deformation, mechanical breakage and nose wear. There are various reasons which cause the tool wears. Rapidly, thermal forces that could cause the wear and mechanical breakage can also be caused by excessive force that causes immediate failure. The machining parameters of the operation are known to be one of the most common factors that cause tool wear. Tool wear mainly depends on the tool, work piece material such as physical, mechanical and chemical properties, cutting parameters, tool geometry, cutting fluid, etc.

Flank wear occurs on the relief face of the tool i.e. on flank of the tool and it is generally occurred by the rubbing of the tool along the machined surface.

Crater wear is of the factor that finds the life of the cutting tool; crater wear becomes so severe that the tool edge is weakened. It occurs on the rake face of the tool and at the end fractures but when tools are used under some economical conditions, the wear of the tool on its flank. The wear can occurs not only gradually but also by abrasive or adhesive wear, due to plastic deformation, through discrete losses of material, by discrete fracture mechanism, or due to combination of these. These effects could be through high mechanical, chemical and thermal loads acted while hard machining. Capability to predict tool wear during hard turning is necessary to determine the optimum cutting variables. It is also beneficial to avoid catastrophic tool failure, which can not only damage the workpiece surface but also affect the cutting tool performance.

In this project to check the wear behavior of uncoated HSS tool and CNT coated HSS tool using SEM image there is requirement of cutting the tool tip for SEM setup machine, and I could not able to cut the tip of the tool due to its high hardness for analyzing the wear on coated and uncoated tool after machining EN8 carbon steel, so on the basis of previous year student who had taken the SEM image of drill tool after and before machining as shown in figure 28 and 29 , we can predict the wear behavior of CNT coated HSS tool and uncoated HSS tool of my research work.

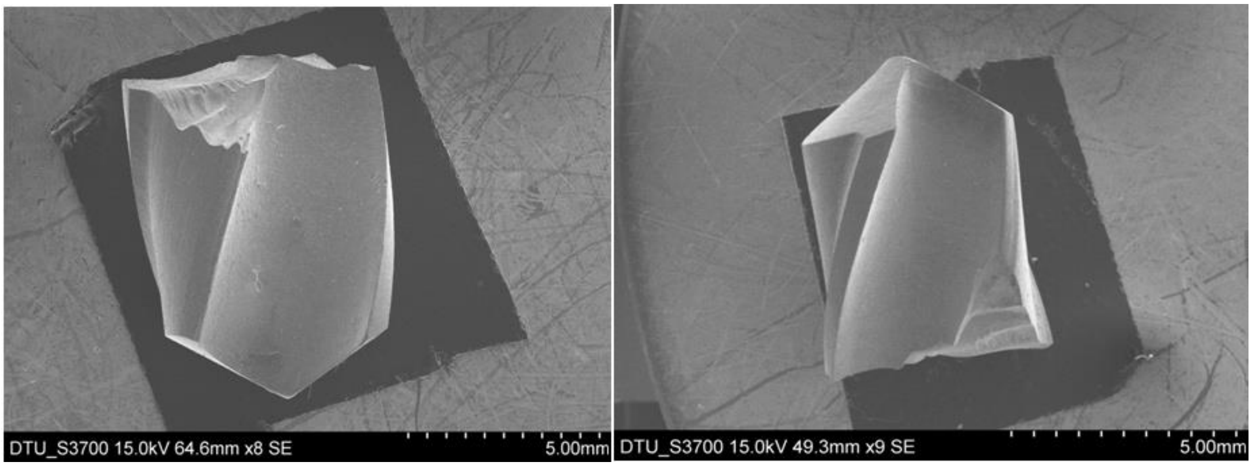


Fig .28: SEM(Scanning Electron Images) of coated and non coated HSS drilling tool before machinating

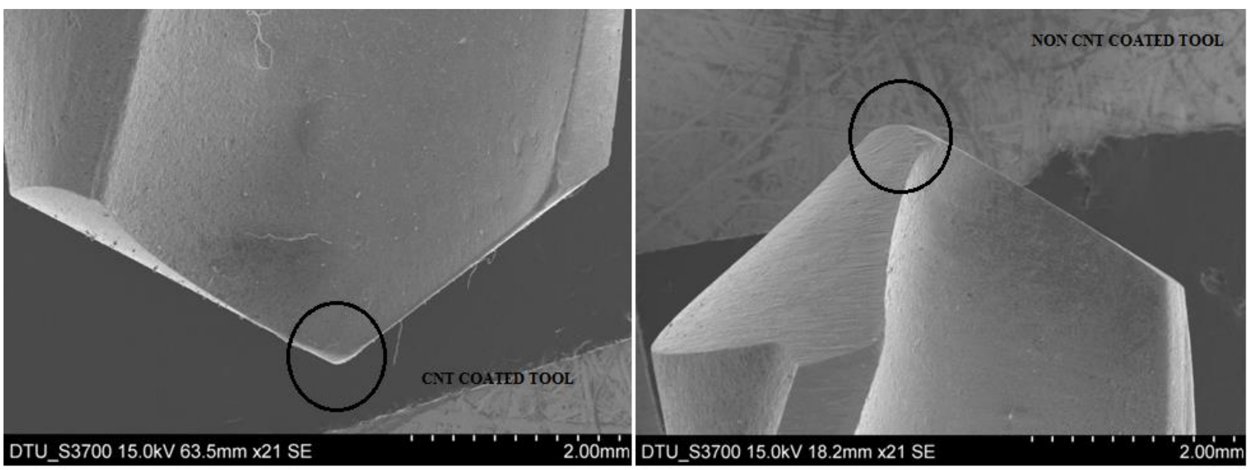


Fig.29 **:** SEM(Scanning Electron Images) of coated and non coated HSS drilling tool after machining on ductile material

Source : Lalit Mohan Verma, a simple method of synthesis of carbon nano tubes (CNT) on high speed steel drilling tool and evaluation of performance while machining", Delhi Technological University, M.tech Hose, New Delhi

SEM images of both coated and non coated drill tool before and after machining showed that CNT coated tools have less wear as compared to non coated tools, so we can predict that tool wear of CNT coated HSS tools is less than that of non coated tool.

SEM photograph of the worn surfaces on the coated tools showing significant wear of CNT coated and non coated cutting tools due to abrasion from hard particles in the workpiece EN8 carbon steel from which can conclude that CNT coated tool have less wear in comparison to uncoated HSS tool . The coated HSS tool was worn due to progressive wear of the CNT coating

When the surface of the cutting tools was coated with CNT, which had tremendous mechanical properties which can be suppressed so that decreasing cutting resistance. Formation of built-up edge reduced which maintained the sharpness of the edge, and ultimately enhance the machinability.

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CHAPTER-09

COMPARATIVE ANALYSIS

9.1 Introduction

This section include the comparison between machining forces i.e. cutting forces, feed forces and axial thrust acting on uncoated HSS tool and CNT coated HSS tool while machining EN8 carbon steel material rod on center lathe machine in dry conditions at different cutting parameters such feed, depth cut and cutting speed . This section also includes the discussion related to overall performance of uncoated and CNT coated tool.

9.2 Experimental comparison between the forces acting on uncoated and coated tool at 0.074 rev/mm feed and 409 rpm cutting speed

Figure 30 shows that graphical representation of data related to forces acting on uncoated and coated tool while machining EN8 carbon steel on centre lathe. This section also includes that comparison between the forces acting on uncoated and coated tool at 0.074 rev/min feed, 409 rpm cutting speed and different values of depth of cut varies from 0.3175mm to 3.175 mm. This analysis revealed that at 0.074 mm/rev feed and 409 rpm speed component of cutting force and feed force acting on uncoated tool are slightly greater than that CNT coated tool but axial thrust force acting on uncoated HSS tool is much higher than that CNT coated tool at different depth of cut, which shows that CNT coated tool have high machinabilty than uncoated tool.

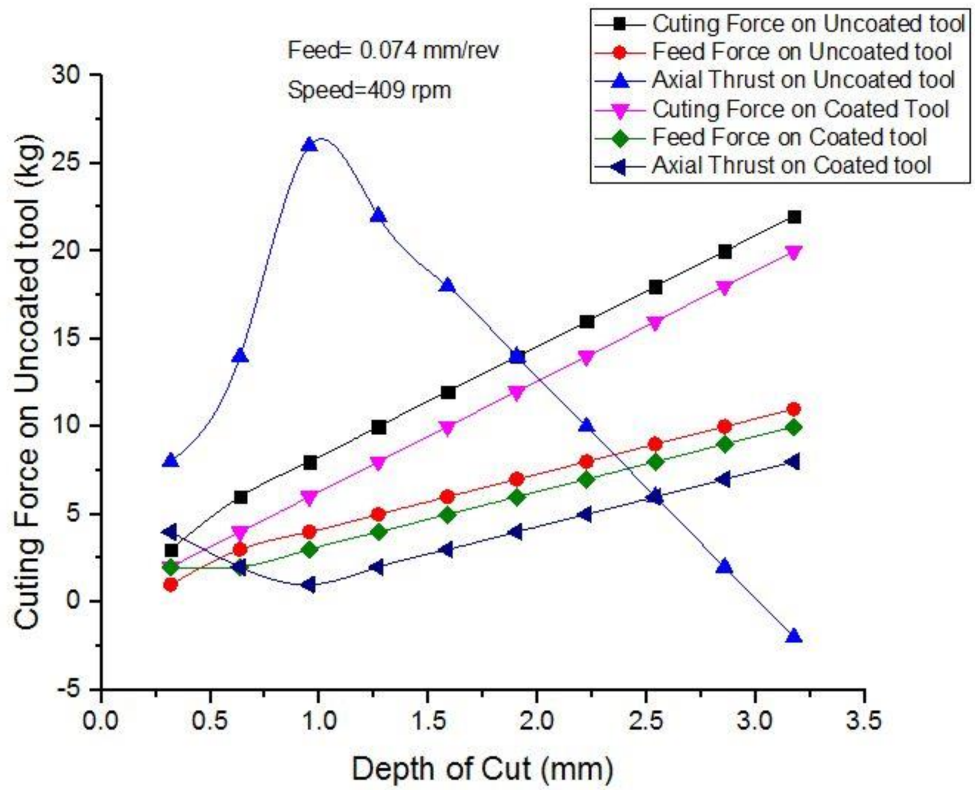

Fig. 30 Comparison between the forces acting on uncoated and coated tool at 0.074 rev/mm feed and 409 rpm cutting speed.

9.3 Experimental comparison between the forces acting on uncoated and coated tool at 0.1168 rev/mm feed and 409 rpm cutting speed

Figure 31 shows that graphical representation of data related to forces acting on uncoated and coated tool while machining EN8 carbon steel on centre lathe using Origin 15 graphing and analysis software. This section also includes that comparison between the forces acting on uncoated and coated tool at 0.1168 rev/min feed, 409 rpm cutting speed and different values of depth of cut varies from 0.3175mm to 3.175 mm. This analysis revealed that at 0.1168 mm/rev feed and 409 rpm speed, the component of cutting force, feed force and axial thrust force acting on uncoated tool are slightly greater than that CNT coated tool at different depth of cut, which shows that CNT coated tool have high machinabilty than uncoated tool and ultimately it would have less wear and higher tool life.

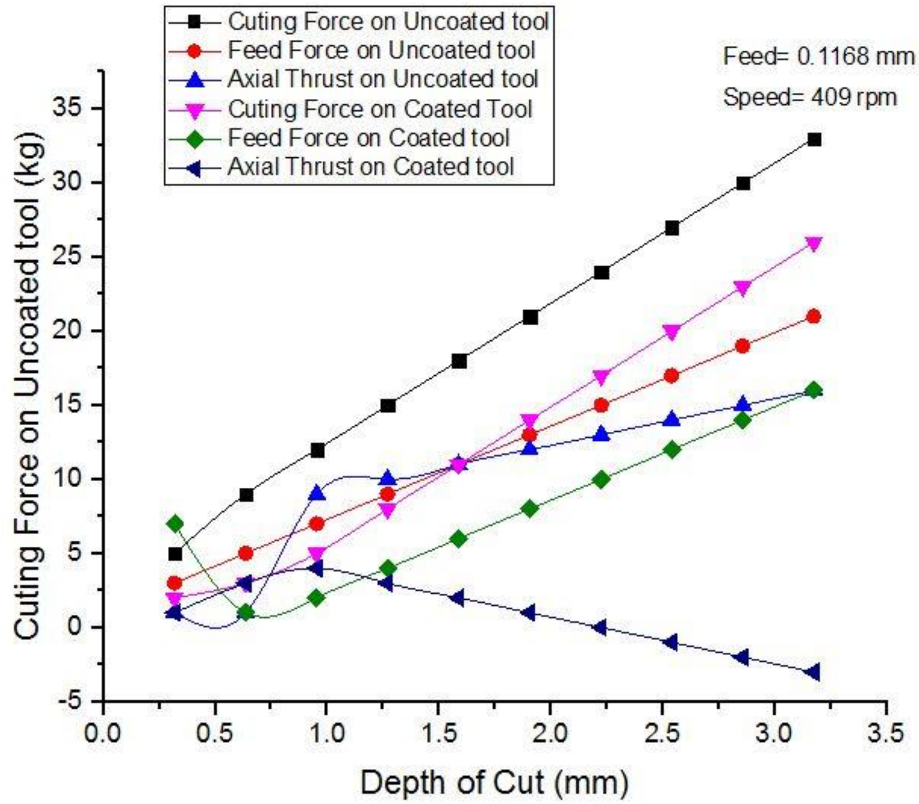

Fig. 31 Comparison between the forces acting on uncoated and coated tool at 0.1168 rev/mm feed and 409 rpm cutting speed.

9.4 Experimental comparison between the forces acting on uncoated and coated tool at 0.1168 rev/mm feed and 409 rpm cutting speed

Figure 32 shows that graphical representation of data related to forces acting on uncoated and coated tool while machining EN8 carbon steel on centre lathe using Origin 15 graphing and analysis software. This section also includes that comparison between the forces acting on uncoated and coated tool at 0.1168 rev/min feed, 409 rpm cutting speed and different values of depth of cut varies from 0.3175mm to 3.175 mm. This analysis revealed that at 0.1168 mm/rev feed and 409 rpm speed, the component of cutting force, feed force and axial thrust force acting on uncoated tool are slightly greater than that CNT coated tool at different depth of cut, which shows that CNT coated tool have high machinabilty than uncoated tool and ultimately it would have less wear and higher tool life.

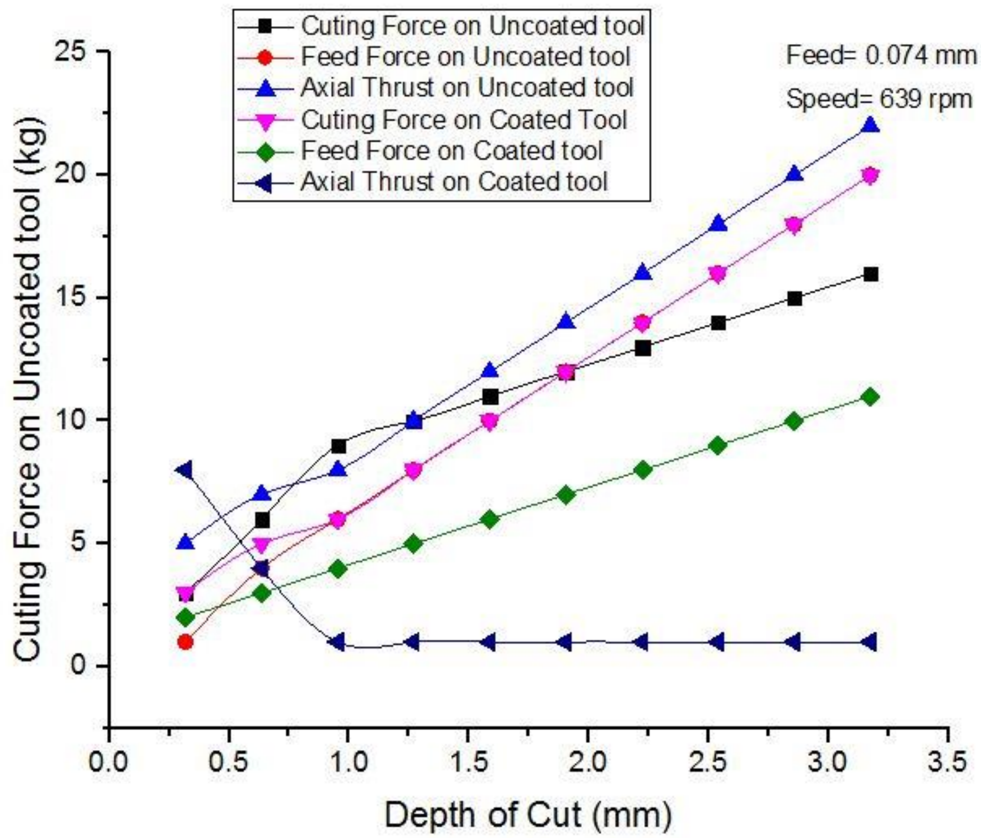

Fig.32 Comparison between the forces acting on uncoated and coated tool at 0.1168 rev/mm feed and 409 rpm cutting speed

9.5 Experimental comparison between the forces acting on uncoated and coated tool at 0.1168 rev/mm feed and 639 rpm cutting speed

Figure 33 shows that graphical representation of data related to forces acting on uncoated and coated tool while machining EN8 carbon steel on centre lathe using Origin 15 graphing and analysis software. This section also includes that comparison between the forces acting on uncoated and coated tool at 0.1168 rev/min feed, 639 rpm cutting speed and different values of depth of cut varies from 0.3175mm to 3.175 mm. This analysis revealed that at 0.1168 mm/rev feed and 639 rpm speed, the component of cutting force, feed force and axial thrust force acting on uncoated tool are slightly greater than that CNT coated tool at different depth of cut, which shows that CNT coated tool have high machinabilty than uncoated tool and ultimately it would have less wear and higher tool life.

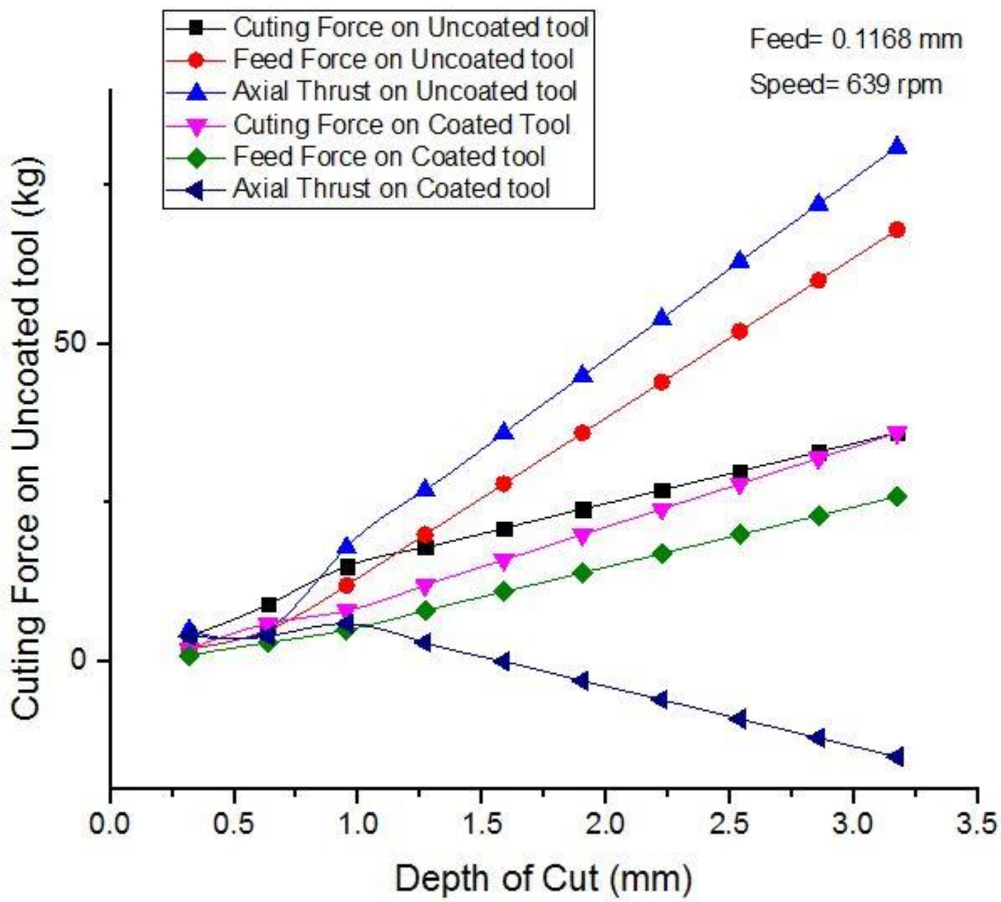

Fig. 33 comparison between the forces acting on uncoated and coated tool at 0.1168 rev/mm feed and 639 rpm cutting speed

Comparative analysis of forces acting on coated and uncoated tool for four for different cutting conditions of feed and speed as discussed above favored CNT coated tool as compared to uncoated HSS tool and it shows that CNT coated tool have greater performance than uncoated HSS tool at different cutting parameters.

CHAPTER-10
CONCLUSION

Experimental study concluded various results outcome with the use of MWCNT coated HSS tool and uncoated HSS tool such as all three forces acting on both tool i.e. coated and uncoated has been measured using dynamometer while machining of EN8 carbon steel rod at different cutting parameters such as depth of cut, feed rate and cutting speed & wear pattern on both coated and uncoated tool using SEM image are concluded and discussion on that results are discussed below:

1. As far as concern of cutting forces Coated HSS tools perform better than uncoated HSS tools. Average magnitudes of forces measured with coated HSS tool were lower than those obtained with uncoated HSS tools at different cutting conditions.
2. Results analysis shows that, the optimal value of both low depth of cut and low feed rate with high cutting speed is profitable to reduce machining force.
3. A cutting speed of 639 rpm in has been given the optimized magnitude of cutting forces in the experimental cutting parameters range. Cutting feed plays a direct effect on cutting force. With the increase in feed there is a direct increase in the cutting forces
4. This study revealed that cost of CNT coating on tool is lesser than the conventionally available coating material like AlTiN, TiC, TiCN etc.
5. Results concluded that, the machining of hard materials such as EN8 carbon steel at higher speeds is improved with the use of CNT coated tools. From the experimental cutting test we can observed that while turning CNT coated HSS tools have better performance and machinabilty in comparison to uncoated HSS at different cutting parameters.
6. The study of microscopic analysis of the worn surfaces of the cutting tools using SEM image revealed that wear of uncoated HSS tool is slightly greater than CNT coated HSS tool and ultimately coated tool have higher tool life than that of uncoated tool. The wear on cutting tool surface increases almost linearly with increase in depth of cut, cutting speed and feed rate.

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