Turning experiment of Ti-6Al-4V by using uncoated carbide insert

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Abstract. Titanium alloy Ti-6Al-4V is widely being used in the blades, discs, rings, airframes, fasteners, components, vessels, cases, hubs, forgings and biomedical implants. Nevertheless, the properties of titanium alloys which are low thermal conductivity, low modulus of elasticity and high chemical activity cause it very difficult to machine. Excessive elevated temperature due to low thermal conductivity of these alloys make it favorable for tool wear. In this paper, an experiment using orthogonal array L4 is conducted to explore the effect of cutting parameters e.g. cutting speed, depth of cut and feed rate in terms of surface roughness and tool wear. The cutting tool uncoated carbide is used in performing orthogonal cutting of Ti-6Al-4V in this study. It is found low cutting speed, feed rate and high depth of cut is favourable in producing good Ra and minimum flank wear.

1. Introduction
Titanium alloys has been widely used in aerospace, automotive, chemical, and biomedical industries from the fact that of its excellent properties such as high-strength to weight ratio, lower density and resistance to oxidation, corrosion, fracture and fatigue [1][2]. Ti6Al4V is the most common titanium alloy used in industries which belongs to α + β alloy group. Titanium alloys are classified based on Al and Mo equivalent. [2] mentioned Al equivalent values indicates the capacity of the alloy to obtain a given hardness while Mo equivalent values indicates the capacity of the alloy to obtain an ultimate tensile stress . From the literature [2], Ti6Al4V alloys has Al equivalent values of 7% whereas Mo equivalent value is 2.5% which it can be classified as near-alpha alloys with 1000 Mpa of ultimate tensile stress. Nonetheless, common problems in machining of titanium alloys such as rapid tool wear, and poor surface quality [3] are encountered due to low thermal conductivity, low modulus elasticity and high chemical activity [4]. Since Titanium alloys exhibits low thermal conductivity, it is reported Titanium alloys are very sensitive with the cutting speed as it can rise cutting temperature tremendously [5]. Therefore, heat generation from the cutting process is determined to be the source of tool-life shorten. Besides, diffusion and oxidation occurred at high temperatures experienced with high cutting speeds dominate wear of cutting inserts during machine titanium alloy. The main driving force for tool wear changes at a certain critical temperature from one dependent on adhesion to one based on diffusion [6]. It is reported as well when machining Titanium alloys, diffusion is the most active wear mechanism for almost tool materials. From previous studies [7], it was reported that uncoated tool and CVD-coated carbide tools exhibit a good performance in dry end milling of titanium.
alloy Ti-6242S. Similar finding is claimed which uncoated tool result with better surface roughness compared to CVD coated tool [8]. This study was conducted to elucidate influence of cutting parameters on surface roughness of Ti-6Al-4V and tool wear using uncoated tool carbide.

2. Material and methods

2.1. Material

The experiments are implemented using titanium alloy Ti-6Al-4V as workpiece material with 120 mm length and 50 mm diameter. Ti-6Al-4V is an alpha-beta alloy where it has 6% of aluminum and 4% of vanadium. The vanadium stabilizes the β phase as the aluminum acts as α stabilizer. Detail composition of Ti-6Al-4V is listed in Table 1. Commonly, growing the β phase content can rises the strength and decreases the ability of machine operation.

| Al   | V   | Fe | C   | Mo | Mn | Si | Titanium |
|------|-----|----|-----|----|----|----|----------|
| 6.37 | 3.89| 0.16| 0.002 < | 0.01 < | 0.01 | 0.01 | Balance  |

Table 1. Composition of Ti-6Al-4V [9].

Uncoated tungsten carbide inserts, type CNMG 120408 H13A from Sandvik Coromant are used in the experiment. The insert is mounted to tool holder type DCLNR2020K12 produced by Sandvik Coromant as well. The tool geometry used has -6° rake angle, -6° inclination angle and -5° tool lead.

2.2. Taguchi method and design of experiments

Increasing in controlled factors always lead to complex of design experiment associates with time consuming and high cost. To overcome the related problems, Taguchi experimental design method is favorable among researchers as it is effective technique for designing process that functions steadily and over a multiplicity of circumstances. In this experiment, two level full factorial design of cutting parameters is used. Cutting speed, feed rate and depth of cut are considered as main factor that affect tool wear and surface roughness ($R_a$). After determining the number of control parameters and their levels, a suitable OA was set up for laying out the design of experiment in evaluation of wear and on the inserts. L4 is selected due to the lowest OA that can accommodate two levels control factors with three parameters. There are total 4 trials are conducted under different combination of parameters as shown in Table 3. In Table 4 it shows the cutting parameter that are used in the present study.
Table 3. L4 orthogonal array.

| Trial | Factors A | Factors B | Factors C |
|-------|-----------|-----------|-----------|
| 1     | 1         | 1         | 1         |
| 2     | 1         | 2         | 2         |
| 3     | 2         | 1         | 2         |
| 4     | 2         | 2         | 1         |

Table 4. Cutting parameter used.

| Factors          | Low level (1) | High level (2) |
|------------------|---------------|----------------|
| (A) Cutting speed (m/min) | 100           | 150            |
| (B) Feed rate (mm/rev)      | 0.23          | 0.53           |
| (C) Depth of cut (mm)       | 0.15          | 0.2            |

As minimum tool wear is desired outcome of this study, therefore the “smaller is the better” characteristic is determined according to signal to noise (S/N) ratio obtain from Taguchi loss function [10] (2):

\[
S/N \text{ ratio} = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} Y_i^2 \right) \quad (1)
\]

where \( n \) is the number of experiment and \( Y_i \) is the observed data. Eventually, a confirmation test was conducted for the verification of result based on optimal combination of parameter.

2.3. Experimental setup

Turning experiment was carried out by using a Computer Numerical Controlled (CNC) lathe machine model T6 Compact Quick Tech powered by 7.5 kW servo moto with maximum spindle speed 4000 rpm. A set of workpieces of Ti-6Al-4V were prepared each with 78 mm effective cutting length and 50 mm diameter respectively. Furthermore, a new cutting insert was used in each new trial set in order to minimize effect of tool wear. The flank wear was measured after 15 minutes of cutting for all trial using optical microscope. Besides, average surface roughness (Ra) was measured using a profilometer model Mitutoyo SJ-410. The Ra values were measured at four different points in 90° increment and the average values were recorded.
3. Results and discussion

3.1. Optimization of cutting parameters

Based on L4 orthogonal array Taguchi experiment design, value of flank wear and average surface roughness $R_a$ were obtained associated with respective S/N ratios are depicted in Table 5. The S/N ratios were reckoned according to “smaller is the better” characteristic as in Eq. 2.

| Trial | A | B | C | Flank wear (mm) | S/N ratio | $R_a$ (µm) | S/N ratio |
|-------|---|---|---|----------------|-----------|------------|-----------|
| 1     | 1 | 1 | 1 | 0.0671         | 23.466    | 1.955      | -5.823    |
| 2     | 1 | 2 | 2 | 0.1897         | 16.386    | 4.817      | -13.656   |
| 3     | 2 | 1 | 2 | 0.5600         | 5.036     | 3.011      | -9.5742   |
| 4     | 2 | 2 | 1 | 0.2726         | 11.289    | 7.335      | -17.308   |

Flank wear and $R_a$ were recorded after 15 minutes of cutting. Figure 2 shows occurrence of flank wear at flank face and crater wear at rake face. Analysis of mean was implemented to identify optimum cutting parameter for designated factors to obtain minimum flank wear and $R_a$. Figure 3 and 4 represent the result of mean plot. The least mean of respective parameter is the optimal level. Therefore, the combination of optimum parameter is listed in Table 5. Cutting speed prevailed significant effect to flank wear and $R_a$ since increasing the cutting speed contribute to high temperature at tool edges. At high cutting speed, heat due to friction increase at region of tool –work interface and tool-chip interface consequently raising of heat generation.
Figure 2. Observed wear of uncoated carbide for trial 1 after 15 minutes (a) flank wear (b) crater wear.

Furthermore, as Ti-6Al-4V has low thermal conductivity, thus most of energy from plastic deformation during cutting was converted into heat and dissipated to the cutting tool instead of being absorbed by the chip and workpiece. Besides, factor of feed rate also pronounced on the flank wear as it always contacts to newly formed surface. Therefore, high feed rate result to high friction thus amend the resultant $R_a$. Based on Table 6, it is recommended to use higher cutting depth. It is because at high cutting depth, tool – chip contact area at rake face increase. Hence tool rake face absorbed more heat from the chip instead of absorbed by flank face.

Figure 3. Main effect plot for flank wear
Figure 4. Main effect plot for $R_a$

Table 6. Optimum cutting parameter

| Parameter       | Value   |
|-----------------|---------|
| Cutting speed   | 100     |
| Feed rate       | 0.23    |
| Depth of cut    | 0.2     |

Based on optimum cutting parameter, a confirmation test was conducted to obtain minimum value of tool wear. Finally, the flank wear was determined as 0.0458 mm which is in aligned to the suggested optimum cutting parameter as exhibit in Figure 5.

Figure 5. Flank wear for suggested optimum cutting parameter
4. Conclusion
The conclusion can be drawn from this study is low cutting speed is favourable in cutting Ti-6Al-4V due to less heat generation for minimum flank wear. It is observed, flank wear and crater wear occurred in cutting Ti-6Al-4V and it directly affected the surface quality of work material. However, it is found to get good R_a and minimum flank wear, higher depth of cut is suggested because of majority of heat is transferred via rake face.

5. References
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