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Investigation of Tool Entry Strategy when Pocket Milling Titanium Alloy, Ti-6Al-4V under Wet Condition

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Abstract. Tool entry strategy determines how the cutting tool enters and moves into the workpiece during pocket milling operation without collision between the tool and workpiece. Optimal selection of tool entry and its parameters settings during pocket milling are crucial in order to improve the tool life and accuracy of the machined part. Pocket milling process is performed purposely to reduce the weight of the parts as it involved high material removal and generally associated with high manufacturing costs. This work aims to investigate the effect of tool entry strategies on the tool wear of TiAlN coated carbide insert when pocket milling titanium alloy, Ti-6Al-4V under wet coolant condition. Two tool entry strategies namely circular and angular ramping were evaluated under rough machining condition. Three main cutting parameters of cutting speed (Vc), feed rate (fz) and depth of cut were used with constant values at 90m/min, 0.1mm/tooth and 2mm respectively using fixed entry angle of 3°. Tool wear was observed and recorded for both circular and angular ramping entry modes at the end of the experiment. Experimental results showed that tool flank wear increases as the number of pass or run increases. During the first run, the recorded flank wear was at 0.016mm and 0.033mm for circular and angular entries respectively. At the fifth or the last run, the recorded flank wear was 0.028mm and 0.041mm for circular and angular entries respectively. It can be clearly concluded that the best tool entry when pocket milling Ti-6Al-4V was circular ramping as compared to angular entry due to the small immersion angle and intermittent tool engagement. These phenomena made it possible to ensure better stability during machining and prolong the tool life thus reducing the machining cost and enhance the overall performance of the pocket milling process.

INTRODUCTION

Ti-6Al-4V is an alpha beta alloy, widely used in aerospace industries due to its unique mechanical properties of high strength-to-weight ratio and low thermal conductivity thus ensuring excellent behavior during its applications. Titanium alloys also comply with the aerospace demand for lightweight parts with its density of 4.5g/cm3 which is about half the weight of steel and Ni-based superalloys [1]. In addition to its attractive properties for aerospace parts, titanium alloys has the ability to withstand high temperature ranging between 500-600 °C [2]. Instead of being absorbed into the material, the heat generated during machining is transferred to the cutting tools thus causing rapid tool wear and tool failure. As such many researchers had categorized titanium and its alloys as difficult-to-machined material [3,4,5] due to short tool life performance.

The growing demands on aerospace manufacturers to produce light weight parts at low cost had resulted in various machining strategies being introduced. This include pocket milling operation which is among the most common

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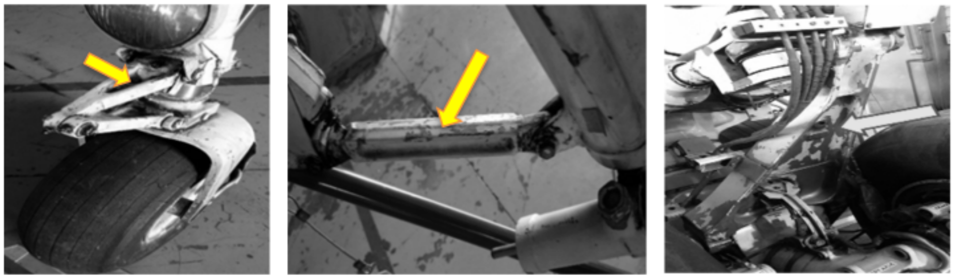
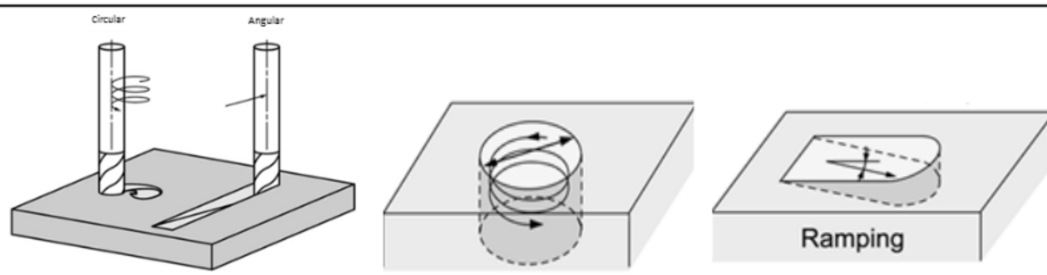
operation in aircraft machining in order to reduce the weight without reducing the strength of the machined parts. The application of pocket milling in the manufacturing of landing gears are shown in Figures 1(a) and 1(b) for private jet Cesna 206 and Figure 1(c) for Boeing 747.



(a) (b) (c)

FIGURE 1. Arrows show pocket milling application in manufacturing landing gears for private jet Cesna 206 ((a) and (b)) and Boeing 747 (c)

In performing pocket milling, the most important operation is creating the initial pocket. At this initial stage, the cutting tool is entering the work material hence, the possibility of wear to occur on the flank of the tool need to be taken into consideration. Herewith, the selection of tool entry strategies is crucial in order to minimize the tool wear at this early stage. This condition becomes more critical when dealing with difficult-to-cut material such as titanium alloy. In general, the most common entry types used in milling operation are circular ramping, angular ramping and plunge. However, the plunge mode is more applicable when using solid end mill and meanwhile most of the insert type cutting tools are not suitable to be used for plunging mode especially when machining titanium alloys. According to C.E.H. Venture and A. Hassui, plunge entry resulted in tool fracture due to the recut chip and significantly high cutting force involved [6]. Hence, the most suitable entry modes for insert type cutting tool are angular and circular ramping as indicated in Figure 2. However, these entry modes are expected to exhibit different tool wear behaviors due to the different tool path patterns which results in different load and impact during tool entry into the workpiece. In due respect, it is important to identify the suitable tool entry modes in order to minimize the tool wear effected in particular at the initial stage whereby the tool entry contributed about 10% of the total flank wear. This situation becomes is crucial when performing pocket milling due to significant effect of the initial wear on the surface integrity of the machined surface. On the other hand, the tool entry parameters are important to minimize the cutting load especially the entry angle in order to ensure lower cutting forces during tool entry thus prolonged the tool life.



(a) (b) (c)

FIGURE 2. Type of tool entries (a) circular vs. angular (b) circular (c) angular

EXPERIMENTAL DESIGN AND SETUP

In this study, machining trials were conducted on a 3 axes HAAS CNC milling machine made from USA as shown in Figure 3. Carbide insert with designated code XOMX060208R-M05 was mounted on a two flutes tool holder (R217.69-1012.0-06-2N) of 12 mm diameter was supplied by SECO TOOLS. Pocket milling experiments were carried on titanium Ti-6Al-4V block (L90mm x W50mm x Dp10mm) using different mode of tool entries under wet condition with water-based cutting fluid. The two types of entries involved were circular ramping and angular ramping available in MastercamX7 software. The cutting parameters selected for both entries strategies were cutting speed 90 m/min, feed rate 0.1mm/tooth and depth of cut 2mm with constant tool entry angle set at 3°. The wear progression was measured using the Dino-Lite Portable Microscope as shown in Figure 4 with magnification of 88 times. New fresh inserts were used for each type of entries during pocket milling. In order to evaluate the tool wear progression, 5 paths for each entry has been performed and measured.

FIGURE 3. HAAS CNC Milling Machine

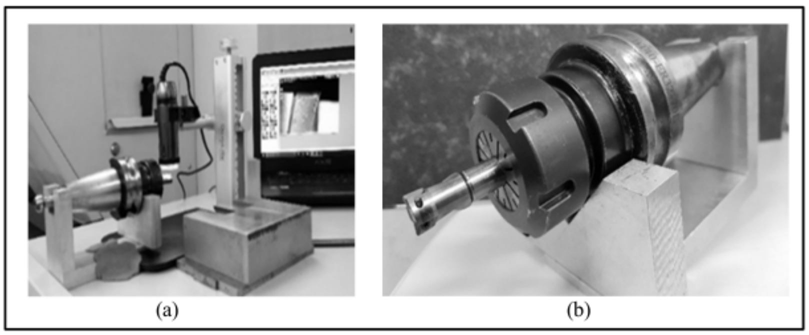


FIGURE 4. Tool wear measurement setup. (a) Dino-Lite Portable Microscope to measure wear and (b) cutting tool setup

RESULTS AND DISCUSSIONS

Tool Wear Evaluation

It was observed that circular and angular entries exhibit a significant result whereby circular entry performs better than angular ramping with respect to tool wear. The comparison results were based on the similar cutting parameters including cutting times and tool entry angle for both entries. Result showed that the minimum flank wear recorded for angular ramping is equal to the maximum flank wear recorded for circular ramping. Circular ramping was found to be more stable as compared to angular ramping. This condition is influenced by the tool path pattern of circular ramping where the small value of immersion angle during machining results in a more stable machining as compared to angular ramping [7] as shown in Figure 5. In addition, circular ramping provides sufficient time for chip evacuations and reduces the possibility of re-cut chips which able to cause the immediate cutting force augmentation. The intermittent tool engagement results in sufficient time and space for the tool to be cooled thus reducing the heat generated during machining hence increased the tool life. Moreover, this condition allowed the coolant to penetrate into the cutting zone hence reduced the temperature generated during the machining process. In machining titanium alloys, cutting temperature is reported as the main contributor in facilitating tool wear. This is mainly due to the properties of titanium alloy which include low thermal conductivity whereby the temperature generated during machining is not absorbed by the material and instead the heat is transferred to the cutting tool and caused rapid tool wear [3].

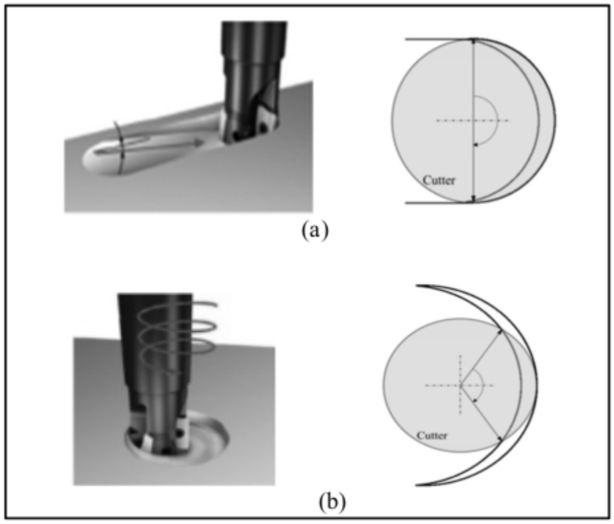


FIGURE 5. Immersion angle of two tool entry strategies [6] (a) angular ramping and (b) angular ramping

Figures 6 and 7 show the paths and cutting tool directions for both circular and angular entries with a total of 5 paths where the depth of cut was fixed at 2mm for every path. Tool wear progressions were measured and recorded for every path. The experiment was performed using climb milling method which is a suitable machining method for titanium alloy [8]. Based on the results obtained, it was observed that tool entries contributed to almost 10% of total wear. This clearly proved that the wear started to occur at the early stage due to entry impact during the tool entering into the workpiece. With this phenomena and results, it is important to select the suitable tool entry in order to reduce the tool wear and prolonged the tool life especially in machining of difficult to machine materials such as titanium alloy. Proper selection of tool entries can help in increasing the tool life. According to the experiment results, it is evident that the best tool entry strategy in the milling of the titanium alloy is circular ramping.

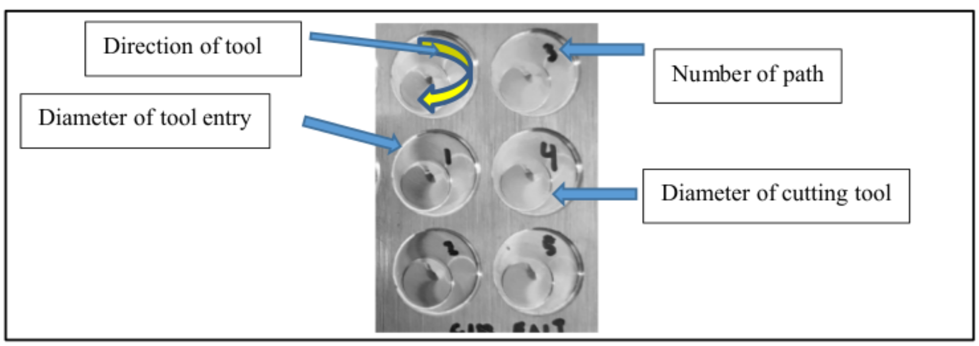


FIGURE 6. Circular ramping with cutting parameter is Vc 90m/min and Fz 0.1mm/tooth.

In addition, the angular ramping path is similar to straight milling path where the size of the slot is equal to the diameter of the tool. Herewith, the immersion angle for straight milling is half of tool diameter tool and results in continuous machining contact area between the tool and workpiece. This condition results in high possibility to generate high friction between the workpiece material and cutting tool thus generating high temperature. Eventually this condition leads to rapid tool wear of the cutting edge. Moreover, the possibility of re-cut chips is also high for angular entry due to the insufficient space for the chip to evacuate from the cutting zone as the slot size is equal to the tool size. This situation also affected the surface roughness of the machined surface. According to the flank wear (Vb) results, angular ramping recorded 0.041mm of flank wear while circular ramping was 0.028mm at the 5th paths (Figure 8).

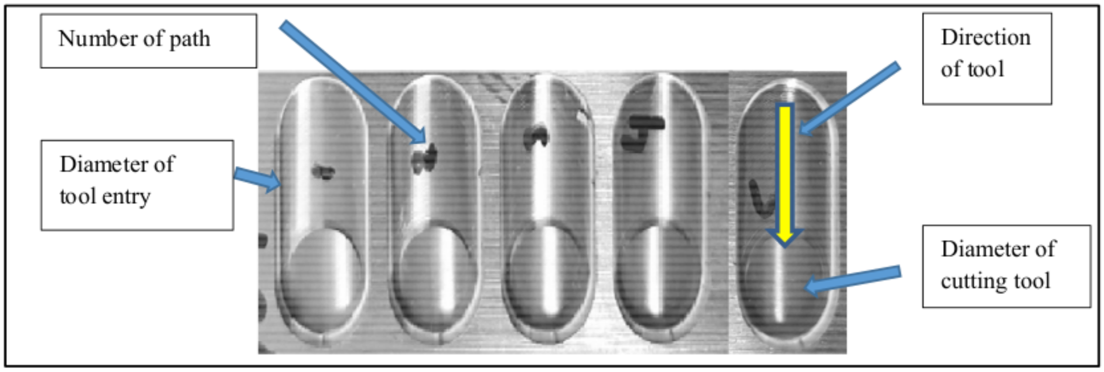


FIGURE 7. Angular ramping with cutting parameter is Vc 90m/min and Fz 0.1m/min

According to the flank wear observation in Figure 8 on the cutting inserts, it was observed that uneven cutting surface starts to occur at the flank face for both entries. However, for the angular ramping results it was found that high cutting force and re-cut chips occurred during the tool entry. Nevertheless, those problems could be solved by changing to a new cutting tool after performing an entry but this may increase the machining times and cost [9].

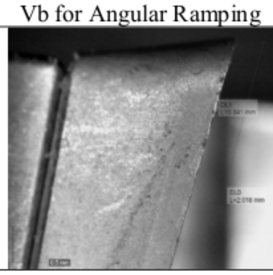
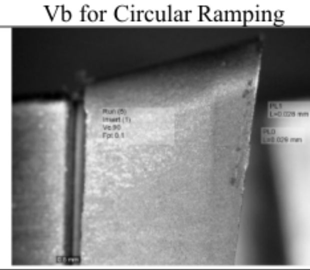
Vb for Angular Ramping	Vb for Circular Ramping
	

FIGURE 8. Flank wear measurement for Vc 90m/min and feed rate 0.1mm/tooth at 5th path.

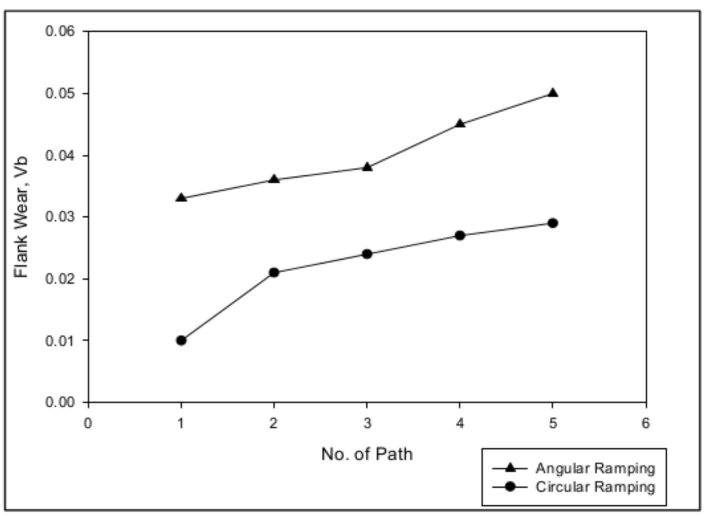


FIGURE 9. Comparison between circular and angular ramping

The graphs illustrated in Figure 9 show the wear progression for angular ramping is stable at the early stage for path 1 to path 3. This is due to the constant tool contact area where the immersion angle is half of the tool size in addition to the small entry angle. Furthermore at this stage, the coating of the cutting tool is still intact to the substrate thus preventing the rapid progression of flank wear. The wear started to increase at paths 4 and 5 due to the coating has been eradicated or worn by the friction between the tool and work material during the machining process hence accelerating the tool wear due to the exposure of the tool substrate direct to the heat generated during machining. In addition the coating has greater hardness value than the substrate. The friction generated at this area causes an extremely rapid tool wear at these stages due to the high cutting speed that gives higher impact. Previous studies on end milling [10] and face milling [11] of titanium alloys using uncoated and coated carbide tools showed that uncoated carbide tools performed better as compared to coated carbide tools in terms of tool life. Moreover, the graph illustrated also shows the wear progression for circular ramping. The wear is observed to increase at a constant rate for every path. The increment was gradual where it is clearly shown that the maximum value of tool wear is slightly equal to the minimum value from that of angular ramping. The increment of wear is due to the results of the toolpath whereby cutting tool is moving in cycloid pattern and the contact area is intermittent as compared to angular ramping.

CONCLUSIONS

This paper discussed the most appropriate tool entry strategy when pocket milling titanium alloy, Ti-6Al-4V under wet condition using emulsified coolant. Results showed that at the first run, the wear was at 0.016mm and 0.033mm for circular and angular entry respectively. At the end of the run (5th path), the recorded flank wear was 0.028mm and 0.041mm for circular and angular entry respectively. Based on these results, it can be suggested that circular ramping was the best tool entry when pocket milling titanium alloy, Ti-6Al-4V using both uncoated and coated carbide tools. Circular ramping is able to provide ample time and enough space for chips evacuation and intermittent tool engagement which ensure the stability and allowing sufficient time for the tool to be cooled as compared to angular ramping.

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