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Performance of Tools Design when Helical Milling on Carbon Fiber Reinforced Plastics (CFRP) Aluminum (Al) Stack

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Abstract. Hole making process is not strictly to the drilling technique where others machining could also influence to the quality in CFRP hole.Therefore, helical milling process becomes as an alternative method to produces bore on CFRP plate thus minimizing the defects. The common defects on CFRP are delamination, splintering and cracking. Meanwhile, if the CFRP stacking together with aluminum plate, burr at exit hole of aluminium plate is produced. Therefore, it is essential to control the critical machining parameters to assure a good quality of the hole. The main objective of this project is to improve the hole quality of CFRP/AL stack in terms of surface roughness using helical milling technique. In addition the cutting force and temperature will be measured as well. There are three levels of cutting speeds; two levels of feed rate and depth per helical path are made accordingly to helical milling characteristics. It was found that all tool design exhibit comparable performance for helical milling process on CFRP/Al stack.

Introduction

Composite materials are more important to aerospace, naval and automotive industry. Application of multi material in aircraft industry such as aluminum stack or titanium stack is increased. In this composite/aluminum or composite/titanium stack, the holes will produce in large numbers for assembly. Hole making process of this material is challenging task to manufacturing engineer because of differential machining properties as reported by Zitoune [1]. A combination of high properties specific strength and stiffness, light weight of carbon fiber- reinforced plastic (CFRP), which make their use especially attractive for aircraft and aerospace application [2].

With the regard to get the better quality characteristics of drilling composites, some problems were encountered such as surface delamination, fiber/resin pullout, burr formation and hole surface roughness. Among the defects caused by drilling, delamination appears to be the most critical during the process [3]. According Tandon et al, in a commercial aircraft like the Boeing 787, about 50 % primary structures in its 787 program are using the composite material. Machining of composites, mainly drilling, is extensively used for producing riveted and bolted joints during assembly operations [4]. As reported by Khashaba, delamination accounts for 60% of all rejections during final assembly of an aircraft. Stress concentration, delamination, and micro cracks significantly reduce the composite performance [5]. Reported by Davim and Reis [6], studied on the drilling on CFRP that helical flute carbide drill is better compare to others cutting tool material due to their hot hardness. Eccentricity of the drill major role in degrading the hole quality [7] the researcher shows that the critical thrust force which produces delamination with increase in drill point eccentricity. Delamination will be straight influence the hole quality of produce as well as surface roughness with significant loss of mechanical toughness. Besides that, most wear mechanism in machining of aluminum alloy are built-up, adherent layer and diffusion. This leads to decrease in tool life and poor machined surface. Recently, Rahim et. al [8] conducted a research on the behaviour of ultrasonic torsional vibration on CFRP using 2 sets of drill geometry. They found that this technique tends to reduced the thrust force and delamination. The objective of this study is to investigate the hole quality as well as cutting force and temperature after applying helical milling techniques in hole making process of CFRP/AL using different processing parameters and cutting tool geometries.

Experimental setup

Helical milling was performed on a CFRP and aluminum plate (Grade 2024) with a thickness of 7.6 mm and 3 mm respectively. Both plates have a same dimension of 300 mm and 100 mm for length and width, respectively. The CFRP composite was made using an unidirectional based on aerospace requirement. The lay-up sequence is starting 0° and then oriented to 90°, followed by 45° and -45° angle. Both materials have a high materials strength compare to other materials and it is widely used in aerospace industries. Aluminum stack were selected based on mechanical properties and it is more cheap compare to titanium. The laminate was prepared in controlled atmosphere and compacters using a vacuum pump.

The experiments were carried out on a Sodick MC 430L vertical machining center. Fig. 1. shows the experimental setup, consists of dynamometer, amplifiers, thermocouple wires and data acquisition software. The detail of cutting parameters are shown in Table 1. The roughness of the machined surface was measured using surface roughness tester (Mitutoyo SJ-400).

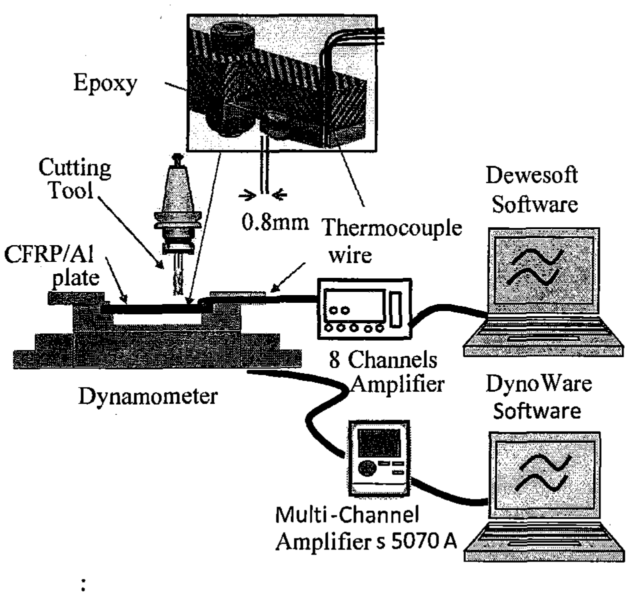

Fig. 1: Experimental Setup

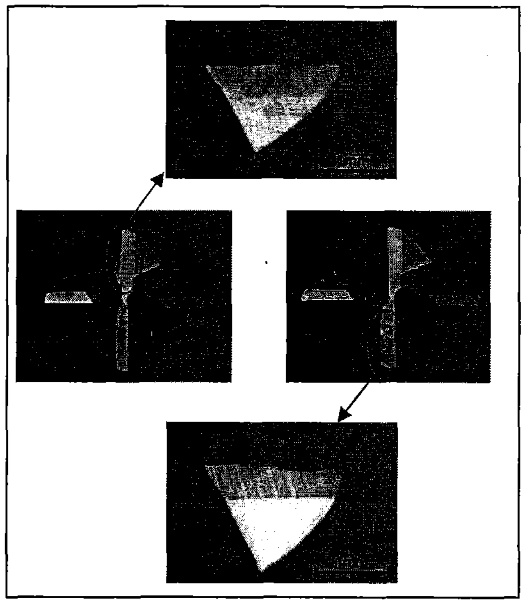

Fig. 2: End mill cutting edge: (a) Design 1 and (b) Design 2

Four flutes end mill cutting tools with the diameter of 6mm were used in the entire experiments as shown in Fig. 2. It was made from cemented carbide (WC-Co) with ISO code of K30 where it have high thermal resistant and hard material. Four types of tool design are being tested in this experiment. They were denoted as 1-1 and 1-5 for flat cutting edge while 2-1 and 2-5 for radius cutting edge as shown in Table 2.

Table 1: Cutting parameters

Cutting speed, V_c (m/min)	90, 120, 150
Feed rate, f (mm/tooth)	0.03, 0.06
Bore diameter, D_b (mm)	8
Depth per helical path, a_p (mm)	0.3, 0.6
Coolant	Dry

Table 2: End mill geometry

	Type of end mill	Helix angle	Tool identification
Design 1	Flat cutting edge	10°	1-1
		20°	1-5
Design 2	Radius cutting edge	10°	2-1
		20°	2-5

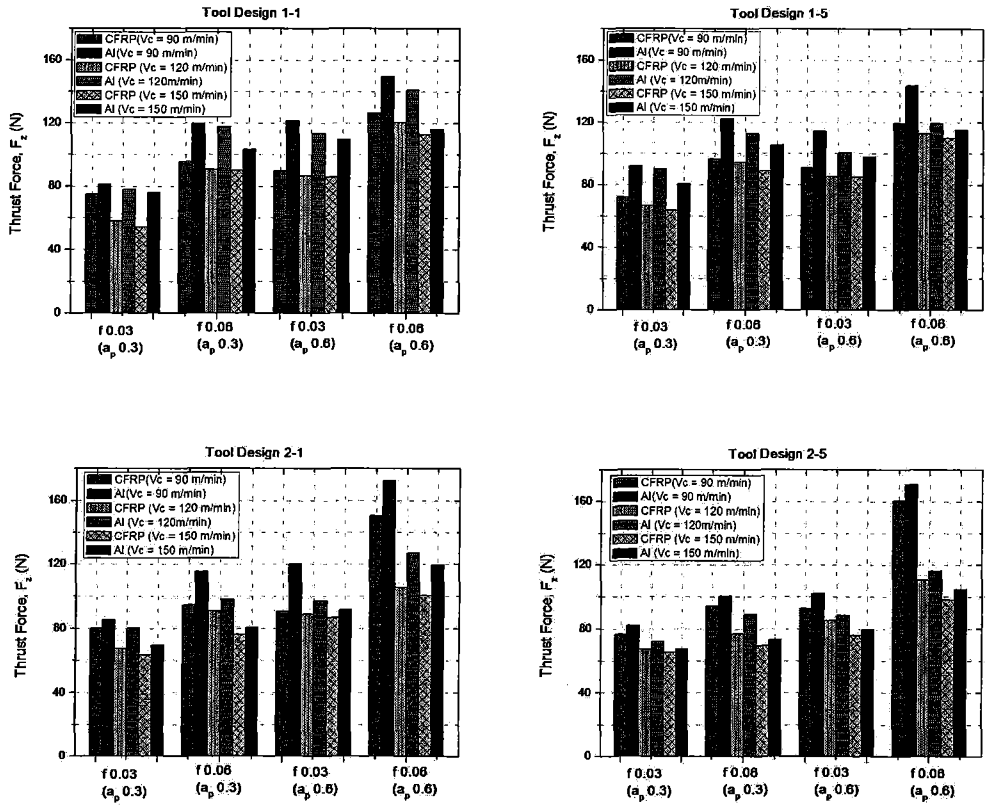

Fig. 3: The result of thrust force for different cutting tool geometries.

Results and Discussion

Thrust Force. Thrust force was analyzed based on the effect of feed rate, cutting speed, depth per helical path and cutting tool geometry. Fig. 3 shows the effect of the mentioned parameter on the thrust force during helical milling on CFRP/Al. It can be noted that increases of feed rate will increase the thrust force. Thrust force rose steeply while entering the aluminum plate compare to CFRP. This is mainly due to the lower impact of the fiber while drilling CFRP. According to [9], the feed rate has a strong correlation with the thrust force which associated with the larger cross-sectional area of the undeformed chip.

Increasing cutting speed from 90 m/min to 150 m/min will slightly decrease the thrust force. Faster rotation spindle speed reduces the contact area between the tool and chip interface, subsequently reduced the coefficient of friction. The value of thrust force decreases as the depth per helical path increased. This value was slightly higher when penetrates the aluminum plate. Cutting tool geometry exhibits insignificant influenced in thrust force. The increasing depth per helical path leads to grow of chip deformation with increasing thickness. This increament will cause in the higher force needed for cutting workpiece. Furthermore, higher depth per helical path will also cause difficulties in removing chip with smaller thickness. This types of chips will compress and increase thrust force in machining process thus maintaining the depth of cut at the same rate.

Cutting Temperature. The workpiece temperature was measured using an embedded thermocouple in the CFRP and Al plate. Fig. 4 shows the influence of process parameter on the workpiece temperature. The workpiece temperature increases with increasing the cutting speeds. Increase in cutting speed results in more heat generated by friction and allows less time for the heat dissipation through the tool. The temperature for Al was higher compare to CFRP. However, workpiece temperature reduces as the feed rate increased. Larger feed rate results in a shorter engagement time which leads to smaller workpiece temperature. It can be seen that the larger a_p of 0.6 mm recorded lower workpiece temperature for both CFRP and Al compared to the a_p 0.3 mm. All cutting tool designs showed a comparable performance in terms of temperature generation.

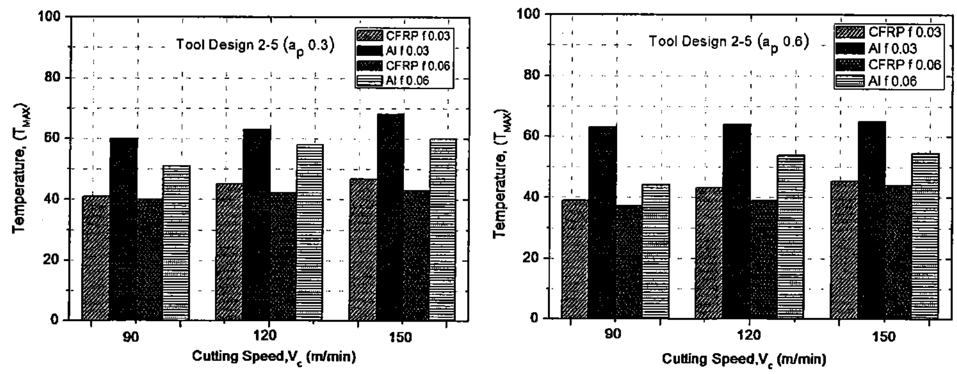

Fig. 4: Cutting temperature on different parameters for CFRP and Al

Surface Roughness, R_a. Aerospace industry has implemented a requirement of surface roughness produced by machining process. The value of surface roughness demand for both CFRP and Al is <3.2μm and <1.6μm, respectively. Designs 1-5 and 2-5 recorded the lowest value of surface roughness of CFRP. It believes that the helix angle plays a significant role in terms of fiber debris transportation. Cutting speed and feed rate showed no significant effect on the performance of roughness on CFRP. Furthermore, higher feed rate produces higher value of surface roughness especially on Al plate. An increase in feed rate is always accompanied by severe formation of feed marks, subsequently deteriorate the surface finish. It can be concluded from the results that the surface roughness value recorded by all cutting tool designs were in the acceptable range.

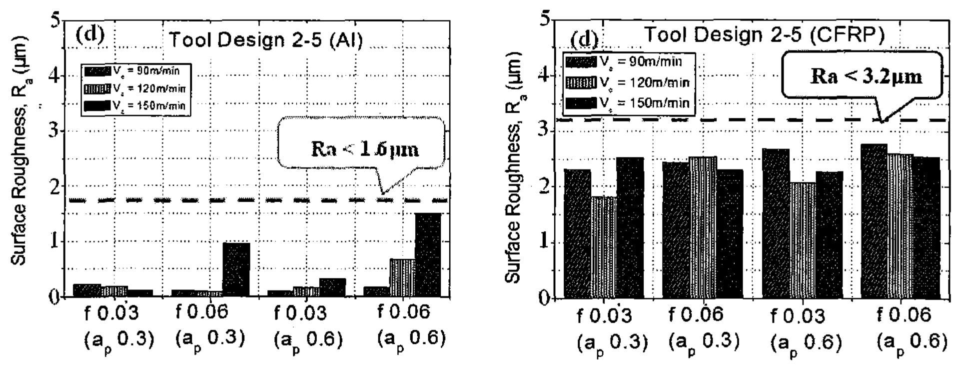

Fig. 5: Surface roughness of CFRP and Al at various machining parameters

Conclusions

From this experiment, the main conclusions can be summarized as follows:

i. It can be suggested that helical milling process, with combination of suitable machining parameters and cutting tool design can be able to produce high quality of hole.
ii. High feed rate and depth per helical cut produced highe value of thrust force.
iii. The values of surface roughness for both CFRP and aluminum were in the acceptable range of an aerospace industry demands.

References

[1] R. Zitoune, V. Krishnaraj, F. Collombet, Study of Drilling of Composite Material and Aluminum Stack, Composite Structure. 92 (2010) 1246-1255.

[2] W.F. Smith, Principles of Materials Science and Engineering, McGraw-Hill, New York, 1990 699-724.

[3] D. Iliescu, D. Gehin, M.E. Gutierrez, F. Girot, Modeling and tool wear in drilling of CFRP, International Journal of Machine Tools & Manufacture. 50 (2010) 204-213.

[4] J. Paulo Davin, Pedro Reis, C. Conceicao Antonio, Drilling Fiber Reinforced Plastics (FRPs) Manufactured by hand lay-up; Influence of matrix, Journal of Materials Processing Technology. 155-156 (2004) 1828-1833.

[5] S. Tandon, V.K. Jain, P. Kumar, K.P. Rajukar, Investigations into machining of composites, Precision Engineering. 12 (1990) 227-237.

[6] J. Paulo Davim, J. Campos Rubio, A.M. Abrao, A novel approach based on digital image analysis to evaluate the delamination factor after drilling composite laminates, Composites Science and Technology. 67 (2007) 1939-1945.

[7] Gay D, Hoa SV, Composite materials design and applications. New York: CRC Press (2003)

[8] E.A. Rahim, T. Ogawa, A. Miura, H. Sasahara, R. Koyasu, Y. Yao, Ultrasonic torsional vibration drilling of aerospace structural material, 6th International Conference on Leading Edge Manufacturing in 21st Century, Japan, 8-10 November 2011. (CD-ROM)

[9] E.A. Rahim, H. Sasahara, A study of the effect of palm oil as MQL lubricant on high speed drilling of titanium alloys, Tribology International. 44 (3), 309-317.