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Experimental investigation for Tool Flank wear and Work piece Surface Roughness of mono and dual material coating on tungsten Carbide insert tool for Turning operation

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Abstract — *Coatings are well known to improve the performance of cutting tools in machining application, such as high-speed machining. Unfortunately, the development of cutting tool for high-speed machining of hard and difficult-to-cut material has remain a problem for quality and economy of production. The present work studies the performance of mono and dual material PVD coated tool in machining of austenitic stainless steel (AISI 304 steel) under high speed turning. The coating material was used AlCrN, TiAlN and TiAlN/AlCrN. The influence of cutting parameter (cutting speed, feed rate) on work piece surface finish and tool life has been analyzed. The coating thickness was measured using SEM analysis and coating material test was done using EDS analysis. The surface roughness of the work piece was measure using Surface Roughness Tester. Tool flank wear of the tool was measured using Tool maker microscope. The wear mechanism at the end of tool life was investigated in detail using scanning electron microscope (SEM). An attempt has been made to analyze the effects of process parameters on Machinability aspects using Taguchi technique. The statistical analysis of variance (ANOVA) is applied to investigate effects of cutting speed and feed rate on tool life and work piece surface roughness. The main aim of thesis work is to study effect of mono and dual materials coating on tungsten carbide tool.*

Keywords- *AISI 304 Austenitic stainless steel, Turning, AlCrN, TiAlN, TiAlN/AlCrN, Tool life, Surface roughness, scanning electron microscope, EDS, Taguchi, ANOVA*

I. INTRODUCTION

Coated tool have compound material structure, consisting of the substrate covered with a hard, anti-friction, chemically inert and thermal isolating layer, approximately from one to few micro-meters thick. As such, coated tools compared to uncoated ones, offer better protection against mechanical and thermal loads, diminish friction and interactions between tool and chip and improve wear resistance in a wide cutting temperature range. Austenitic stainless steels are characterized by a high work hardening rate, low thermal conductivity and high resistance to corrosion. Stainless steels are known for their resistance to corrosion. But their Machinability is more difficult than the other alloy steels due to reasons such as having low heat conductivity, high BUE tendency and high deformation hardening [1, 10].The high tool wear and poor surface finish are common problem in machining of austenitic stainless steel [2, 9, and 10].

Surface coating of tribological applications is associated with deposition temperature ranging from room temperature to over 1000^{0}C. The coating thickness ranges from microns to several millimeters. Typically, the atomistic methods produce the thinnest coating. Some methods involve high deposition temperatures that may give undesired phase transformations, softening or shape change of the coated component. An important benefit of PVD and CVD processes is the high flexibility as to composition and structure of the coatings, and these processes are today successfully utilized to coating a large variety of mechanical components.

(a) Physical vapor deposition- Physical vapor deposition (PVD) covers a broad family of vacuum coating processes in which the employed material is physically removed from a source by evaporation or sputtering. Then, it is transported by the energy of the vapor particles, and condensed as a film on the surfaces of appropriately placed parts under vacuum. Chemical compounds are deposited by either using a similar source material, or by introducing reactive gases (Nitrogen, oxygen, or simple hydrocarbons) containing the desired reactants, thus reacting with metal from the PVD source. Typical deposition temperatures range from 150 to 500 ^{0}C.

(b) Advantage of PVD coating process-
Deposition temperature range 150 to 500^{0}C. PVD films can be produced without any chemical interaction with the substrate. PVD coated tool is used for medium finishing and finishing operation. The thin film layer produces by PVD [13].

II. LITERATURE REVIEW

R.J.Talib *et al* (2013) [3] observed that the TiCN has reduced the friction coefficient from 0.45 to 0.17. Turning test result shows that the TiCN-coating with a thickness of 15.1 µm, the tool life has been increased more than 9 times.

Samir K. *et al* (2007) [4] studied wear mechanisms and tool performance of Cemented carbide inserts TiAlN PVD coated inserts during wet and dry machining of AISI 4140 steel. The analysis based on the experimental results lead to strong evidence that conventional coolant has retarded effect on TiAlN coating under high speed machining. Higher cutting speed less built-up edge found.

Yueh-Jaw Lin *et al* (2008) [5] studied wear progressions and tool life enhancement with AlCrN PVD coated cemented carbide inserts in high-speed dry and wet steel lathing on SAE 4140 steel. It is found that 260 m/min, Alcrona (AlCrN) performs near 95% better in tool wear than TiAlN coated carbide tool under the same machining conditions. It was also revealed that part of adhered metal would be plucked away taking grains of tungsten carbide and binder from the cutting insert material. Therefore, thermal pitting, micro adhesion and low levels of micro abrasion came into picture. Thus, micro-fatigue, micro-abrasion, and micro-adhesion wear mechanisms are activated under wet condition, while high levels of micro-abrasion can be observed under dry condition implicated.

Renato Francoso de Avila *et al* (2006) [6] the TiN coated carbide tool outperformed the uncoated tool with regard to the crater wear resistance, providing lower width and depth.

Renato Francoso de Avila *et al* (2006) [8] the TiN coated carbide tool outperformed the uncoated tool with regard to the crater wear resistance, providing lower width and depth.

P.C. Jindal (2003) [7] studied the performance of PVD applied TiN, TiCN and TiAlN coated cemented carbide tools in turning. Coated tools were evaluated in turning of Inconel 718, medium carbon SAE 1045 steel, and ductile iron at low and high cutting speeds. TiAlN coated tools showed the best metal cutting performance, followed by the TiCN and TiN coated tools. The superior performance of the TiAlN coated tools, which was even greater at higher speeds, is related to the coating's higher resistance to abrasive and crater wear. These characteristics are a result of the higher hot hardness and oxidation resistance of TiAlN at the temperatures normally encountered at the tool tip during machining operations.

R.M'Saoubi *et al* (2013) [8] studied the particular, a remarkable tendency for TiN to exhibit plastic deformation was revealed while TiSiN exhibited a more brittle behavior evidenced by adhesive wear and micro chipping, TiAlN and AlCrN on the other hand exhibited less work piece adhesion.

Ihsan Korkut *et al* (2004) [9] studied determination of the optimum cutting parameter when dry turning of AISI 304 austenitic stainless steel using (TiC/TiCN/Al2O3/TiN) multilayer coated cemented carbide cutting tools. A decrease in tool wear was observed with increasing the cutting speed up to 180 m/min. A further increasing cutting speed 210 m/min tool wear started to increase at this cutting speed. Surface roughness was also decrease with increased with increasing cutting speed. This can be attributed to the presence of built-up-edge at lower cutting speed. In homogenous distribution of chip thickness at the lower cutting speed may also indicate the variation in the cutting forces and this may be another reason for poor surface finish due to force fluctuations.

Zafer Tekiner *et al* (2004) [10] studied the effect of cutting parameters on surface roughness, flank wear and built up edge in turning of AISI 304 austenitic stainless steel with WC ISO P10 cemented carbide tool for the experiment. The increase of cutting speed and the decrease of flank wear can be seen. The flank wear is decrease while feed rate is rising from 0.2 to 0.25 mm/rev; and then it is starting to increase when it is rising 0.3 mm/rev. Surface roughness values obtained from at 165 and 180 m/min cutting speeds were little higher than the one obtained from at 150 m/min. The effect at the feed rate values on surface roughness, the values from 0.2 and 0.25 mm/rev are close to each other. On the other hand, the surface roughness value was observed higher than the others. They were seen that cutting speed increased and built up edge value decrease and feed rate increase built up edge value increase.

G. Skordaris *et al* (2014) [11] studied the effect of mono and multilayer PVD films on the cutting performance of coated cemented carbide insert. The overall film thickness was approximately 8 µm. The film structure consists of one, two and four layers. The number of layer increases, the film hardness grows. Increased number of layers of the latter film improves significantly its brittleness and tool life.

W.Y.H. Liew (2010) [12] studied the performance of TiAlN/AlCrN nano-multilayer coated, TiAlN single-layer coated and uncoated carbide tools in low-speed milling STAVAX (modified 420 stainless steel) under flood and mist lubrication. In machining STAVAX with a hardness of 40 HRC, the coated tool subjected to delamination, attrition and abrasive wear throughout the duration of testing. During machining STAVAX with a hardness of 55 HRC, three distinct stages of tool wear occurred, (i) initial wear by delamination, attrition and abrasion, followed by (ii) cracking at the substrate and (iii) the formation of individual surface fracture at the cracks which would the enlarge and coalesce to form a large fracture surface. The TiAlN/AlCrN coated tool exhibited higher resistance against delamination and abrasive wear than the TiAlN coated tool. The cracking resistance and hardness of the coating and oxidation of the coating during machining appeared to have significant influences on the resistance of the tool against these wear mechanisms. A longer cutting distance was required to cause TiAlN/AlCrN coated tool to crack and fracture. This was due to the substrate receiving greater protection against cracking and fracture as a result of the coating being removed at a slower pace by abrasion and delamination. The likeliness of the uncoated tool to chip crack and fracture, and the severity of abrasion increased with an increased with an increase in the hardness of the work piece. Poor surface finish observed using TiAlN coating compared to TiAlN/AlCrN coating.

III Material and method

In this study, a work piece made of AISI 304 Bright grade steel was used. Its sizes were 60 mm diameter and 250mm length. The experimental studies were carried out on a Tornodo-300/Coleshester CNC Lathe. The experiments were conducted under wet cutting conditions cutting oil was servo cut 51 with 5% concentration with distil water used. The tool holder used was model MTJNL 2525M16.TiAlN, AlCrN and TiAlN/AlCrN-PVD coated (TNMG 160408-5) inserts were used as the cutting tool material. The surface roughness was measured using a Mitutoyo SJ-210 portable device within the sampling length of 2.5 cm. Mitutoyo's Tool Maker's microscope was used measure tool flank wear Fig. 1 shows the experimental arrangement.

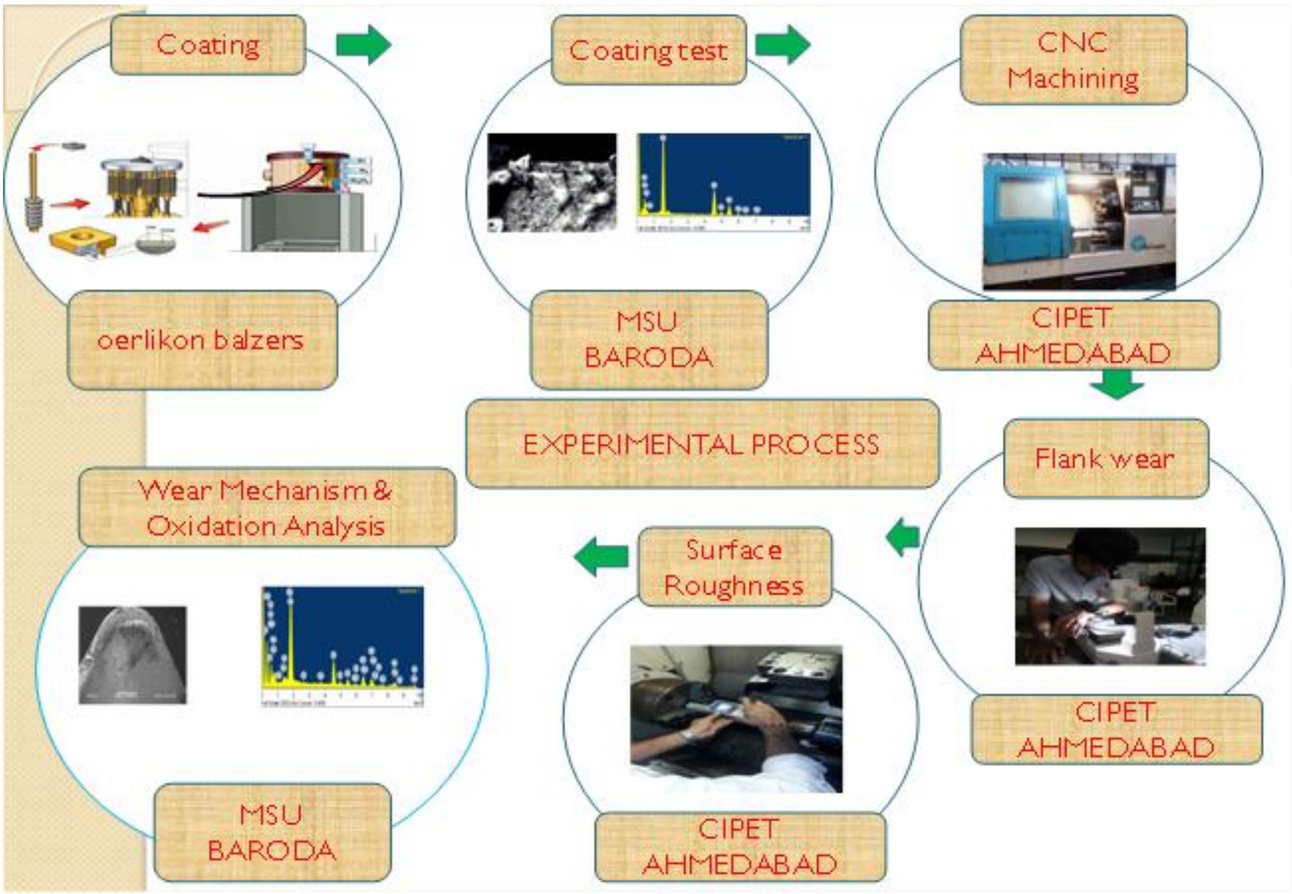


Figure 1: Experimental Process

The level of cutting parameter ranges and the initial parameter values were chosen from the manufacturer's handbook recommended for the tested material. These cutting parameters are shown in Table 1.

Table 1: Cutting Parameters

Cutting Parameters	Level 1	Level 2	Level 3
Types of coated tool	TiAlN	AlCrN	TiAlN/AlCrN
Cutting speed(m/min)	150	180	210
Feed rate(mm/rev)	0.2	0.25	0.3

The Taguchi method and L9 Orthogonal Array were used to reduce number of the experiments. The design of experiments (DOE) and measured surface roughness and tool flank wear.

IV COATING CHARACTERISATION AND THICKNESS MEASUREMENT

To measure thickness of coated material on substrate, specimen cut using EDM wire cut machine and specimen cross section was polished and measured using an electron scanning microscope. Three reading were taken on each specimen and the average value is reported as the (mean) coating thickness. Coating thickness of three samples was near to 8 µm. SEM of coated insert did at MSU Baroda.

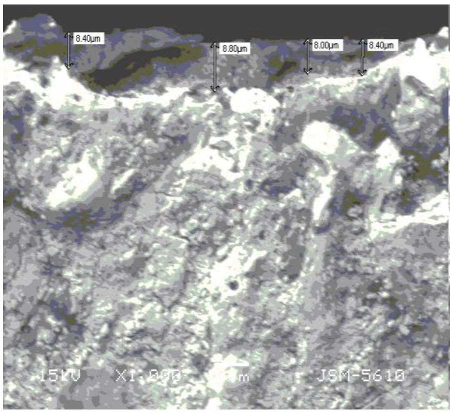


Figure 2: SEM image of TiAlN/AlCrN Coated tool

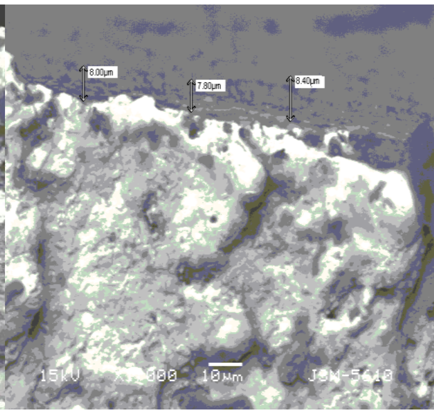


Figure 3: SEM image of TiAlN Coated tool

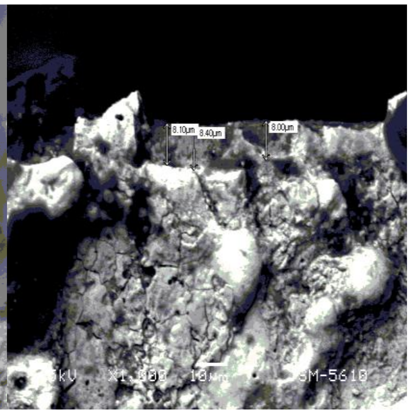
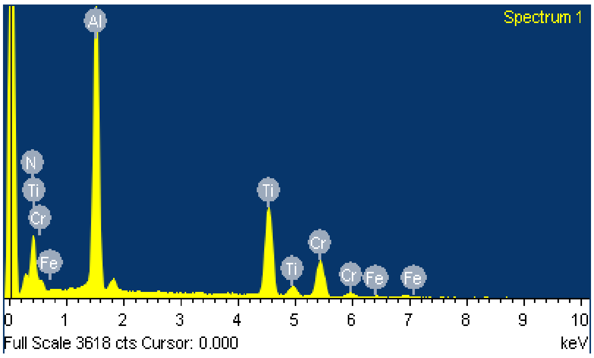


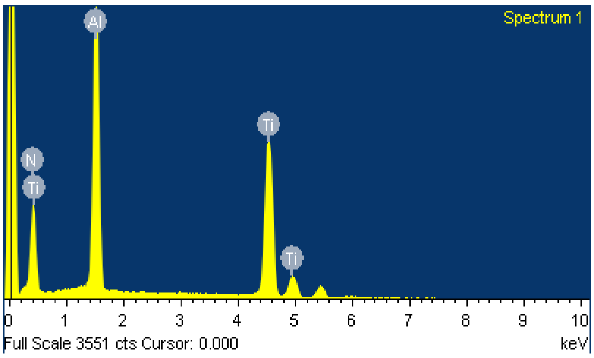
Figure 4: SEM image of AlCrN Coated tool

I have used Energy-Dispersive X-ray spectroscopy to measured chemical composition of coated tool



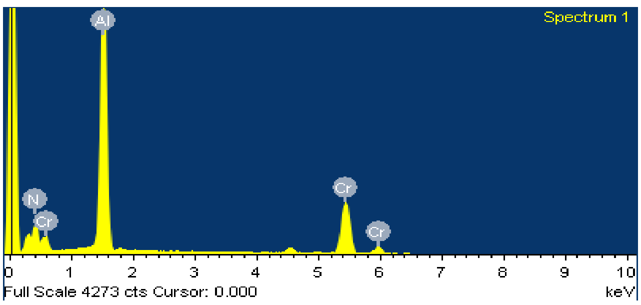
ELEMENT	WEIGHT%	ATOMIC%
N K	23.80	45.40
Al K	29.97	29.67
Ti K	27.67	15.43
Cr K	17.65	9.07
Fe K	0.91	0.43
Totals	100.00	

Figure 5: EDS analysis of the TiAlN/AlCrN coated tool



ELEMENT	WEIGHT%	ATOMIC%
N K	31.73	55.36
Al K	24.78	22.45
Ti K	43.49	22.19
Totals	100.00	

Figure 6: EDS analysis of the TiAlN coated tool



ELEMENT	WEIGHT%	ATOMIC%
N K	21.24	40.46
Al K	40.19	39.75
Cr K	38.57	19.79
Totals	100.00	

Figure 7: EDS analysis of the AlCrN coated tool

V RESULT & DISCUSSION

5.1 FLANK WEAR VARIATION

For TiAlN coated tool flank wear increase with increasing cutting speed from 150 m/min to 180 m/min and feed rate from 0.2 mm/rev to 0.25 mm/rev. For TiAlN coated tool flank wear increase with increasing cutting speed from 180 m/min to 210 m/min and feed rate from 0.25 mm/rev to 0.3 mm/rev. For AlCrN coated tool flank wear decrease with increasing cutting speed from 150 m/min to 180 m/min and feed rate from 0.25 mm/rev to 0.3 mm/rev. For AlCrN coated tool flank wear increase with increasing cutting speed from 180 m/min to 210 m/min and decreasing feed rate from 0.3 mm/rev to 0.2 mm/rev.

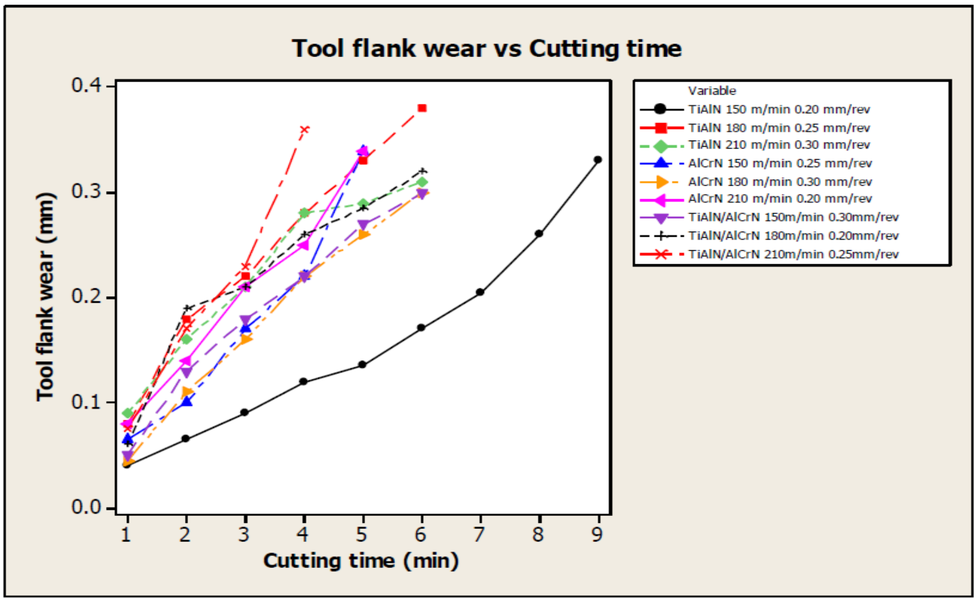


Figure 8: Progressive flank wear

For TiAlN/AlCrN coated tool flank wear increase with increasing cutting speed from 150 m/min to 180 m/min and decreasing feed rate from 0.3 mm/rev to 0.2 mm/rev. For TiAlN/AlCrN coated tool flank wear increase with increasing cutting speed from 180 m/min to 210 m/min and feed rate from 0.2 mm/rev to 0.25 mm/rev.

5.2 SURFACE ROUGHNESS VARIATION

For TiAlN coated tool work piece surface roughness increase with increasing cutting speed from 150 m/min to 180 m/min and feed rate from 0.2 mm/rev to 0.25 mm/rev. For TiAlN coated tool work piece surface roughness increase with increasing cutting speed from 180 m/min to 210 m/min and feed rate from 0.25 mm/rev to 0.3 mm/rev. For AlCrN coated tool work piece surface roughness increase with increasing cutting speed from 150 m/min to 180 m/min and feed rate from 0.25 mm/rev to 0.3 mm/rev. For AlCrN coated tool work piece surface roughness decrease with increasing cutting speed from 180 m/min to 210 m/min and decreasing feed rate from 0.3 mm/rev to 0.2 mm/rev. For TiAlN/AlCrN coated work piece surface roughness decrease with increasing cutting speed from 150 m/min to 180 m/min and decreasing feed rate from 0.3 mm/rev to 0.2 mm/rev. For TiAlN/AlCrN coated work piece surface roughness increase with increasing cutting speed from 180 m/min to 210 m/min and feed rate from 0.2 mm/rev to 0.25 mm/rev.

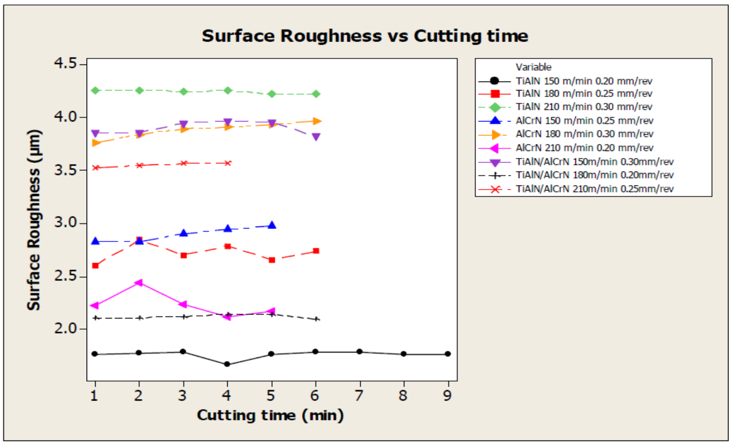
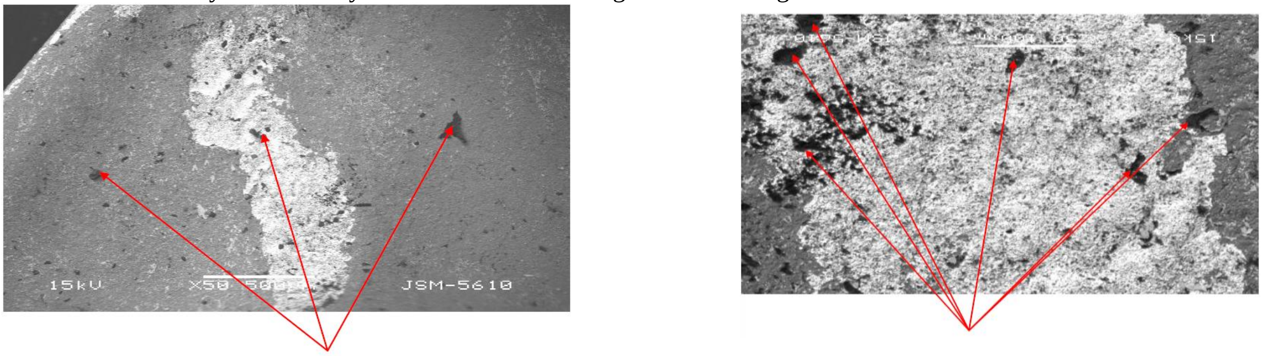


Figure 9: Progressive surface roughness

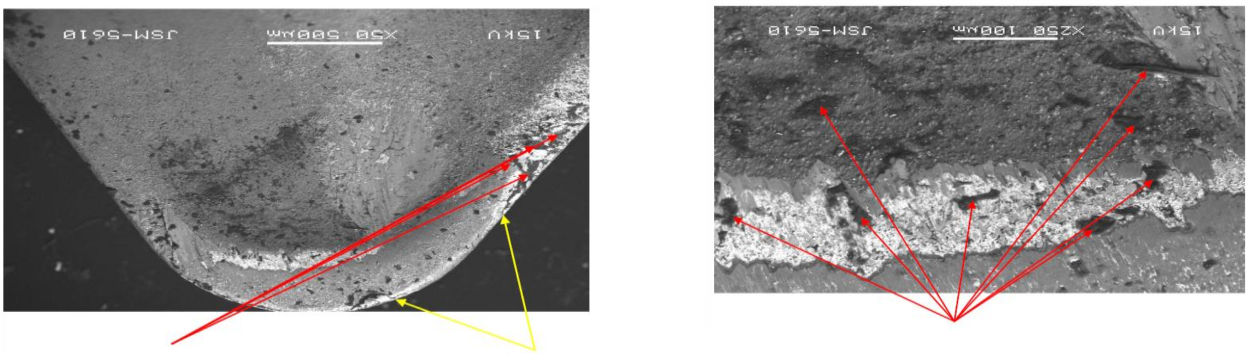
5.3 MICRO WEAR MECHANISM

For studying wear mechanisms analysis SEM analysis was used. SEM uses a focused beam of high electrons to generate a variety of signal at the surface of solid specimens. In SEM microscopy application data is collected over a selected area of the surface of the sample and a two dimensional image is generated that displaces spatial variations in property including chemical characterization, texture and orientation. Sliding wear is noticed in occurrence of grooves parallel to the metal flow direction. Shows micro-abrasion indicated by microgrooves parallel to contact direction. Micro-attrition indicated by micro cavity. I have taken SEM image different magnification.



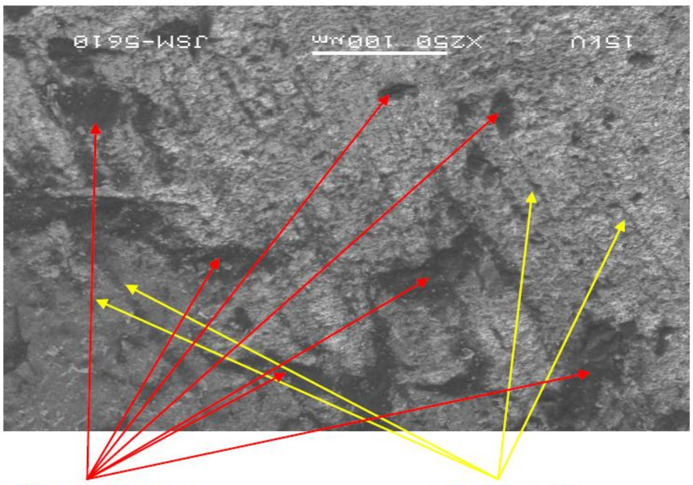
Material- Adhesion Material -Adhesion

Figure 10: SEM image for TiAlN coated tool at cutting speed 150 m/min and 0.20 mm/rev feed rate



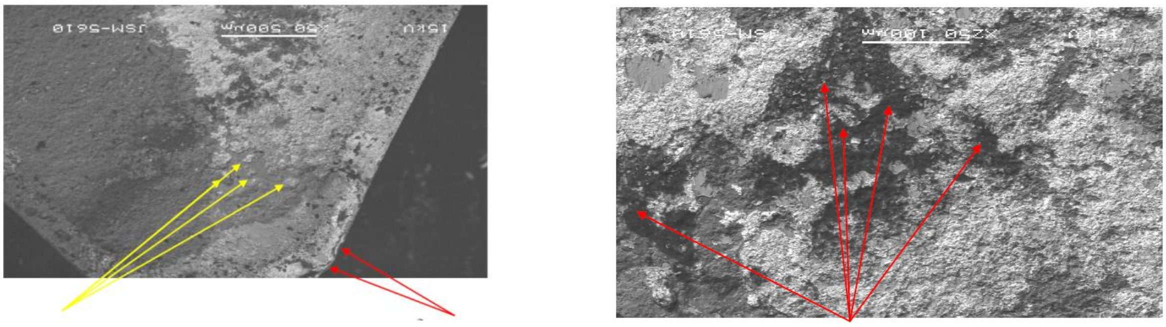
Material- Adhesion Micro-fatigue crack Material -Adhesion

Figure 11: SEM image for TiAlN coated tool at cutting speed 210 m/min and 0.30 mm/rev feed rate



Material- Adhesion Micro- Abrasion

Figure 12: SEM image for AlCrN coated tool at cutting speed 210 m/min and 0.20 mm/rev feed rate



Micro-attrition Micro-fatigue crack Material -Adhesion

Figure 13: SEM image for TiAlN/AlCrN coated tool at cutting speed 210 m/min and 0.25 mm/rev feed rate

SEM image was taken after tool flank wear 0.300.From figure 10 was taken for TiAlN coated tool at cutting speed 150 m/min and 0.20 mm/rev which showed micro-adhesion resembling at higher and lower scale. Figure 11 was taken for TiAlN coated tool at cutting speed 210 m/min and 0.30 mm/rev which showed micro- adhesion and micro-fatigue crack. Figure 12 was taken for AlCrN coated tool at cutting speed 210 m/min and 0.30 mm/rev which showed micro-adhesion and micro- abrasion. Figure 13 was taken for TiAlN/AlCrN coated tool at cutting speed 210m/min and 0.250 mm/rev which showed micro-adhesion, micro-attrition and micro fatigue crack.

5.4 OPTIMIZATION

Taguchi Method was developed by Dr. Genichi Taguchi, a Japanese quality management consultant. Different coated tools used in turning process. Influence of different process parameters such as coating, cutting speed and feed rate on the response such as tool life of tool and surface roughness of work piece were analyzed in this section. In Taguchi methodology signal to noise ratio plays a vital role in determining influence of process parameters. As Tool life of tool to be maximized and surface roughness of work piece to be minimized so accordingly signal to noise ratio was calculated by considering ‘larger is better’ and ‘smaller is better’ criteria respectively. S/N ratio was calculated by following Equation.

$\eta = -\ \eta = -10\log10(MSD)$〗

Where, η is the S/N ratio and the value of MSD (Mean Square Deviation) changes according to objective of the experiment.

For larger is better quality characteristics, MSD = (1/〖Y1〗^2 +1/〖Y2〗^2 +1/〖Y3〗^2 +⋯⋯⋯⋯+1/〖Yn〗^2)

For smaller is better quality characteristic, MSD == (〖Y1〗^2+〖Y2〗^2+〖Y3〗^2+⋯.....+〖Yn〗^2)

Table 2: S/N Ratio for tool flank wear 0.300mm at Tool life & Surface roughness

Run No.	Types of Coating	Cutting Speed (Vc) m/min	Feed Rare (f) mm/rev	Tool life	SN Ratio for Tool life	Surface roughness	SN Ratio for Surface roughness
1	TiAlN	150	0.2	11.35	21.09992	1.763	-4.92505
2	TiAlN	180	0.25	3.93	11.88785	2.735	-8.73915
3	TiAlN	210	0.30	2.71	8.659386	4.218	-12.5021
4	AlCrN	150	0.25	4.36	12.78973	2.972	-9.46098
5	AlCrN	180	0.3	6.24	15.90369	3.959	-11.9517
6	AlCrN	210	0.2	4.41	12.88877	2.174	-6.74519
7	TiAlN/ AlCrN	150	0.3	3.77	11.52683	3.818	-11.6367
8	TiAlN/ AlCrN	180	0.2	3.18	10.04854	2.094	-6.41953
9	TiAlN/ AlCrN	210	0.25	1.8	5.10545	3.567	-11.0461

Table 3: S/N Ratio for response table for Tool life & Surface roughness

Level	Types of coating	Cutting speed	Feed rate	Level	Types of coating	Cutting speed	Feed rate
1	13.88238469	15.13882467	14.67908	1	-8.72211	-8.67425	-6.02992
2	13.86073112	12.61336173	9.927677	2	-9.38596	-9.0368	-9.74873
3	8.893606502	8.884535903	12.02997	3	-9.70077	-10.0978	-12.0302
Delta	4.99	6.25	4.75	Delta	0.97	1.42	6.00
	2	1	3		3	2	1
For Tool life				For Surface roughness			

For Tool life the different values of S/N ratio between maximum and minimum are (main effect) also shown in Table 2. The cutting speed that has the highest difference between values 3. Based on the Taguchi prediction that the larger different between value of S/N ratio will have a more significant effect on cutting time. Thus, it can be concluded that increasing the cutting speed will decrease the tool life significantly. The Taguchi design was conducted to obtain tool life values high. The level values obtained from MINITAB 14 Program according to the Taguchi design are given in Table 3. Accordingly, Figure 14 and Table 3 show that the first level of A factor (coating), the first level of B factor (cutting speed) and the first level of C factor (feed rate) are higher. Consequently, optimum cutting conditions for the experiments to be conducted will be (1 1 1) TiAlN coating, 150m/min for cutting speed and 0.2 mm/rev for feed rate.

For Surface roughness the different values of S/N ratio between maximum and minimum are (main effect) also shown in Table 3. The feed rate that has the highest difference between values 6.00. Based on the Taguchi prediction that the larger different between value of S/N ratio will have a more significant effect on surface roughness. Thus, it can be concluded that increasing the feed rate will increase the surface roughness significantly. The Taguchi design was conducted to obtain surface roughness values law. The level values obtained from MINITAB 14 Program according to the Taguchi design are given in Table 3. Accordingly, Figure 15 and Table 3 show that the first level of A factor (coating), the first level of B factor (cutting speed) and the first level of C factor (feed rate) are higher. Consequently, optimum cutting conditions for the experiments to be conducted will be (1 1 1) TiAlN coating, 150m/min for cutting speed and 0.2 mm/rev.

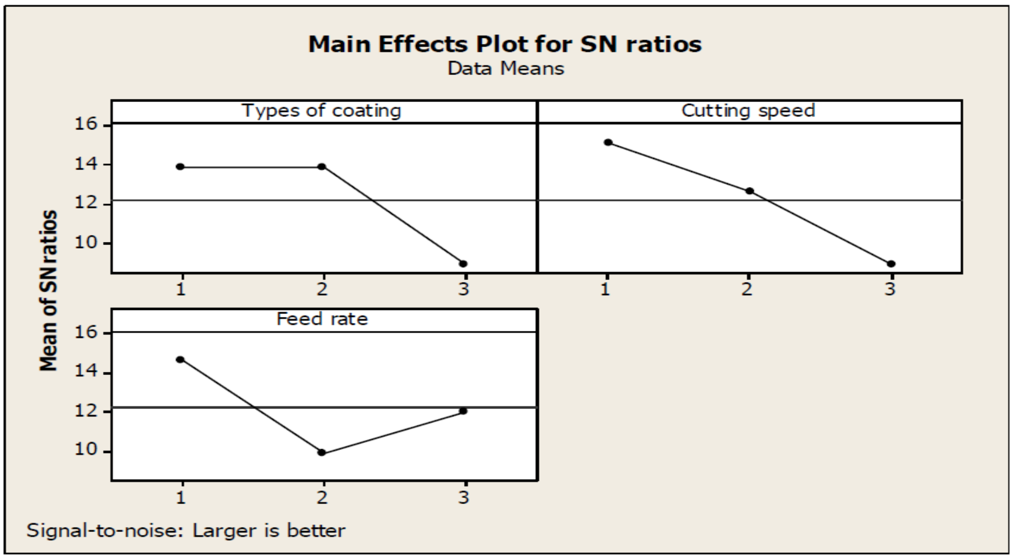


Figure 14: The graphics of mean of S/N ratios versus factor levels (Tool life)

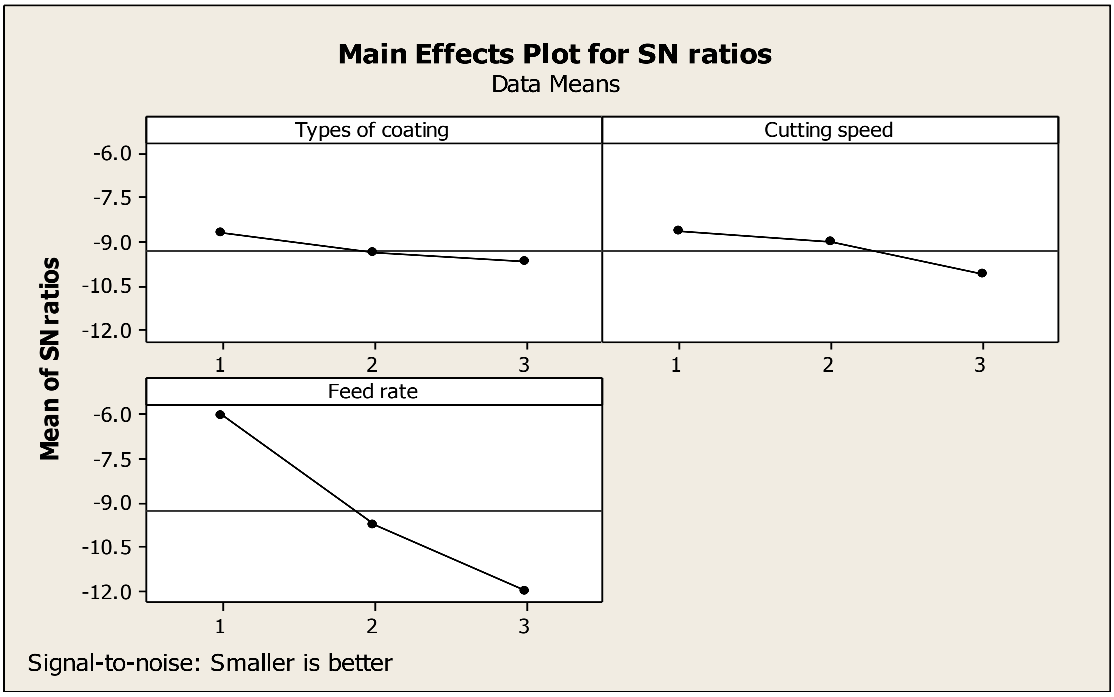


Figure 15: The graphics of mean of S/N ratios versus factor levels (Surface roughness)

Study of ANOVA for a given analysis helps to determine which of the factors need to control and which do not. Once the optimum condition is determined, it is usually good practice to run a confirmation experiment. In case of fractional factorial, only some of the tests of full factorial are conducted. The analysis of the partial experiment must include an analysis of confidence that can be placed in the results. So analysis of variance is used to provide a measure of confidence. The technique does not directly analyze the data, but rather determines the variability (variance) of the data. Analysis provides the variance of controllable and noise factors. By understanding the source and magnitude of variance, robust operating conditions can be predicted. I did manual calculation of ANOVA.

5.5 CONCLUSION

The coating was applied by physical vapor deposition process. Because of property of coating material, thermal conductivity decrease, mechanical property increase and heat transfer coefficient decrease. However, tool flank wear and surface roughness were decreased significantly with the uses of coated tool.

Among the entire coated tool, TiAlN coated tool shows better performance in terms of, tool life and surface roughness compared to AlCrN and TiAlN/AlCrN coated tool at cutting speed 150 m/min and feed rate 0.20 mm/rev. This is due to; during cutting process Al oxide protective layer forms and reduces built-up edge formation. With the uses of TiAlN coated tool in machining of AISI 304, we can obtain lower tool flank wear means more tool life and lower surface roughness compare to other coated tool. Hence machining efficiency can be improved with uses of such kind of coating material.

Analysis of variance shows the comparison of the result of variance ratio F theoretically as well as with the help of MINITAB software. Also it indicates percentage effect of all the parameters on tool life and surface roughness. From ANOVA calculation, we can conclude that cutting speed affect most (29.80%) on tool life, feed rate were affect most (91.60%) on surface roughness.

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