Experimental investigation of machining parameter on hole quality in drilling Ti-6Al-4V

R A Rashid¹, M N Murad², R Hamidon², S Shariffuddin² and M A M Ali²

¹Centre for Diploma Studies, Universiti Malaysia Perlis, Kampus UniCITI Alam, 02100 Padang Besar, Perlis, Malaysia.
²School of Manufacturing Engineering, Universiti Malaysia Perlis, Kampus Tetap Pauh Putra, 02600 Arau, Perlis, Malaysia.

Abstract. Titanium alloys (Ti-6Al-4V) are greatly recommended for high performance applications because of their outstanding properties such as low weight, high corrosion resistance and high strength. However, drilling Ti-6Al-4V generates high cutting temperature, especially during high speed drilling (HSD), increased the chemical reactivity of Ti-6Al-4V, thus leading to poor hole quality. High cutting speed increases the temperature during the drilling process, therefore, it is important to consider this factor to achieve better hole quality. This study focuses on the correlation of machining parameter and the quality of the hole produced in terms of hole diameter, roundness and surface roughness. The experiment was conducted using a 6 mm diameter of coated (TiAlN) carbide tool under MQL and MQCL conditions with varying cutting speeds of 65, 75, 85 and 95 m/min and constant 0.02 mm/rev feed rate.

1. Introduction

Drilling is a common metal cutting process and widely used in aircraft frame, automotive, defense and medical industry. It has been reported that 50 – 70% of all production time is used to make a hole [1]. Usually, drilling is the final step in the fabrication of mechanical components and the process is considerably economical important. Cutting speed and feed rate are two significant machining parameters as cutting speed increased, drilling temperature also increased during the processes. Hence, the selection of appropriate cutting speed is necessary to achieve better hole quality and minimum surface roughness.

Drilling Ti-6Al-4V is difficult due to low thermal conductivity and high chemical reactivity leading to high generated heat at the cutting zone and massive adhesion to the drilling tool. These factors negatively lead to many drilling problems. The quality of the drilling hole is critical, especially in the aircraft frame assembly. The reliability and safety of aircraft depend on the assembly accuracy. Poor quality of drilling hole detrimental the fatigue life of the fastened joint as well as the functionality of drilled components. Also, it increased the cost and time for necessitating secondary processes such as reaming and deburring. Nearly all Ti-6Al-4V applications involve the drilling process, and it is required to meet the desired tolerance. Consequently, it is important to select the proper machining parameters to improve hole quality.

Numerous researchers have been discussed and examined several issues regarding the quality of the hole during the drilling process. Abele et al. [2] reported that cutting speed more impactful on hole quality while the role of feed rate was marginal. In contrast, Galloway [3] pointed out low feed rate reduces out the roundness while high cutting speed and feed rate increased the hole deviation [4]. Most of the literature presents out laid emphasis on the hole quality concerning cutting speed and feed rate, however, the conclusion is contradictory.
2. Experimental procedure
Drilling experiment was performed on a three-axis CNC milling machine (Tong Tai EZ-5). The experiment was carried out using MQL and MQCL, and both methods were used Karanja oil as medium lubrication. For this experiment, Ti-6Al-4V size 94 x 70 x 14 mm was selected as the workpiece material. A special jig was used to secure the workpiece tightly to avoid chatter. Coated (TiAlN) carbide tools with diameter 6 mm were used during the drilling trials. The experiment was carried under four cutting speeds of 65, 75, 85 and 95 m/min and feed rate remained constant at 0.02 mm/rev.

Hole diameter and roundness were evaluated using Coordinate Measuring Machine (CMM) model Mitutoyo Crysta-Plus M. Figure 1(a) shows the experimental setup for hole diameter and roundness measurement. The accuracy of the measurement was obtained by probing 12 points on the drilled hole at the entrance, middle and exit locations as shown in Figure 1(b). Surface roughness measurement was taken using an Accretech Handysurf E-35 equipped with a portable stylus as seen in Figure 2(a). Measurement was made at four equidistant locations (0°, 90°, 180°, 270°) along the hole surface and the average value was taken (Figure 2b).

![Figure 1](image1.png)

Figure 1. (a) Experimental setup for hole diameter and roundness measurement (b) Point position of measurement:

![Figure 2](image2.png)

Figure 2. (a) Experimental set up for surface roughness measurement (b) Roughness measurement point
3. Result and discussion

3.1 Hole diameter

Figure 3 and 4 show the results of hole diameter at three distinct locations when drilling Ti-6Al-4V under MQL and MQCL conditions, respectively. It can be seen that the diameter of the machined hole varies slightly under various cutting conditions. Under MQL condition, hole diameter increased at cutting speed of 75 m/min and decreased as the cutting speed increased, while under MQCL condition, hole diameter decreased as the cutting speed increased but slightly increased back at cutting speed of 95 m/min. Previously, it has been reported that hole diameter is reduced at low speed and increased feed rate [5]. The inconsistent results may be a lack of other influential factors such as tool vibration and the coolant-lubricant not well delivered to the workpiece [6].

![Figure 3. Hole diameter under MQL condition using coated (TiAlN) carbide drill](image1)

![Figure 4. Hole diameter under MQCL condition using coated (TiAlN) carbide drill](image2)

3.2 Roundness

Figure 5 and 6 presented the result of roundness when drilling Ti-6Al-4V under MQL and MQCL conditions, respectively. Under the MQCL condition, the values of roundness are increased as the cutting speed increase. The result is probably due to the increasing tool wear at the cutting edge which may affect the cutting stability. While under MQL condition, the result shows equally 0.04 mm. This
situation could be due to micro-weld on the hole resulted from adherence or smeared workpiece material [7]. Yahya [8] also explained about the non-uniform result of roundness is due to the vibration of high loads on the cutting during high speed machining. Also, it has been reported that by drill deflections at the commencement of drilling, the difference in lip height of cutting edges and drill tip geometry affected the roundness error.

![Figure 5. Hole roundness under MQL condition using coated (TiAlN) carbide drill](image1)

![Figure 6. Hole roundness under MQCL condition using coated (TiAlN) carbide drill](image2)

3.3 Surface roughness
The average surface roughness value for each drilling experiment under MQL and MQCL conditions are shown in Figure 7. Several researchers [9, 10, 11] have been asserted that surface roughness tends to increase as the cutting speed increase during machining Ti-6Al-4V due to the temperature generated. Higher temperature tends to be concentrated at the cutting edge which leads to catastrophic failure. However, the graph shows no specific trends in the value of surface roughness as the cutting speed increase. This may due to the cooling technique that has been approached during the experiment. As reported by a few researchers [12, 13, 14], vegetable oils offer good physiochemical properties and has been suggested as an excellent coolant-lubricant in reducing the tool chip contact
length and heat dissipation during high speed machining. It can be said that the trend on the graph has been arguably answered, where vegetable oils have a great influence on surface roughness.

![Graph showing average surface roughness versus cutting speed under MQL and MQCL condition using coated (TiAlN) carbide drill.](image)

**Figure 7.** Average surface roughness versus cutting speed under MQL and MQCL condition using coated (TiAlN) carbide drill

4. Conclusion
In this research work, hole quality is measured in terms of hole diameter, roundness and surface roughness. The current study presented a comparison between different cutting speeds under different cooling conditions.

1. According to most of the researchers, the hole diameter deviation is decreased as cutting speed increased. However, other factors such as tool diameter, tool material and tool overhang should be considered as well for preferable results.
2. Similar to hole diameter deviation, other controlling factors such as fixture or machine tool vibration and damping properties also contribute to roundness error.
3. Higher cutting speed and low feed rate have resulted in improved surface quality, however the cooling condition also influence for the better result. The inconsistent result of surface roughness could be argued that surface roughness depends not only on cutting speed but also on cooling conditions that play an important role on surface roughness.

5. References
[1] Shokrani A, Dhokia V and Newman S T 2012 International Journal of Machine Tools & Manufacture Environmentally conscious machining of difficult-to-machine materials with regard to cutting fluids *Int. J. Mach. Tool. Manu.* **57** 83–101
[2] Abele E, Elsenheimer J, Hohenstein J and Tschanerl M 2005 Influence of drill dynamics on bore quality *CIRP Ann-Manuf. Techn.* **54** 83–6.
[3] Galloway D F 1957 Some experiments on the influence of various factors on drill performance. *Trans ASME* **79** 191–231
[4] Furness R J, Wu CL, Ulso A G 1996 Statistical analysis of the effects of feed, speed, and wear on hole quality in drilling *J. Manuf. Sci. Eng.* **118** 367–75
[5] Syed I, Bahr B, Sha J and Tadayon, F 2002 Experimental study of hole quality in drilling of titanium alloy (6AL-4V) *SAE Transactions* **21**-26
[6] Waqar S, Asad S, Ahmad S, Abbas C A and Elahi H 2017 Effect of drilling parameters on hole quality of Ti-6Al-4V titanium alloy in dry drilling. *Mater. Sci. Forum* **880** 33-36 Trans Tech Publications.
[7] Abdelhafiez A M, Soo S L, Aspinwall D K, Dowson A and Arnold D 2015 Burr formation and hole quality when drilling titanium and aluminium alloys *Procedia CIRP* **37** 230-235
[8] Çelik Y H 2014 Investigating the effects of cutting parameters on the hole quality in drilling the Ti-6Al-4V alloy *Mater. Tehnol.* **48(5)** 653-659
[9] Cantero, J L, Tardio M M, Canteli, J A, Marcos M and Miguelez M H 2005 Dry drilling of alloy Ti–6Al–4V Int. J. Mach. Tool. Manu. 45(11) 1246-1255
[10] Sharif S and Rahim E A 2007 Performance of coated-and uncoated-carbide tools when drilling titanium alloy—Ti–6Al4V J Mater. Process. Technol. 185(1-3) 72-76
[11] Li R, Hegde P and Shih A J 2007 High-throughput drilling of titanium alloys Int. J. Mach. Tool. Manu. 47(1) 63-74
[12] Rahim E A and Sasahara H 2011 A study of the effect of palm oil as MQL lubricant on high speed drilling of titanium alloys Tribol. Int. 44(3) 309-317
[13] Rahim E A and Sasahara, H 2011 Investigation of tool wear and surface integrity on MQL machining of Ti-6AL-4V using biodegradable oil P. I. Mech. Eng. B-J. Eng. 225(9) 1505-1511
[14] Lawal S A, Choudhury I A, and Nukman Y 2013 A critical assessment of lubrication techniques in machining processes: a case for minimum quantity lubrication using vegetable oil-based lubricant J. Clean. Prod. 41 210-221