euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

Preliminary experimental study on ultrasonic assisted diamond turning Ti6Al4V alloy

W. S. Yip , S. To *, Y. Deng

State Key Laboratory in Ultra-precision Machining Technology, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong SAR, China

**Corresponding author. E-mail address: sandy.to@polyu.edu.hk*

Abstract

The extensive applications of Ti6Al4V α+β phase titanium alloys in aviation and biomedical industries are common nowadays, mainly due to their poised superior advantages such as good strength-to-weight ratio, excellent fatigue resistance and high corrosion resistance. However, titanium alloys are regarded as difficult to cut materials because of their low thermal conductivity at elevated temperature which causes unfavourable to machine process. Localized heat at the tool tip during machining speeds up tool wear, high temperature is intensified at the tool work-piece interface which deteriorates the tool life ultimately, leads to poor surface finish and surface integrity. In this paper, ultrasonic assisted diamond turning (UADT) of titanium alloys were conducted, which is newly applied in ultra precision machining area. The surface roughness of Ti6Al4V alloys after UADT by ultra precision machining was found to be improved. Important machining parameters such as cutting speed, feed rate and depth of cut were adjusted as variables during experiments. The influences of these machining parameters on the surface integrity of Ti6Al4V were examined and they were expected to contribute to the optimization process of UADT machining parameters in ultra precision machining.

Keywords: Ultrasonic assisted diamond turning; Ultra-precision machining; Surface roughness; Titanium alloy

1. Introduction

Owing to excellent physical properties of titanium alloys such as high strength-to-weight ratio, heat resistance and extraordinary corrosion resistance, they were widely used in many industries [1]. However, titanium alloys possessed low elastic module and high chemical sensitivity which limited applications due to high complexity machining processes [2]. Also, these materials held low thermal conductivity which hindered heat transference from cutting zone, localized heat at the tool tip especially at flank and rake surface speeded up tool wear. Utilizing liquid lubricants were proposed to solve this problem as lubricants dispersed heat to surrounding during machining and thus improving and lengthening the tool life[3]. However, uses of lubricants caused environmental and cost concern. Therefore, machining of titanium alloys always involved high cost and treated as unfeasible [4].
Most of researches were focused on UADT with high tolerance on surface finishing currently, however, inadequate studies of UDAT in titanium alloys were on the area of ultra precision machining. In this paper, UADT of titanium alloys which is newly applied in ultra-precision machining was developed to improve the surface integrity of titanium alloys.

2. Experimental setup

The ultra precision machine, Moore Nanotech 350FG (4 axis Ultra-precision machine) was used in the UADT. The ultrasonic tooling system SONX UTS one was installed to provide 80kHz frequency vibration during turning process. The surface roughness of machined surface was measured by Wyko NT8000 Optical Profiling System. The overall experimental set up was shown in the Figure 1.

Figure 1 Experimental set up of UADT

3. Machining parameter setup

The machining parameter combinations and resulted surface roughness in the experiments were shown in Table 1. Other parameters were kept constant while only one parameter was adjusted in each experiment.

Experiment no.	Spindle speed (rpm)	Depth of cut (um)	Feed rate (mm/rev)	Voltage (v)	Surface Roughness in Sa (nm)
1	218	3	10	30	72
2	268	3	10	30	75
3	318	3	10	30	81
4	268	2	10	30	71
5	268	3	10	30	75
6	268	4	10	30	95
7	268	3	6	30	152
8	268	3	8	30	135
9	268	3	10	30	75

Table 1: Machining parameters and surface roughness in experiments

4. Results and discussion

4.1 Influence of spindle speed on surface roughness

According to experiments no.1-3 in Figure 2, overall reduction on surface roughness was 12.5% by adjusting spindle speed from 318rmp to 218rpm. The significant increase of surface roughness was found when spindle speed was from 268rpm to 318rpm. The surface roughness increased with increased spindle speed. The interaction between tool and machining surface was related to tool-workpiece contact ratio(TWCR) in UDAT, TWCR was improved when the spindle speed decreased. So, the cutting temperature was diminished, thus lowered cutting force and was favourable to surface roughness.

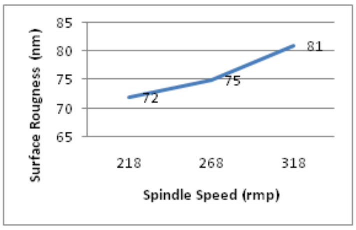


Figure 2 Relation between spindle speed and surface roughness

4.2 Influence of depth of cut on surface roughness

According to experiments no.4-6 in Figure 3, it was shown that 34% increase of surface roughness when depth of cut varied from 2um to 4um. A significant reduction on surface roughness was noted when depth of cut increased from 3um to 4um. At depth of cut of 2um, larger vibration energy caused smaller friction force induced by aerodynamic cushion effect, therefore surface roughness was enhanced. On the other hand, the highest value of surface roughness appeared at a depth of cut 4um, higher of tool-workpiece contact time resulted to heat concentration at the machining surface. The consequences accelerated the tool wear, damaged the cutting edge and led to poor surface finishing(Figure 5a).

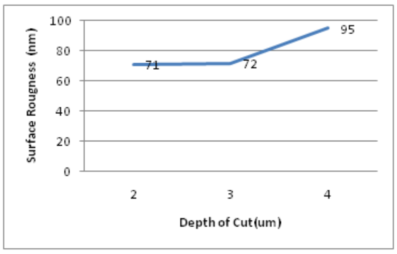


Figure 3 Relation between the depth of cut and surface roughness

4.3 Influence of feed rate on surface roughness

According to experiment no.7-9 in Figure 4, the surface roughness was changed moderately when the feed rates from 6μm/rev to 8μm/rev; There was a significant reduction in surface roughness when the feed rate was changed from 8μm/rev to 10μm/rev. The surface roughness was reached to the lowest value at 10μm/rev(Figure 5b). The surface roughness decreased with feed rate increased. The reason was that the vibration effect in UDAT was intensified when the feed rate increased. Less friction was produced between tool and working surface, it lowered the heat generated during machining process. Surface roughness of final machining surfaces were improved as a result.

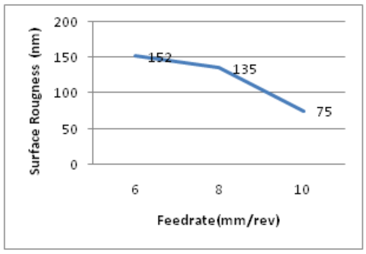
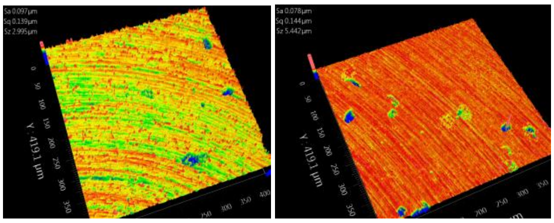


Figure 4 Relation between the feed rate and surface roughness



(a) (b)

Figure5: Surface Roughness of experiment (a) no.6 (Sa= 97nm) (b) no.9(Sa= 98nm)

5. Conclusion and Further work

UADT in ultra-precision machining provided a new solution to solve machining problems in titanium alloys. The findings of this study could be concluded as follow:

i. Smaller spindle speed decreased surface roughness. It was due to smaller spindle speed lowered the contact time between workpiece and the tool in UADT.

ii. Smaller depth of cut caused better surface roughness. The vibration effect was significant at small depth of cut and made effective heat transference to outside. The lowest surface roughness appeared at depth of cut 2um.

iii. Surface roughness was improved when the feed rate increased. The higher vibration energy was created at high feed rate and this energy acted as cushion effect to lower the friction force and resulted to better surface roughness

The cutting force, tool wear and chip morphology of titanium alloys by the proposed machining technology will be investigated in next step. On the other hand, titanium alloys after electropulsing treatment (EPT) combined with ultrasonic vibration assisted in ultra precision machining will be examined in the future. It is expected that this integrated machining technology will improve the machinability and surface integrity of titanium alloys in ultra precision machining.

Acknowledgment

The authors would like to present their honest thanks to the Research Committee of The Hong Kong Polytechnic University and the innovation and technology commission of the Hong Kong Special Administration Region of the People's Republic of China for their financial support (Project No.: PolyU GHP/044/12SZ).

References

[1] Maurotto, A., Muhammad, R., Roy, A., & Silberschmidt, V. V. (2013). Enhanced ultrasonically assisted turning of a β-titanium alloy. Ultrasonics , 1242-1250

[2]Muhammad, R., Maurotto, A., Roy, A., & Silberschmidt, V. V. (2012). Hot Ultrasonically Assisted Turning of β-Ti Alloy. Procedia CIRP , Vol.1, pp.336-341

[3]MACHINING TITANIUM AND ITS ALLOYS. Machining Science and Technology: An International Journal , Volume 3, Issue 1, pp.107-139

[4]Maurotto, A., Siemers, C., Muhammad, R., Roy, A., & Silberschmidt, V. (2014). Ti Alloy with Enhanced Machinability in UAT Turning. Metallurgical and Materials Transactions , Vol.45(6), pp.2768-2775