The Techniques Employed in Milling of CFRP to Reduce Material Damages

K. M. John, S. Thirumalai Kumaran

Abstract: ***Carbon fiber reinforced polymer composites are extensively used in aircraft industries because of high strength (load-bearing material). In application, machining process required near net shape for avoiding rejection of components and it is highly challenging and hard to produce good quality holes and surface. In this article, reviewing various techniques which involved to bring good surface finish in milling of CFRP composites and addresses machining parameters, tool geometry, material, coatings and environmental condition techniques. This current review work will be helpful for researchers to implement new advanced techniques to avoid material damages in their future work.***

Keywords: ***CFRP, delamination, milling, surface roughness.***

I. INTRODUCTION

Carbon fiber reinforced polymer composites (CFRP) are widely used in engineering sectors because of its excellent properties which are non-corrosive and high strength to weight ratio. Especially, it is broadly utilized as load-bearing panels and other structural components in advanced automobiles and aircrafts. Machining CFRP is very challenging to produce good quality surface when compared to machining of alloys and conventional metals because composites are heterogeneity and anisotropic characteristics [1].

Milling is an unavoidable machining process in assembly section of industries because components are modified to final desire shape with appropriate dimensions to assemble. In modification (milling process) of CFRP composite, various damages will occur which are delamination, fibre pull out, fluffing, tool wear, improper material removal and poor surface finish. In recent years, many researchers are employed various techniques to reduce material damages in drilling and trimming of composite materials because the damage leads to rejection of components. Selection of proper machining techniques is highly challengeable in advanced composite materials. Due to this, there is a need to understand the scientific advances on machining of composite materials. This is the main initiation of current paper for reviewing various machining techniques which adopted for milling process on CFRP material. The outcomes of these techniques is presented in detail with respect to machining parameters of depth of cut, traverse rate (feed per tooth) and spindle speed.

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II. MACHINING OF QUALITY ASPECTS

The evaluation of machined surface is necessary for quality machining to avoid rejection of parts in advanced manufacturing industries. For quality aspects of milling, these are the factors to quantify which are delamination factor, fiber pull-out, material removal rate and surface roughness.

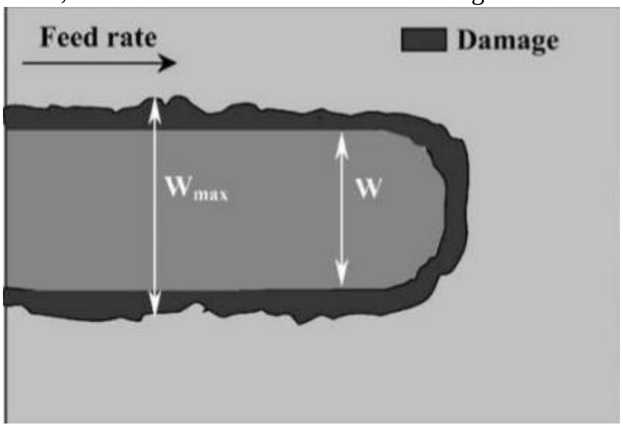

Fig. 1.Delamination factor measurement. [2]

A. Delamination

Delamination is a separation of ply induced by milling on fiber reinforced polymer composite laminates and it is a severe issue in composite material application because it affects specific strength of the material. Quantifying delamination in milling is differ from drilling and it was classified to three types [3] which are type I (surface damage) and type II (fiber protrusion) and type I/II (combination of fiber protrusion and surface damage). Figure 1 shown clear picture about measurement of damage (delamination) by microscope and the delamination factor can be calculated by the following equation [4]:

$$F_d = W_{max} / W \qquad (1)$$

where W_{max} is maximum width of delamination (damage) and W is nominal width.

III. MACHINING TECHNIQUES

A. Machining parameters and different tools

Tool material, coating, geometry and machining parameters of cutting speed, feed rate and depth of cut are the most influential technique to produce better surface quality. Researchers are focused their studies in employing of different tool geometries (rake angle, flutes, helix angle etc), material, coating, varying cutting parameters and fiber cutting angle for high quality machining on CFRP composite material.

Preliminary milling study was done by Hocheng et al. [5] on UD-CFRP composites at different cutting speed of 500, 1500 and 3000 rev/min, feed rate range of 50 to 150 mm/min and fiber orientation (cutting angle) of 0°, 90° and 45°. Authors identified an optimum cutting parameters for good surface finish (minimum surface roughness and burr) and its influences on composite. They recommended 0° orientation cutting direction for minimum burrs, cutting forces and good surface finish at feed rate of 0.1 mm/tooth and cutting speed of 50m/min. Influence of process parameters on delamination factor and surface roughness was studied by Davim et al. [2] with two-flute and six-flute cemented carbide milling tool. Good surface finish and lower delamination factor was achieved in 2-flute end mill at low feed rate of 200 mm/min and cutting speed of 38 m/min. Delamination factor was raised at higher feed rate in both end mill tools.

Kilickap et al. [6] investigated end milling on CFRP with different machining parameters of cutting speeds (31.4, 62.8 and 94.2 m/min), feed (100, 150 and 200 mm/min) and depth of cut of 1.5 mm and two number of end mill flutes (3 and 4) on machined surface quality. They concluded that increases of feed rate and cutting speed, higher delamination were obtained but it decreases in 4-flute end mill and good surface finish were obtained in higher cutting speed in both end mill tools. As like above studies, an effect of process parameters on delamination and surface roughness was investigated by Khairusshima et al. [7]. The results displayed that feed rate is a main contributor to produce lower delamination factor and surface roughness. They found optimized milling parameters of feed rate (211.32 mm/min), cutting speed (3061 rpm) and depth of cut (0.72 mm) for good surface finish and lower delamination with uncoated solid carbide tool.

Hu et al. [8] did slot milling test using polycrystalline diamond tool on C/SiC composites. Authors concluded the surface integrity (delamination) results based on the various cutting parameters of cutting speed (20, 40, 60 and 80 m/min) and feed rate (0.01 and 0.02 mm/z) and cutting direction (fiber orientation of 90° and 0°). Higher feed rate gives poor surface roughness, exhibits delamination I/II (both surface damages and fiber protrusion) and higher cutting force and good surface finish were obtained at 90° fiber orientation compared to 0° fiber orientation milling. Influence of weaving pattern on delamination in milling of CFRP composite with different geometry of PCD tool was investigated by Hintze et al. [9]. They concluded that tool geometry has less influence than yarn undulation in surface integrity (delamination). The same author [10] studied delamination occurrence and propagation when milling of CFRP composites in different orientation of fiber (0°, 45°, 90°, 135° and 180°). They demonstrated that minimum delamination was achieved at an optimum cutting angle range of 0° to 90° and maximum was obtained at 90° to 180° cutting angle.

Kalla et al. [11] developed a prediction model for finding cutting forces in helical end milling of unidirectional and multi-directional laminates and compared with the results of experiments. They found that predicted cutting forces have good agreement with unidirectional laminates and not with multi-directional laminates. The occurrence of debonding damage when milling of UD-CFRP at cutting angle of 90° was found by Li et al. [12]. The defect analysis and cutting force was studied by He et al. [13] on milling of carbon fiber reinforced plastic composite by different cutting parameters of rotation speed (3000, 4000 and 5000 rpm), feed (120, 160 and 200 mm/min), constant depth of cut of 2 mm and fiber orientations (0°, 45°, 90° and 135°). They found severe delamination at 90° cutting angle on top layer of CFRP at higher cutting speed and constant feed rate. Similarly, Ghafarizadeh et al. [14] also studied based on different fiber orientation surface milling of CFRP in experimental and compared with finite element analysis. They noticed that cutting forces doesn't exhibits similar trend for different fiber orientation cutting. At 0° milling, damage due to compressive force is developed more when compared to other cutting directions. Numerical model of surface damage results was confirmed by SEM images of the machined surface.

B. Environmental changes

For improving machinability of CFRP, researchers are implementing cooling techniques such minimum quantity lubrication (MQL), flood cooling, cryogenic cooling, etc for delamination-free and high finish surface machining. This section discuss about various environmental techniques and their results on milling of CFRP composite material.

Chilled air affects surface finish on milling of CFRP. In the year of 2013, Khairusshima et al. [15] studied the effect of chilled air (-10°C) on quality of machined surface on milling of CFRP material and compared the results with dry milling condition. They found that chilled air machining gives better results than dry condition machining in delamination and surface roughness at constant feed rate of 0.035 mm/rev and cutting speed of 179 m/min. Good surface finish and lesser delamination was observed in cryogenic machining studies of Morkavuk et al. [16] and compared with dry machining. These results was obtained at combination of lower feed rate of 500 mm/min and higher spindle speed of 8000 rpm and they observed higher thrust force at cryogenic environment because of harder structure but it produces lower delamination.

C. Coated tools

Effect of different type of coated tools on machining CFRP laminates are reviewed briefly and clearly addresses the issues and advantage of coated tools on milling. Hosokawa et al. [17] tested side milling on CFRP by two types of diamond-like carbon coated (unbalanced magnetron sputtered, arc ion plated) carbide tool with different helix angles for improving surface integrity. It was found that

Diamond coated-double helix angle carbide tool was used for milling experiment on unidirectional CFRP laminate by Yigit Karpat and Naki Polat [18]. Authors revealed the results that surface roughness was increased with number of slot increases and they identified the issues of diamond coating which is fractured due to abrasive carbon fiber and edge rounding. Konneh et al. [19] employed TiAlN-coated 2-flute tool on milling of CFRP at different machining parameters of spindle speed (15000, 25000 and 35000 rpm), feed (3, 9, 15 mm/min) and depth of cut (50, 100, 150 µm) for minimizing delamination damage.

Authors achieved minimum delamination in TiAlN coated tool at combination of moderate spindle speed of 25000 rpm, depth of cut of 100 µm and low feed rate of 3 mm/min when compared to other literature works. Uhlamann et al. [20] conducted milling experiments by CVD-diamond and SiC interlayer-coated tool on CFRP composites at various cutting speed and feed rate. Authors achieved potential results in both diamond and SiC interlayer end mill tools.

IV. CONCLUSION

This comprehensive review paper clearly showed various techniques which employed in milling of carbon fiber reinforced polymer composite for minimizing delamination, burr and producing good surface finish. Based on this, following conclusions are identified as follows.

1) Coated tools are essential for minimizing delamination. Even though, some drawbacks are noticed that, coatings are fractured while machining larger number of material and it not a cost-effective technique.
2) Cryogenic machining is hazardous when compared to other techniques. Chilled air assisted machining gives better results than cryogenic machining on milling of composites. Limited literatures (studies) are available in machining at different environmental conditions.
3) Machining parameters are the key technique which applicable in all other technique for reducing damages. Even though, machining parameters is not that much influential on machined surface quality as compared with other machining techniques. But at a same time, cutting angle (fibre orientation) is a significant method for controlling delamination and to produce quality surface.

From this literature studies, machined surface quality was observed with various machining techniques and it initiates researchers to implement cost effective and advanced machining techniques in future.

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