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# 9[illegible]NTERNATIONAL CONFERENCE
# on [illegible]ALITY in RESEARCH (QiR)

# PROCEEDING

## Industrial, Manufacturing, Material Engineering, and Management
## VOL II

Depok, 6 - 7 September 2006

UNIVERSITY OF INDONESIA
FACULTY OF ENGINEERING

Yanvar Abu Fairuz

# FOREWORDS from

## Dean of Faculty of Engineering, University of Indonesia

The Conference on Quality in Research (QIR) is annual event organized by the Faculty of Engineering, University of Indonesia. Since started in 1998, it has become an excellent forum of discussion for all researchers from research institutions and universities all over the country of Indonesia. The 1st and 6th conference on QIR had been successfully organized as a high quality national conferences, and starting from 7th conference on QIR, the conference has been organized to invite presentations of research papers internationally.

The 9th International Conference on Quality in Research having a theme of "Gaining Competitive Advantages Through Engineering Research" is to provide an international forum for exchange of the knowledge, information, experience and results as well as the review of progress and discussion on the state of the art and future trend various issues and developments in the multifield of scientific and technology. The main purposes of this conference are to provide a forum for free discussion of new ideas, development and applications, including techniques and methods to stimulate and inspire pioneering work, to provide opportunities for students and young engineers to meet their experienced peer and to provide a meeting that will enforce progress, stimulate growth and advance the state of knowledge in the multifield of science and technology.

We would like to express our heartiest to thank to all authors and participants for their active participations in the 9th International Conference on Quality in Research – QIR 2006, and also to all the paper reviewers, member of the technical committees, and member of the organizing committees, for their support to the success of this conference. Last but not least, we would also like to invite all participants to the next conference on Quality in Research – QIR 2007.

Faculty of Engineering, University of Indonesia
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# FOREWORDS

The 9th International Conference on Quality in Research (QIR) having a theme of "Gaining Competitive Advantages Through Engineering Research" being the third time to go internationally, has invited limited papers from other country like Japan and Malaysia. The conference is organized in parallel session focusing on the 6 (six) research areas such that many researchers and peer groups may focus their discussion on the relevant topics. All submitted papers had been reviewed by the technical committees appointed and had been arranged in to 6 (six) sub-themes according to the following fields:

- Energy, Process and Environmental Engineering and Management
  Energy and environmental issues, combustion technology, fluid mechanics and thermal fluid machinery, thermodynamics and heat transfer, geotechnical and environmental engineering, etc
- Industrial, Manufacturing, Material Engineering, and Management
  Production Engineering, Supply Chain Management, Innovation System, Maintenance System, Quality Management System, Human Factors Engineering, Organizational System, Fabrication and Industrial Automation, Manufacturing System: Control Management and Information Technology, CAD/CAM/CIM, etc
- Biomaterial, Biomedical Engineering and Biotechnology
  Biomedical numerical modeling, Biomaterial, Biosensor, Biocompatibility, Biomechanics, Biotechnology, Biomedical Instrumentation, Biomedical Imaging
- Design and Infrastructure Engineering and Management
  Product design and development, composite: materials and applications, structural dynamics, mechanics of materials, Construction Management, Public Infrastructures and Services, Structural Engineering, etc
- Information and Computation Engineering
- Nanotechnology
  Nano structured material, Nanotechnology, Nanocomposite, Nanoporous Materials, MEMS, Self Assembled Monolayer, Thin Film, Nanomagnetic Materials, Etc

The main purposes of this conference are to provide a forum for free discussion of new ideas, development and applications, including techniques and methods to stimulate and inspire pioneering work, to provide opportunities for students and young engineers to meet their experienced peer and to provide a meeting that will enforce progress, stimulate growth and advance the state of knowledge in the multifield of science and technology.

The Organizing Committee,
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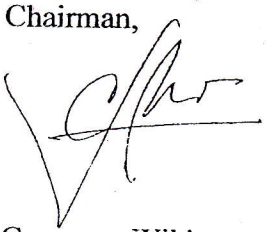

Gunawan Wibisono, Ph.D

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HALAMAN PENGESAHAN

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No. / /2009 Tanggal: / /2009

| | |
|---|---|
| Judul | : **Effects of Cutting Conditions and Chip Formation in Titanium Alloy Machining.** |
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Dengan ini menyatakan sebenarnya bahwa artikel saya yang berjudul: " **Effects of Cutting Conditions and Chip Formation in Titanium Alloy Machining"** adalah benar telah terbit pada **Proceeding of The 9th International Conference on Quality Research, Vol. II: Industrial, Manufacturing, Material Engineering and Management, Depok, Indonesia, 2007.**

Dalam artikel Prosiding ini, saya sebagai penulis ke **satu.**
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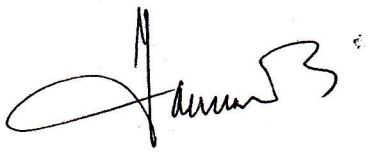

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# Effects of Cutting Conditions and Chip Formation in Titanium Alloy Machining

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*Abstract*—**Tool life is the one of the most important arameters in the machining research area. Most esearchers have dealt the effect of cutting variables on tool fe by the one-variable-at-a-time method. This approach eeds a separate set of tests for each combination of cutting ondition and cutting tool. The approach required large mount of cost and cannot consider the combined effect of utting conditions on response. The purpose of this research s to develop tool life model which take into account the ombined effect of cutting variables (cutting speed, feed rate, nd depth of cut) by using design of experiment. The effects f cutting variables are investigated by the application of actorial design method. The first-order of tool life model are enerated. The cutting tests are conducted using Cubic Boron Nitride (CBN) as cutting tool when turning of itanium in dry cutting condition.**

*Keyword*—**tool life, fractional factorial, CBN, dry urning, titanium 6Al-4V**

## I. Introduction

Titanium and titanium alloy products is used mainly n the aerospace industry due to the exceptional strength-o-weight ratio, elevated temperature performance and corrosion resistance. The applications of titanium are nostly in jet engine and airframe components where those are subjected to temperatures up to 600°C and for other critical structural parts. The usage is widespread in both commercial and military aircrafts. Titanium alloys fall into four major groups, classified by their alloying elements and microstructures: pure titanium, alpha, alpha beta and beta phases. The most commonly used alloys are the alpha-beta group. Titanium 6Al-4V, member of this group, comprises more than 50 percent of all titanium alloys used today.

Titanium alloys has some certain characteristics that limits on its machinability. Some of these are given as follows: low thermal conductivity, chemical reactivity with the cutting tools materials at tool operating temperatures, a relatively low modulus of elasticity. Due to those characteristics, titanium has been generally turned with uncoated carbide, CBN/PCBN and Poly Crystalline Diamond (PCD). Uncoated carbide tools are suitable at low speed machining conditions while CBN/PCBN are employed at high speed machining (Che Haron 2001,Ezugwu et al 2003).

Machinability data of titanium is usually acquired from the experimental studies. For saving the time and cost, the experimenters used statistical design of experiment. Statistical design of experiment is the process of planning the experiments so that the appropriate data should be collected which may be analysed by statistical methods resulting in valid and objective conclusions (Montgomery 1991). Statistical design of experiment will produced the data uniformity and reduces the total number of experiments.

The objective of the study is to establish the tool life model of CBN cutting when turning Titanium 6Al-4V. It is necessary to employ theoretical models making it feasible to do predictions in function of operation conditions such as spindle speed, feed rate, cutting depth, tool geometry and so on. The study will investigate the wear progression, the failure mode of cutting tool and the significant factors that affect the CBN tool life.

## II. Research Methodology

### A. *Design of Experiments*

The present study takes into account the simultaneous variation of speed, feed, depth of cut and CBN contents as variables. The result will produce the tool life as a response. Factorial designs are used widely in experiments involving several factors where it is necessary to study the combined effect of these factors on responses. The meaning of factorial design is that each complete trial or replication of all the possible combinations of the levels of the factors is investigated.

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The proposed relationship between the machining responses (tool life, cutting forces) and machining independent variables can be represented by the following:

$$T=C(V^{w} f^{y} d^{x}) \quad (1)$$

where $T$ is the tool life in minutes, $V$, $f$, and $d$ are the cutting speeds (m/min ), feed rates (mm/rev ), and depths of cut (mm) respectively, and $C$, $l$, $m$, $n$ are constants. Eq. (1) can be written in the following logarithmic form:

$$\ln T = \ln C + l \ln V + m \ln f + n \ln d \quad (2)$$

The first-order model can be expressed as:

$$y = b_0 x_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 \quad (3)$$

where $y$ is the measured tool life to a logarithmic scale, $x_0 = 1$ (dummy variable), $x_1 = \ln V$, $x_2 = \ln f$, $x_3 = \ln d$, $b_0 = \ln C$, and $b_1$, $b_2$ and $b_3$ are the model parameters. In the present study, the parameters of Equation (3) will be estimated by using a computer package. To develop the first-order model, $2^{4-1}$ partial factorial design will be used. A design consisting of 8 experiments was conducted.

TABLE 1
LEVEL DESIGNATION OF DIFFERENT PROCESS VARIABLES

| Level | V (m/min) | F (mm/rev) | D (mm) | CBN content |
|---|---|---|---|---|
| -1 (Low) | 180 | 0.05 | 0.1 | Low |
| 1 (High) | 300 | 0.25 | 1.00 | High |

### B. *Work piece material, Machine and cutting inserts*

A 150 mm diameter x 300 mm long bar of Titanium 6Al-4V was used for the tests. The machining tests were carried out on a Cincinnati Avenger 200T CNC lathe. A MCLNR 2020K09 tool holder was used to provide an 85° cutting edge angle and - 5° rake angles. The cutting tools used were Kennametal grade KD050 and KD081 designated CNGA 120408S1020, in order to investigate the influence of CBN content. All of the experiments were conducted in dry condition. Depending on the cutting condition and wear rate, machining was stopped at various interval of time varying from 5 sec to 1 min to record the wear of the insert. Flank wear was considered as the criteria of tool failure and the wear was measured using a Mitutoyo toolmaker's microscope. The machining was stopped when an average flank wear was greater than 0.30 mm or fracturing happened.

## III. Results and Discussions

### A. *Statistical Analysis*

Table 2 shows the experimental conditions together with the measured tool life values. The results were transformed to half-normal probability plot as in Figure 1. The figure shows the factors (depth of cut, cutting speed, feed rate) and the interaction (cutting speed-cutting depth), which may have an effect to cutting tool life.

Then, analysis of variance (ANOVA) was applied to calculate the main effects of cutting speed ($V$), feed rate ($f$), depth of cut (d), and CBN content together with their two-level interaction effects on tool life. The ANOVA output and the calculated $F$ ratios are shown in Table 3 for each significant effect.

The 5 per cent level for testing the significance of the main effects and the interaction was used. Table 3 shows that depth of cut is most significant, and followed by cutting speed and cutting speed-depth of cut interaction. Feed rate is not significant because its "Prob > F" values greater than 0.1. Even if the feed rate has a greater value than 0.1, this term will not be neglected in order to take into account the feed rate contribution to tool life. While the CBN content does not have any effect to tool life absolutely.

TABLE 2
EXPERIMENTAL CONDITIONS AND RESULTS

| Run | Factors | | | | Tool life (sec) |
|---|---|---|---|---|---|
| | Cutting speed (m/min) | Feed rate (mm/rev) | Cutting depth (mm) | CBN content | |
| | A | B | C | D | |
| 1 | 300 | 0.05 | 1.0 | Low | 40 |
| 2 | 180 | 0.05 | 0.1 | Low | 1740 |
| 3 | 180 | 0.25 | 0.1 | High | 820 |
| 4 | 300 | 0.25 | 0.1 | Low | 130 |
| 5 | 180 | 0.05 | 1.0 | High | 150 |
| 6 | 180 | 0.25 | 1.0 | Low | 10 |
| 7 | 300 | 0.05 | 0.1 | High | 420 |
| 8 | 300 | 0.25 | 1.0 | High | 10 |

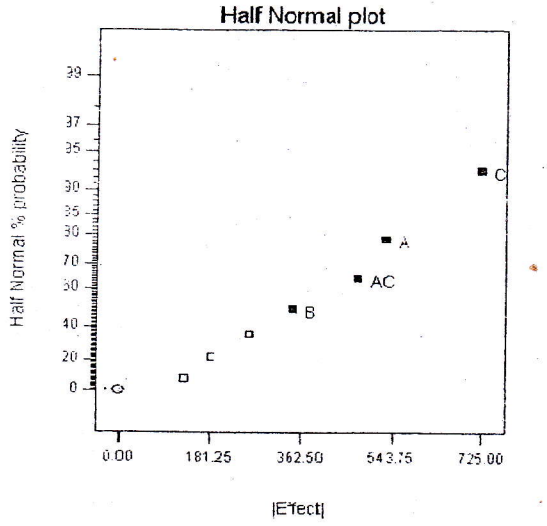


Fig. 1 Half normal % probability plot

TABLE 3
ANOVA FOR SELECTED FACTORIAL MODEL [PARTIAL SUM OF SQUARES]

| Source | Sum of Squares | DF | Mean Square | F Value | Prob > F |
|---|---|---|---|---|---|
| Model | 2,302,000 | 4 | 575,600 | 7.27 | 0.0675 |
| *A* | 561,800 | 1 | 561,800 | 7.10 | 0.0761 |
| *B* | 238,000 | 1 | 238,000 | 3.01 | 0.1813 |
| *C* | 1,051,000 | 1 | 1,051,000 | 13.28 | 0.0356 |
| *AC* | 451,300 | 1 | 451,300 | 5.70 | 0.0969 |
| Residual | 237,500 | 3 | 79150.00 | | |
| Corr Total | 2,540,000 | 7 | | | |

The CBN content seems to be suitable for interrupted cutting than continuous cutting as in this experiment. The *R*-squared statistic indicates that the first-order model explains 90.65 % of the variability in tool life (T). The calculation also indicates that the model has an adequate signal to noise ratio.

The normal probability plots of the residuals and the plots of the residuals versus the predicted response for tool life are shown in Figures 2 and 3, respectively. A check on the plots in Figures 2 and 3 revealed that the residuals generally fall on a straight line implying that the errors are distributed normally.

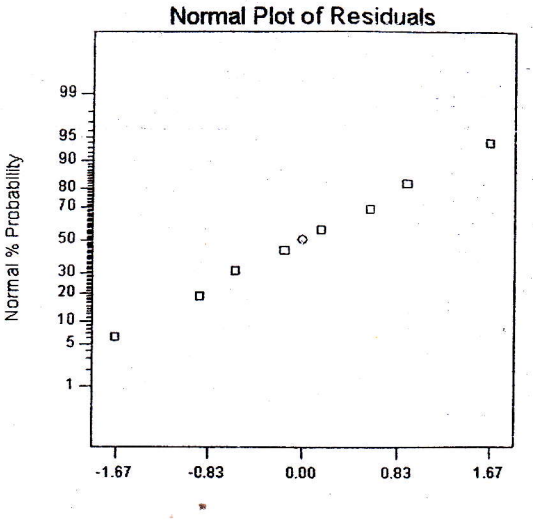


Fig. 2. Normal plot of residuals for tool life data

This implies that the models proposed are adequate and there is no reason to suspect any violation of the independence or constant variance assumption. It means that the proposed model using partial factorial design is suitable for running the experiment. But, in order to obtain a more precise result, the second-order model is proposed.

### *B. Tool wear and tool life*

Figure 4 shows the flank wear progression curves of CBN tool at the different cutting conditions. The flank wear progressions were generally divided into three stages: the rapid initial, the relative steady state and finally the abrupt of wear.

The flank wear rate was rapid at higher cutting speeds, feed rates and depth of cuts. There are several types of wear mechanisms that can influence the tool wear and subsequently the tool life. The observed wear mechanisms were abrasion, attrition, adhesion, diffusion-dissolution, chipping and fracture.

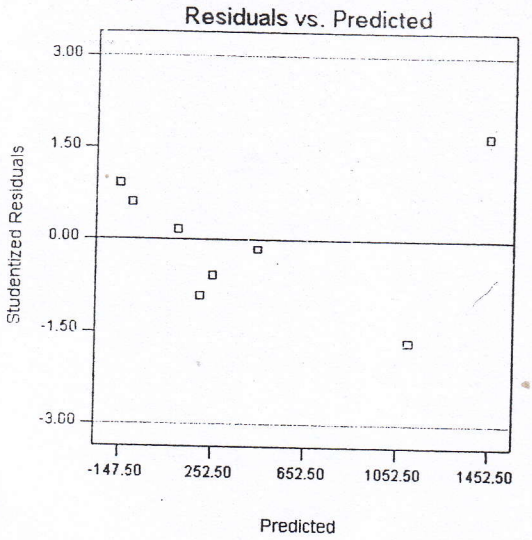


Fig. 3. Residuals vs predicted responses plot

Figure 5(a) show clearly rubbing and attrition wear mechanism. At the lower cutting speed, temperatures are low so that the wear based on plastic shear or diffusion does not occur. The flow of metal past the cutting edge is more irregular, laminar, a built-up edge may be formed and contact with the tool may be less continuous. Under these conditions larger fragments may be torn intermittently from tool surface (Trent 1991). But in this test, the well-defined built-up edge has not appeared.

Beside the abrasion and attrition, cutting tool wear can also be ascribed to the chemical reaction and adhesion between the tool and work materials. During the processing, especially dry cutting, the temperature increases rapidly. The increasing temperature will induce the tendency for the titanium to weld to the tool during machining. If the material welded to the tool received [illegible] dynamical stress, this eventually results in chipping [illegible] severe failure. Figures 5(b) and 6(b) show the [illegible] surface of CBN tool due to severe failure.

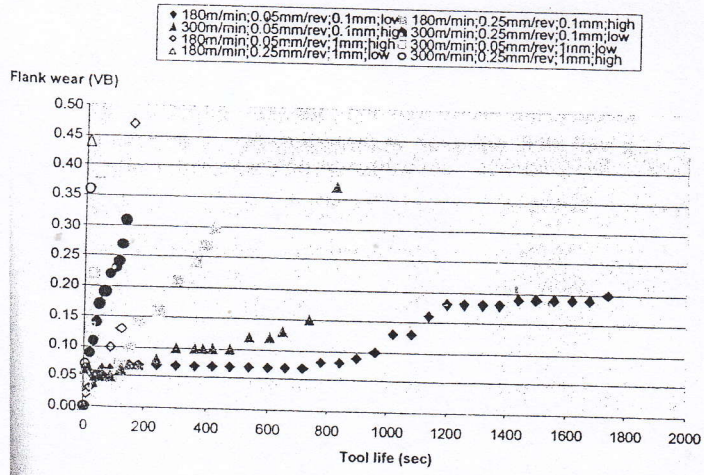


Fig. 4. Flank wear progression curves

Another wear mechanism which present in [illegible] experiment is dissolution and diffusion of the cutting tool. The dissolution-diffusion mechanism caused the crater formation in the chamfered edge land. Figures 5(a) and 6(a) show the formed crater obviously.

Figure 7 also show results of cutting tool life on some cutting parameters at different depth of cut. Based on the figure, depth of cut is the most influencing factor to the tool life, followed by cutting speed and feedrate.

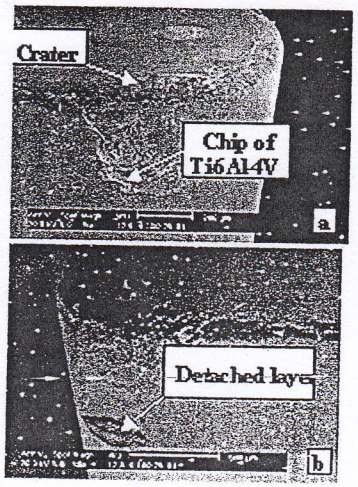


Figure 5: SEM micrograph of CBN tools while machining Ti-6Al-4V at cutting speed 180 m/min, feedrate 0.25 mm/rev (a) depth of cut 0.1 mm, (b) depth of cut 1 mm

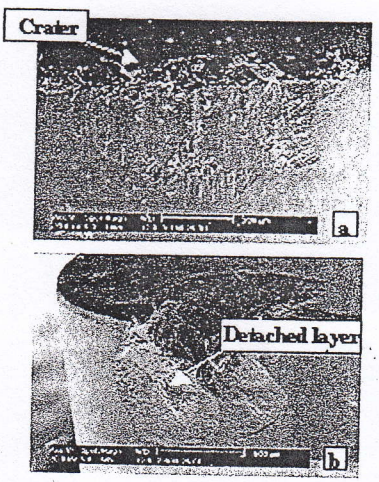


Fig. 6. SEM micrograph of CBN tools while machining Ti-6Al-4V at cutting speed 300 m/min (a) feedrate 0.25 mm/rev and depth of cut 0.1 mm, (b) feedrate 0.05 mm/rev and depth of cut 1 mm

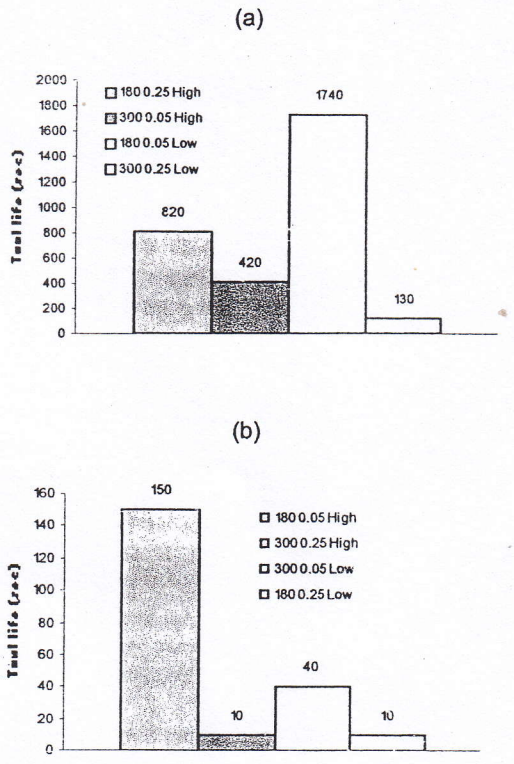


Fig. 7 Tool life at different depth of cutting (a) 0.1 mm (b) 1 mm

Figures 5(b) and 6(b) confirmed the influence of depth of cut to tool wear mechanism. In this case, higher depth of cut enlarged the possibility of tool to severe failure and shortens the tool life. It is suggested to use lower depth of cut in finish machining of titanium using CBN tool. It seems that CBN content (grade) give small significance level of to tool life. Lower CBN content gave a relatively good performance and it is parallel to the finding of Ezugwu et al (2003).

### C. *Chip formation*

Figures 8 and 9 show the differences of two formed chips at the different cutting speeds and depth of cuts. The depth of cut will influence the width of chip, type of flakes and peak shape of flakes. Chip formed in turning at a depth of cut 1 mm has approximately 2.5 times wider than chip formed at depth of cut 0.1 mm. The bigger flake and the smaller flake were formed at a depth of cut 0.1 mm. The smaller flake was formed at the right side. At the depth of cut of 1 mm, the smaller flakes were not formed. The sharper peak shape was formed at the depth of cut 0.1 mm than at the depth of cut 1 mm. While the interval of flakes depend on the cutting speed.

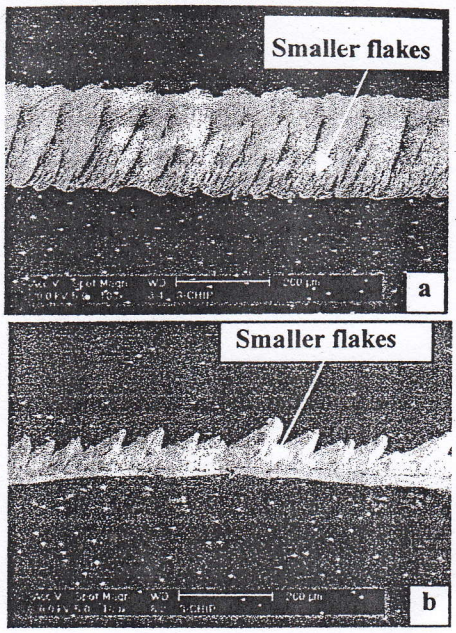


Fig. 8.Chip formed at cutting speed 180 m/min, feed rate 0.25 mm/rev and depth of cut 0.1 mm (a) top view (b) side view

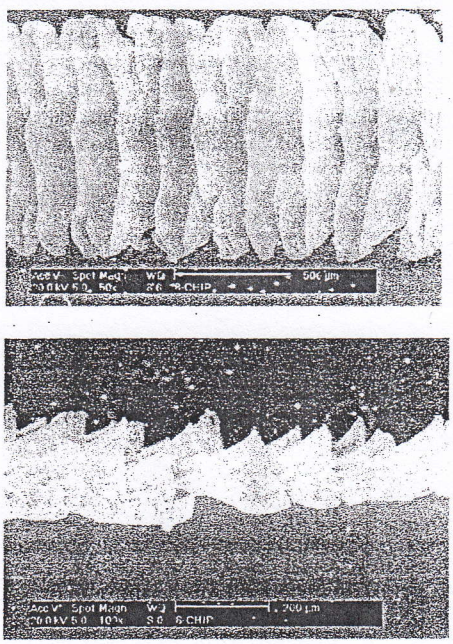

Fig.9. Chip formed at cutting speed 300 m/min, feed rate 0.25 mm/rev and depth of cut 1 mm (a) top view (b) side view

## IV. Conclusions

It has been shown in this work, machining of titanium 6Al-4V with CBN cutting tool, the partial factorial design can be applied in designing the experiments. The design is very helpful in the running of expensive cutting tool-material combinations. The work showed that the depth of cut is the most significant factor to tool life, followed by

cutting speed and feed rate. The lower depth of cut is more significant to prolong the tool life at the cutting speed range of 180 –300 m/min. It showed that there is no contribution of CBN content to tool life.

CBN tool has three stages of wear process: rapid initially, slowly wear progress and abruptly failure. The dominantly wearing mechanism present was abrasion, attrition, adhesion, diffusion-dissolution, chipping and fracture. The cutting speed induced attrition wear. While chipping and fracture was generated by higher depth of cut. Diffusion-dissolution was induced by increasing temperature during turning operation. Beside the bigger flakes, some smaller flakes were formed when turning at lower depth of cut. The width and height of formed chip are depended on depth of cut while interval between peaks of flakes is depended on cutting speed.

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