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The Effect of Drill Point Geometry and Drilling Technique on Tool Life when Drilling Titanium Alloy, Ti-6Al-4V

F.R. Wong[1,*], S. Sharif[2], K. Kamdani[1], E.A. Rahim[1]

[1]Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia (UTHM)
Parit Raja, Batu Pahat, 86400 Johor, Malaysia
email:anyssa_may@yahoo.com

[2]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia,
81310 Skudai, Johor, Malaysia
email:safian@fkm.utm.my

Abstract:

An experimental investigation was conducted to determine the effect of drill point geometry and drilling methods on tool life and tool wear in drilling titanium alloy, Ti-6Al-4V. Uncoated carbide drills with different type of geometry under various cutting speeds and drilling methods were used in the investigation. Experimental results revealed that both the drill geometry and drilling techniques affect the tool wear and tool life performance when drilling Ti-6Al-4V. It was also found that peck drilling outperformed direct drilling in terms of tool life all cutting speeds investigated. Non uniform wear and chipping were the dominant failure mode of the tools tested under most conditions.

Keywords: Titanium alloy, Peck drilling, Uncoated carbide, Drill point geometry

1. Introduction

Extensive use of titanium and its alloys had been recorded in various applications such as in aerospace industry, automotives, sport equipments, automotives, biomedical, petroleum industry and marine applications [1]. The utilization has progressed rapidly due to the attractive characteristics of the materials which include high strength to weight ratio at elevated temperatures, corrosive resistance, fracture resistance characteristics, longer service life and compatibility to composite structures [2,3]. However, machinability of titanium and its alloys can be considered poor due to its high chemical reactivity on tool materials, high temperature strength and low modulus of elasticity [4,5].

Drilling has been an essential technique in aerospace industry and is widely used to produce holes with high quality at low cost and short processing time [6]. For the few decades, many researchers have studied the machinability of titanium alloys especially in turning [7-12] and milling [13-17] operations. Meanwhile, reports on drilling of titanium and its alloys are still limited [2, 18-21].

Previous study on drilling of Ti-6Al-4V with uncoated and coated carbide drills revealed that Supernitride coated tool recorded the lowest tool wear rate and subsequently followed by TiAlN coated and uncoated carbide tool at the cutting speed of 25m/min [6]. Meanwhile, Sakurai et al. [18] focused on the machinability of Ti-6Al-4V

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under various cutting strategies which include intermittent deceleration feed drilling, the use of high pressure coolant and vibratory drilling. They reported that intermittent deceleration feed drilling recorded the lowest tool wear hence improved the tool life. Detailed experimental work using Ti-6Al-4V and Ti-48Al-2Mn-2Nb had been carried out by Mantle et al. [19]. They found that the thrust force and torque when drilling Ti-6Al-4V was lower than when drilling Ti-48Al-2Mn-2Nb. Arai and Ogawa [20] suggested that the application of high pressure coolant could extend the tool life when drilling of Ti-6Al-4V. In summary, it was found that the main contributors for poor performance of cutting tools were rapid tool wear and chip adhesion to the cutting edges.

This study is undertaken to investigate the effect of drill point geometry and drilling technique on tool life and tool wear when drilling Ti-6Al-4V with uncoated carbide tool.

2. Experimental Details

Titanium alloy, Ti-6Al-4V was used as the workpiece material. The workpiece was prepared into rectangular shape with dimension 153mm x 78mm and 10mm thickness. The mechanical properties and chemical compositions of the material are shown in **Tables 2.1** and **2.2** respectively.

All the drilling trials were conducted on a Mazak VARIAXIS 500-5X CNC machining centre as shown in **Figure 2.1**. Drilling experiments were carried out at various cutting speeds of 50, 60 and 70m/min with constant feed of 0.1mm/rev in direct and peck drilling modes.

The type of cutting tool used was solid uncoated carbide tool (WC/Co) drills with diameter 6 mm. The drill geometry and detail specifications are shown in **Table 2.3**.

Table 2.1: Mechanical properties of Ti-6AL-4V

Properties	Value
Tensile Strength (MPa)	960-1270
Yield Strength (MPa)	820
Elongation (%)	≥8
Reduction In Area (%)	≥25
Density (g/cm^3)	4.42
Modulus of Elasticity Tension (GPa)	100-130
Hardness (HV)	330-370

Table 2.2: Chemical composition of Ti-6AL-4V (Wt %)

Al	V	Fe	C	Mo	Mu	Si	Ti
6.37	3.89	0.16	0.002	<0.01	<0.01	<0.01	Balance

Figure 2.1: MAZAK CNC Machining centre

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Table 2.3: Specification of the drills.

	Tool A
	
Type of drill	2 flutes-twist drill
Point angle	130^{o}
Helix angle	25^{o}
Flute length (mm)	29
Web thickness (mm)	0.63
	Tool B
	
Type of drill	2 flutes-twist drill
Point angle	146^{o}
Helix angle	32^{o}
Flute length (mm)	20
Web thickness (mm)	0.55

Without dismounting the drill from the tool holder, the tool wear was measured using a Nikon toolmakers' microscope at 30× magnification. The experiment was stopped after drilling at the 25th hole or until the tools met any one of the following tool life criteria; average non-uniform flank wear ≥0.15 mm, maximum flank wear ≥0.2 mm, chipping ≥0.2 mm or catastrophic failure. In this study, the tool specimens were prepared to investigate the tool wear patterns and failure modes.

The SEM equipped with Energy Dispersive X-Ray Spectroscopy (EDAX) was used under various magnifications to capture the appropriate tool wear images and to determine the elements that adhered on the worn tools.

3. Results and Discussion

3.1 Tool life

The effect of various cutting speeds on the tool life for both types of drill with different type of drilling modes (direct and peck) are shown in **Tables 3.1** and **3.2,** and **Figures 3.1**, **3.2** and **3.3**. The drill life reduced significantly with an increase in cutting speed as a result of increase cutting temperature and stress conditions hence accelerates the growth of tool wear [3,11]. Tool A recorded a very short tool life when compared to Tool B for both direct and peck drilling. Tool A suffered rapid wear growth and breakage in few seconds during direct drilling. The longest tool life of 33.6 seconds was obtained with Tool B at cutting speed of 50m/min during peck drilling. An increment of 31% in tool life was achieved by Tool B when compared to Tool A under the same cutting condition. The higher tool life obtained by Tool B was probably due to the effect of the longer cutting edge which improves the cutting action. The peck drilling was seem to outperformed direct drilling for both tools when higher tool lives were recorded at all cutting speeds investigated. **Tables 3.1** and **3.2** show the failure mode and tool life for Tool A and Tool B for both type of drilling; direct and peck drilling.

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Table 3.1: Tool life and tool failure mode data for direct drill at 0.1mm/rev

Vc	Tool life (sec)		Failure mode	
(m/min)	Tool A	Tool B	Tool A	Tool B
50	3.93	10.16	Chipping	Flank wear
60	2	4.6	Breakage	Flank wear
70	0.95	1.68	Breakage	Flank wear

Table 3.2: Tool life and tool failure mode data for peck drill at 0.1mm/rev

Vc	Tool life (sec)		Failure mode	
(m/min)	Tool A	Tool B	Tool A	Tool B
50	25.68	33.6	Flank wear	Flank wear
60	17.46	14.88	Chipping	Chipping
70	15.21	7	Chipping	Chipping

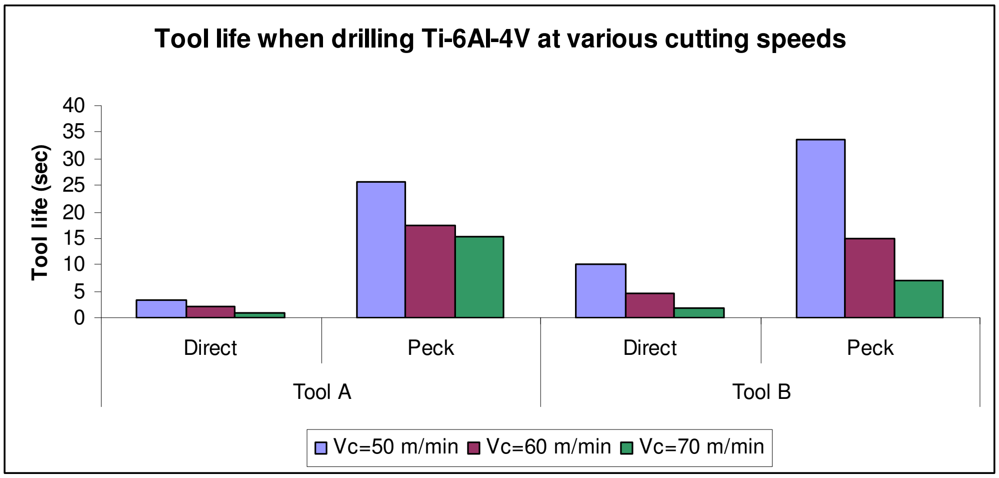

Figure 3.1: Comparison of tool life when drilling Ti-6Al-4V with Tool A and Tool B at various cutting speeds, at constant feed rate of 0.1 mm/rev for direct and peck drilling.

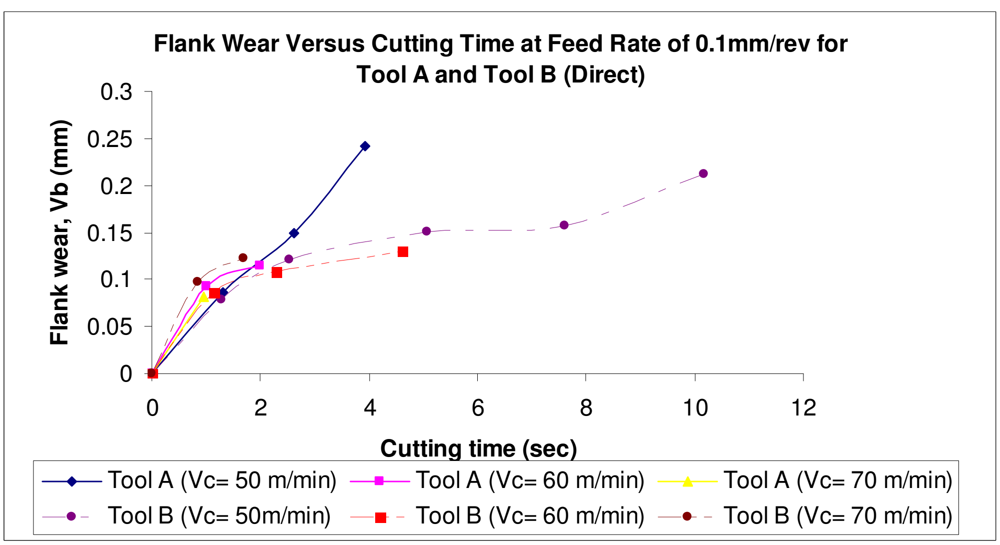

Figure 3.2: Flank wear versus cutting time when direct drilling Ti-6Al-4V with Tool A and Tool B at various cutting speeds and at constant feed rate of 0.1mm/rev.

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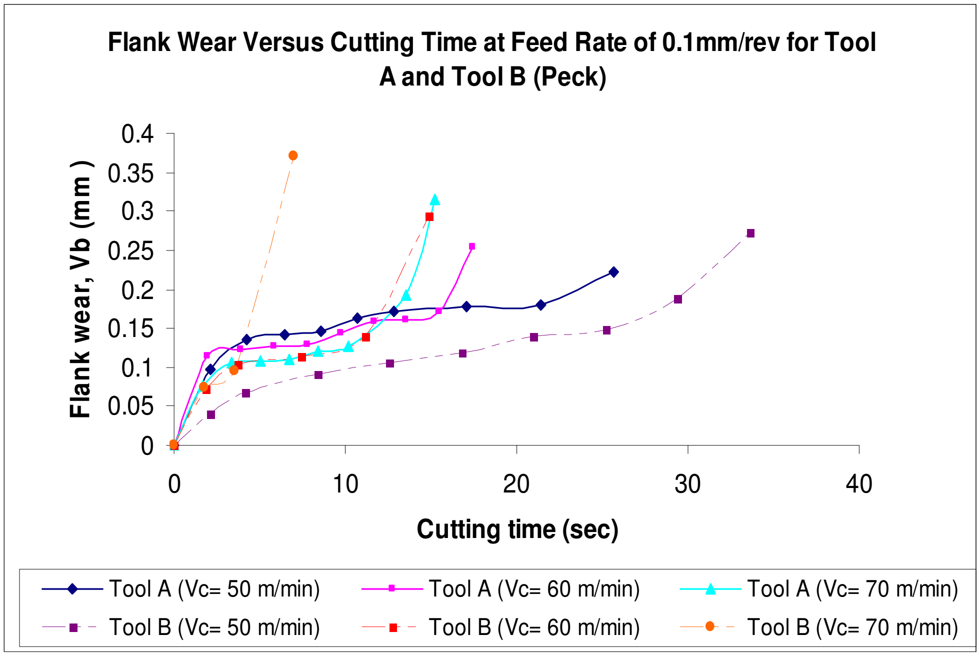

Figure 3.3: Flank wear versus cutting time when peck drilling Ti-6Al-4V with Tool A and Tool B at various cutting speeds and at constant feed rate of 0.1mm/rev.

3.2 Tool Wear and Failure Mode

Figures 3.2 and **3.3** show the development of tool wear for Tool A and Tool B respectively at various cutting speeds; 50, 60 and 70m/min. It was found that the tool wear rate for Tool B grow gradually when compared with Tool A. All the drills experienced a premature failure under 1 minute of cutting time. As a result, fewer holes were produced when using Tool A. Tool A experienced breakage when direct drilling after the 2^{nd} hole at cutting speed of 60m/min. At 70m/min, rapidly breakage occurred after drill the 1^{st} hole. Unlike Tool A, Tool B exhibited a lower tool wear rate as shown in **Figures 3.2** and **3.3**. It can be seen that initially the flank wear grew steadily and increased as drilling continues.

Non-uniform flank wear and micro chipping were also observed in Tool B during direct drilling for the entire cutting speeds. Figure 3.1 also shows that non-uniform flank wear and micro chipping were observed in Tool A when peck drilling at all cutting speeds. Adhered titanium material was observed on the flank face of the drill. This is well expected since titanium has a tendency to weld to the cutting tool during machining and may promote chipping at the cutting edges after extended drilling [14,15]. According to Sharif et al. [15], the major contributors to the occurrence of chipping of the cutting edge were adhesion and attrition wear.

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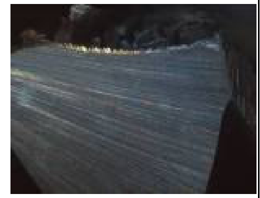
Cutting speed, Vc (m/min)	**Failure Mode for Tool A**		**Failure Mode for Tool B**	
	Direct	**Peck**	**Direct**	**Peck**
50				
60	Breakage			
70	Breakage			

Figure 3.4: Tool failure mode when drilling Ti-6Al-4V at various cutting speeds and at constant feed rate, 0.1mm/rev for Tool A and Tool B in direct and peck drilling.

4. Conclusions

1. Tool B gave the best tool life performance when drilling Ti-6Al-4V at the lower cutting speed of 50m/min during peck drilling. Therefore, lower cutting speed and peck drill (method of drilling) should be employed when drilling Ti-6Al-4V in order to achieve better tool life performance.

2. Tool wear was found to develop progressively with cutting time at low cutting speed when drilling Ti-6Al-4V using both methods of drilling. However, at high cutting speed, the tool failed rapidly with regardless of the drilling methods.

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3. The dominant tool failure mode when peck drilling Ti-6Al-4V for Tool B was excessive chipping. Meanwhile, non-uniform flank wear and micro-chipping were the dominant failure for Tool A in direct drilling and Tool B in peck drilling. However for Tool A, the tool rapidly broke after drilling few holes when direct drilling was applied.

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