Research Inventy: International Journal of Engineering And Science
Vol.13, Issue 2 (February. 2023), PP 60-73
Issn (e): 2278-4721, Issn (p):2319-6483, www.researchinventy.com

Machining Of Titanium Alloy by Turning Using Coated Tools

Enoch Ding, Dr Mohan Reddy Moola
Department Of Mechanical Engineering Curtin University, Malaysia,9800,Miri,Sarawak

Abstract
In this modern era, industry had improved vastly due to various new technology being implemented. The application of titanium during late 1940 gives an outstanding good result in tissue compatibility. Although, during 1950 and 1960 a few internal fixation devices were used in United States, the usage of titanium alloy is rapidly in England. In early 1970, titanium alloy started to gain popularity as implant materials. This competition within industry in producing good product is highly beneficial for consumer. Titanium alloy is known for their high chemical reactivity and causing high temperature during machining. Usage of Titanium alloy has been widely use in modern aerospace industry due to its perfect combination in physical properties and also metallurgical. Both Titanium and Titanium alloy are known as non-ferrous metal which its high strength properties are well maintained even experiencing high temperature. It has better wear and corrosion resistant in any condition. Due to its poor machinability, a proper cutting parameter will be investigated in order to improve machinability of cutting tools. Another criteria reviewed in this report is to improve surface finish which is also an important criteria in improving machinability. For this experiment, the cutting parameter and cutting tools used were analyzed by research done in literature review. The cutting tools selected for this experiment are PVD coated carbide tools where it has the resistance in machining titanium alloy. Design made for this experiment were done by using Design Expert Software where Central Composite Design (CCD) and Response Surface Methodology (RSM) results were further analyzed. From the software, it has found that the minimum value for surface roughness found and tool wear are 0.929µm and50.7µm respectively. From the analysis made in the software, it has found out that feed rate contributes highest effect towards surface roughness while feed rate and depth of cut effect contributes to tool wear.

Date of Submission: 01-02-2023 Date of Acceptance: 10-02-2023

I. Introduction

Usage of Titanium alloy has been widely use in modern aerospace industry due to its perfect combination in physical properties and also metallurgical. Both Titanium and Titanium alloy are known as non- ferrous metal which its high strength properties are well maintained even experiencing high temperature. It has better wear and corrosion resistant in any condition. The reason behind costly titanium product is due to poor machinability and its extraction process of titanium. It is found that, it is hard to machine titanium alloy in order to achieve a good surface finish and surface integrity due to its poor machinability. The reason why Titanium Alloy were used widely in aerospace industry is because reaction of Titanium-alloy with composite like carbon, sulfur, nitrogen and oxygen causes forming insoluble compound which resulting in poorer Titanium-alloy machining. Application of titanium alloy is widely used in aerospace industries due to their corrosion resistance and strength to weight ratio. This is confirmed in (Pawar et al., 2012) as titanium alloy has a density of 40% lower and also Young's modulus of 55% comparing to steel. Titanium was shown to be a very chemically reactive and will result in tendency to weld on cutting tools which lead to chipping and shorter tool life. It is also due to it slower thermal conductivity which increases tool or workpiece temperature. Titanium alloy has high yield stress to tensile strength ratio which is more than 0.9 and flow stress increases vastly when strain rate is more than 103s-1 which ease the machining process. Saw tooth chip or known as segmentation in the form of chips, occurs during the machining of titanium alloy. Lower elastic modulus could cause workpiece deflection which moves away form cutting tools. This happens when cutting edge is moving forward and workpiece spring back which leads to deflection, chatter and vibration. Furthermore, most of hardened tools in the market are not suitable in machining titanium alloy because of chemical affinity which leads to chemical wear on the cutting tools. Chips could also weld easily on tool to form a buildup edge. Like other metals, titanium can crystallize in different type of crystal structure at various range of temperature. A complete transformation from one to another crystal structure is called "allotropic transformation "while transformation temperature is called "transition temperature ". Most of titanium alloy and pure titanium crystalize at low temperature in the form of hexagonal

Close packed structure (HCP) which are known as α titanium. However, at a higher temperature, body centered cubic structure (BCC) is characteristically stable and known as β titanium. For pure titanium, β transition temperature is approximately 882ċ. The schematic diagram for both hexagonal close packed (HCP) α titanium and body centered cubic (BCC) β titanium. Some of Titanium's characteristic is high strength to weight ratio, corrosion resistance and low modulus of elasticity. For machine building purposes, pure titanium is not advisable due its changes in microstructural phase which change linearly with change of temperature. This process know as allotropic transformation which changes from alpha base to beta phase which influence the mechanical properties of the materials. (Rahmanet al., 2003; Ezugwu and Wang, 1997; Yang and Liu, 2007). Research made by (Veiga andVadim, 2012; Machado and Walbank, 1990) state that Alpha (α) stabilizing element which consisting of Al, O, N and C is used to increase temperature of allotropic transformation prevent phase transformation to improves usability of Titanium alloys. For Beta (β) stabilizing element consisting Mo, Cr, Mn, Ni, V, Fe, Nb, Cu, Si is to reduce temperature of phase transformation.

1.0 Introduction

Usage of Titanium alloy has been widely use in modern aerospace industry due to its perfect combination in physical properties and also metallurgical. Both Titanium and Titanium alloy are known as non- ferrous metal which its high strength properties are well maintained even experiencing high temperature. It has better wear and corrosion resistant in any condition. The reason behind costly titanium product is due to poor machinabilityand its extraction process of titanium. It is found that, it is hard to machine titanium alloy in order to achieve a good surface finish and surface integrity due to its poor machinability. The reason why Titanium Alloy were used widely in aerospace industry is because reaction of Titanium-alloy with composite like carbon, sulfur, nitrogen and oxygen causes forming insoluble compound which resulting in poorer Titanium-alloy machining. Application of titanium alloy is widely used in aerospace industries due to their corrosion resistance and strength to weight ratio. This is confirmed in (Pawar et al., 2012) as titanium alloy has a density of 40% lower and also Young's modulus of 55% comparing to steel. Titanium was shown to be a very chemically reactive and will result in tendency to weld on cutting tools which lead to chipping and shorter tool life. It is also due to its lower thermal conductivity which increases tool or workpiece temperature. Titanium alloy has high yield stressto tensile strength ratio which is more than 0.9 and flow stress increases vastly when strain rate is more than 103 s-1 which ease the machining process. Saw tooth chip or known as segmentation in the form of chips, occurs during the machining of titanium alloy. Lower elastic modulus could cause workpiece deflection which moves away form cutting tools. This happens when cutting edge is moving forward and workpiece spring back which leads to deflection, chatter and vibration. Furthermore, most of hardened tools in the market are not suitable in machining titanium alloy because of chemical affinity which leads to chemical wear on the cutting tools. Chips could also weld easily on tool to form a build up edge . Like other metals, titanium can crystallize in different type of crystal structure at various range of temperature. A complete transformation from one to another crystal structure is called " allotropic transformation " while transformation temperature is called " transition temperature ". Most of titanium alloy and pure titanium crystalize at low temperature in the form of hexagonal close packed structure (HCP) which are known as α titanium. However, at a higher temperature, body centered cubic structure (BCC) is characteristically stable and known as β titanium. For pure titanium, β transition temperature is approximately 882 ċ. The schematic diagram for both hexagonal close packed (HCP) α titanium and body centered cubic (BCC) β titanium. Some of Titanium's characteristic is high strength to weight ratio, corrosion resistance and low modulus of elasticity. For machine building purposes, pure titanium is not advisable due its changes in microstructural phase which change linearly with change of temperature. This process know as allotropic transformation which changes from alpha base to beta phase which influence the mechanical properties of the materials. (Rahman et al., 2003; Ezugwu and Wang, 1997; Yang and Liu, 2007). Research made by (Veiga and Vadim, 2012; Machado and Walbank, 1990) state that Alpha (α) stabilizing element which consisting of Al, O, N and C is used to increase temperature of allotropic transformation prevent phase transformation to improves usability of Titanium alloys. For Beta (β) stabilizing element consisting Mo, Cr , Mn, Ni , V, Fe, Nb , Cu , Si is to reduce temperature of phase transformation.

1.1 Turning operation

Longitudinal turning which is a process of 3D turning process. The process of turning in longitudinal turning is where cutting tools is in a constant movement parallel horizontally to the workpiece (Taneja et al., 2012). In turning, two different surface is determined which is work surface where its is surface removed during turning process. The other one is machined surface where it is newly cut surface. Rake face is surface produced by formed chip flows and flank face is surface which moves across newly produced surface. Intersection in between flank face and rake face is known as cutting edge.

2.0 Cutting Tool Analysis

from research by ((Machado and Walbank, 1990; Rahman et al., 2003; Ezugwu and Wang, 1997; Yang and Liu, 2007; Hua and Shivpuri, 2004) is to determine the best condition for machining Titanium alloy in few factor such as cutting speed, V (m/min), feed rate, f (mm/rev) and depth of cut, d (mm) in machining aerospace building using experimental conducted in lab with coated carbide cutting tools with various size of nose radius. The purpose of this research is to help manufacturing industries to reduce manufacturing cost and defect product which resulting to a better economic sustainability. TiCn and AlSiTin coating (by arc evaporation) shows a better performance in turning process in wet and minimum quantity liquid (MQL) condition. Not all of the coating is acceptable such as HfC coating which shows greater tool wear comparing to uncoated tools. In (Kumar & Ramamoorthy, 2007) , they had made an experiment for TiCN and ZrN coated cutting tools with different cutting force, surface roughness and cutting temperature. However, the result obtained that in minimal quality liquid (MQL) shows the best performance comparing to wet and dry turning. The factor leads to this result is because of minimal cutting fluid supplied at high pressure and high velocity penetrates into the tool chip which causes reduction in frictional factor to the cutting force. The reduction in cutting force which lowering cutting temperature during minimal quality liquid (MQL) application leads to a better surface finish. Experiment shows in (Dongre et al. 2017) shows that during MQL condition, it has lower cutting force due to high proportion of oil content and lubrication capacity of the mist is much more higher comparing to flooded and dry condition. This can further being reaffirmed by experiment conducted by (Pramanik, 2014) that shows that tool wear increases vastly after 5 minute , where cutting operation at a low speed of 100 m/min without the presence of coolant. The experiment also showed that tool wear for all material increased as cutting speed increases. Stress, vibration and also temperature is one of the contributing factor which increases cutting tool damage. Most of damages such as chemical wear, thermal diffusion, chipping and plastic deformation is causes as temperature increases. Frequency of cyclic force determine to increase perpendicularly with cutting speed with a value of 260 Hz approximately. However, cutting speed where cutting force start to increase proportional to cutting speed are found lower in machining of titanium alloy. Hence, this is one of the factor causes machining of titanium alloy speed to increase. In experiment made by (City, 2020) shows that carbide, sintered diamond and natural diamond are better in machining titanium alloy. Further investigation made by (City, 2020) shows that polycrystalline cubic diamond (PCD) tools shows satisfying performance in machining titanium alloy. Experiment made by (Nithyanandam, Das, and Palanikumar 2015) shows that by using 2.3 µm thickness of PVD coated TiA1N coated tool gives a good average surface roughness during a cutting speed of 200m/min and feed of 0.25mm/rev. From the result of (Nithyanandam, Das, and Palanikumar 2015) shows that feed is one of factor contributing to surface roughness. Another finding in (MARANCHIK J et al., 1968) state that surface roughness were found to increase in new cutting tool compared with used cutting tool. In machining of titanium alloy, materials that experiencing high strain, strain rate andtemperature will lead to few condition which will damage surface finish of titanium alloy with easily. (City, 2020). (Nithyanandam, Das, and Palanikumar2015) wrote that a good surface finish is obtained when machining with a high speed Ti6Al4V alloy in turning with a lower feed rate and depth of cut. Result in (Ibrahim et al., 2009) experiment did also shows that surface roughness is influenced by feed rate value which lower feed rate gives better surface finish.

2.1 Tool Wear

The performance of cutting tool is usually examined by their life on basis on several wear criteria where flank wear contributes a big factor in influencing the stability of cutting edge and dimensional tolerance of work surface. Tool flank side is the main factor causing tool wear in both coated and uncoated tool. Hence, it is advisable to use sharp, positive edge tools with ample clearance and stale cutting condition with well clamped work part to producea high performance cutting with minimal vibration during the process of machining titanium alloy. choosing a suitable tool is important in improving cutting performance in vital condition during machining of titanium alloy. Notching happen due to hardened top layer of titanium touches the tool. This happens at the depth of cut line. Machining titanium will result in Built Up Edge (BUE) due to its chemical reactivity with tool materials which resulting in chemical and crater wear. Due to high chemical reactivity of titanium alloy in contact with CBN and PVD tools which is the factor contributing to tool wear. Crater wear occurs during huge and repeatedly sliding contact in between chip and rake face of cutting tools. As cutting moves further, crater grows bigger which changing the geometry of tool. In order to improve resistance towards crater wear, the chemical characteristic between cutting tools and workpiece is one of the parameter need to be reduced. (Pawar et al., 2012).Flank wear is a tool wear which gives a loss in cutting tool material because of continuous sliding between flank face and newly cut surface of the workpiece. To reduce flank wear, it is advisable to use a harder tool. (Pawar et al., 2012). Tool edge which lead to deformation and fracture behavior of the tools. Physical vapor deposition (PVD) coatinggives no degradation in fracture strength. Due to titanium alloy has a very poor machinability which may caused by high chemical reactivity which occurring a weld on cutting tools during machining process. CVD and PVD coating tools usually use in machining titanium alloy especially PVD -TiA1N Carbide tools which will give better wear resistance, chemical stability and also better tool life and machining processes. Recently, various of carbide cutting tools is coated with hard coating through Chemical vapor deposited (CVD) or Physical vapor deposited (PVD). However, PVD tools have been found to perform better comparing to CVD tools due to PVD thin coating canbe deposited in . Journal in (Ahsan et al., 2012) state that PVD coated carbide tools shows better performance as cutting tools.

3.0 Design Of Experiment

The objective for this experiment is to ensure the best cutting parameter in machining titanium alloy by turning using coated tools. Determination of this experiment are based on the surface finish and also tool wear. Surface roughness tester (Mituyo brand) being used to determine the surface roughness while optical microscope used to have a better view on tool wear. The design of this experiment are design by using Design Expert software where the suggested value are tabulated in table 3. By using central composite design (CCD) in design expert software, it shows that 16 run test need to be done based on the three parameter which is cutting speed (Rpm), feed rate (mm/min) and depth of cut (mm). In order to analyze the effect of surfaceroughness, Response Surface Methodology (RSM)are used as analyzing purposes. By RSM, central composite design (CCD) will be used to investigate and optimize the cutting parameter which influence the surface finish on titanium alloy rod.

3.1 Workpiece And Equipment Material

The equipment and materials used are Three pieceof titanium rod Ti-6Al-4V , 600mm length and 50mm diameter 8 sets of PVD coated carbide , noseradius 0.8 with a negative rake angle. Kyocera tool holder and Gap bed lathe machine. For this study, the composition of titanium alloy are as follows: 89.661 % Titanium (Ti), 6 % Aluminum (Al), 4 % Vanadium (V) , 0.18 % Iron (Fe), 0.01 % Nitrogen (N), 0.009 % Hydrogen (H) and 0.12 % Oxygen (O).

4.0 Results And Discussion.

This experiment is conducted by using gap bed lathe machine which uses PVD coated tools as the cutting tools. From the experiment, results will be collected for analyzing surface finish and tool wearcondition by investigating the relationship between the cutting parameter. The data collected which designed by Design Expert Software are being tabulated

4.1.1 Surface Finish Analysis

Table 1 : Surface Roughness Value

RUN	SPEED (Rpm)	Feed Rate (mm/min)	Depth (mm)	Surface Roughness (µm)
1	190	0.6	1	8.506
2	190	0.35	1	4.916
3	190	0.1	1	0.929
4	190	0.35	1.8	5.471
5	190	0.35	1	5.169
6	190	0.35	0.16	4.890
7	150	0.2	1.5	2.235
8	150	0.5	0.5	8.526
9	150	0.2	0.5	1.987
10	150	0.5	1.5	6.095
11	100	0.35	1	5.770
12	300	0.2	0.5	2.091
13	300	0.5	1.5	7.116
14	300	0.2	1.5	2.848
15	300	0.5	0.5	8.711
16	420	0.35	1	4.609

4.1.2 ANOVA Analysis

From Design Expert Software, analysis being done based from the data received for the experiment. In this section, analysis by ANOVA being used in order to analyze the design. From the design given, by seeing in fit summary it suggest that linear model is suggested while for cubic model is aliased. The fit summary for this part is tabulated.

Table 2 : Fit Summary

Source	Sequential p-value	Lack Of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	**<0.0001**	**0.1816**	**0.9127**	**0.8702**	**Suggested**
2FI	0.0737	0.2211	0.9442	0.8785	
Quadratic	0.5801	0.2005	0.9382	0.8383	
Cubic	0.2005		0.9948		Aliased

From the result collected from the experiment, the suggested model are input in the model where Linear model based on the value for both adjusted and predicted R^2. The reason why this model is chosen because it has the lowest value comparing to other two model. By referring to the model suggested, equation are shown by the software as below.

$$\begin{aligned} SurSSace\ Roughness &= -0.567665 \\ &+ 0.000147 \times Speed \\ &+ 16.67967 \times Feed\ Rate \\ &- 0.311403 \times Depth \end{aligned}$$

From the analysis in fit summary, ANOVA analysis are used in order to investigate the cutting parameter for the suggested model. The ANOVA analysis are tabulated.

Table 3 : ANOVA Analysis

Source	Sum Of Squares	df	Mean Square	F-Value	p-Value	
Model	85.18	3	28.39	53.27	<0.0001	Significant
A-Speed	0.0021	1	0.0021	0.0039	0.9515	

B-Feed Rate	84.85	1	84.85	159.20	<0.001	
C-Depth	0.3244	1	0.3244	0.6087	0.4504	
Residual	6.40	12	0.5330			
Lack Of Fit	6.36	11	0.5785	18.08	0.1816	Not significant
Cor Total	91.58	15				

From table 3, it shows that for the model source are significant and lack of fit are not significant are good sign because this shows that the design fits the model. From the analysis, it states that model F value of 53.27 shows the model is significant. This means that it has a 0.01 % chance for F- value to occur due to noise. By analyzing further for the p- value, it shows that only for case B feed rate are significance due to the value which lesser than 0.001. Further analyzed in the mean square column, from this model it shows that feed rate hasthe highest value obtained which is 84.85. This shows that feed rate are the most contributingfactor which affecting surface roughness. The Lack of Fit F-value of 18.08 implies the Lack of Fit is not significant relative to the pure error. There is a18.16% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good because we want the model to fit.

Table 4 : Fit Statistic

Std Dev	0.7301		R^{22}	0.9302
Mean	4.99		**Adjusted** R^{22}	0.9127
C.V.%	14.63		**Predicted** R^{22}	0.8702
			Adeq Precision	22.8468

From table above, it shows that predicted R^2 of 0.8702 is in reasonable agreement with adjusted $R^2$of value 0.9127 which has a difference of less than 0.2. The value of R^2 which near to 1 shows thatthis model are good. The Adeq precision measures signal to noise ratio where ratio greater than 4 is desirable. From the model in table 4 shows that Adeq precision is 22.847 shows adequate signal.

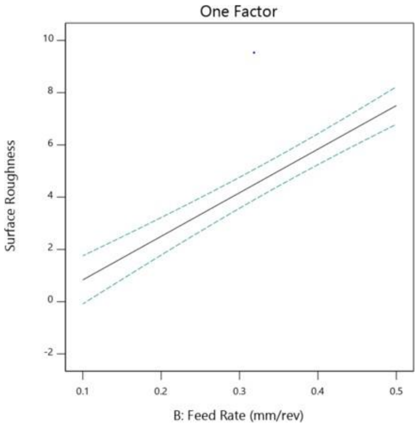

Figure 1 : Surface Roughness Vs Depth

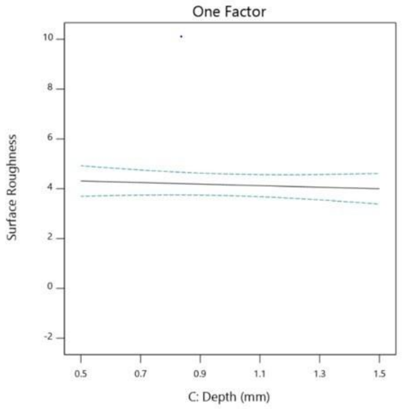

Figure 2 : Surface Roughness Vs Feed Rate

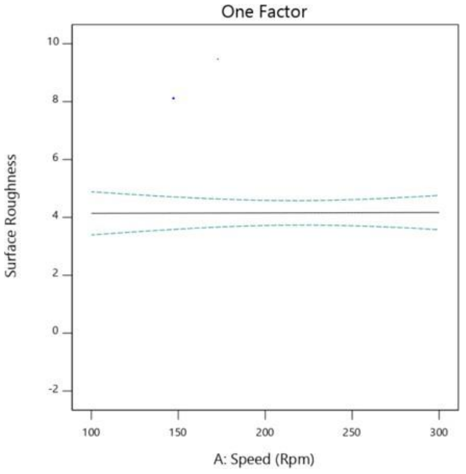

Figure 3 : Surface Roughness Vs Speed

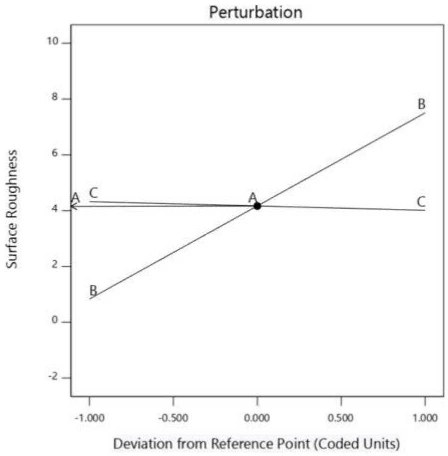

Figure 4 : Perturbation Graph

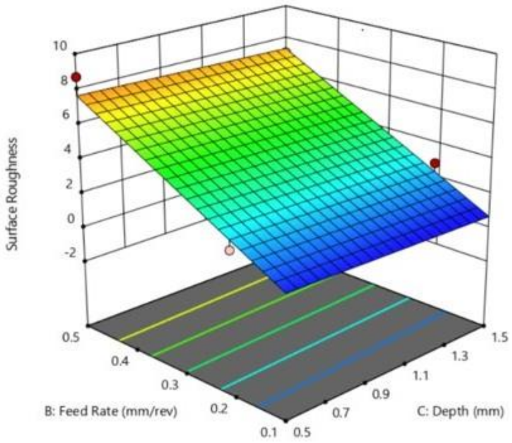

Figure 5 : 3D Graph For Feed Rate And Depth

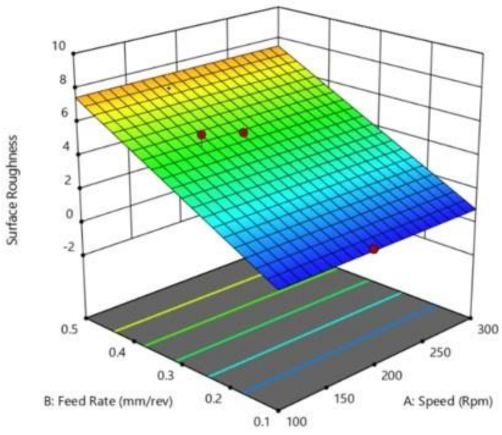

Figure 6 : 3D Graph For Feed Rate And Speed

From figure 1, it shows linear relationship between surface roughness and depth. The actual factor of speed and feed rate were set to 200 rpm and 0.3 mm/rev respectively. From what we observed, it shows that as depth of cut increase, surface roughness increase. However, by analyzing from the graph, it shows that the value has only slight increment in the relationship between depth of cut towards surface roughness. This shows that depth of cut factor doesn’t really affecting the surface roughness significantly by observing from the graph obtained shown in figure 8. From the graph in figure 2, it shows the linear relationship between feed rate and surface roughness. What have been observed are that when feed rate increase, surface roughness increases too. From this graph, actual factors for speed and depth were set to 200 rpm and 1 mm respectively in determining one factor which are feed rate. The increment of surface roughness with feed rate shows significantrelationship where we can observe from the graph in figure 2. This shows that feed rate gives a major effect in surface roughness.

The graph from figure 3, shows the linear relationship between speed and surface roughness model graph. The actual factor of feed rate and depth were set to 0.3 mm/rev and 1 mm respectively. From what being observed here, the graph look alike with figure 1. However, by analyzing from the graph, it shows that the value has only slight increment in the relationship between speed towards surface roughness This shows that the effect of cutting speed does not bring any major effect on surface roughness has thesame factor with depth of cut.

Perturbation model graph shows that the steepest line gives major effect influencing the surface roughness. Line A represented by speed, line B are feed rate and line C are depth. In this perturbation graph, it the actual factor for each cutting parameter being set where speed is 200 rpm, feed rate is 0.3 mm/rev and depth of 1 mm. From what the linear model graph shows that line B has the steepest line which is feed rate. This shows that feed rate has the most contribution in affecting thesurface roughness. For line A and C, it shows that only slight effect toward surface roughness. Hence,in order to have a better surface roughness, feed rate contributes the major aspect comparing todepth of cut and cutting speed. It is because higher feed rate would give higher pressure on workpiece which increases friction that causing higher surfaceroughness value.

The 3-D graph shown that the relationship between depth and feed rate towards surface roughness. The cutting speed being set to 200 rpm where depth of cut and feed rate value were analyzed for their relationship towards surface roughness. By observing figure 5, at a feed rate of 0.5 mm/rev and depth of 0.5 mm has the highest value for surface roughness. This shows that, even at lowest depth of cut, as the value of feed rate increases, it significantly shows a significant effect towards surface roughness. This can be further discussed, when feed rate is at 0.1 mm/rev and depth are at 0.5mm has a the lowest value for surface roughness. The value shows that, when increasing depth of cut and decreasing feed rate will also leads to better surface roughness. Hence in order to achieve better surface roughness value, feed rate value need to be lower down to reduce pressure on workpiece which influencing the surface roughness.

From the 3-D surface in figure 6, it shows the relationship between speed and feed rate toward surface roughness. By setting depth of cut into 1 mm, at feed rate of 0.5 mm/rev and speed of 100 rpm shows the highest surface roughness value. From the graph, it shows when feed rate at 0.1 mm/rev and speed of 100 rpm it has the high value of surface roughness. This reaffirmed the statement made from discussion in figure 4 where feed rate is the most contributing factor towards surface roughness. Furthermore, as we can see when cutting speed increases to 300 rpm, it still appear in the blue color zone which has lower value comparing to the yellow color zone where value of surface roughness were higher. Analyzing from this, in order to improve surface roughness, by decreasing feed rate value and increasing speed could possibly be done.

4.2.1 Tool Wear Analysis

Table 5 : Tool Wear Value

RUN	SPEED (Rpm)	Feed Rate (mm/min)	Depth (mm)	Tool Wear (µm)
1	190	0.6	1	1389
2	190	0.35	1	727.4
3	190	0.1	1	218.37
4	190	0.35	1.8	476.69
5	190	0.35	1	293.0
6	190	0.35	0.16	89.43
7	150	0.2	1.5	122.48
8	150	0.5	0.5	142.94
9	150	0.2	0.5	50.7
10	150	0.5	1.5	886.79
11	100	0.35	1	1120.9
12	300	0.2	0.5	255.71
13	300	0.5	1.5	1162.35
14	300	0.2	1.5	1139.44
15	300	0.5	0.5	1314.40
16	420	0.35	1	712.84

From Design Expert Software, analysis being done based from the data received for the experiment. In this section, analysis by ANOVA being used in order to analyze the design. From the design given, by seeing in fit summary it suggest that linear model is suggested while for cubic model is aliased. The fit summary for this part is tabulated in table 6**.**

Table 6 : Fit Summary

Source	Sequential p-value	Lack Of Fit p-value	Adjusted R^2	Predicted R^2	
Linear	**0.0201**	**0.5788**	**0.4321**	**0.1738**	**Suggested**
2FI	0.9916	0.5060	0.2509	-1.1070	

Quadratic	0.4660	0.4857	0.2435	-1.7785	
Cubic	0.4857		0.5934		Aliased

In table 6 , from the result collected from the experiment, the suggested model are input in the model where Linear model based on the value for both adjusted and predicted R^2. The reason why this model is chosen because it has the lowest value comparing to other two model. By referring to the model suggested, equation are shown by the software as below.

$$Tool\ Wear = -825.82281 + 2.09186\ \times speed + 1913.03279 \times SSeed\ rate + 329.60234\ \times depth$$

Equation 2 : Final Equation

From the analysis in fit summary, ANOVA analysis are used in order to investigate the cutting parameter for the suggested model. The ANOVA analysis are tabulated in the table 7 below.

Table 7: ANOVA Analysis

Source	Sum Of Squares	df	Mean Square	F-Value	p-Value	
Model	1.899 E+06	3	6.330 E + 05	4.80	0.0201	Significant
A-Speed	4.179 E+05	1	4.179 E+05	3.17	0.1003	
B-Feed Rate	1.116 E+06	1	1.116 E+06	8.47	0.0131	
C-Depth	3.634 E+05	1	3.634 E+05	2.76	0.1226	
Residual	1.581 E+06	12	1.318 E+05			
Lack Of Fit	1.487 E+06	11	1.352 E+05	1.43	0.5788	Not significant
Cor Total	3.480 E+06	15				

From table 7, it shows that for the model source are significant and lack of fit are not significant are good sign because this shows that the design fits the model. From the analysis, it states that model F value of 4.80 shows the model is significant. This means that it has a 2.01 % chance for F- value to occur due to noise. By analyzing further for the p- value, it shows that only for case B feed rate are significance due to the value which lesser than 0.0500. Further analyzed in the mean square column, from this model it shows that feed rate has the highest value obtained which is 1.16E+06. This shows that feed rate are the most contributing factor which affecting surface roughness. The Lack of Fit F-value of 1.43 implies the Lack of Fit is not significant relative to the pure error. There is a57.88% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good because we want the model to fit.

Table 8 : Fit Statistic

Std Dev	363.00		R^{22}	0.5457
Mean	631.42		**Adjusted** R^{22}	0.4321
C.V.%	57.49		**Predicted** R^{22}	0.1738
			Adeq Precision	6.7069

From the table 8 above, it shows that predicted R^2 of 0.1738 not as closed to adjusted R^2 of value 0.4321 which has a difference of more than 0.2. This may indicate a large block effect or a possible problem with your model and/or data. Things to consider are model reduction, response transformation, outliers, etc. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. From table 15, it shows a ratio of 6.707 indicates an adequate signal. This model can be used to navigate the design space.

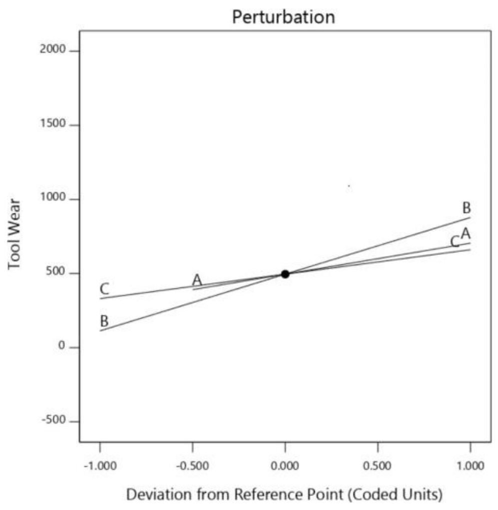

Figure 7 : Perturbation Graph On Tool Wear

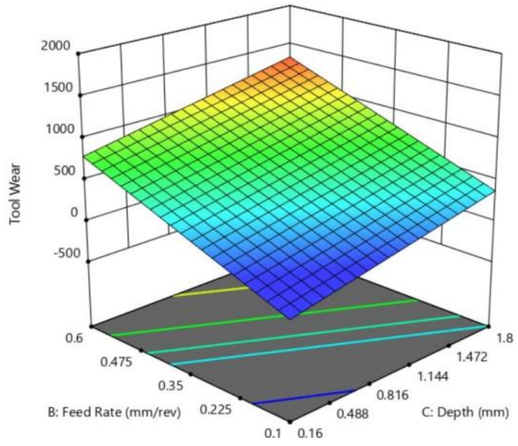

Figure 8 : 3D Graph On Feed Rate And Depth

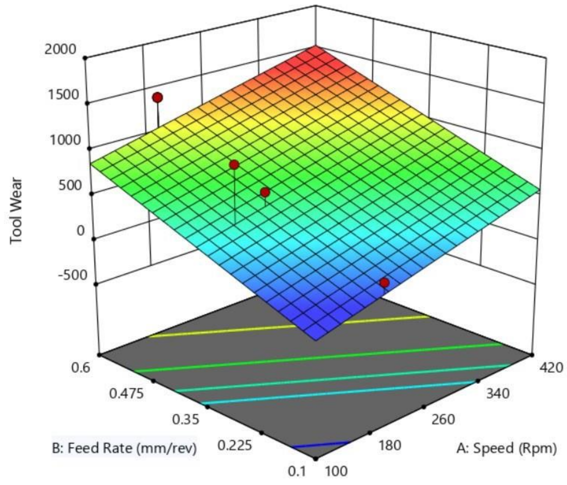

Figure 9 : 3D Graph On Feed Rate And Speed

From the graph obtained from Design Expert Software in figure 7, it shows that the steepest line are line B which also feed rate followed by depth of cut. Referring to the graph, the steepest line contributes to the highest factor for tool wear are feed rate and followed by depth of cut.. This is because, when the value of feed rate and depth of cut increases, the contact point between cutting tool and workpiece increases too. This especially causes high pressure acting on cutting tool which increases tool wear. However, speed in Rpm shows the lowest effect towards tool wear. This is becausethe cutting speed are set within a safe range which were reviewed in chapter 2 section which makes speed not influencing towards tool wear significantly.From figure 8, it shows that at when feed rate of 0.6 mm/rev and depth of cut 1.8 mm has the highest value for tool wear at the speed of 200 rpm. This can be observed in above 3D graph atthe red color zone where at the highest feed rate and depth of cut value leads to higher tool wear. However, when lowering down the value of feed rate and depth of cut which being observed in the blue color zone, leads to a lower tool wear value. Asdepth of cut and feed rate increases, tool wear increases too due to the higher contact point on cutting tool which gives higher pressure leads to higher tool wear value. Hence, to obtain lower toolwear value, lowering feed rate and depth of cut is an important parameter to be considered. Analyzing from figure 16, it shows that when speedat 420 rpm , feed rate at 0.6 mm/rev while depth ofcut being set to 1 mm shows the highest value toolwear. The reason why the value increases when speed and feed increases is because at higher speed and feed , it leads to higher crater wear occurring due high temperature produced during machining. The contact point of cutting tools and workpiece gives higher value of crater wear when feed increases at highest cutting speed. However, by increasing speed and decreasing feed rate value can still obtain a better tool wear value as we can see in the graph above where speed increases, it still within the green color zone. This is because, the value of feed rate has been decreases. Hence, in order for a poor tool wear from occurring, decreasing feed rate and speed can be considered.

5.0 Conclusion

This experiment focused on the cutting parameter which influenced the surface finish on titanium alloy and tool wear analysis for PVD coated carbide tools in dry turning operation. The cutting parameter chosen was speed, depth of cut and feedrate. From the experiment being done, it shows that for both surface roughness and tool wear are majorly influenced by feed rate followed by depth of cut. This is because as feed rate and depth of cut increases, both surface roughness and tool wear increases too.For a conclusion, the experiment done are considered as a successful experiment. The analysis and observation of surface finish and tool wear on titanium alloy and PVD coated carbide cutting tool had being identified. Both surface finish and tool wear based on cutting parameter were successfully analyzed.

Reference List

1. Ahsan, K. B., Mazid, A. M., Clegg, R. E.,& Pang, G. K. H. (2012). *Study on carbide cutting tool life using various cutting speeds for α - β Ti-alloy machining*. *55*(2), 600–606
2. City, Bhujbal Knowledge. 2020. “Challenges in Machining of Titanium Alloys with Proper Tooling & Machining Parameters - A Review” 16 (4): 25–43.
3. Dongre, G., Shaikh, J., Dhakad, L., Rajurkar, A., & Gaigole, P. (2017). *Analysis for Machining of Ti6Al4V Alloy using Coated and Non-Coated Carbide Tools*. *137*, 134–141. https://doi.org/10.2991/iccasp-16.2017.22
4. Ezugwu, E. O., & Wang, Z. M. (1997). *Materials Titanium alloys and their machinability*. *68*, 262–274
5. Ibrahim, G. A., Haron, C. H. C., & Ghani, J. A. (2009). *Surface integrity of Ti-6Al-4V ELI when machined using coated carbide tools under dry condition SURFACE INTEGRITY OF Ti-6Al-4V ELI WHEN MACHINED USING COATED CARBIDE TOOLS UNDER DRY CUTTIN GCONDITION*. *January*.
6. Kumar, C. H. R. V., & Ramamoorthy, B. (2007). *Performance of coated tools during hard turning under minimum fluid application*. *185*, 210–216. https://doi.org/10.1016/j.jmatprotec.2006.03.148
7. Machado, A., & Manufacturing, A. (2017). *Machining of titanium and its alloys : A review*. *January 1990*.
8. Nithyanandam, J., Das, S. L., & Palanikumar, K. (2015). *Influence of Cutting Parameters in Machining of Titanium Alloy*. *8*(April), 556–562.
9. Pawar, P., Joshi, S., Tewari, A., & Joshi, S. (2012). *Tool wear mechanisms in machining of titanium alloys*. *345*, 4–8.
10. Pramanik, A. (2014). Problems and solutions in machining of titanium alloys. *International Journal of Advanced Manufacturing Technology*, *70*(5–8), 919–928. https://doi.org/10.1007/s00170-013-5326-x
11. Taneja, J., Bector, M., & Kumar, R. (2012). *Application of Taguchi Method for Optimizing Turning Process by the effects of Machining Parameters*. *1*, 263–274.

1.2