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Study on Tool Wear Mechanism during Milling of JFRP Composite

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Abstract**-** Nowadays, JFRP (Jute Fiber Reinforced Polymer) composite is known as an eco-friendly, cost-effective, lightweight, higher stiffness product and the demand of this composite is increasing tremendously in various application like automotive, aerospace, marine and domestic upholstery. In order to achieve the required shape and design of this composite, machining is essential during the assembly stage. Thus, machining arises some difficulties in where tool wear is one of the major drawbacks during machining of the milling process. The cutting parameter of machining influences on the output performance of the product. The main purpose of this study is to find out the effect of milling parameters such as feed rate, cutting speed, depth of cut on the output responses like tool wear which generates during milling on JFRP composite. The machining was done by using a solid carbide cutting tool of 8 mm width and the experiments were conducted according to the CCD (Central Composite Design).

Keywords- *JFRP, Tool Wear, CCD, Solid Carbide Cutting Tool*

I. INTRODUCTION

The importance of JFRP composite has quickly expanded in the fields of various applications such as aviation, automotive, marine, and domestic appliances [1]. Fiber-reinforced polymer (FRP) has a particular specific quality, high modulus of strength, great production rate, good dimensional perfection. The mix of two different properties makes a stronger bond and rarely found in other compounds [2]. FRP composites are usually fabricated through hands lay-up technique, winding, extrusion, vacuums bagging, and molding [3]. However, a certain machining process is needed to get a close design, fittings, and tolerances. Machining processes are known as milling, drilling, slotting, turning, etc. FRP composites are the formation of two different properties in one compound to increase the thermal and mechanical properties [4]. Jute fiber and epoxy resin are two different components in where reinforcement is jute fiber and epoxy resin is the polymer that plays an important role to form bonding with the fiber. JFRP composites are recently used as complex interconnections between the matrix and reinforcement. The machining of JFRP influences the materials and creating different types of problems. During machining fiber breakage, lattice splitting, fiber pull out generate and make difficulties in machining [5]. JFRP is a great degree of grating while machining and influence the execution of cutting devices with surface quality. Accordingly, the cutting tool and cutting conditions are necessary for the machining of composite materials. However, the demand for JFRP is increasing but the limited research is done to solve the machining problem at an optimum level. Some researchers focused on the machining of FRP composites in comparison to increase productivity compared to traditional machining. Palanikumar et al. [6] focused on the machining of glass fiber composite machining. Until now, no research has been conducted to find out the machining performance on the JFRP panel. Actually, machining of JFRP in a different machining parameter is quite hard due to discontinuity, anisotropic nature and different percentages of reinforcement and matrix material.

The research on JFRP panel machining has become one of the major aspects to find out the variation of toll wear in a view of different cutting speed, feed rate and depth of cut. In this study, machining on the JFRP panel has been focused to find out machining outcomes on tool wear.

II. METHODS

The experimental process was conducted on different compositions of the JFRP panel by using the CNC machine. The fabrication was done using a hands lay-up technique. The composite panel was made in 60% reinforcement and 40% matrix material which consists of 5 alternatives layers of jute fabric. The panel dimension was 200 mm x 200 mm x 5 mm. Fig. 1 shows the illustration of the JFRP panel. An uncoated carbide-cutting tool with a diameter of 8.0 mm, an overall length of 60 mm, helix angle 300 with two flutes were used. Fig. 2 and Table 1 show the cutting tool and geometrical properties of the solid carbide tool respectively. Chemical and physical properties are demonstrated in Table 2 and Table 3. A CNC machine of 7.5 kW spindle power and a maximum spindle speed of 12000 rpm was used. The tool wear of the cutting tool was measured by using Nikon Measuring Microscope MM-400 (Fig.3). After 200 mm distance traveling of the cutting tool, the tool wear was recorded. Fig. 4 shows the machining set up of the JFRP panel. The machining set up is known as the clamping method. The panel was screwed on an aluminum supported tool. Fig. 5 shows the illustration of the machining line on JFRP panel. Table 4 represents the general information of the JFRP panel. The selected composite was machined following DOE Table 5.

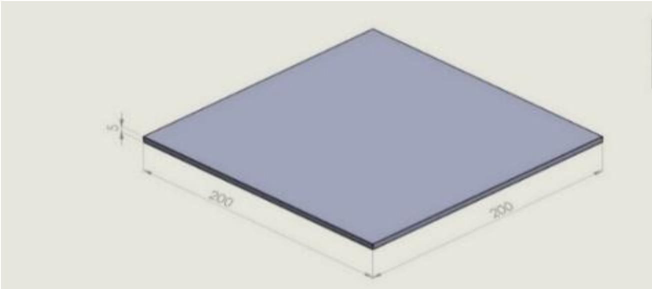

Figure 1. Illustration of JFRP panel

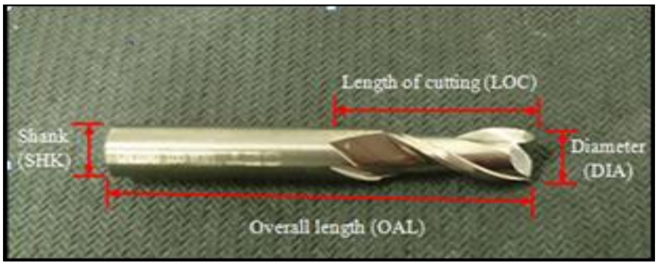

Figure 2. Carbide cutting tool

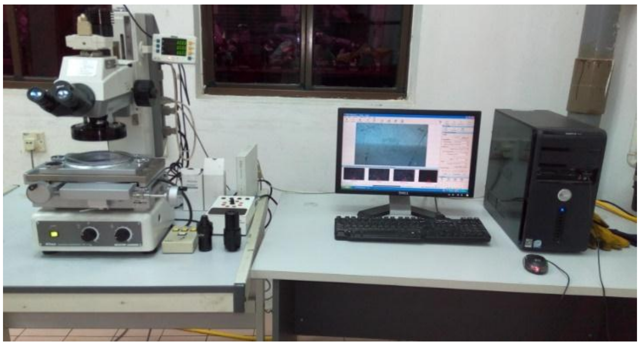

Figure 3. Nikon Measuring Microscope

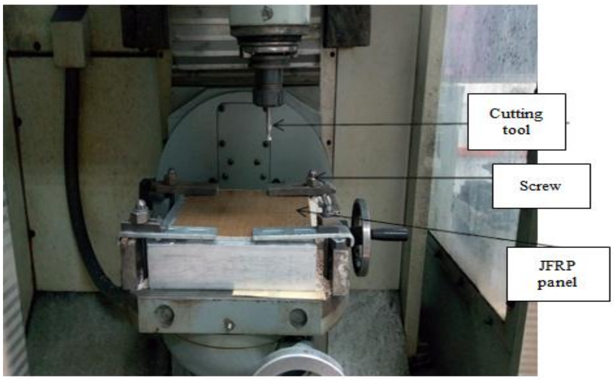

Figure 4. Machining set up

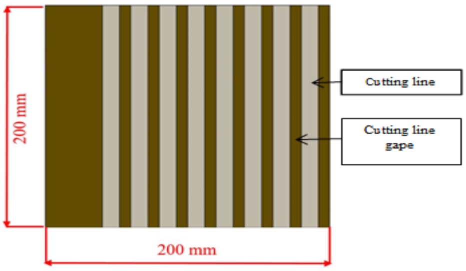

Figure 5. Machining line on JFRP panel

TABLE I. GEOMETRY OF UNCOATED CARBIDE CUTTING TOOL

DIA (mm)	SHK (mm)	OAL (mm)	LOC (mm)
8.0	8.0	60.0	20.0

TABLE II. CHEMICAL COMPOSITION OF UNCOATED CARBIDE CUTTING TOOL

Element	Weight %
Tungsten Carbide, WC	88.4–90.0
Cobalt, Co	9.5–10.5
VC+Cr3C2	0.5–1.1

TABLE III. PHYSICAL PROPERTIES OF UNCOATED CARBIDE CUTTING TOOL

Density, g/cm3	Hardness, HRA
14.35 ± 0. 1	9.18 ± 0.5

TABLE IV. GENERAL INFORMATION OF JFRP PANEL

Panel	Property
Resin type	Modified epoxy. Hexply @ 914
Tg resin	190^{o}
Yarn type	Tossa grade 1
Fabric type	Woven

TABLE V. EXPERIMENTAL DESIGN

Run	Spindle speed (rev/min)	Feed Rate (mm/min)	Depth of cut (mm)
1	3500.00	250.00	1.50
2	6328.43	250.00	1.50
3	3500.00	250.00	1.50
4	3500.00	250.00	1.50
5	3500.00	391.42	1.50
6	3500.00	250.00	0.79
7	5500.00	150.00	2.00
8	3500.00	250.00	1.50
9	3500.00	250.00	2.21
10	3500.00	108.58	1.50
11	1500.00	350.00	2.00
12	1500.00	150.00	1.00
13	3500.00	250.00	1.50
14	5500.00	350.00	1.00
15	671.57	250.00	1.50

III. RESULT AND DISCUSSION

A. *Wear mechanism*

Wear is recognized as the meaning of material removal from a rolling or sliding component due to friction with a mating surface. Wear mechanism means the microscopic examination of the worn area by considering the complex changes during friction [7]. The wear region in Figure 6 is shown by the shiny region which was taken under the Nikon Measurement Microscope and 6 (a) reveal a polished surface area under the observation of SEM. The continuation of machining increased the shiny and polished area on the cutting edge. This finding also the same as Iliescu et al. [8] stated that due to the abrasive nature of the composite panel, the tool wear region becomes more shiny and smooth under SEM.

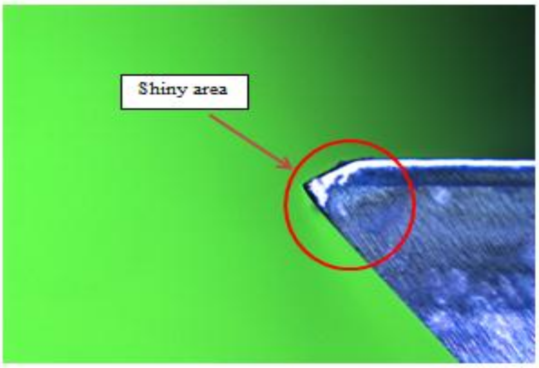

Figure 6. Wear region observed with Nikon Measurement Microscope

The cutting edge of the carbide cutting tool (Figure 7 (a)) has been observed under the SEM and it can be seen that the cutting edge is very smooth and polished. This means that the abrasive wear present in the cutting tool due to the powdering of the JFRP chips and fibers which react as abrasive particles during the machining of JFRP. The cutting edge of the cutting tool has been magnified under SEM as shown in Figure 7 (b), it can be seen that several voids are observed as a few particles were pulled out from the cutting tool edge. Figure 6 (c) shows that at higher magnification, the black dots which could be pulled of soft cobalt during milling JFRP. The continuous friction of these two factors at the cutting edge during machining leads to abrasive wear [9]. Wang et al.[10] reported that the smooth wear area is found in the cutting tool during the milling of CFRP composite.

B. *Output response of tool life*

Tool wear is a basic aspect that should to be examined as it is one of the main problems run into in assembling industry amid machining operations. In this experiment, data on tool wear was collected throughout the experiment. The cutting tool was discarded when the flank wear (V_B) attained its permissible cutting limit of 0.3 mm (ISO, 1989). The flank wear (V_B) increased due to the increase of feed rate, spindle speed and depth of cut. Table 6 shows the results of tool life for all the cutting parameters.

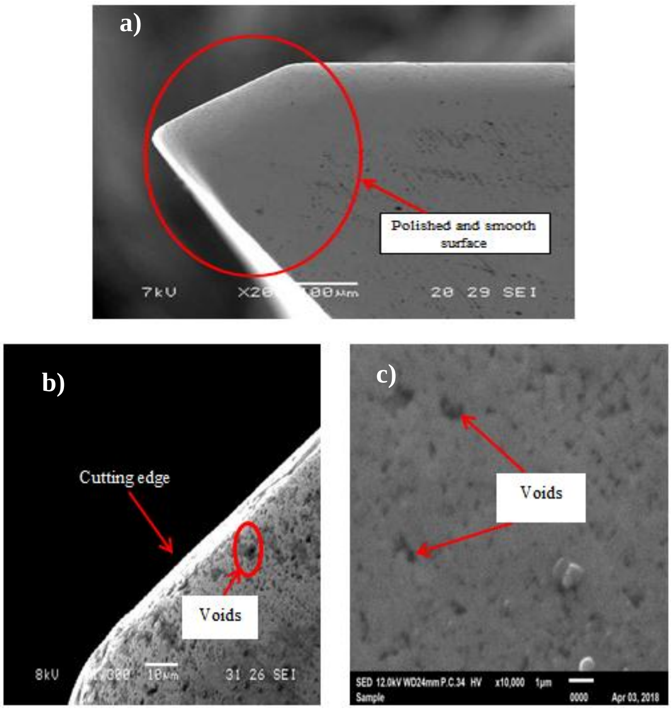

Figure 7. SEM picture of tool wear (a) under SEM (b) on the cutting edge under SEM with a magnification of 1300 (c) on the cutting edge under SEM with a magnification of 10000.

TABLE VI. RESULTS OF TOOL LIFE IN MINUTES FOR ALL CUTTING PARAMETERS

Run	Input Variables			Response
	Spindle Speed (rev/min)	Feed Rate (mm/min)	Depth of Cut (mm)	Tool Life (min)
1	3500.00	250.00	1.50	21.6
2	6328.43	250.00	1.50	14.4
3	3500.00	250.00	1.50	21.6
4	3500.00	250.00	1.50	21.6
5	3500.00	391.42	1.50	13.5
6	3500.00	250.00	0.79	22.08
7	5500.00	150.00	2.00	30.66
8	3500.00	250.00	1.50	21.6
9	3500.00	250.00	2.21	18.9
10	3500.00	108.58	1.50	41.6
11	1500.00	350.00	2.00	17.55
12	1500.00	150.00	1.00	39.84
13	3500.00	250.00	1.50	19.8
14	5500.00	350.00	1.00	11.31
15	671.57	250.00	1.50	35.88

Figure 8 shows that the graph of tool wears at various spindle speeds with a constant feed rate of 250 mm/min and depth of cut 1.50 mm. It can be observed that the flank wear of carbide cutting tool increased with the increase of distance traveled at different spindle speeds during the machining of

JFRP panel. It could be seen from the figure that as the spindle speed 671.57 rev/min traveled 13000 mm distance the flank wear reached 0.307 mm which is maximum of allowable tool life (ISO, 1989). The figure also shows that the flank wear 0.308 and 0.311 mm were achieved at the spindle speed 3500 rev/min and 6328.43 rev/min, after traveling 9000 mm and 7800 mm distance, respectively. The tool wear at spindle speed 6328.43 rev/min also shows that the tool wear was the highest compared to the spindle speed 3500 and 671.57 rev/min. This was expected as milling is interrupted machining process in which heating of the tool edges is repeated during machining, thus generate high temperature surrounding the cutting tool and leading to high tool wear.

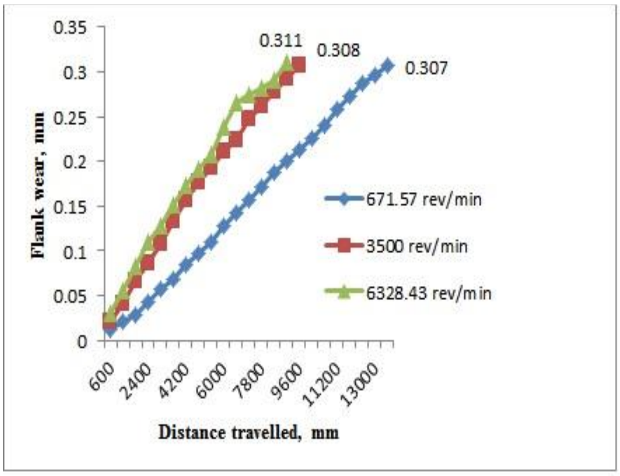

Figure 8. Tool wear of carbide cutting tool in different spindle speed (feed rate = 250 mm/min, depth of cut =1.5 mm)

Figure 9 shows that the data for tool life at spindle speed 671.57, 3500, 6328.47 rev/min with a constant feed rate 250 mm/min and depth of cut 1.50 mm. It can be observed that the tool life decreased whenever the spindle speed increased from 671.57 to 6328.43 rev/min. It also can be seen that the spindle speed 671.57 and 6328.43 rev/min gives the tool life of 35.88 (highest) and 14.4 (lowest) min during the machining of JFRP panel to reach the critical limit of flank wear. It can be concluded that the tool life of the carbide cutting tool decreased 39.79% and 33.33% as the spindle speed increased from 671.57 to 3500 rev/min and from 3500 to 6328.43 rev/min, respectively. This could be happened due to the high heat generated by the motion of the cutting tool at high cutting speeds, with more friction between the cutting tool and the work material occurring during machining, thus leading to a shorter tool life for the cutting tool [11].

Figure 10 illustrates that the graph of tool wears at a various feed rates of 108.58, 250, 391.42 mm/min with a constant spindle speed 3500 rev/min and depth of cut 1.50 mm.

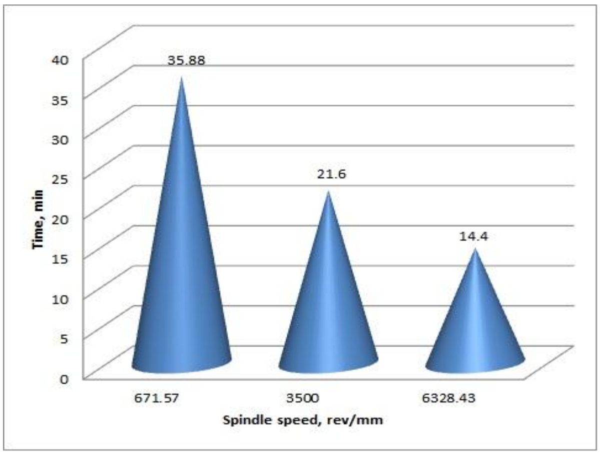

Figure 9. Tool life of cutting tool with different spindle speed (feed rate =250 mm/min, depth of cut= 1.50 mm)

It can be observed that the flank wear of the carbide cutting tool increased with the increase of distance traveled at different feed rates. It could be seen from the figure that as the feed rate 108.58 mm/min traveled 10200 mm distance during the machining of JFRP panel and the flank wear reached 0.309 mm which is maximum of allowable tool life (ISO, 1989). The figure also shows that the flank wear achieved 0.307 and 0.311 mm as the feed rate was 250 mm/min and 391.42 mm/min, after traveling 9000 mm and 8400 mm distance, respectively. The tool wear at feed rate 391.42 mm/min also shows that the tool wear was highest compared to the feed rate of 108.58 and 250 mm/min. This phenomenon is seen due to the high feed rate generate high temperatures with fast traversing of the cutting tool during the machining of JFRP panel. A similar opinion was reported in Palanikumar & Davim [12] that, in the machining of GFRP higher feed rate resulting in higher tool wear.

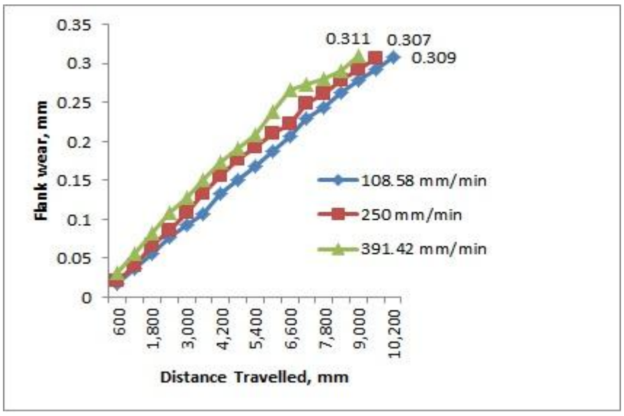

Figure 10. Different feed rate effect on tool wear with same cutting speed and depth of cut (spindle speed=3500 rev/min, depth of cut =1.50 mm)

The data of the tool life at a different feed rates of 108.58, 250 and 391.42 mm/min with a spindle speed of 3500 rev/min and depth of cut 1.50 mm are shown in Figure 11. It can be reported that the tool life was decreasing whenever the feed rate increased from 108.58 to 391.42 mm/min. It also could be observed that feed rate of 108.58 and 391.42 mm/min gives the tool life 41.6 and 13.5 min. It can be seen that the tool life decreased by 48.07% with an increase in feed rate from 108.58 to 250 mm/min. As the tool life decreased by 37.5% when the feed rate increased from 250 to 391.42 mm/min in where the tool life was 21.6 and 13.5 min. The percentage of reduction in the tool life was observed to be higher at higher feed rates compared to the lower feed rates. This was to be expected as at lower feed rates the machining of the workpiece is stable due to the low traverse of the cutting tool. However, at a higher feed rate, high tool wear was observed because of the high heat generated by the high traverse of the cutting tool. This can influence the stability of the machining because of high friction thus leading to high tool wear [13].

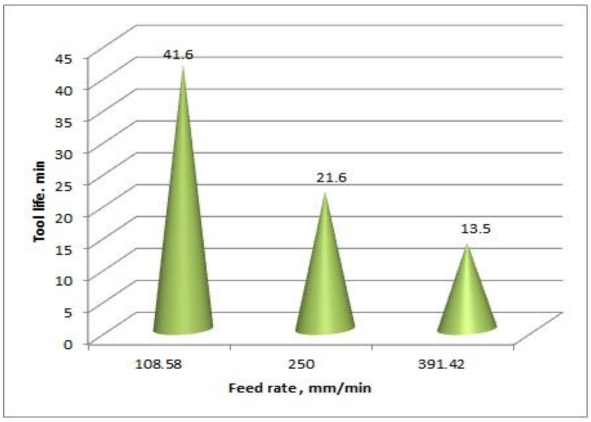

Figure 11. Tool life on different feed rate (spindle speed=3500 rev/min, depth of cut=1.50 mm)

Figure 12 shows that the graph of tool wears at depth of cut 0.79, 1.50 and 2.21 mm with a constant spindle speed 3500 rev/min and feed rate 250 mm/min. From the Figure 11, it can be reported that when the depth of cut is higher then the tool wear is also high. It could be seen from the figure that as the depth of cut 0.79 mm traveled 9600 mm distance, the flank wear reached at 0.301 mm which is maximum of allowable tool life (ISO, 1989). It also can be seen that the depth of cut 1.5 and 2.21 mm achieved the flank wear 0.307 and 0.311 mm, after traveling 9000 and 8400 mm distance respectively. The tool wear increase rapidly because of high surface contact between the composite panel and the cutting tool that shows more surface removal during milling. In this situation, the systems become heavily loaded and lead to high rate of wear. According to Rawat & Attia [14], during their observation on the machining of GFRP, the temperature at the cutting edge of the cutting tool was proportional to the depth of cut. Thus at a higher depth of cut, the temperature was higher compared to the lower depth of cut.

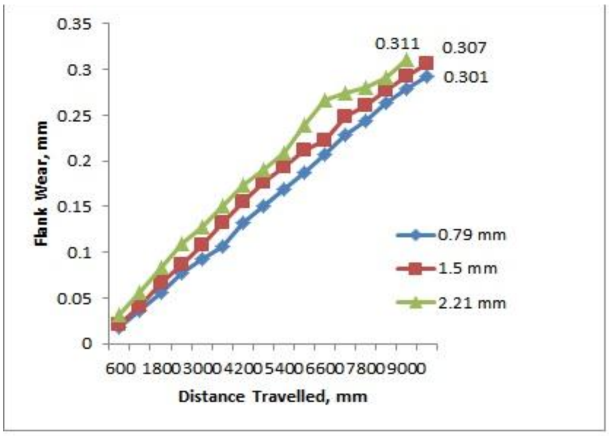

Figure 12. Comparison of tool wear at different depth of cut (spindle speed =3500 rev/min, feed rate = 250 mm)

The histogram Figure 13 shows the data for tool life of cutting tool at depth of cut 0.79, 1.50, 2.21 mm with a spindle speed 3500 rev/min and feed rate 250 mm/min. It can be observed that the tool life decreased whenever the depth of cut increased from 0.79 to 2.21 mm. The figure also shows that the depth of cut 0.79 and 2.21 mm gives the tool life 22.08 and 18.9 min. It can be seen that the tool life decreased by 2.17% with an increase of depth of cut from 0.79 to 1.50 mm during the machining of JFRP panel. As the depth of cut increased from 1.50 to 2.21mm than the tool life decreased by 12.5% and the value of tool life was 21.6 and 18.9 min. It can be concluded that the longest tool life (22.08 min) is achieved in the lowest depth of cut (0.79 mm). This is acceptable because, at lower depths of cut, the contact area between the cutting tool and work material is less, leading to less material removal and longer tool life. But as the depth of cut increases, the contact area and the friction between the cutting tool and work material also increases. As a result, the generated heat damages the cutting tool during the removal of chips and result in high tool wear [15].

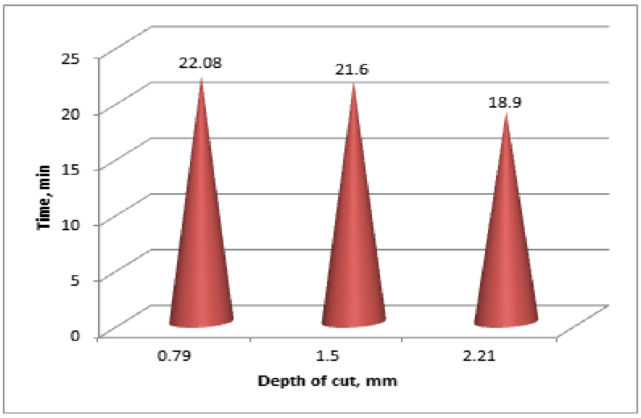

Figure 13. Tool life comparison in different depth of cut (spindle speed =3500 rev/min, feed rate = 250 mm/min)

C. Growth of Tool Wear

Figure 14 shows the growth of tool wear during the machining on JFRP panel at various spindle speeds with a feed rate 250 mm/min and depth of cut 1.50 mm. It could be observed in figure 13 (a) that the tool wear under higher spindle speed (6328.43 rev/min) was higher comparing the lower spindle speed (671.57 rev/min). The growth of tool wear is faster in higher spindle speed because the heat generated surrounding the cutting tool is higher compared to lower spindle speed. The researcher also reported that heat transfer usually happens at higher spindle speeds compared to the lower spindle speed [16].

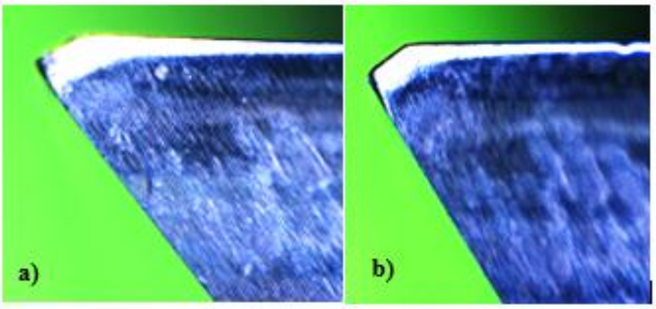

Figure 14. Nikon Measurement Microscopic Picture (a) cutting tool speed 6328.43 rpm and (b) 671.57 rpm with a constant feed rate 250 mm/min and depth of cut 1.50 mm.

Figure 15 shows the growth of tool wear at various feed rates with a constant spindle speed 3500 rev/min and depth of cut 1.50 mm. It can be observed from Figure 8 that the tool wear was higher at the highest feed rate 391.42 mm/min (fig.6(b)) compare to the lowest feed rate 108.58 mm/min (fig. 6(a)). It also shows that the growth of tool wear is higher compare to Figure 8 (a) and Figure 8 (b) and reached the critical limit of flank wear after traveling a short distance. This could be due to the higher traversing rate generate at a higher feed rate and increased the growth of tool wear [13].

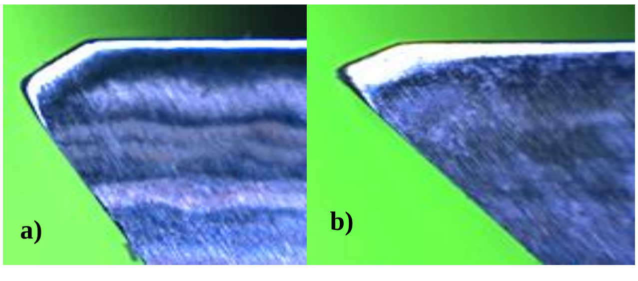

Figure 15. Growth of tool wear at various feed rates (a) 108.58 mm/min (b) 391.42 mm/min (spindle speed = 3500 rev/min, depth of cut = 1.50 mm)

Figure 16 exhibits that the growth of tool wears at different depth of cut with a constant spindle speed 3500 rev/min and feed rate 250 mm/min. It can be seen in figure 9 (b) that the growth of the tool wear is higher at the highest depth of cut (2.21 mm). Figure 9 also shows that the depth of cut 0.79 mm gave the lowest growth of tool wear and traveled a long distance to reach the critical limit of flank wear and the higher depth of cut 2.21 mm gave the highest growth of tool wear rate. This could be because as the depth of cut increased then the thermal stress also increased and softened the matrix material which affects the performance of the cutting tool [14] (Rawat & Attia, 2009).

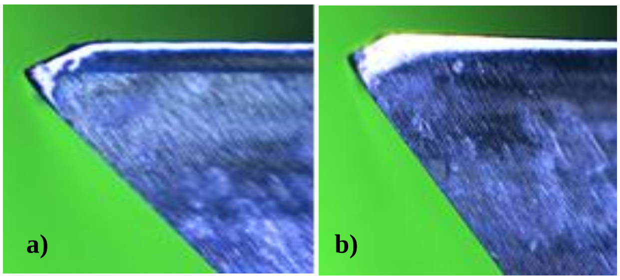

Figure 16. Growth of tool wear at various depth of cut (a) 0.79 mm mm (b) 2.21 mm (spindle speed = 3500 rev/min, feed rate = 250 mm/min)

IV. CONCLUSIONS

In the investigation of the above study, it was found that spindle speed, feed rate and depth of cut have an effect in tool wear. During machining on JFRP panel, it was observed that higher spindle speed (6328.43 rev/min), feed rate (391.42 mm/min) depth of cut (2.21) gives the highest flank wear and decreased the tool life of carbide cutting tool. The tool life increased at a lower depth of cut (0.79 mm). This experimental table gives us the range of machining parameter to achieve the lowest tool wear and better tool life.

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