Effect of Coating on Machining Performance of Hard Surfaces

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Abstract— Machining of the material in the hardened state is one of the challenging tasks. But this is possible due to development or innovation in the area of cutting tools. Machining of the material in the hardened state gives good surface finish as given by the grinding at the minimum cost and time. Many researchers have analysed the effect of machining parameters on the tool wear, machining force and surface roughness as well as compared the coated and the uncoated tool life to suggest which tool is preferable. The aim of this work is to analyse the effect of titanium based coatings on the tool wear, surface roughness, machining forces, temperature of the cutting tool and the type of chip formation. In this work three type of coatings - TiN,TiCN and TiAlN are used on the ceramic inserts for machining (turning) of AISI A2 tool steel and further an ANOVA was carried out to investigate statistical significance among all cutting parameters. It shows that speed has been found to be the most dominant factor in the tool wear, tool temperature and machining force but feed has been found to be the most dominant factor in for surface roughness. Grey relation analysis is used to optimise cutting condition. The result indicated that, the TiAlN coating tool has less tool wear followed by TiCN and TiN but in terms of roughness, TiN showed better result, except dimension accuracy. Due to higher tool wear, TiN coated tool gives relatively lower dimensional accuracy.

Key words: ANOVA; Coating Material; Hardning surface; Machining; TiAIN Coating; Cutting tool

I. INTRODUCTION

A. Manufacturing:-

Manufacturing is the transforming raw material, part or component into finished good by the various manufacturing process that meets a customer's expectation and specification. It generally employs a man – machine setup with various division of labour in small or large production [1]

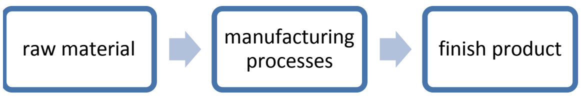


Fig. 1.1: manufacturing

B. Manufacturing process:-

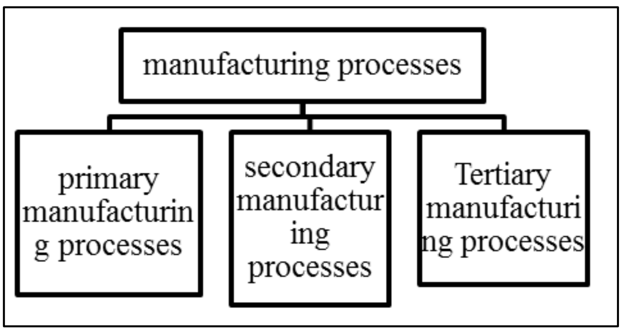


Fig. 1.2: classification of manufacturing process

C. Hard machining:-

Hard machining is the machining of material in hardened state and this hardness is define on a particular scale like in Rockwell hardness on C scale the hardness is above 45 HRC, but generally, the process concerns hardness of above the 60 HRC. This much hardness is obtain by the heat treatment, case hardening, by adding some alloying element in the base material [2]

D. Hard turning:-

One of the new machining technologies is Hard Turning. In this turning is done of the material in harden state. And the output in term of surface roughness gives similar to grinding process. If the migration of processing from grinders to lathes can be achieved, the cost of machining can be reduced because less floor space will be required, overall investment will be lower, complex contours can be machined, material removal rate will be 4-5 times greater, and configuration changes will be made faster.

Machining is a material removal process that is used to produce a required shape from a workpiece material. Hard turning is a method that can be used to removeSunwanted/excess materialSfrom the hardened workpiece in order to get its required shape and surface finish in the form of chips. Precise part can be produced by hard turning without having the workpiece to undergo a secondary process such as grinding and lapping. The application of hard turning is further enhanced with the use of new materials for making cutting tools such as cubic boron nitride (CBN) and ceramics [2]. As a result of this, more research is being done in the evaluation of these cutting tools made from different material for use in the hard turning process.

Hard turning is defined as the turning of the hard material whose hardness above the 45 HRC (industries > 60 HRC) with the help of cutting tool and no cutting or lubrication.Before 1980s to produce a part of good surface quality industries preferred grinding as a finishing process. Later many researcher work in the field of development of tool material and tool geometry and then new toll material are developed like PCBN, CBN, coated tool etc due to development of these tool material we can easily machine hard material under a certain cutting parameter it took lesser time then the part manufacture by soft machining and then grind and less cost per part without compromising its surface quality.

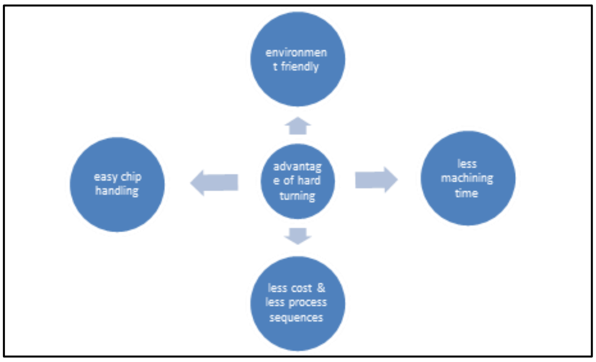


Fig. 3: Advantage of hard turning

II. OBJECTIVE

In this work it is proposed to study the effect of different coating on the tool wear, tool temperature, machining force and the surface generation of the work piece in term of roughness. Work piece is used for this work is AISI A2 tool steel. Optimum condition were identified using grey relation analysis.

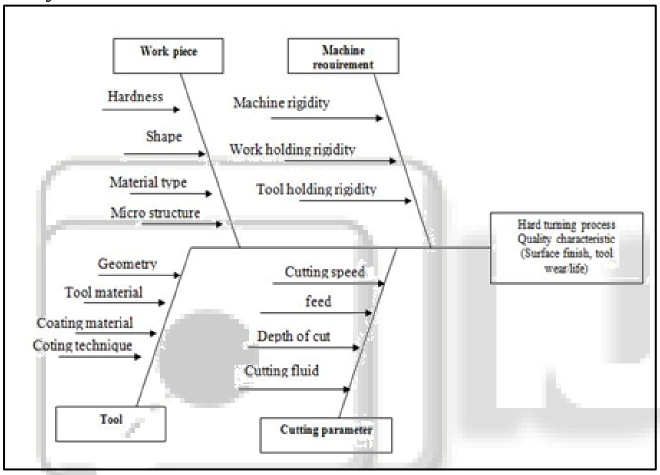


Fig. 2.1: fishbone diagram for hard turning

III. EXPERIMENTAL INVESTIGATION

In this experimental work turning of A2 tool steel was carried out with different titanium based coating material tool insert.

A. Machining of hard material (AISI A2 tool Steel)

In this work, the focus is on the machining (turning) of hard material such as A2 tool steel. It is generally used where the hard cutting edge is our primary requirement such as in manufacturing of components in auto and aerospace industries. In general during the hard machining the lubricant is not used due to this hard machining is economical and ecofriendly. So during this work we try to find the effect of coating on the performance of the cutting tool and the effect of various process parameters.

B. Work piece material

The work piece is A2 tool steel which is cold work steel. Its diameter is 25 mm and length is 3500 mm. Initially the work piece hardness is 26 HRC but after heat treatment (hardening) its hardness increases up to 60 HRC. The work piece is shown below in the fig-4.1

Fig. 3.1: work material

A2 is an air or an oil hardening chromium-molybdenum-vanadium alloyed material tool steel. It has a very fine grain structure which gives it a superior-quality steel characteristic. It possesses the deeper hardening ability, high compressive strength, good wear resistance, good hardenability and high stability after hardening. A2 tool steel is ideal for making thin parts that are normally prone to cracking during heat treatment.

1) Composition of A2 tool steel

Carbon	Manganese	Silicon	Mo	Cr	V
1.0	0.6	0.3	1.1	5.3	0.2

Table 3.1: composition of A2 tool steel [37]

2) Physical data of A2 tool steel

Property	Value
Density	7.86 g/cm^3
Melting point	1424 ^{0}c
Bulk modulus	140 GPa
Poisson’s ratio	0.27 – 0.3
Elastic modulus	190 – 210 Gpa
Thermal Expansion coefficient	10.7*10 $^{-6}$ /c
Shear modulus	78Gpa

Table 3.2: physical value of A2 tool steel [37]

C. Power hexa cutter:-

The length of the rod is 3500 mm which is difficult to heat treat so it is divided in small parts of 250 mm length with the help of power hexa cutter.

D. Muffle furnace:-

Initially the hardness of AISI A2 tool steel is 25 to 30 HRC. To increase the hardness heat treatment (quenching) is required. Quenching is the process in which material is heat above the austenite temperature then hold for a small time then cool with a very high rate. Quenching is generally done for increase the hardness and hardness increase due to phase transformation (martensitic transformation). Martensitic is the hardest phase which is brittle in nature. Muffle furnace is used for heat treatment the work piece of length of 250mm and diameter 25 mm. is heat upto 950oc then hold for 30 min then quench in water.

E. Lath grinder:-

After heat treatment (quenching) the surface of work piece become black and rough due do oxide layer form on the outer surface so for the measuring of surface hardness (generally Rockwell hardness), the surface should be clean. So for cleaning of this surface, wolf lathe grinder of type (GL3F) with straight wheel and cup grinding wheel was employed.

Type	GL3F
Serial No.	B61399
Volts.(AC/DC)	220-250
No load Speed	8000 rpm max.

Watts Input (full Load)	400 watt
Approx. Weight	8.5 kg

Table 3.3: specification of lath grinder

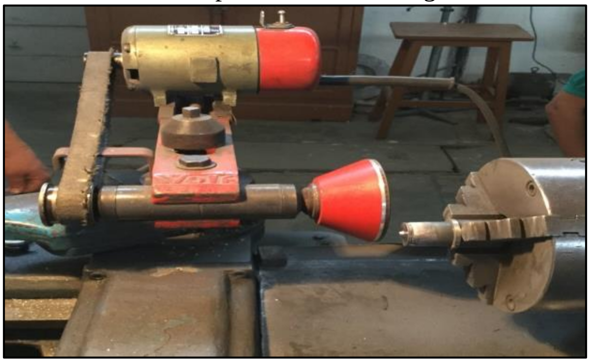


Fig. 3.4: lathe grinder

F. Machine tools

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

Fig. 3.5: lathe machine

Height of centers	220 mm
Swing over bed	500 mm
Swing over cross slide	270 mm
Swing in gap (optional)	720 mm
Distance between centers	1000 mm
Spindle Nose / Bore	A2-6* / 53 mm
Spindle Speed range	16 from 40-2040 forward 7 from 60-1430 reverse
Feed range (longitudinal)	60 from 0.04-2.24 mm/rev.
Spindle power	11 kw
Feed range (cross)	60 from 0.02-1.12 mm/rev.
Lead screw pitch	6 mm
Metric threads	48 from 0.5-28 mm
Inch threads	60 from 56-1 tpi
Module threads	40 from 0.25-14 mm
Diametral pitch (optional)	43 from 112-2 mm
Tailstock sleeve travel	200 mm
Main motor power	7.5 (std.) / 11.0 (opt.) kw

Table 3.4: lathe machine specification [29]

G. Force measurement

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

The three components of forces are
Fx: axial component
Fy: radial component
Fz: tangential component

The cutting forces were measured with a Dynamometer (Kistler- 9257B) mounted on the lathe. The charge signal generated at the dynamometer was amplified using charge amplifiers (Kistler Type 5070A10100)

1) Dynamometer Specification

Dynamometer (type - 9257B)
Manufactured by – Kistler Instrumente AG, CH-8408 Winterthur, Switzerland

2) Machine specification of Multichannel Charge Amplifier:--

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

IV. EXPERIMENTAL PROCEDURE

Initially, the length of the workpiece was 3500 mm; this length of workpiece is difficult to machine and handle as a single unit, so it was divided into a small length of 250 mm with the help of power hexa cutter. The resultant workpiece is 25 mm diameter and 250 mm length. Then both the ends of the workpiece were faced and centered on the lathe with the help of carbide twist drill for easy holding. The hardness of the a2 tool steel before heat treatment was around 28 to 30 HRC; to increase hardness quenching is required. The workpiece was heated up to 950 ^{o} c in the muffle furnace then it was held at this temperature for 30 to 40 min. after which it was quenched in the water. After heat treatment, the upper surface or outer skin of the workpiece became dull (black) due to oxide formation so it was necessary to clean this oxide layer for measurement of hardness. This oxide layer was cleaned by the lathe grinder with the use of straight of cup grinder wheel. After this, we measure the hardness on the Rockwell hardness tester and hardness was measured to be around 60 HRC.

The workpiece was held on the lathe with the help of job carrier and with the support of tail stock. For measuring the force Dynamometer was mounted on the carriage and tool holder was mounted on the dynamometer as shown in the figure [4.]. For measuring the temperature a digital temperature indicator was used with thermocouple this thermocouple was joined on the rake face of the insert by the soldering. In this work to analyse the effect of coating on the machining of hard material three type of coatings were used on the insert for comparison in terms of cutting force, surface roughness and tool wear (tool life) with the variation of speed, feed rate and depth of cut irrespective of hardness.

In this work three levels of speed, feed rate and depth of cut were varied for the each coating so 9 experiments for each coating. For each experiment tool travel was 180 mm distance and radial, axial and cutting forces were measured with the help of dynamometer. The temperature was measured by the digital temperature indicator and tool wear was measured by the fesem. The surface roughness was measured by using surf cam flex 50a and white layer was measured by an optical microscope. For each experiment new edge was used for cutting so that the tool wear for each experiment can be measured separately.

V. COMPARISON OF DIFFERENT COATING MACHINING FORCE

During the turning, all three forces radial force, axial force and tangential or cutting force were measured with the help of dynamometer. The radial force was larger in all followed by tangential and axial force. If geometrical conditions were same then these forces varied coating to coating. Because every coating material has different properties. TiAlN shows higher machining forces followed by TiN and TiCN and this is show in graph below.

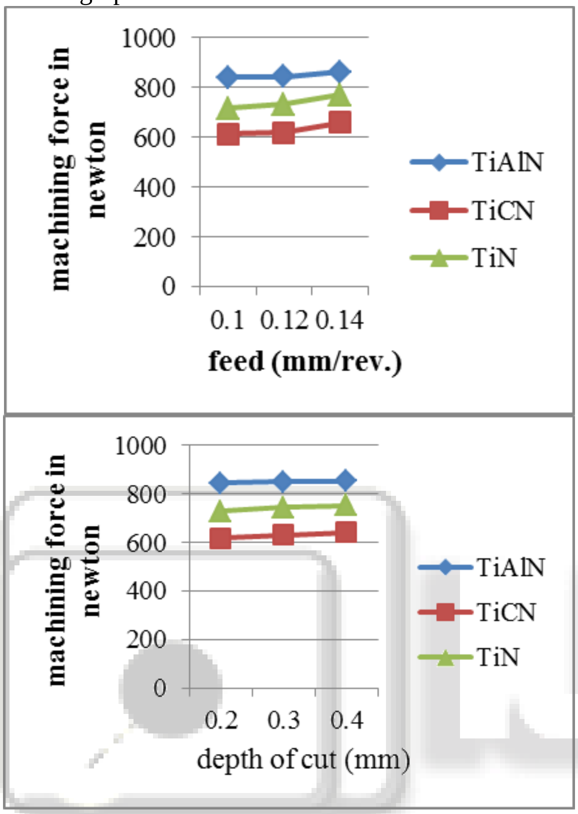
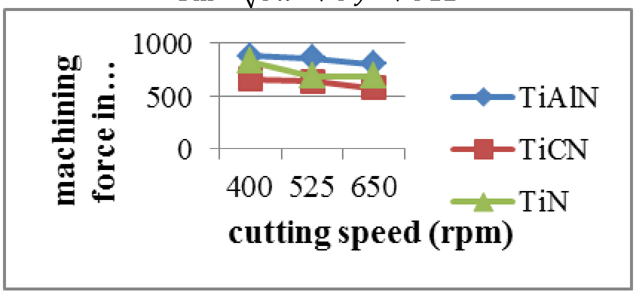


Fig. 5.1: comparison of force with speed, feed and doc

Machining force was calculated by:-

$$Fm = \sqrt{Fx^2 + Fy^2 + Fz2}$$



From the above graph it has been observed that as cutting speed increases, machining force decreases; As cutting speed increases, machining force decreased; that happened because, as speed increases heat generation increases, which softens the work material and therefore, less force was required for machining.

In rest two graphs the variation of machining force with the feed and depth of cut is shown respectively. And it has been observed that as feed and depth of cut increase there was an increase in chip cross section, so more force is required for material removal.

From the second and third graph an observation has been made that as feed and depth of cut increase it increase the chip cross section area so more force is required for material removal.

In each graph separate line was drawn for the each coating. In TiAlN coating force required was high followed by TiCN and TiN. That is because coefficient of friction for each coating was different as described in table no. 1.

A. Surface roughness:-

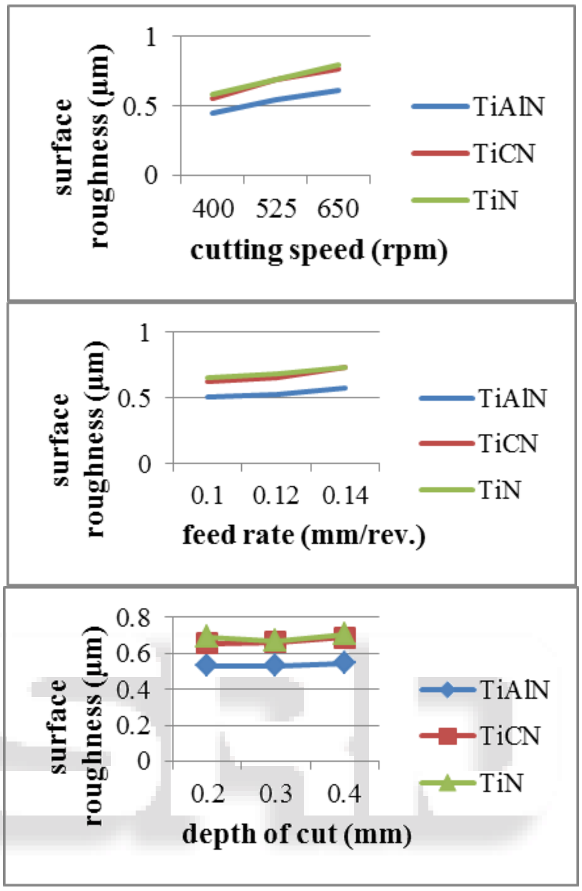


Fig. 5.2: Roughness vs speed, feed & depth of cut

From the first graph it has been analyse that as cutting speed increase the tool wear increase due to this the effect of chatter or vibration increase which directly affect the surface roughness. Second aspect was as speed increase tool wear increased and due to tool wear there was small increase in nose radius as nose radius increase surface roughness decrease. Second aspect was influence is very less so as speed increase surface roughness increased. In the graph first tool wear of TiAlN coated tool is less followed by TiCN and TiN so surface roughness is less in case of TiAlN followed by TiCN and TiN coated tool.

In the graph second as feed increase surface roughness was also increased. The peak to valley distance in the machining has been direct related to the square of feed and inverse relation with the nose radius. So as feed increase roughness was increase and depth of cut was not much affect the surface roughness. TiAlN shows the less surface roughness followed by TiCN and TiN.

B. Flank wear:-

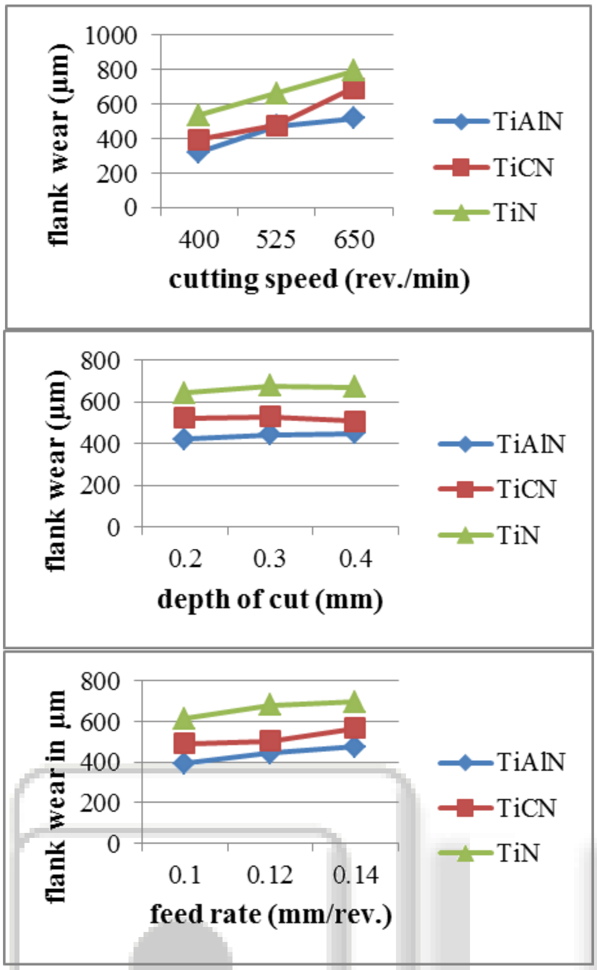


Fig. 5.3: comparison of flank wear of different coating

From the first graph observeation has been made that as cutting speed increases, tool wear also increases and from the ANOVA it is observed that the cutting speed was the most significant factor then feed and very less affect by depth of cut.

In all the graph tool flank wear was minimum for TiAlN coating followed by TiCN and TiN coating. Tool wear is dependent on the hardness of tool material, stability at the high temperature and wear property of the tool and geometrical shape. Here TiAlN has high hardness followed by TiCN and TiN so tool wear was in the same trand. Flank wear was on an average 50% higher in TiN coated tool as compared to TiAlN coated tool and wear in TiCN coated tool on an average 20 % higher as compared to TiAlN coated tool. At the high temperature chemical wear becomes a leading wear mechanism (chipping of nose radius).

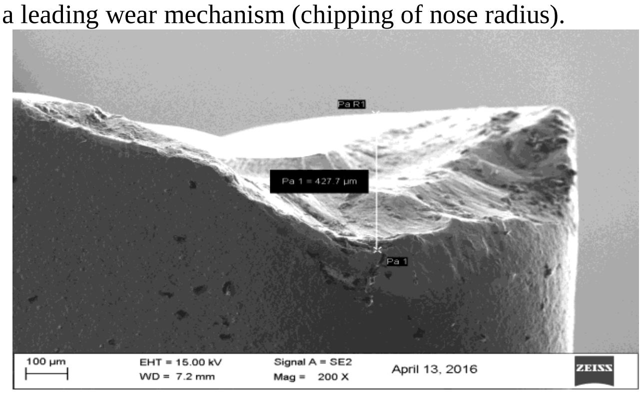
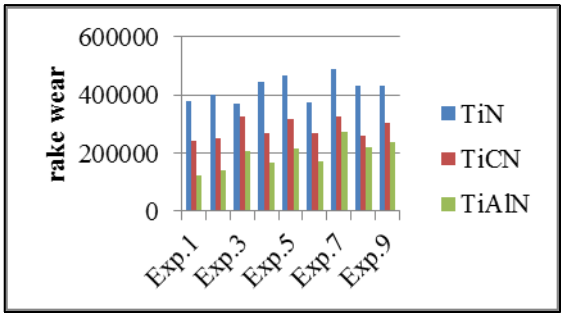


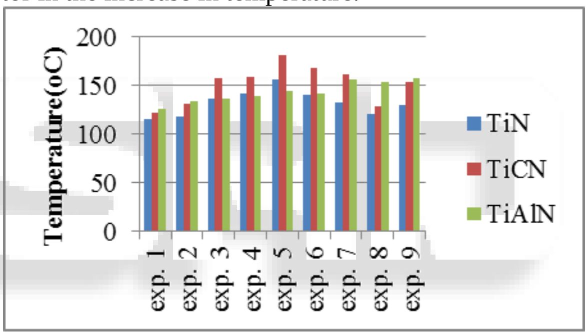
Figure tool wear for TiN, TiCN and TiAlN for exp. 5



In the above graph rake wear was shown for the each coating and individual experiments. It was observed that the rake wear was highest for the TiN coating followed by TiCN and TiAlN coating.

C. Temperature:-

Temperature was measured with the help of digital temperature indicator; it was connected by the k type thermocouple at the rake face at 0.3 mm distance from the interface by soldering/ brazing. If the temperature increases, it affects the tool wear rate, the quality of the surface, wear resistance of tool, hardness, and strength of the tool. If the depth of cut increases the temperature at the rake face also increased because tool-chip contact length increased. The cutting speed and depth of cut were the most dominant factor in the increase in temperature.



The comparison of Temperature for each coating and each experiment was shown in the graph above. In the graph, sometimes TiCN shows high temperature (experiment 3, 4, 5, 6, and 7) and for the rest experiment TiAlN coating shows high temperature. This temperature depends upon the thermal conductivity of the coating material.

D. Material removal rate:-

Material removal rate was measured by formula because all the values of parameters were known. Material removal rate can easily be calculated by the formula written below

Material removal rate (mrr) = $\pi(D^2 - d^2)fN$

D- Diameter of the work piece before machining (mm)

d- Diameter of the work piece after machining (mm)

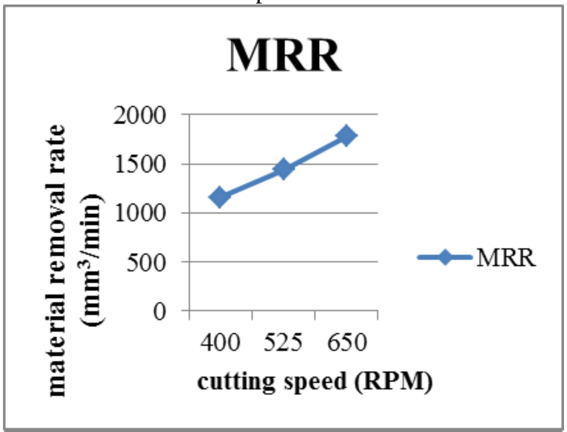
f – Feed rate (mm/rev)

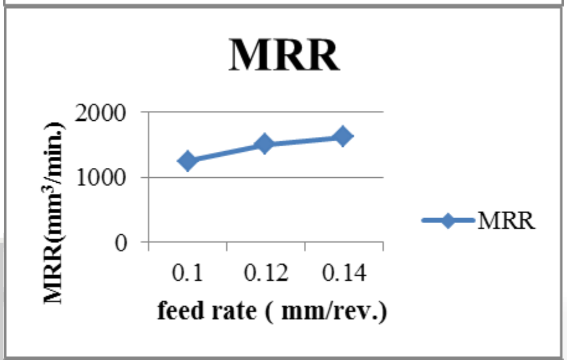
N – Speed (rpm)

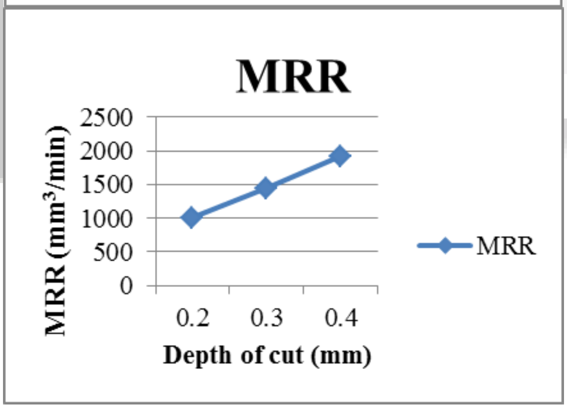
Sn.	Speed	Doc	Feed	Diameter (D)	Diameter (d)	MRR (mm^3/min)
1	400	0.2	0.1	25	24.6	623.2919
2	400	0.3	0.12	25	24.4	1117.4
3	400	0.4	0.14	25	24.2	1731.14
4	525	0.2	0.12	25	24.6	981.68
5	525	0.3	0.14	25	24.4	1711.02

6	525	0.4	0.1	25	24.2	1622.946
7	650	0.2	0.14	25	24.6	1417.989
8	650	0.3	0.1	25	24.4	1513.14
9	650	0.4	0.12	25	24.2	2411.235

Table 5: Experimental result







From the above figure it has been observed that the as there is an increase in cutting speed, feed rate and depth of cut material removal rate increased.

VI. Result & Future Scope

1) Tool wear was higher in TiN coating followed by TiCN and TiAlN coating. Speed was the most dominant factor followed by feed and depth of cut.
2) Surface roughness was minimum in TiAlN coating followed by TiCN and TiN coating.
3) Machining force was minimum in TiCN followed by TiN and TiAlN coated tool.
4) Tool temperature was minimum at TiAlN coating followed by TiN and TiCN.
5) Material removal rate increased with increase in cutting speed, feed rate and depth of cut.
6) Segmented and saw tooth chip were form during the machining of hard material, but not in the fixed or regular pattern.

VII. Future Scope

1) It's easy to measure temperature of cutting tool but difficult to measure at tool work interface. So a model can be developed by which tool work interface temperature can be measured easily.
2) Response surface methodology (RSM) may be used for analysis process instead of Taguchi's method.

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