TOOL LIFE INVESTIGATION IN DRY TURNING OF INCONEL 718 WITH PVD TiAlN-COATED WC INSERT

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ABSTRACT

Performance of tool life for coated carbide tool during turning Inconel 718 in dry condition was studied in order to increase the efficiency in turning process and reduce the machining cost. Coated carbide tool with thin layer of PVD TiAlN, CNMG 120408-QM 1105 was used to turn Inconel 718 with hardness 20.25 HRC. Taguchi method with the orthogonal array L_9 was use in this experiment with the parameter v=60, 70, 80m/min, f=0.2,0.25,0.3mm/rev and d=0.3, 0.4, 0.5mm. Signal-to-noise ratio and analysis of variance (ANOVA) were employed to study the performance of tool life. According to results, cutting speed was significantly influence to the tool life, followed by feed rate and depth of cut. Increment in speed and feed rate will increase flank wear and shorten the tool life. v=60m/min, f=0.2mm/rev and d=0.3mm is the optimum parameter for tool life. It was discovered that flank wear rate gradually increase in the initial machining and accelerate significantly after flank wear width reach 0.1mm. Flank wear, crater wear, notch wear and nose wear are the wear occurs on the carbide tool during turning Inconel 718. Through the SEM, abrasion, attrition and adhesion are the wear mechanisms which can be seen on the cutting tool.

Keywords: *Dry Turning, Inconel 718, Tool life, Flank wear, Taguchi method.*

INTRODUCTION

Inconel 718 is one of the important alloys among the Nickel and Nickel-based alloy. Inconel 718 has found its niche in many industries, owing to its unique properties such as high oxidation resistance, corrosion resistance even at very high temperatures and retains a high mechanical strength under these conditions as well. This material is widely used in as aircraft engine parts, chemical processing, pressure vessels, steam turbine power plants, space vehicles, medical applications, marine applications, pollution control equipment, and automotive sector.

Inconel 718 is considered to be most difficult to machine materials. Its high alloy content and high strength even at elevated temperatures offers plastic deformation resistance during machining that leads to rapid work hardening. These conditions create the formation of sub surface residual stresses at the machined surface that further causes dimensional instability (K.Srinivasulu 2008). Its low thermal conductivity causes high temperature is generated at tool tip even at low cutting speed. Good mechanical properties together with work hardening lead to increase cutting force (Liao 2008) and it causes many problem and leads to early tool failure. In addition chips are easy to weld on the tool to form build up edge (BUE) (Alauddin 1996). Even though this nickel-based alloy contains carbide particle (Cr, TiC, WC) as to improve creep resistance (Krain 2007), it consists of abrasive carbide that contributes to a reduction in tool life (Sharman 2001).

Planning the experiments through the Taguchi orthogonal array has been used quite successfully in process optimization by Hwang (2009), Tzeng (2009), etc. Therefore, this study applied a Taguchi L9 orthogonal array to plan the experiments on turning operations. Three controlling factors including cutting speed, feed rate, depth of cut with three levels for each factor were selected. The S/N ratio analysis is then applied to examine how the turning operation factors influent the tool life. An optimal parameter combination was then obtained. Additionally, the ANOVA was also utilized to examine the most significant factors for the turning process.

EXPERIMENTAL WORK

The work material used in the experiment is Inconel 718 which contains C 0.05, Mn 0.05, Si 0.09, P 0.007, S 0.001, Cr 18.19, Ni 53.59, Co 0.04, Mo 3.03, Nb+Ta 5.30, Ti 0.94, Al 0.60, B 0.004, Ta 0.001, Cu 0.02, Fe 18.30, Ca <0.01, Mg <0.0025, Pb < 0.0001, Bi 0.00001, Se <0.0001, Nb 5.3. with a hardness value hardness 20.25 HRC. The geometry of the work material is 195mm length and 102.8 mm round. A standard tool holder (DCLNR 2020 K 12) with 125mm length was used in the exprimental work along with PVC TiAlN coated tool inserts ISO designation of CNMG 12 04 08-QM. The side cutting edge angle, rake angle (γ) and inclination angle (λ) are 95°, -5° and -6° respectively, nose radius is 0.8mm. Several turning test were performed under controllable cutting condition to minimise error. Nine inserts were evaluated at three diferent combination of cutting parameter. The cutting parameters were used during experiment are shown in Table 1. No coolant was used during experiment.

Table 1 Lathe experiment plan

Factor	Level		
	1	2	3
Speed, *v* (m/min)	60	70	80
Feed, *f* (mm/rev)	0.20	0.25	0.30
Depth of cut, *d* (mm)	0.3	0.4	0.5

Experiment procedure

Turning experiments of Inconel 718 were performed using turning operation on a CNC Turning Tornado T4 with maximum spindle speed of 6000 rpm. Below are experiment procedure to evaluate the carbide insert tool life accordance with the ISO 3684:1993 standard. Figure 1 shows the flowchart of the process:

1. Sample will be cut into small length to that a length/diameter ratio not greater than 10. Material end will be supported to avoid chattering during machining.
2. Before experiment, the workpiece will be clean-up cut by 2 mm to removed any scale on the surface.
3. CNC will be programmed according to specified speed, feed and depth of cut.
4. After cutting length reach 20mm, turning machine will be stopped. Cutting tool will be dismounted form the machine. Here, TiAlN insert and inconel chip will be examined under 3-axis Mitutoyo microscope.
5. Relationship between service duration and width of the flank wear land will be observed. The flank wear will be measured at different time intervals (which is converted from the distance of tool travel) during turning. Thus, value for the width of flank wear VB_B will be recorded every subsequent 20mm.

6. The flank wear limit based on ISO standard which are 0.3mm and 0.6 for flank wear average, V_B and flank wear maximum, V_B max respectively. Hence, experiment will be continued until the value of flank wear reach the limit. The selection of cutting speeds shall be chosen so that the tool life at high speed exceed 5 minutes. The experiment will be immediately stopped if premature or catastropic failure occure.
7. Further observation using SEM will be done to observe thoroughly especially wear land and particle that adhered on the insert surface.
8. Similar process will be done for the rest of the parameters.

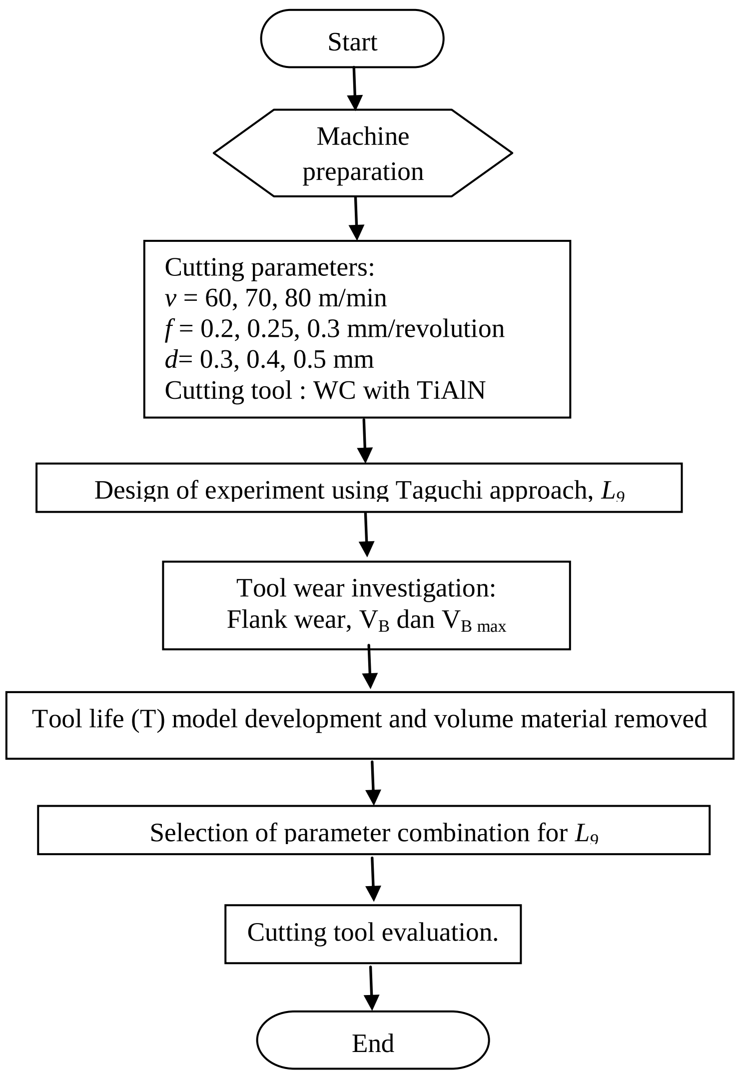


Figure 1 Experimental procedure

Experiment design

The purpose of this experiment is to identify the parameter effect on cutting tool life. Taguchi approach has been chosen in developing design of experiment. In the Taguchi method, the signal to noise ratio (S/N) was used for a noise-insensitive design.

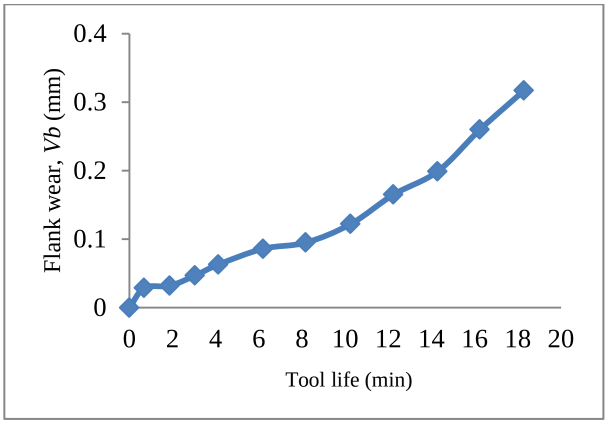
The goal of this research was to produce maximum tool life in Inconel turning operation. Bigger T values represent better or improved tool life. Therefore, a bigger the better quality characteristic was implemented and introduced in this study (Montgomery 2007). The larger the S/N ratio, the more insensitive to noise; In this study, the main effect plot of the S/N ratio will be analyzed to propose a combination of cutting condition which is insensitive to noise. Total nine number of experiment has been performed randomly according Taguchi L_9 orthogonal arrangement. Table 2 shows the experiment design.

Table 2 Experiment design using Orthogonal Taguchi L9

Experiment	Factor		
	1	**2**	**3**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

RESULT AND DISCUSSION

There were nine experiment sessions have been done with different parameters, the value of flank wear was recorded to plot flank wear-cutting time graph. It was discovered that the wear pattern is quite similar between experiments. Figure 2a is one of the experiment results; it shows the longest time recorded during Inconel 718 machining time. The shape of wear patterns are similar with the typical graph of flank wear done by previous experimenter (Figure 2b) such as Groover (2007), Boothroyd (1989) and so forth. Tool wear at beginning stage of machining and increase steadily. Once flank wear, V_B reaches 0.1 mm, wear rate become worse. Experiment will be stopped when V_B reach the wear limit which is 0.3 mm.



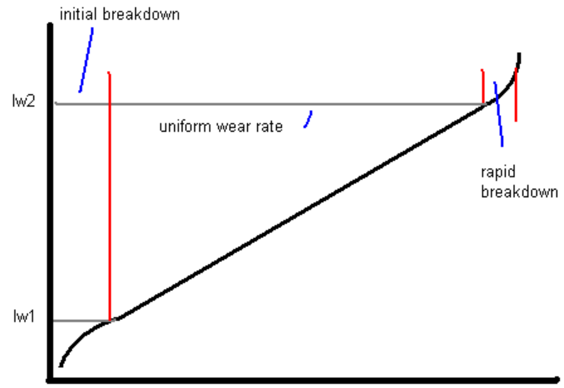


Figure 2 Flank wear-tool life graph (a) Experiment 1: v = 60 m/min, f =0.2 mm/revolution, d =0.3 mm; (b) Typical wear rate (G.K. Lal, 2005)

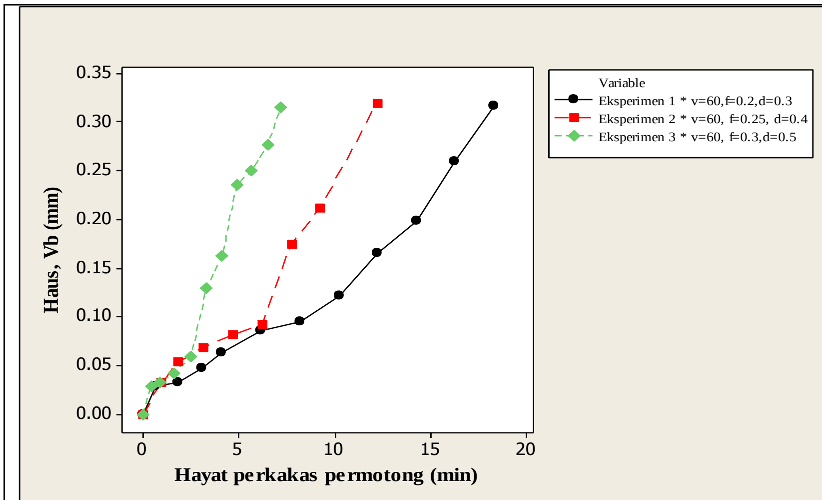
Table 3 is an experiment result using Taguchi approach. It was recorded that the machining time from various parameters were between 8-18 minutes to reach tool failure.

Table 3. Experiment result using Taguchi method.

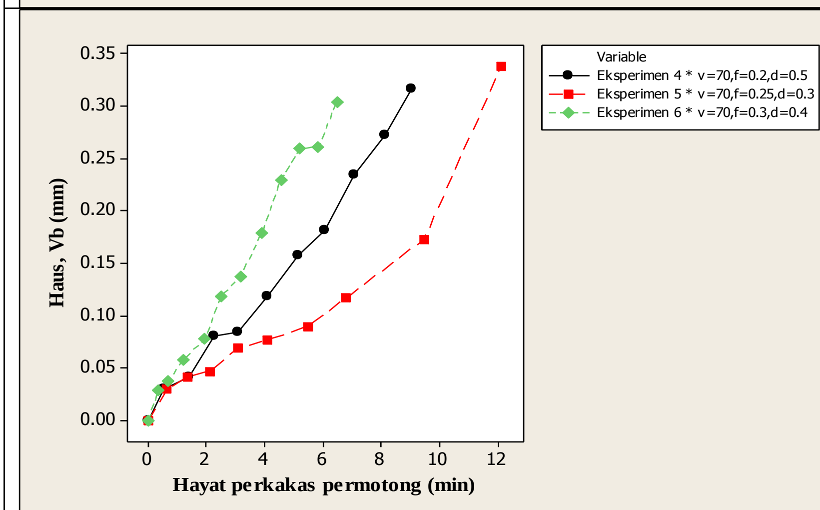
Experiment	1 (v)	2 (f)	3 (d)	V_B(mm)	$V_{B\ max}$ (mm)	Cutting tool life (min)	Surface roughness (µm)
1	1	1	1	0.317	0.348	18.23	2.3160
2	1	2	2	0.319	0.389	12.21	2.5895
3	1	3	3	0.315	0.394	7.19	1.4425
4	2	1	3	0.317	0.364	9.10	1.1740
5	2	2	1	0.338	0.479	12.12	1.1890
6	2	3	2	0.304	0.362	6.48	1.0440
7	3	1	2	0.354	0.425	10.6	1.8720
8	3	2	3	0.331	0.410	8.2	3.8070
9	3	3	1	0.316	0.436	10.10	5.1515

The data gathered during experiment was compiled as shown in Table 4, from these three graphs, generally can be seen that the combination feed rate and depth of cut under constant speed lowering cutting tool life.

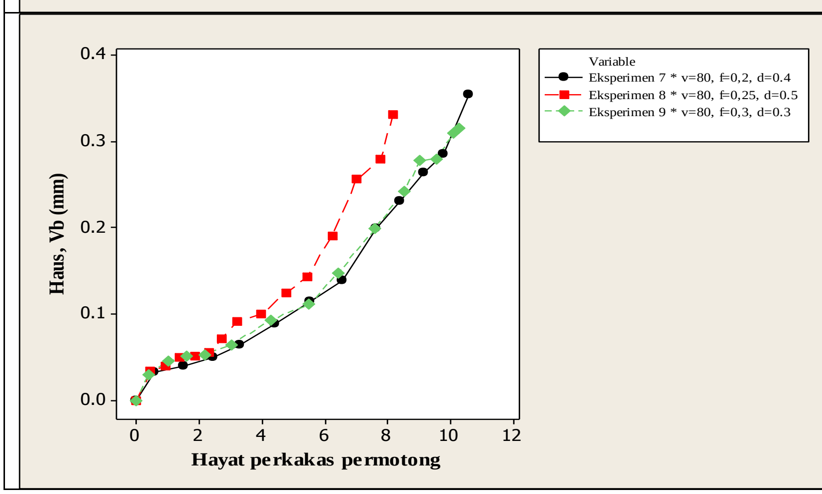
Table 4 Comparison wear rate at different speed



V = 60 m/min



V = 70 m/min



V = 80 m/min

Figure 3 is the comparison effect of depth of cut on tool life. Generally, It can be seen that the higher depth of cut the shorter tool life.

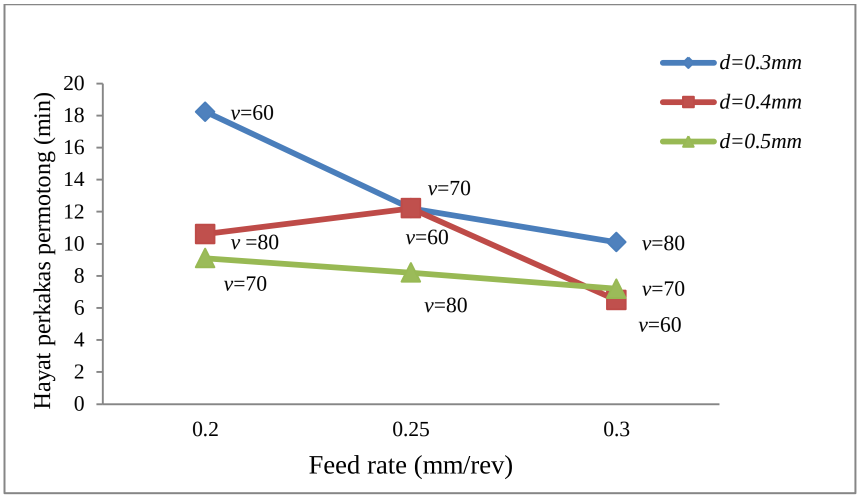


Figure 3 Tool life vs. Feed rate

Cutting parameter analysis

Minitab has been chosen in analyzing result, P value for depth for depth of cut, *d* and feed rate, *f* are 0.019 and 0.022, which are below α = 0.05 of significant level, whereas P value for speed, V is 0.055, slightly more than α= 0.05, Therefore, at 95% confident interval, P value indicates depth of cut and feed rate significantly contribute to tool life. These parameter levels are valid for experiment.

Figure 4 shows the response table and main effect plot each factor in dry turning in order to increase tool life. From these result, cutting speed proved to be the most important factor in selecting combination of cutting conditions. For the S/N ratio, the optimal combination consisted of depth of cut level 1, feed rate level 1 and speed level 1 proved the longest tool life. Additionally, Table 5 gives the results of the analysis of variance (ANOVA). According to result, the factor A, the cutting speed with 69.83% of contribution, is the most significant controlled parameters for the turning operation; followed by feed rate with 29.51% contribution and depth of cut with 0.66%.

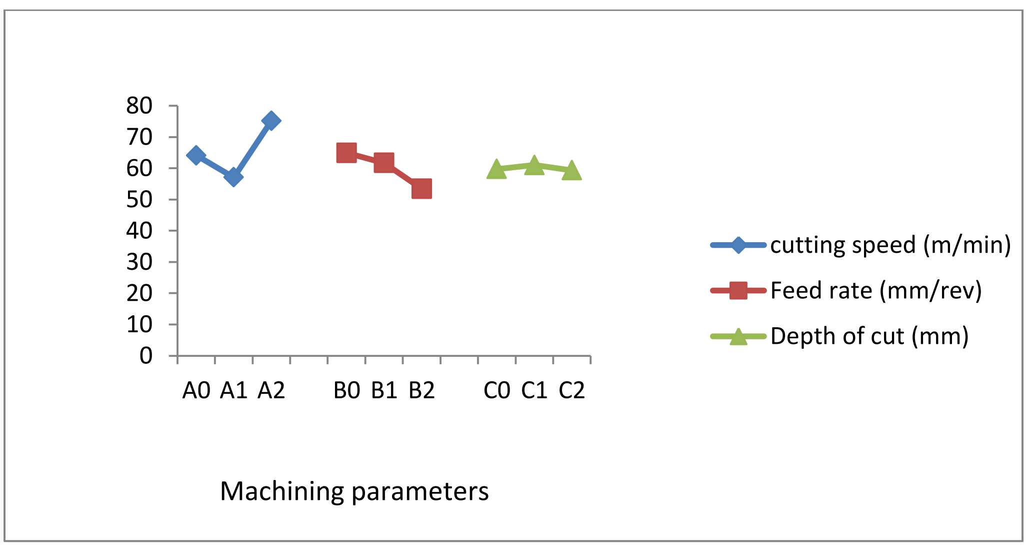
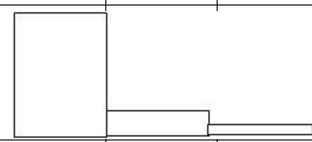


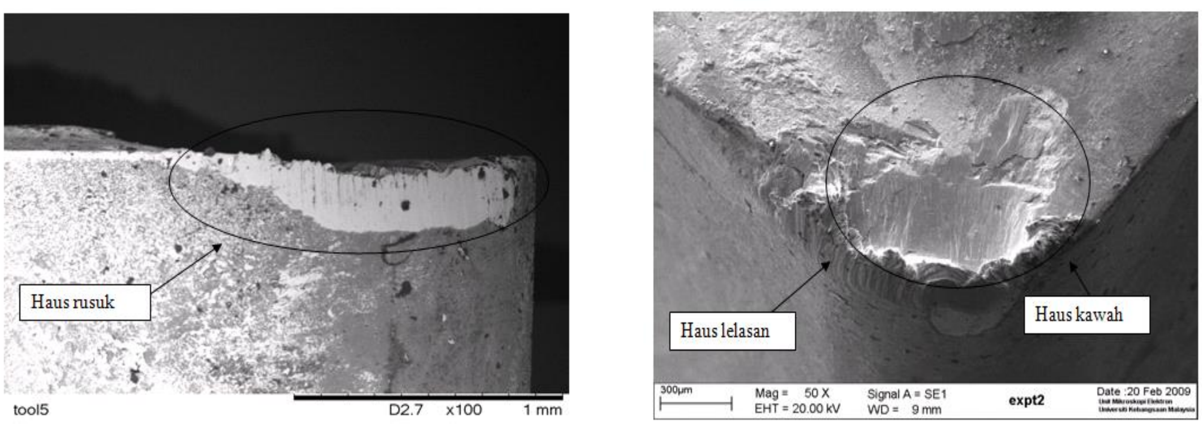
Figure 4 Main effects plot for S/N ratios (dry cutting, tool life)

Table 5 Pareto ANOVA for tool life (dry cutting, tool life)

Factor and Interaction		A speed	B Feed	C doc
Sum at factor	0	64.08	64.90	59.72
	1	57.08	61.68	61.00
	2	75.10	53.45	59.31
Sum of Sqrs of diff (S)		495.02	209.19	4.66
Contribution ratio(%)		69.83	29.51	0.66
Pareto Diagram				
Cumulative contribution		69.83	99.31	100

Wear

Flank wear, notch wear, nose wear and crater wear are the failures that occur in machining Inconel. It agrees with Devillez et al (2007) conclusion, mentioning that flank wear and notch wear are major mode of failure in turning of Inconel. Study by Ezugwu et al (2004) found the dominant failure was nose wear. Muammer et al. (2007) also found build-up edge, flank edge wear and crater wear during machining.



(a) (b)

Figure 5 Severe flank wear (a) abrasive wear and notch wear (b)

As shown in Figure 1, several types of tool wear were exhibited, flank wear occurred at flank tool region and results from abrasion between newly machined workpiece and tool contact area, plastic deformation. Crater wear occurs on the tool rake surface, it was affected by thermal softening or diffusion wear. As the cutting speed is increased, adhesive and abrasive wear rates increase because of increase of cutting temperature and rate of distance slid. Here, the hardness of material drops known as thermal softening which lead to increase abrasive wear and plastic deformation at the cutting edge. According to Ezugwu et al. (2003), poor themal conductivity of Inconel 718 causes local cutting temperature which exceed 1000ºC and then increases the rate of fusion. Build up edge (BUE) formation caused by significant adhesive phenomenon during turning as shown in Figure 6, this formation occurred when small particle of Inconel adhere to edge of cutting tool due to friction during chip flow and caused crater wear at the rake face of cutting tool.

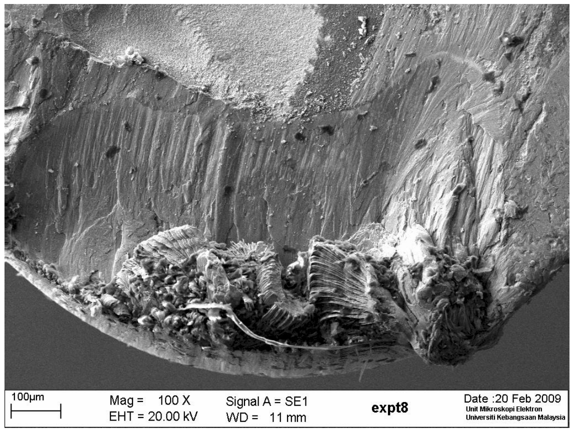


Figure 6 Edge buildup (BUE) on a TiAlN tool used to machine Inconel 718 at a low cutting speed.

The specimen underwent microanalysis using SEM/EDAX indicated that adhesion (attrition) and diffusion between two material (cutting tool and workpiece) when turning under dry condition. The strong bonding revealed between the chip and tool material at high temperature as those shown in Figure 7.

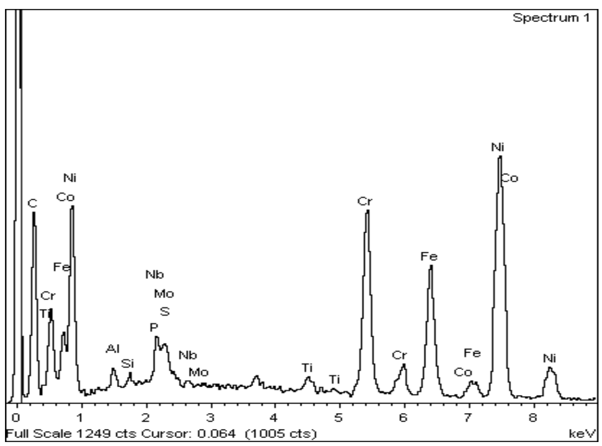


Figure 7 SEM EDAX indicates workpiece element adhered on the tool surface

An apparent sticking layer formed on the tool face near cutting edge indicates that bonding between chip-tool interface had occured. The bonding is likely originated from the driving force of very large stresses or high chemical affinity between tool and chip. This leads to tool failure when the sticking layer peel the TiAlN coating of cermented carbide tool and expose the base material (WC) for further tool wear.

CONCLUSIONS

In this study, evaluation of tool life of Inconel turning 718 using TiAlN is carried out with variable such as change in depth of cut, feed rate and speed under dry cutting condition. The analytical results are summarized as follows:

1. From the graphs of tool wear, it can be seen that the wear of insert can be segeregated into three distinch phases, initial breakdown condition, uniform wear rate during second phase and rapid breakdown during final phase. It was recorded that tool life ranged between 6-18 minutes.
2. Flank wear, crater wear, notch wear and flaking occured during experiment. Crater wear can be seen during inital stage of experiment experiment. Abrasive and adhesive wear mechanism contribute to the failure of cutting tool.
3. The research results shows that the flank wear grow slowly during initial stage and become uniform in high slope after VB reach 01 mm. Depth of cut is considered as prime factor that significantly influence tool life, followed by feed rate and cutting speed.
4. Through ANOVA, the percentage of contribution to the turning process, in sequence, is the cutting speed, the feed rate, and depth of cut with 69.83, 29.51 and 0.66 respectively. Hence, the cutting speed is the most significant controlled factor for the turning operation when the tool life is considered.
5. Optimum cutting parameters for Inconel 718 dry turning parameter are v = 60 m/min, f = 0.2 mm/revolution, d = 0.3 mm.

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