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# PERFORMANCE OF CVD COATED CARBIDE TOOL BY OPTIMIZING MACHINING PARAMETERS DURING TURNING TITANIUM ALLOY Ti-6AL-4V ELI IN FLOODED CONDITION

M.S. Asiyah<sup>1</sup>, M.A. Sulaiman<sup>1</sup>, R. Shahmi<sup>1</sup>, R. Zuraimi<sup>1</sup>,  
E. Mohamad<sup>1</sup>, C.H. Che Haron<sup>2</sup> and J.A. Ghani<sup>2</sup>

<sup>1</sup>Faculty of Manufacturing Engineering,  
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,  
76100 Durian Tunggal, Melaka, Malaysia.

<sup>2</sup>Faculty of Engineering and Built Environment,  
Universiti Kebangsaan Malaysia,  
43600 Bangi, Selangor, Malaysia.

Corresponding Author's Email: mohdamri@utem.edu.my

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**ABSTRACT:** In metal cutting, one of the important elements which must seriously consider is cutting tools. Carbide cutting tool is widely used in machining process for various metal types. This paper presents the performance of cutting tools in turning Ti-6AL-4V ELI using the CVD coated carbide tool under flooded conditions. Experimental design of this study is based on Factorial method. Two Level Factorial designs were selected to arrange the cutting parameters of cutting speed with a range of 100 to 140m/min, feed rate with 0.15 to 0.20mm/rev, and depth of cut was kept constant at 0.35mm. Flank wear was measured using a three axis microscope. The values were recorded for each length of the workpiece until flank wear ( $V_{b_{avg}}$ ) average reaches the tool life criterion,  $V_{b_{avg}} = 0.3\text{mm}$  followed by International Standard ISO 3685. From the result obtained, it is found that lowest cutting speed and feed rate resulted in longer tool life while highest cutting speed and feed rate resulted in a much shorter tool life. Based on the ANOVA analysis, cutting speed is the most significant factor followed by feed rate. Mathematical modelling was developed and the error between experimental results and generated model is 19%. The optimum responses are obtained at cutting speed 100m/min, feed rate 0.15mm/rev, and this give out the longest tool life of 15.43minutes while shortest tool life, 4.07 minutes was obtained at cutting speed of 140m/min and feed rate 0.20 mm/rev. The error value of optimization between experimental and model is 0.19%. From this research, even though titanium alloy, Ti-6Al-4V is considered as material

with low machinability, there are suitable cutting parameters available to give out the longest tool life thus reducing machining cost.

**KEYWORDS:** *Tool Life; Titanium Alloy Ti-6Al-4V ELI; Two Level Factorial; Optimization*

## 1.0 INTRODUCTION

Chemical Vapor Deposition (CVD) carbide cutting tool is the types of cutting tools that are frequently used in metal cutting due to its availability, performance and being cheaper than diamond and cubic boron nitride. During machining, the cutting edge wear is fast and extensive due to friction, high temperature, and load [1]. In usual cases of cutting tool usage, it will be used until they reach their maximum tool wear which can vary in the duration of the usage. Prior research that is regarding the cutting tool life always focuses on the elimination or minimization of the tool wear. The improvement of the cutting tool's wear will result in cost reduction and quality surface improvement during machining. Coated carbide tools are used extensively in the metal industry, especially for material removing process such as turning operations [1-2]. There are several causes that permitted tool failure in the course of machining that uses carbide cutting tool under normal cutting conditions and one of it is flank wear [3-4]. Investigations were carried out in order to study the tool wear on some cutting tool materials [5]. It is concluded from the research that flank wear criterion can be found by using the plotted tool life and in addition to that, discover that by using high speed in turning operation will ultimately lead to a shorter tool life.

Another aspect that needs to be considered in affecting the cutting tool life is the material to be machined. Carbide cutting tool can machine a great deal of material types and this includes some super alloy such as Titanium alloy, Inconel 718, etc. These types of material are difficult to be machined due to its fabulous characteristics such as high specific strength or are often known as strength-to-weight ratio, which is upheld at elevated temperature, their resistance to fracture is very high and excellent corrosion resistance even when subjected to high heat or thermal activity [6-9]. Another way in optimizing the tool life is by studying the tool wear behavior and controlling the

machining parameters [10]. Therefore, the aim of this paper was to investigate the influence of machining parameters to the tool wear of the CVD carbide tool during turning of Ti-6Al-4V ELI. The machining operation was performed under flooded conditions.

## 2.0 EXPERIMENTAL

The work material used in the experiment is titanium alloy Ti-6Al-4V ELI with 32 HRC/317 HV and additional with Extra Low Interstitial. The titanium used is in cylindrical shape with its diameter 100mm and 150mm length. In this experiment, the cutting tool used is CVD coated carbide inserts from Sandvik with rhombus shape CNGG 120408 SGF S05F.

Two level factorial designs were used to conduct the experiment. The factorial designs from the Design Expert software was created to cover all possible combinations of machining parameters; cutting speed, feed rate, and depth of cut. The machining experiments were performed in flooded condition. The cutting parameters used during the experiment are shown in Table 1. The selection of cutting parameter is based on the previous research, but a different cutting cooling condition.

Table 1: Cutting process parameter

Factors	Level	
	-1	1
Cutting speed, $v$ (m/min)	100	140
Feed rate, $f$ (mm/rev)	0.15	0.2
Depth of cut, $d$ (mm)	0.5	

Optical microscope was used for the measurement of flank wear on the cutting tool by either according to the average flank wear ( $V_{bavg}$ ) or maximum flank wear ( $V_{bmax}$ ). The turning operation tested and stopped until the  $V_{bavg}$  reached 0.3mm. The 0.3mm  $V_b$  is the standard recommended criteria which define a tool life endpoint by the ISO 3685:1993. The data were recorded after completing each of cutting length set.

### 3.0 RESULT AND DISCUSSION

#### 3.1 Tool Life

Table 2 shows the CVD carbide cutting tool life in minutes respected to each of the parameters. The cutting tool that was chosen to assess the tool life performance is CVD carbide tool and the experiment is conducted under flooded machining. In order to fulfil the design experiment requirement, six experiments were conducted at various cutting speeds of 100, 120 and 140 m/min respectively. Result on the Table 2 shows the maximum value of tool life is 15.43 minutes with cutting speed of 100 m/min and feed rate of 0.15 mm/rev. While the minimum value obtained by cutting speed of 140 m/min and feed rate of 0.20 mm/rev with 4.07 minutes.

Table 2: Experimental results

Run	Factor 1 A:Cutting Speed (m/min)	Factor 2 B:Feed Rate (mm/rev)	Responses Tool Life (minute/s)
1	100	0.20	13.85
2	120	0.17	6.53
3	140	0.20	4.07
4	100	0.15	15.43
5	140	0.15	6.48
6	120	0.17	7.18

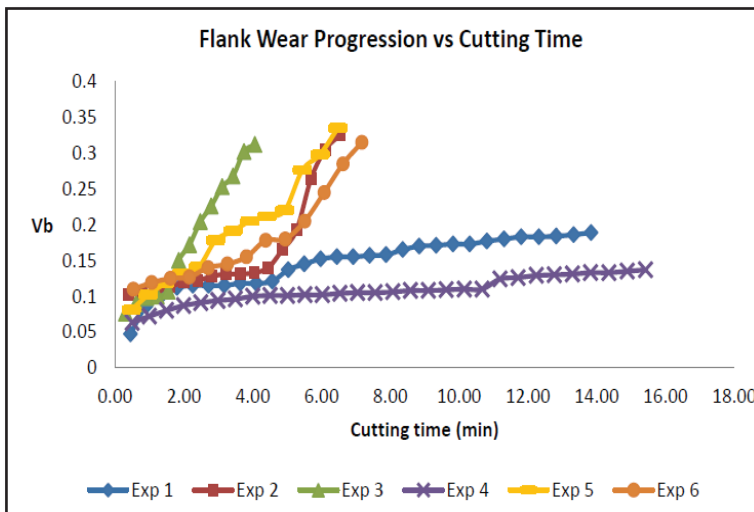


Figure 1: Graphical representation of the experiments results

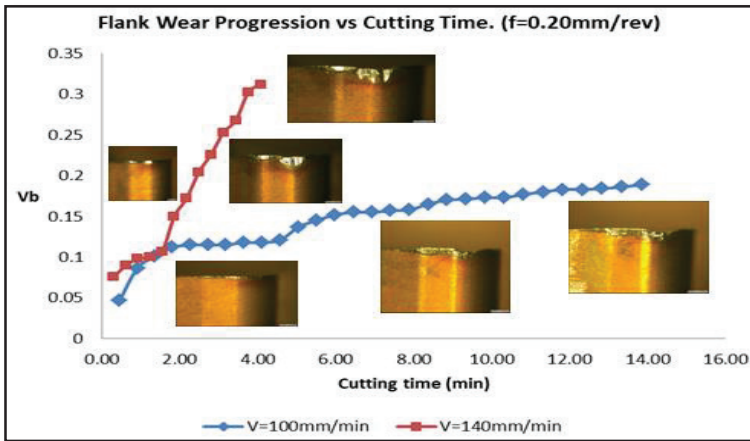
Figure 1 shows the graphical representation of the experiments results flank wear progression vs. cutting time for each of the experiment. It is shown that experiment with the lowest cutting speed (100m/min) produces the longest tool life compared to experiment with a much higher value of cutting speed 120 and 140 m/min.

### **3.2 Wear Progression on Cutting Tool**

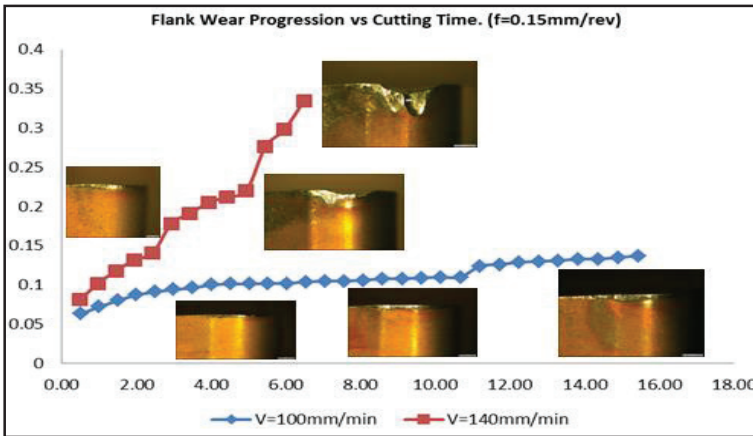
Determining the tool life of a cutting tool is usually measured by the flank wear. The main reason for this is because flank wear measurement is very simple with the help of equipment such as a toolmaker microscope while other criterion of flank wear such as crater wear requires more complex method and advance measurement instrument such as SEM (Scanning Electron Microscope). Figures 2(a-b) show the comparison of the experimental results were made in respect to different cutting speed and feed rate. It is found that the tool wear progression can be classified to three stages which are:

- Early stage with quick, small but steady wear rate
- Middle stage with almost constant wear rate
- Final stage with the drastic increase of tool wear

This finding was agreeable with other previous studies which found the wear occurred rapidly at the initial stage, gradually increased at the second stage and extremely increased at the final stage [6–10].



(a)



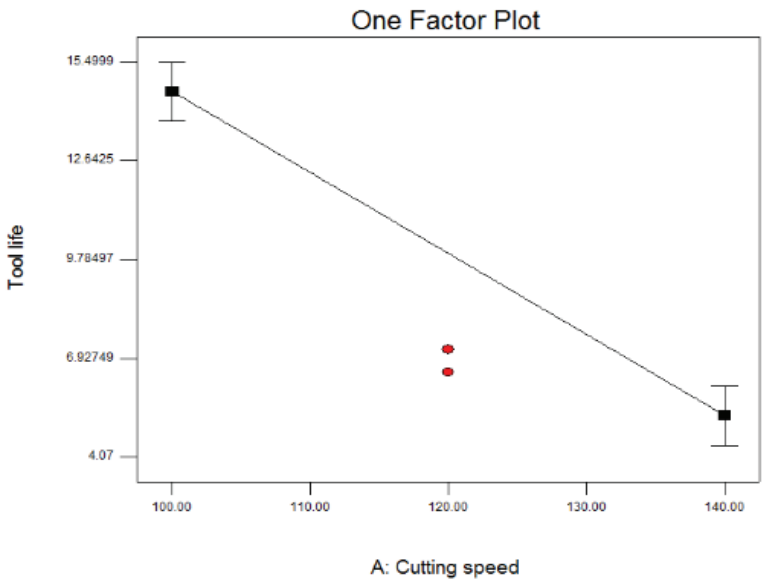
(b)

Figure 2: (a) Progressions of flank wear and (b) tool life (min) for different cutting speed and feed rate values with depth of cut kept constant at 0.5mm

Figure 2(a) shows the tool wear progression and tool life in minute for cutting speed 100 and 140 m/min, at feed rate 0.2 mm/rev. It is shown that the longest tool life, 13.85 min was produced at cutting speed 100 mm/min compared to 140 mm/min, 4.07 min. Same pattern was found in Figure 2(b), where the highest cutting speed produced shorter tool life, 6.48 min meanwhile longer tool life, 15.43 min at low cutting speed. Besides, from these figures, it found that increase the feed rate values, 0.15 to 0.2 mm/rev, the tool life was slightly reduced almost 2 minutes, 15.43 to 13.85 minutes. From these results, increasing the cutting speed and feed rate will reduce the tool life related to flank wear.

At the highest cutting speed and feed rate, high temperature generated at cutting zone where contributed to high wear on the flank and as a result of this, tool wear ( $V_{bav}$ ) increase rapidly thus reduces the tool life. Luo et al. [10] observed that when the temperature is very high due to a greater cutting speed, the layer on the tool face become soft. Hence it would be easily abraded by the hard particle of the work material, causing the tool wear to be accelerated. From the results, it can be concluded; changes in cutting speed were seen to be the dominant factor in determining the tool life while the feed rate less significant. However, feed rate primal effect on surface roughness of the machined surface.

Figures 3(a) and 3(b) showed the slope patterns and interaction between tool life vs cutting speed, and tool life vs feed rate respectively. From these results that were obtained, it can be concluded that the increase of cutting speed and feed rate will reduce the tool life related to flank wear. High temperature that were generated during machining are among the factors that influence the wear on the flank due to the higher cutting speed and ultimately reduce the tool life. The higher cutting speed of machining, higher temperature will be generated to the cutting zone even with the presence of coolant [11].



(a)



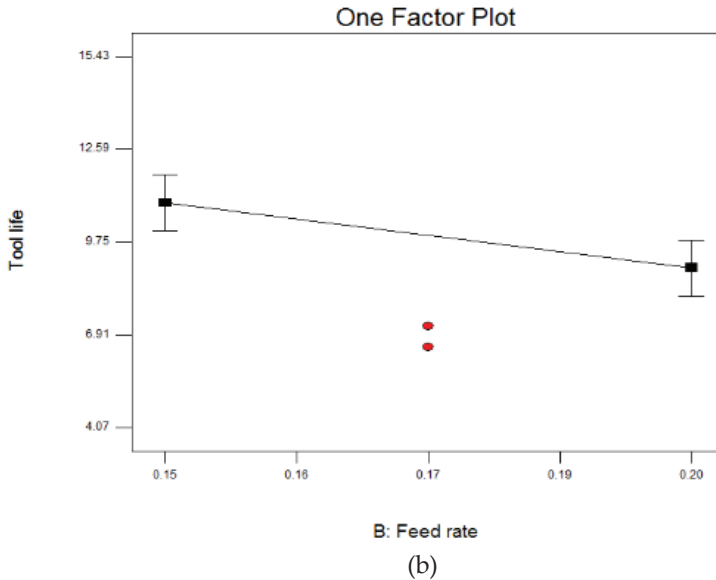


Figure 3: (a) Slope patterns and (b) interaction between tool life vs cutting speed and tool life vs feed rate respectively

It was also observed that machining under flooded condition does not imply a significant difference on tool wear compared to dry machining due to the high speed of machining [12]. Aside from the high temperature accumulated, high stress that were generated on the cutting tool are also among the factor that contributed tool wear and making both of these factors a significant cause of tool wear. During machining, due to the high speed machining that were used, it will ultimately results to a higher shear stress on the cutting tool material which are beyond its ability to withstand and in extension to that, this will lead to a failed cutting tool by fracture.

### 3.3 Tool Life Modeling

On the analysis stage, the analysis of variance (ANOVA) was selected. Confidence level of 95% was used for the analysis with the model type with p-value (Prob> F) less than 0.05 are considered significant. Table 3 below shows the tool life model for ANOVA where the prob> F is < 0.001 is much lower than significant value (0.05) that indicate model terms are significant. In this analysis where A is cutting speed and B is feed rate, both of the model are significant with the value of "Lack of Fit" = 0.82 which means that it is not significant and the tool life model fits. The final equation in terms of actual factors;

$$\text{Tool Life} = 45.035 - 0.234 * \text{Cutting Speed} - 39.9 * \text{Feed Rate} \quad (1)$$

The predicted data that were acquired from the mathematical model can be compared with the actual tool life data from the experiment by using the Equation (1).

Table 3: ANOVA for tool life model

Sources	Sum of Squares	Degree of Freedom	Mean Square	F Value	Prob > F	Condition
Model	91.68	2	45.84	239.09	0.0042	Significant
A	87.70	1	87.70	457.41	0.0022	
B	3.98	1	3.98	20.76	0.0450	
Curvature	12.83	1	12.83	66.94	0.0146	Significant
Residual	0.38	2	0.19			
Lack of Fit	0.17	1	0.17	0.82	0.5324	Not Significant
Pure Error	0.21	1	0.21			
Total	104.90	5				

Parameter optimizations are conducted to identify the combination of factor levels that satisfies the requirements placed on each response and factors [13]. Through RSM and careful design of the experiments, a maximized cutting tool lifetime can be efficiently achieved by the optimization of a response (output variable) that is influenced by several independent variables (input variables). The numerical optimization for tool life model improvement that was conducted is shown in Table 4. The goal of this optimization was set to maximum indicating that the tool life will be optimized until the maximum value is obtained. The lower limit and upper limit for the optimization is selected from the experimental data itself with the value of 4.07 minutes and 15.43 minutes of tool life. The cutting speed and feed rate that were set in range is between 100-140 m/min and 0.15-0.20mm/rev respectively.

The solutions generated by the Design Expert Software are shown in Table 4. There are a number of solutions suggested by the software and it is ranked by the most optimum parameter and followed by other value of optimization parameter. The first rank parameter is the best for optimization; hence it is selected for optimization parameters. The high desirability will be selected for the confirmatory trial [10-13].

Table 4: Optimization parameters

	A:Cutting speed, m/min	B:Feed rate, mm/rev	Tool Life, min
DOE	100.27	0.15	15.46
Validate	100.27	0.15	15.43
% error			0.19

The error in Table 4 that was obtained which is 0.19% is also calculated to measure the uncontrollable factors in the experiment which is noise.

## 4.0 CONCLUSION

Throughout this experiment, CVD carbide tools are able to machined titanium alloy Ti-6Al-4V ELI at low cutting speed in flooded condition. The tool wear progression has a distinct pattern in which once the wear progression reaches  $V_b = 0.20$  mm the wear will increase drastically until it reaches 0.30 mm. It was found that higher cutting speed and feed rate will result in shorter tool life and in contrary low cutting speed and feed rate will increase tool life. Besides, ANOVA analysis also indicates that cutting speed is most significant factor in determining the tool life than feed rate.

## ACKNOWLEDGMENTS

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