MACHINABILITY STUDIES OF TITANIUM COATINGS ON TUNGSTEN CARBIDE INSERTS

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Abstract: Cutting tool is a vital part in machining process .The quality of machining and its performance depends on several factors such as cutting forces, speed, feed, depth of cut working under various environments. Due to the development in" hard to machining of materials" there is a need for improvement of cutting tools and its performance. The main aim of this project work is to study and optimize the performance of coated tungsten carbide turning tool during dry machining of high hardness EN24 grade alloy steel. With the help of plasma assisted physical vapor deposition (PVD) coating method, Titanium nitride and Aluminum Titanium Nitride coatings were developed with a thickness 2-4 microns on uncoated tungsten carbide inserts. Taguchi design of experimental method was used to optimize process parameter using L9 orthogonal array, the experimental work was carried out by varying the input parameters like cutting speed, feed rate, depth of cut at different levels, which influences cutting forces and material removal rate. SEM analysis were studied to characterize the coated cutting tool. An improvement of 83.12% in the material removal rate with Titanium nitride coatings and 18.18% improvements in Aluminium titanium nitride were observed

Keywords: PVD Coatings, Taguchi Design of Experiment, Orthogonal array, machinability, Material Removal Rate, Cutting Forces.

INTRODUCTION

Now a day's different cutting tools are used for machining the hardened materials in the different industrial applications. The manufacturers want to improve productivity, quality of the components and they want to increase the tool life, to achieve those properties they are going for coating the carbide inserts with different coating materials. The tool manufacturers also aim 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 to maintain required accuracies of the product. The Same cutting tools were being used from many of the years, but due to the continuous improvement in enhancing the life of the cutting tools, different methods are in progress for producing the good quality tools.

To achieve high productivity and precision, most of the cutting tools used in manufacturing industries utilize hard coatings. These hard coatings gives very good properties, such as high wear resistance, good thermal stability and hardness. Recently, nanostructured coatings have been developed that consist of nano crystalline phases that provide excellent protection to the substrates, even under extreme machining conditions. Several techniques, including physical vapour deposition (PVD) and chemical vapor deposition (CVD), are used to deposit the nanostructured coating over cutting tools. The cathodic arc process is one such PVD technique, where high-ionization-level plasma is used to produce a dense coating. Tool coatings can improve the machinability performance of difficult-to-cut hardened materials.

Machining of high HRC hardened material such as EN24 alloy steel is difficult to machine with the uncoated tool. When the machining is done with uncoated inserts, the material removal rate is very poor and cutting forces are very high resulting in poor surface finish. Hence there is a need for improvement in the uncoated cutting tool. The economical way to achieve this goal is only by development of coatings on uncoated surfaces. In the present study, different coatings such as Titanium Nitride (TIN), Aluminum Titanium Nitride (AlTiN) coatings were developed on WC inserts. A systematic study was conducted to see whether there was an improvement in performance of the coated tools. It is found that there was an improvement in the material removal rate of 83.14% with Titanium Nitride (TiN) coatings and 18.18% improvements with Aluminum Titanium Nitride coating. There is a considerable decreases in the cutting forces of 66.99% with Titanium Nitride coating and 16.74% with Aluminum Titanium Nitride coating.

The titanium nitride hard coating is used in metal cutting industry on a large scale to improve the surface of cutting tools. PVD coated TiN is bringing many benefits to every tribological system. When tool nose radius increased then the cutting forces are decreased and increased tool radius for same depth of cut reduces tool-chip contact area and linear contact length. This situation decreases the cutting force and by these means heat generation during the machining diminishes and low heat generation facilitates the machining of heat resistant materials. [2]

Das, Das and Routara (2014) investigated the hard work piece of EN24 steel with coated carbide tools and Taguchi DOE and grey relation was used to optimize the process parameters. The regression analysis was used to predict the empirical model with adequacy of 95% confident level. Better Surface finish of 0.40 µ was obtained in hard machining. Feed was having power and influence over others parameters for surface finish. Das, Panda and Dhupal (2017) studied chemical vapour deposition method based coated tool for machining hard AISI 4340 steel under dry condition. The results showed that it is more appropriate option than high-cost CBN tool.M. Adinarayana: Performed the experiments for Dry turning operation with EN 24 alloy steel by the use of PVD coated tool insert and conventional lathe (PSG A141). The tests were carried out for a 500 mm length of work material. The results showed the optimality conditions as speed: 740rpm, feed: 0.09 mm/rev, and depth of cut: 0.10 mm. The contribution of different process parameters on response variables has been established by using the ANOVA technique. Allaudin et al modelled the cutting forces and observed that cutting force increase with an increase in feed and axial depth of cut. Flank and crater wear are the two main wear mechanisms that limit cutting tool performance. Flank wear is caused when the relief face of the tool rubs against the machined surface and on other hand crater wear occurs on the rake face of the tool and affects the geometry at the chip tool interface, which in turn affects the cutting force.

METHODOLOGY

The methodology adopted in this study is shown in the fig.1 .The Selection of the coatings on the cutting tools is important aspect in improving the cutting tool performance. Many researchers have developed good surface coatings on cutting tools, an attempt has been made in this study to increase the material removal rate, tool life and decreases the cutting forces. There are few coating methods which are used for the coatings on cutting tools viz. physical vapour deposition (PVD) and chemical vapour deposition (CVD). The PVD technique is suitable for the coatings on tungsten carbide inserts. In this study, Titanium nitride and aluminum titanium nitride coatings were deposited on the inserts by using plasma assisted cathodic arc physical vapour deposition technique to maintain 2-4 microns thickness uniformly throughout the coatings

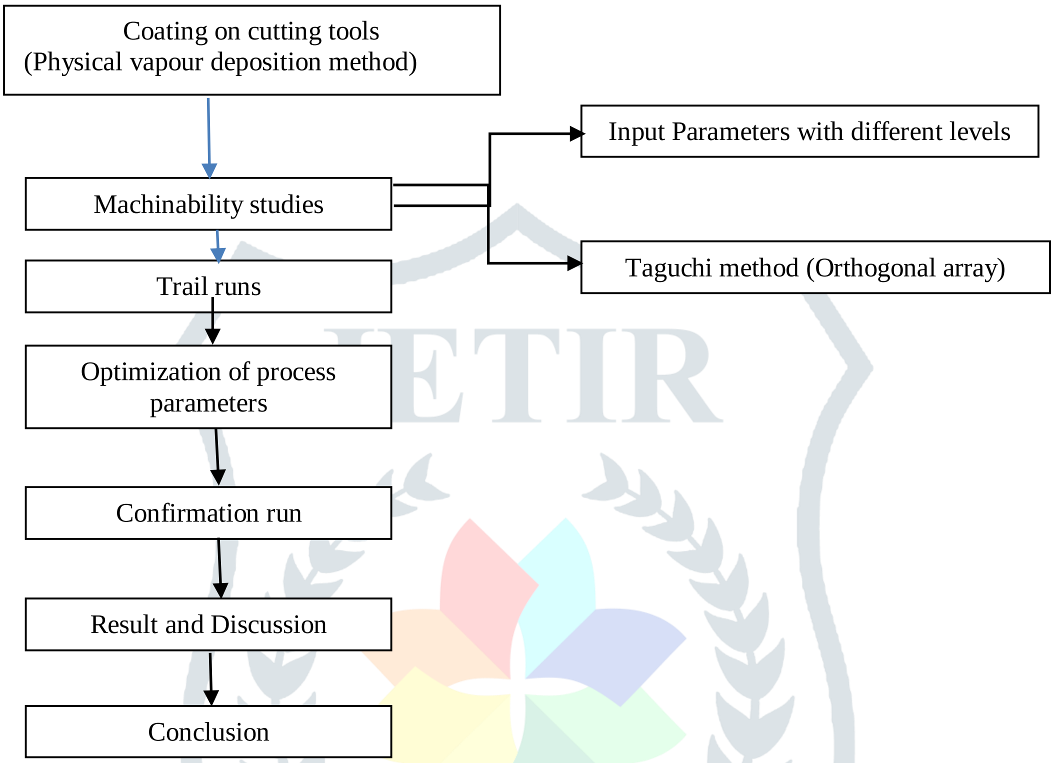

Fig.1: Flow chart of Methodology

The experimental work was conducted on precision semi-automatic lathe machine of Turbo make .To optimize output parameters namely material removal rate, cutting forces and tool life , the input parameters such as depth of cut, spindle speed and feed rate are varied at different levels. For three parameters at three levels according Taguchi design of experiments using L9 orthogonal array was selected. It means that 9 experimental trials are to be carried out to study the three variables and three levels. The results are analyzed using Minitab software,. The optimum results obtained after analysis are cross verified with the confirmation run .The confirmation run results supports and validates the final obtained results.

EXPERIMENTAL WORK

In the present study, EN24 steel is used as a work piece material**.**EN24 is a very high strength steel alloy which is supplied hardened and tempered. The grade is a nickel chromium molybdenum combination- this offers high tensile steel strength, with good ductility and wear resistance characteristics. With relatively good impact properties at low temperatures, EN24 is also suitable for a variety of elevated temperature applications**.** The size of the work piece is Ø60×400 mm so that the ratio of L/D <10.The hardness of material is 38±2 HRC

Key features:

1. Very high strength steel alloy.
2. Easy to heat treat and temper.
3. Supplied hardened & tempered.
4. Good combination of strength, ductility and wear resistance

Table 1: Chemical composition of EN-24 Material

Material	C	Mn	Mn	S	P	Ni	Ti	Cr	Mo
EN24 Alloy	0.38	0.85	0.22	0.016	0.018	1.30	0.1	1.08	0.27

Cutting tool materials must be harder than the working material, and the tool must be able to withstand the heat generated in the metal-cutting process. Also, the tool must have a specific geometry, with clearance angles designed so that the cutting edge can contact the workpiece without the rest of the tool dragging on the workpiece surface. The angle of the cutting face is also important, as is the flute width, number of flutes or teeth, and margin size. In order to have a long working life, all of the above must be optimized, plus the speeds and feeds at which the tool is run.

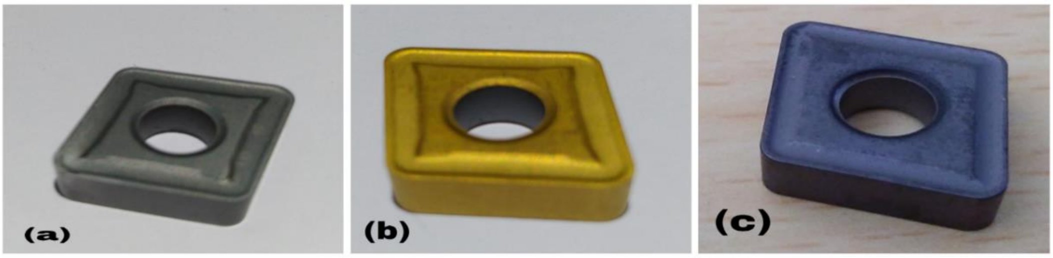

Fig.2 Images of cutting tools (a) Uncoated insert (b) TiN coated insert (c) AlTiN coated insert

Table 2: Properties of Tungsten Carbide Inserts

Chemical formula	WC
Molar mass	195.85 g·mol−1
Appearance	Grey-black lustrous solid
Density	15.63 g/cm3
Melting point	2,785–2,830 °C
Boiling point	6,000 °C
Solubility	Soluble in HNO 3, HF
Thermal conductivity	110 W/(m·K)

Figure.2 (b) shows the TiN coated insert. Titanium Nitride coating with its familiar gold color remains the most popular general purpose coating. These coatings exhibits excellent wear resistance, thermal stability, and low coefficient of friction and reduces built up edge and thus improves thermal transfer of heat away from the tool. The Vickers hardness of TiN coated insert is 2300, oxidation temperature is 600^0C, and coating thickness is around 2-4 microns.

Figure.2 (c) shows the AlTiN coated insert. Aluminum Titanium Nitride, black in colour. The AlTiN is a chemical compound of the three elements Aluminum, Titanium, and Nitride. The coating thickness varies between 2 - 4 microns. The special feature of the AlTiN coating is the very high resistance to heat and oxidation. This is partly due to the Nano hardness of 38 GPa. 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 1000^0C and has compare to the TiN coating a 400^0C higher resistance to heat. Cooling is not mandatory.

A lathe is a machine that rotates a workpiece about an axis of rotation to perform various operations such as turning, knurling, drilling and facing, with tools that are applied to the workpiece to create an object with symmetry about that axis The workpiece is usually held in place by either one or two centers, at least one of which can typically be moved horizontally to accommodate varying workpiece lengths In the present work Turbo make lathe being is used with swing over the bed350mm and distance between centers550mm with a speed range of 45-900rpm

Fig.3 Turbo Lathe Machine

In the present work UILDO.15 make lathe-tool dynamometer is used with 500Kgf in x, y, z directions. It is used to measure forces during machining process. Empirical calculations of these forces can be cross-checked and verified experimentally using these machine tool dynamometers. Machine-tool dynamometers are increasingly used for the accurate measurement of forces and for optimizing the machining process. The forces during machining are dependent on depth of cut, feed rate, cutting speed, tool material and geometry, material of the work piece and other factors such as use of cooling during machining.. The sensing system measures the deflection in strain gauges and these signals are modified into other quantity and computed in the form of forces on the display system.

Fig.4 Lathe Tool Dynamometer

The DS-852G weighing machine is used to weigh the chips and subsequently computed material removal rate .The actual material removal rate is compared with the theoretical value of the material removal rate it is having a unique It is having VFD display. Which shows the high accuracy scale for precision measurement.

In the present study TiN, AlTiN coating materials were selected for developing coating layers on the tungsten carbide inserts by physical vapour deposition (cathode arc vapour deposition) method at Balzer's Oerlikon coating machine, make Oerlikon-Balzer's Ltd., India). The experiments were conducted using coated and uncoated inserts. A solid bar EN-24 alloy steel of 60mm diameter and 400mm length was used as a work piece material. A lathe (Turbo LX175) was used for conducting the experiments. The cutting forces are measured using lathe tool dynamometer (UILDO.15). The experimentation for this work was based on Taguchi's design of experiments (DOE) and L9 orthogonal array. Number of experiments to be conducted increases when the number of the process parameters involved at various levels are more. Obtain optimum results with less number of experiments saves cost and money, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. In this work, three cutting parameters namely, cutting speed, depth of cut and feed rate were considered at three level for experimentation as shown in Table 3. For a three factors, three level experiment, the suitable Taguchi orthogonal array is L9. The response obtained from the trials conducted as per L9 array experimentation was recorded and further analyzed. Table 4 shows the experimental results for uncoated tungsten carbide using L9 orthogonal array. The machining forces such as feed force(Fx), thrust force(Fy) and cutting force (Fz) were measured by using a tool dynamometer, where the cutting parameters were analyzed using Minitab software for the both material removal rate and cutting forces. Similarly the experimental results for TiN coated and ALTiN coated inserts are shown in Table. 5 and Table. 6 respectively.

Table 3: variable factors and level values

Controllable factors	Level 1	Level 2	Level 3
Spindle speed (rpm)	120	250	600
Feed rate(mm / rev)	0.21	0.30	0.51
Depth of cut (mm)	0.10	0.20	0.30

Table 4: Experimental Results –Uncoated WC inserts

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 5: Experimental Results –TiN coated Inserts

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	9.58	3	12	5
2	120	0.3	0.2	10.11	4	20	8
3	120	0.51	0.3	7.39	5	27	13
4	250	0.21	0.2	4.62	3	10	8
5	250	0.3	0.3	11.08	6	23	12
6	250	0.51	0.1	4.85	3	6	5
7	600	0.21	0.3	6.49	5	6	8
8	600	0.3	0.1	6.31	1	1	3
9	600	0.51	0.2	5.94	4	1	7

Table 6: Experimental Results –ALTiN coated Inserts

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	2	3	14	8
2	120	0.3	0.2	2.43	3	15	9
3	120	0.51	0.3	2.98	4	18	13
4	250	0.21	0.2	3.24	4	12	9
5	250	0.3	0.3	7.15	9	14	15
6	250	0.51	0.1	2.24	3	10	6
7	600	0.21	0.3	6.21	4	7	8
8	600	0.3	0.1	6.01	3	6	7
9	600	0.51	0.2	5.45	4	6	8

Results and Discussion

The experimental results were analyzed by using Minitab software to find out the most influential factors of cutting speed, feed, and depth of cut, on the out parameters of cutting forces (F_x, Fy, Fz) in work piece, and the material removal rate. In the experimental trials the results collected for the cutting forces for the uncoated, TiN, & AlTiN tool inserts

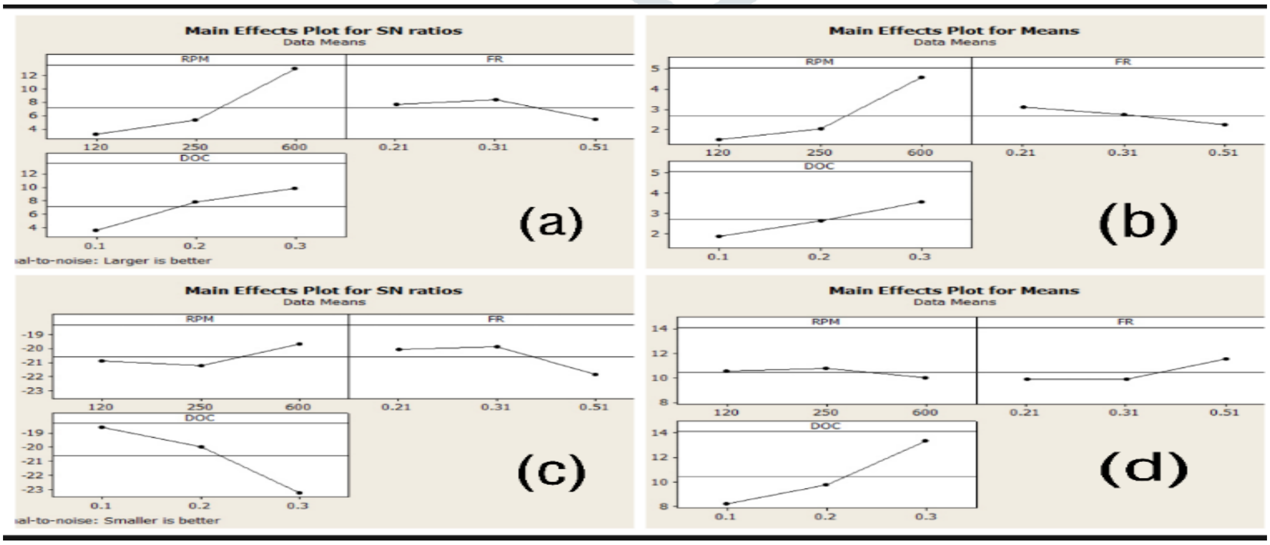

Fig.6 Main effect plot for the cutting force and material removal rate (MRR) uncoated WC tool (a) S/N ratio of MRR (b) mean of MRR (c) S/N ratio of cutting forces (d) mean of cutting forces

From the fig.6 it is observed that S/N ratio for the cutting forces the smaller is better. The minimum cutting forces are obtained at Fx=4 N, Fy= 6N, and Fz=7N respectively for the uncoated WC inserts when the input parameters are v=6000rpm f=0.21 mm/rev and depth of cut =0.1mm .Similarly S/N ratio for material removal rate (MRR) the larger is the better. From the figure.6 it is observed that the maximum MRR is obtained at v=6000rpm f=0.21 mm/rev and depth of cut =0.3mm

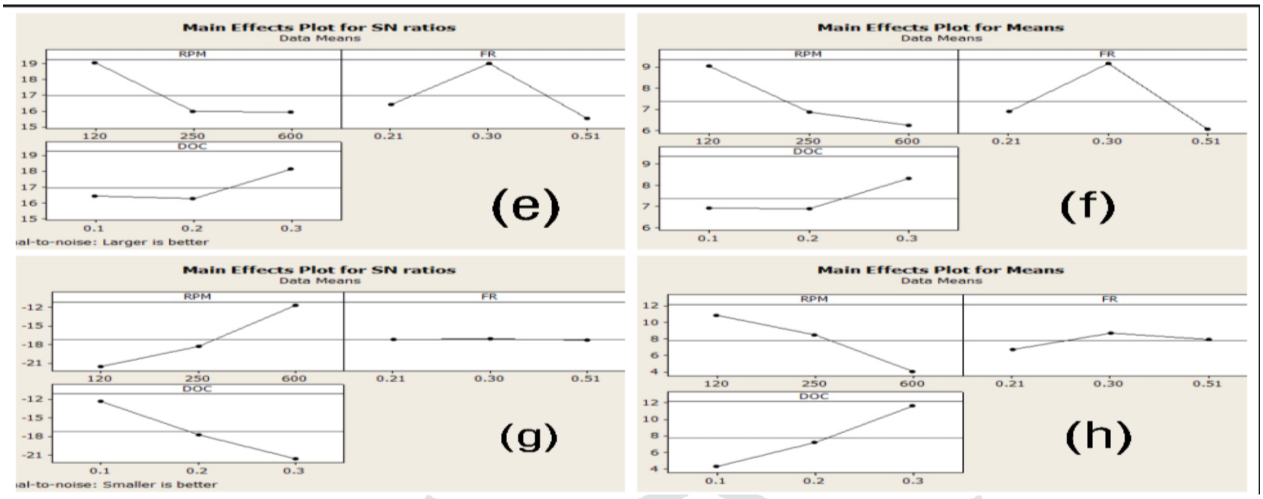

Fig.7 Main effect plot for the cutting force and material removal rate (MRR) TiN coated WC tool (e) S/N ratio of MRR (f) mean of MRR (g) S/N ratio of cutting forces (h) mean of cutting forces

From the fig.7, it is observed that the minimum cutting force Fx=1N,Fy=`1N and Fz= 3N are obtained at the input parameters of v = 600 rpm, f = 0.3 mm/rev, d = 0.1 mm ( L8 trail) and the minimum cutting forces Fx= 3N Fy=`5N and Fz= 6N for the Aluminum Titanium Nitride(AlTiN) coated inserts, the input parameters are v = 600 rpm, f = 0.31mm/rev, d = 0.1 mm.The maximum material removal occurs at speed (v) = 120rpm, feed rate = 0.30mm/rev, depth of cut = 0.3 mm

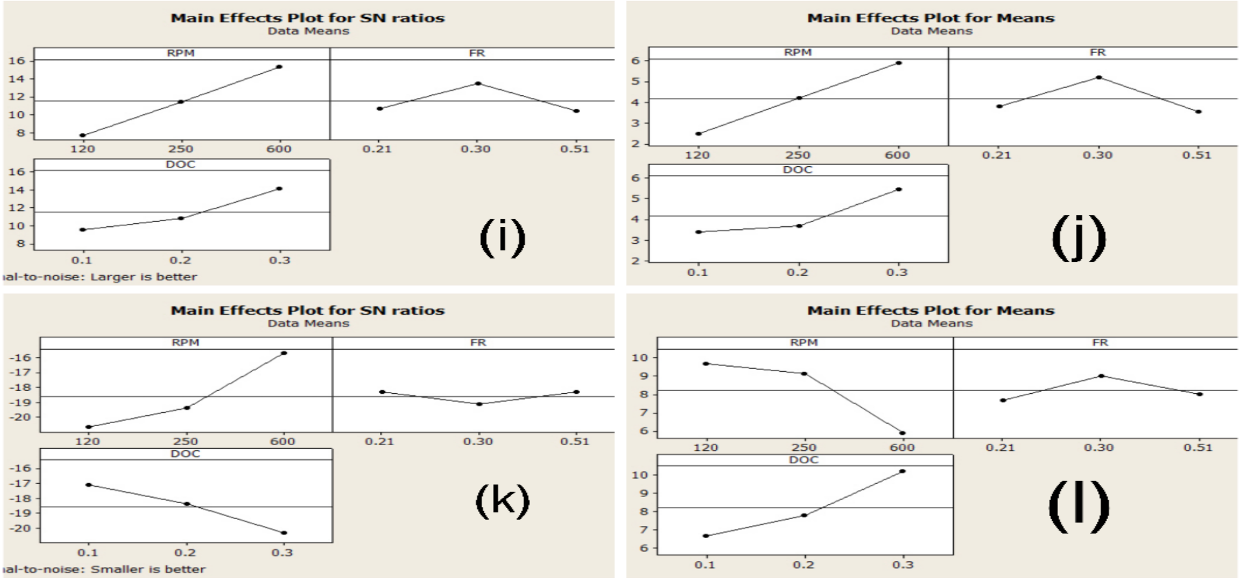

Fig.8 Main effect plot for the cutting force and material removal rate (MRR) ALTiN coated WC tool (i) S/N ratio of MRR (j) mean of MRR (k) S/N ratio of cutting forces (l) mean of cutting forces

From the Fig.8 the optimal values of cutting forces are observed at speed (v)= 600 rpm, feed rate=0.21mm/rev and depth of cut 0.1and maximum material removal rates are obtained at (v)= 600 rpm, feed rate=0.30mm/rev and depth of cut at 0.30mm

SEM Analysis

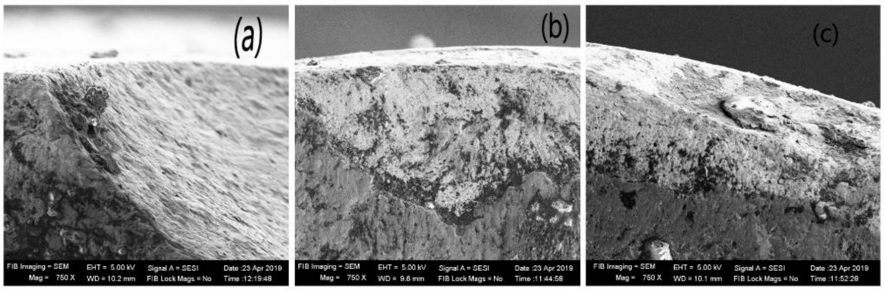

Fig.9 micro structure images of cutting tools. (a) Uncoated WC insert. (b) TiN coated inserts (c) AlTiN inserts

Fig.9, shows the wear morphology of different cutting tools like uncoated WC insert, TiN coated inserts and ALTiN inserts. The SEM microstructure images show maximum worn out of cutting edges occurred for uncoated WC inserts when compared to TiN and AlTiN coated cutting inserts and has higher wear at the nose radius compared to the TiN and AlTiN

CONCLUSION

The following conclusion can be drawn this study

1. The study investigated the actual material removal rate and theoretical material removal rate and found to be nearly same value. As compared to coated tool to uncoated tool material removal rate is high. In this work the more material removal rate obtained in Titanium Nitride cutting tool as compared to Aluminum Titanium Nitride coated tool and uncoated tool
2. The highest material removal rate obtained at (TiN coated) spindle speed V=250 rpm, feed rate f=0.31 and depth of cut=0.3mm.
3. It is found that there was an improvement of 83.12% in the material removal rate with Titanium nitride coatings and 18.18% improvements in Aluminum titanium nitride when compared with the uncoated tungsten carbide inserts
4. The cutting forces decreases by 66.99% with TiN and There is minimal decrease in the cutting forces of 16.74% with ALTiN when compared to uncoated

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I. REFERENCES

[1] B. NavinSek 2014 improvement of cutting tools by tin PVD hard coating 365-382

[2] Nikhil Bharat[1], Dr Kalyan Chakraborty[2] 2014Machinability of E-24 Steel (817M40) International Journal of Latest Trends in Engineering and Technology 001-007

[3] Atul Prabhakar Kulkarni and Vikas G. Sargade 2015 Characterization and Performance of AlTiN, AlTiCrN, TiN/TiAlN PVD Coated Carbide Tools While Turning SS 304 Materials and Manufacturing Processes, 30: 748–755

[4] S. Prabhu, R. Ambigai & B. K. Vinayagam 2018 Performance analysis of AlTiN/AlCrN coating on cemented carbide cutting tool using fuzzy logic analysis Australian Journal of Mechanical Engineering.

[5] Endrino, J.L.; Fox-Rabinovich, G.S.; GeyHard, C. AlTiN, AlCrN PVD coatings for machining of austenitic stainless steel. Surface and Coatings Technology 2006, 200, 6840–6845

[6] Sarakinos, K.; Alami, J.; Konstantinidis, S. High power pulsed magnetron sputtering: A review on scientific and engineering state of the art. Surface and Coatings Technology 2010, 204 (11), 1661–1684.

[7] Wang S., Wu X., "Investigation on the microstructure and mechanical properties of Ti–6Al–4V alloy joints with electron beam welding", Materials and Design, 36: 663–670, (2021).

[8] Chen, L.; Du, Y. A comparative research on physical and mechanical properties of (Ti, Al)N and (Cr, Al)N PVD coatings with high Al content. International Journal of Refractory Metals and Hard Materials 2007, 25, 400–404.

[9] Mahendra Korat, Neeraj Aggarwal (2012), "Optimization of different machining parameters of EN 24 alloy steel in CNC turning by using of Taguchi method", International Journal of Engineering Research and Applications, Vol. 2(5), pp.160-164.

[10] W.H. Yang, Y.S. Tarng (1998), "Design optimization of cutting parameters for turning operations based on the Taguchi method", Journal of Materials Processing Technology, Vol.84, PP.122–129.

[11] Raman Kumar, Jasper Singh Ray and Avnet Singh Virk"Analysis the effects of process parameters in EN24 alloy steel During CNC turning by using madm", International Journal of Innovative Research in Science, Engineering and Technology, vol. 2, 2013, pp. 1131-1145.

[12] Hari Singh, Pradeep Kumar, Optimizing cutting force for turned parts by Taguchi 's parameter design approach, Indian Journal of Engineering & Material Science Vol12, April 2005, PP.97-103.