Machinability Studies on PVD Coated Carbide Tools

[1]Raveendra GV, [1]Peetla Karthik Sai, [1]Naveen Kumar N, [1]Sunil G, [2]N Naga Suresh Babu

[1]UG Student, School of Mechanical Engineering, REVA University, Bangalore, India

[2] Assistant Professor, School of Mechanical Engineering, REVA University, Bangalore, Karnataka, India

Abstract: Cutting tools are very important in machining process. The productivity and quality of the process directly depends on the performance of the cutting tool. Tool coating can improve the machinability performance of difficult to cut materials such as titanium alloys.

In the current work high speed turning of EN-24 alloy was carried out to determinate the performance of various coated cutting tools. Tungsten carbide inserts were coated with AlCrN and TiAlN which is deposited by PVD coating. This study has been undertaken to investigate the machinability studies on Physical vapour deposition (PVD) coated tungsten carbide tools. The tools are PVD coated with AlCrN and TiAlN coatings. These tools are used to machining EN-24 which an alloy is obtained by through hardening of a steel alloy. Different parameters are varied such as cutting speed, feed rate and depth of cut in order to optimize process parameters. The main aim is to increase the material removal rate and decreases cutting forces.

The experiments were conducted by using Taguchi method with L9 orthogonal array. In this experiment three parameters namely cutting speed, feed rate and depth of cut were considered at three levels. The cutting forces are taken in x, y,z directions and material removal rate is calculated for each trail.Mini tab 18 was the software used to analyze the results. There was improvement in metal removal rate and decrease in cutting force of the coated tools when compared to uncoated tools.

Keywords: Machining, PVD Coating, TiAlN coating, AlCrn coating, Carbide tool, Tungsten Carbide Tool.

INTRODUCTION

In this industrial era, machining of different materials is done daily the tools which are used must be long lasting in order to reduce the cost of expenditure on tools. In order to increase the tool life the tool hardness must be greater than the material which is to be machined, and the machining process must be taken in a controlled temperature as the machining produces lot of heat when the depth of cut is increased suddenly, in that case a coolant must be used to reduce the temperature because due to heat material properties will vary

High productivity is the most important requirement in the machining process. But high productivity at the cost of poor surface finish is not acceptable. Surface roughness is considered as an index of product quality which makes it as the most desired outcome along with productivity. It measures the finer irregularities of the surface texture. A good quality turning surface can lead to improvement in strength properties and functional attributes of parts like friction, wearing, light reflection, heat transmission, coating and ability of distributing and holding a lubricant. Various process parameters viz. cutting speed, feed rate, depth of cut, cutting environment, cutting insert, tool geometry, work-piece material etc. are responsible for the ability to obtain the desired surface roughness. Previous studies reflect the effects of cutting speed, feed rate, depth of cut, rake angle on the surface roughness. This study emphasizes on the use of coated inserts so as to reduce the use of lubricant and reduce environment pollution.

Now-a-days 80% of all machining operations are performed with coated carbide cutting tools. Hard turning had replaced application range of grinding in the areas of manufacturing shafts, gears, axles and other mechanical components made of materials having hardness range more than 45 HRC. This is due to the fact that hard turning reduces the cost per product in obtaining the surface finish close to grinding operation with higher productivity, less set up time, less costly equipment and an add on ability to machine complex contours. The specific cutting energy for the hard turning is found to be smaller than the specific grinding energy. Trends toward machining difficult to cut materials lead to the development of high-performance thin layer coatings. Mostly carbide tools are processed by physical vapor deposition (PVD) so as to from a coating of material with properties like higher wear resistance and thermal shocks. Titanium based hard thin films are mostly used due to higher wear resistance, thermal shocks and corrosion property and also impart lubricity at the chip tool interface to reduce friction. Luca Settineri studied the properties and performances of innovative coated tools for turning EN24. Coatings surface qualification included SEM analysis.

H. Sert and F.Okay: observed that minimum tool wear was achieved from TiN coated at highest speed of cutting at V=250 m/min the biggest value of wear rating ranging from V=100 to 250 m/min was found out for Ceramic cutting tools. TiN coated carbide tools are more suitable than TiAlN coated tools at higher speed of cutting. At a speed of 100 m/min, TiAlN coated tools achives maximum tool life, similarly TiN coated tools achieve tool life at a cutting speed of 250 m/min

METHODOLOGY

The methodology followed in this study is shown below in the form of a flow chat where the selection of coatings and the input parameters are discussed and the process to be followed is shown. The selection of coating is an important aspect and many researcher's developed durable coating layers. We intended to increase the material removal rate, tool life and reduce the cutting forces as much as possible. There are different coating methods such as physical vapor deposition (PVD) and chemical vapor deposition (CVD) the selection of which method for coating is to be chosen wisely, in this study we decided to follow pvd coating procedure. Because it is suitable for coatings tungsten carbide tip tools. In this study Titanium Aluminum Nitride and Aluminum Chromium Nitride coatings are coated on the inserts using cathode arc physical vapor deposition technique of thickness varying from 2-5 microns uniformly throughout the inserts

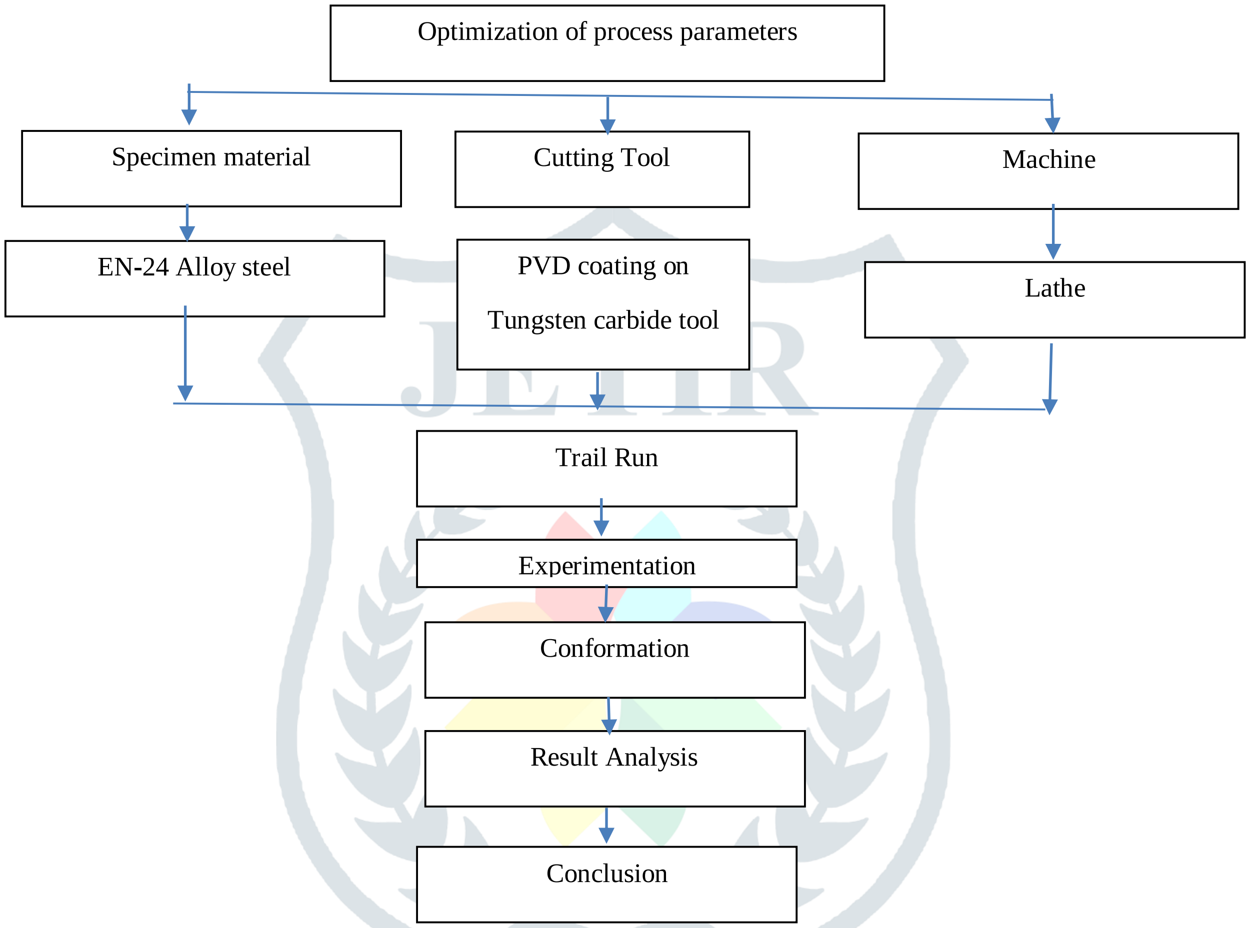

Fig.1: Flow Chart of Methodology

As Shown in the fig.1 the methodology the process of the experiment is carried out. The machining process is carried out in a semi-automatic lathe machine, to optimize the output parameters such as cutting forces, material removal rate and increase in tool life by varying the input parameters such as depth of cut, feed rate and spindle speed. The varying of input parameters is carried out by using taguchi method where the three variable and three levels are increased into 9 experimental input values. The results are analyzed by using a Minitab software.

EXPERIMENTAL WORK

In the present experimental study EN-24 alloy steel is used as a workpiece. The material is a very high strength steel alloy the material contains different composition of other materials such as chromium, molybdenum and other materials the dimensions of the EN-24 material is Ø60×400 mm the hardness of the material is 38 $\pm$ 2 HRC

Material	Carbon	Manganese	Silicon	Phosphorus	Nickel	Titanium	Chromium	Molybdenum
EN-24	0.38	0.85	0.016	0.018	1.30	0.1	1.08	0.27

The workpiece is harder in order to machine we need an harder tool which can withstand the heat generated during the machining process the workpiece needs a greater clearance angle and must need a good rake angle. In order to have a greater tool life, the tool needs to be stronger than the workpiece which is to be machined and it also depends on the feed rate, spindle speed.

PVD Coating Process

The pvd coating of AlCrN (Aluminum Chromium Nitride) and TiAlN (Titanium Aluminum Nitride) are coated on

Tungsten Carbide tip tools the coating is done in different steps.

1) Cleaning: The cleaning process is carried out very much accurately, the dust present on the tool to be coated is removed by ultrasonic cleaning. In case any pre-treatment is needed the tool is placed in a vacuum chamber to eliminate material residues. If any porous surface layers are present, micro blasting process is used to remove it.
2) Pre-heating: The tool to be coated is pre-heated above 400^0C, the heated tool is placed in the coating chamber for the PVD coating to be done.
3) Coating: The coating process is done by vaporising the required amount of material and is deposited on the tool to be coated.
4) Analysis: The coated tool is analysed in different ways; Metallography is used to know the atomic structure of the coating. Layer analysis is done in order to know the thickness of the coating on the tool. Surface and cutting-edge measurement is done in order to know the cutting speed and rake angle.

Experimental Procedure

The properties of the coating material are,

TiAlN (Titanium Aluminum Nitride):

Titanium aluminum is a refractory compound that possesses a number of valuable properties, such as high micro hardness and chemical and thermal stability. TiAlN has a variety of applications: as a component in special refractories as a material for crucibles for anoxic casting of metals, and as a precursor for wear-resistant and has a color of violet bronze

1) Colour – Violet Bronze
2) Hardness – 33 +/- 3 (Gpa)
3) Serving Temperature – 900^0C

AlCrN (Aluminum Chromium Nitride)

Aluminum Chromium Nitride, Bright Grey in color, is a harder, smoother variation of TiAlN. Created for abrasive and high temperature applications (1100^0C). AlCrN creates an aluminum oxide layer during the cutting process. It is increasing in AlCrN, popularity for drilling, counter boring and milling. The AlCrN is a chemical compound of the three elements Aluminum, Chromium, and Nitride. The coating thickness in between 1 to 4 micrometers

The special feature of the AlCrN coating is the very high resistance to heat.

This is partly due to the Nano hardness of 38 Gpa. As a result, it follows that the coating system despite a higher cutting speed and higher cutting temperature remains stable. Compared to un-coated tools, AlCrN coating, depending on the application, increase an up to 14 times longer service life.

The highly aluminum containing coating is very well suited for precision tools, that cut hard materials like hardened steels, cast iron, alloy steel. The maximum applicant temperature is 1100^0C

1) Colour- Bright Grey
2) Hardness – 36 +/- 3 (Gpa)
3) Serving temperature – 1100^0C

MACHINING:

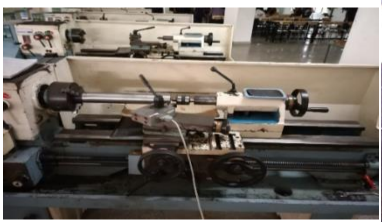

Fig.2: lathe machine

Fig.3: Lathe Tool Dynamometer

Lathe-tool dynamometer is used with 500Kgf in x, y, z directions. It is used to measure forces during machining process. lathe-tool dynamometer is used with 500Kgf in x, y, z directions. It is used to measure forces during machining process.

Machining is done on the EN24 work piece which is a strength steel alloy of hardness 248/302 HB. Machining process is carried out by varying feed rate, depth of cut and spindle rotation speed. The process of varying is carried out by Taguchi method.

Table 1: Design of experiment for main factors (input)

Controllable Factor	Level 1	Level 2	Level 3
Cutting speed rpm	$V_1 = 120$	$V_2 = 250$	$V_3 = 600$
Feed rate mm/rev	$F_1 = 0.1$	$F_2 = 0.3$	$F_3 = 0.5$
Depth of cut mm	$d_1 = 0.1$	$d_2 = 0.2$	$d_3 = 0.3$

Table 1 shows the different experimental parameters which are used as inputs for machining En-24 material. The 3-levels are converted to 9 levels by taguchi method and the machining process is carried out.

The machining is carried out in a normal lathe machine and the feed rate is obtained by change of gears where f_1 = AC1, f2=AC5 and f_3 = BC3

Table.2 shows the expansion of the 3 input levels to 9 input levels by using taguchi method.

FORMULAS:

The formulas used are to calculate the metal removal rate.

$$Cutting\ speed = \frac{\pi DN}{1000}$$

$$D = Dia\ of\ the\ rod\ mm$$

$$N = rpm$$

$$MRR = Vcfd$$

$$Vc = Cutting\ speed$$

$$f = feed\ rate$$

$$d = depth\ of\ cut$$

Table 2: **Experimental results of uncoated carbide tip tool**

Experimental trials	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	material removal rate (gms/min)	cutting forces (Kgs)		
					Fx	Fy	Fz
1	120	0.21	0.1	1.03	5	11	10
2	120	0.3	0.2	1.67	6	14	10
3	120	0.51	0.3	1.74	7	21	11
4	250	0.21	0.2	2.27	5	10	9
5	250	0.3	0.3	2.91	7	24	11
6	250	0.51	0.1	0.94	5	18	8
7	600	0.21	0.3	6.05	7	17	15
8	600	0.3	0.1	3.62	4	6	7
9	600	0.51	0.2	4.01	11	12	11

Table 2 shows the experimental reading after the machining process is taken places by using uncoated carbide tip tool to machine EN-24 and the material removal rate and cutting forces are recorded in the table.

Table 3: **Experimental results of TiAlN coated carbide tip tool**

Experimental trials	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	material removal rate (gms/min)	cutting forces (Kgs)		
					Fx	Fy	Fz
1	120	0.21	0.1	9.3	3	13	7
2	120	0.3	0.2	9.98	3	13	8
3	120	0.51	0.3	8.1	4	19	13
4	250	0.21	0.2	3.9	3	13	7
5	250	0.3	0.3	11.56	5	17	10
6	250	0.51	0.1	4.89	3	10	8
7	600	0.21	0.3	3.19	4	7	8
8	600	0.3	0.1	3.35	2	5	5
9	600	0.51	0.2	10.86	5	8	10

Table 4 shows us the experimental readings after the machining process is taken places by using TiAlN coated carbide tip tool to machine EN-24 and the material removal rate and cutting forces are recorded in the table.

➢ Coating: Table 5: **Experimental results of AlCrN coated carbide tip tool**

Experimental trials	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	material removal rate (gms/min)	cutting forces (Kgs)		
					Fx	Fy	Fz
1	120	0.21	0.1	1.56	3	12	6
2	120	0.3	0.2	2.49	4	18	10
3	120	0.51	0.3	3.02	3	14	10
4	250	0.21	0.2	2.46	3	14	7
5	250	0.3	0.3	7.03	5	21	13
6	250	0.51	0.1	2.52	3	11	7
7	600	0.21	0.3	3.06	5	12	10
8	600	0.3	0.1	3.25	4	9	8
9	600	0.51	0.2	10.89	4	11	9

Table 5 shows us the experimental readings after the machining process is taken places by using AlCrN coated carbide tip tool to machine EN-24 and the material removal rate and cutting forces are recorded in the table.

As we can see when we compare table 3 with table 4 & table 5 the cutting forces have come down compared to uncoated tool and metal removal rate is increased.

Results and Discussion

The experimental results were analyzed using Minitab software, the results are generated by the parameters such as depth of cut, feed and cutting speed on the outer parameters of cutting forces (F_x, Fy, Fz) in work piece and material removal rate.

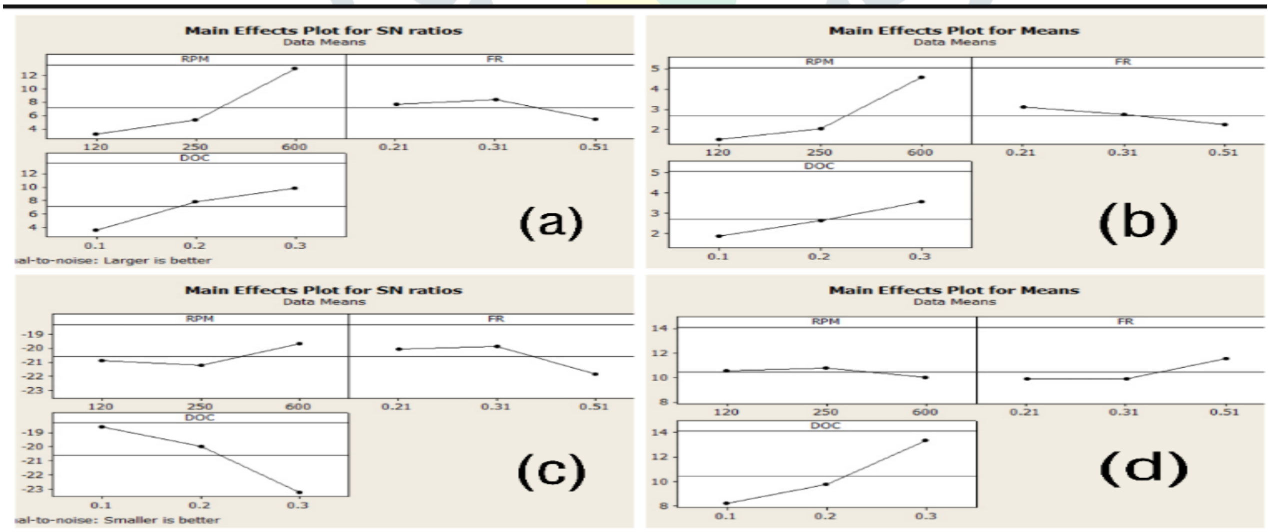

Fig.1: Main effect plot for the cutting force and material removal rate (MRR) uncoated carbide tool (a) S/N ratio of MRR (b) mean of MRR (c) S/N ratio of cutting forces (d) mean of cutting forces

The cutting forces to the S/N ratio the smaller is better. The minimum cutting forces are obtained at $f_x = 4$N, $f_y = 6$N, $f_z = 7$N which are obtained at the level 8 for the cutting speed = 600rpm, feed rate = 0.32mm/rev and depth of cut =0.1mm. The SN ratio is minimum at speed=120rpm, feed rate=0.21mm/rev and depth of cut=0.3mm,

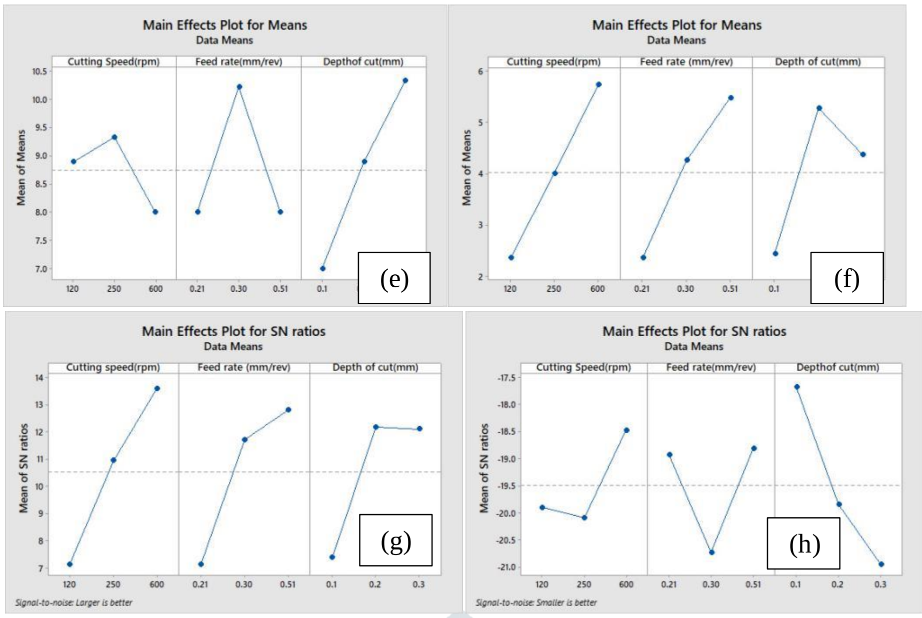

Fig.2: Main effect plot for the cutting force and material removal rate (MRR) AlCrN coated tool (e) Means of CF, (f) mean of MRR (g) S/N ratio of cutting forces (h) SN ratio of MRR

The cutting forces to the S/N ratio the smaller is better. The minimum cutting forces are obtained at $f_x = 4N$, $f_y = 9N$, $f_z = 8N$ which are obtained for input parameters level 8 for the cutting speed = 600rpm, feed rate = 0.32mm/rev and depth of cut =0.1mm. The maximum metal removal rate has found at level 9 for the cutting speed = 600rpm, feed rate = 0.51 and depth of cut = 0.2mm.

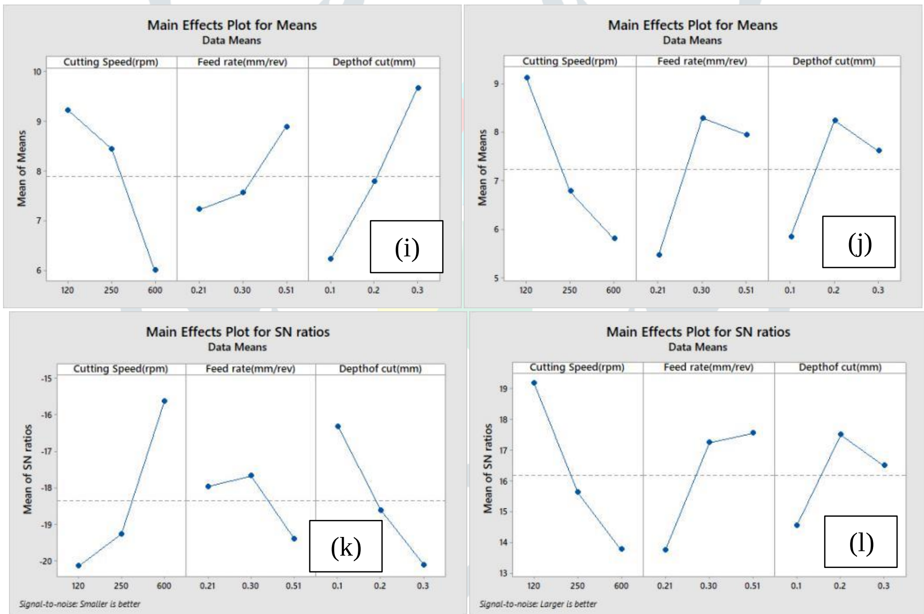

Fig.3: Main effect plot for the cutting force and material removal rate (MRR) TiAlN coated tool (i)Means of CF, (f)mean of MRR (k) S/N ratio of CF (l) SN ratio of MRR

The cutting forces to the S/N ratio the smaller is better. The minimum cutting forces are obtained at $f_x = 2N$, $f_y = 5N$, $f_z = 5N$ which are obtained for input parameters level 8 for the cutting speed = 600rpm, feed rate = 0.32mm/rev and depth of cut =0.1mm. The maximum metal removal rate has found at level 5 for the cutting speed = 250rpm, feed rate = 0.3 and depth of cut = 0.3mm.

ANALYSIS OF THE RESULTS

After the machining is carried out on the EN24 work piece the metal removal rate of the tool is increased and the cutting forces are also varied compared to un-coated tool and the coated tool. The tools are kept under scanning electron microscope for analysis.

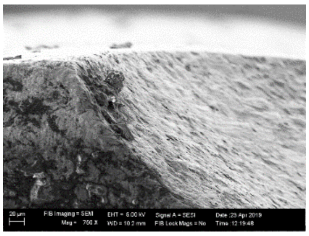

Fig.4:Uncoated tool under sem analysis at

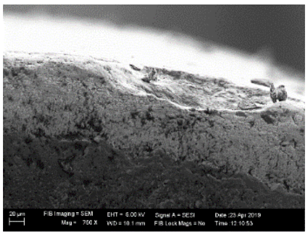

Fig.5:TiAlN coated tool under sem analysis at 750x

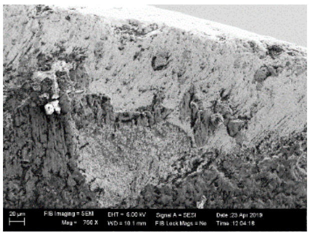

Fig.6:AlCrN coated tool under sem analysis at 750x

After the SEM analysis we can observe that the uncoated too tip is worn out and is clearly visible in fig.4. Where as in TiAlN the wear is less compared to uncoated tool shown in fig.5, fig.6: shows the wear of AlCrN which is less compared to fig.4, and fig.5. When the coated tools are used for machining the EN-24 material the tool wear is minimum and the cutting forces are reduced by increasing metal removal rate compared with uncoated tool. The increase in wear resistance can also be seen in the SEM analysis.

CONCLUSION

The following conclusion can be drawn this study

1. The experimental study shows that actual metal removal rate will be almost same as the theoretical metal removal rate. As compared to the coated tools with the uncoated tool we found that the coated tool will remove more metal and is less wear occurance.
2. The highest metal removal rate is found in TiAlN of 11.56 grams/min, compared to AlCrN and uncoated tool.
3. It is found that there was an improvement of 91.04% in the material removal rate with TiAlN coatings and 80% improvements in AlCrN when compared with the uncoated tungsten carbide inserts.
4. The cutting forces are reduced upto 51.98% in AlCrN, and 108.4% inTiAlN tools when compared with uncoated tungsten carbide inserts.

ACKNOWLEDGMENT

We would like to thank REVA UNIVERSITY, Bangalore for the help conducting experiments and co-operation for this research work. We would like to thank Oerlikon Balzers coating India Pvt.Ltd for providing us coating facility and also we would like to thank Central Manufacturing Technology Institute for helping us in doing SEM analysis tests.

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