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CFRP Milling Machining – Using Solid Carbide Endmill: A Research Review

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ABSTRACT: Carbon fiber reinforced plastic composites possess excellent mechanical properties, and therefore these materials are widely used industries like the automobile, defense, medical aerospace sectors. However, the machining of CFRP materials is difficult, but the mechanical machining of these material is prime requirement to meet dimensional accuracy. With showing this problem, the main objective of the present paper is to review those solid carbide end mill that are used for milling carbon fiber reinforced polymer composites during trimming, slotting operation. In this context, this paper gives a detailed review and discussion of the following: (i) the machinability of CFRP including cutting force, tool wear, surface roughness, delamination and (ii) advanced tool geometries of solid carbide tools and coatings In conclusion, it can be stated that advanced tool geometry of solid carbide tools with specify coating are often necessary in order to effectively and appropriately machine required quality features when working with CFRP composites.

KEY WORDS: Tool Geometry, Solid Carbide End Mill, Surface Roughness, Cutting Force, Tool Coating, CFRP Milling.

I.INTRODUCTION

Composite materials such as Carbon Fiber Reinforced Plastics (CFRP) characterized for having excellent properties, like light weight, high strength to weight ratio and high specific stiffness to weight ratio. These properties are very much imperative and make them attractive for automotive, defense, medical equipment, Industrial applications, aerospace applications. Carbon fibre reinforced plastics have been widely used for manufacturing aircraft and spacecraft structural parts because of their particular mechanical and physical properties such as high specific strength and high specific stiffness. Milling of these composite materials, irrespective of the application area, can be considered a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. With regard to the quality of machined component, the principal drawbacks are related to surface delamination, fibre/resin pullout and inadequate surface roughness of the machined area. Among the defects caused by milling, delamination appears to be the most critical.
In order to overcome these difficulties, it is necessary to develop procedures to select appropriate cutting parameters, due to the fact that an unsuitable choice could lead to unacceptable work material degradation. Factors such as cutting parameters, tool coating, and tool geometry must be carefully selected aiming to obtain best performance on the milling operation, i.e., best machined surface, which represents minimal damage to the machined component and satisfactory machined surface. Therefore, this paper aims to present a literature survey on the milling operation of carbon fibre reinforced plastic. Attention will be focused on tool coating, cutting parameter, tool geometry and their effect on the caused on the cutting force, surface roughness, delamination, and tool wear. Achieving an acceptable surface quality with conventional methods of machining is found to be extremely difficult due to the composite's anisotropic and non-homogeneous nature. It is very important to understand the mechanisms of material removal and the kinetics of machining process affecting the performance of cutting tools for achieving the desired quality of the machined surface. With regard to quality of machined component during milling, the principal drawbacks are usually, surface delamination, fiber pullout, burning, fuzzing and inadequate surface roughness of the machined surface.
Similarly, there are many drawbacks when the laminates undergo milling operation. But since, very a smaller number of research studies has been done on milling of CFRP, hence it creates a research gap to investigate the laminates under various cutting and load conditions during milling process. To control the geometrical tolerance in composite laminates, it is essential to perform machining operations. Milling is usually performed in CFRP laminates to machined slot, trimmed surface, helical milling.

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II. EFFECT OF SOLID CARBIDE TOOL GEOMETRY ON PERFORMANCE

Tool geometry like change in helix angle, number of flute, type of cutter means staggered, helical, multi tooth have measure influence on following parameter.

A. Cutting Force

Changing geometry of solid carbide tool effect to force during machining. R. PRAKASH (2019)3 .et al used three number of solid carbide tool with same diameter with changing type of helix angle and its type and experiment cutting force with various three tools. S. GARA (2018)8 .et al used one number of solid carbide tool with single diameter by varying left and right helix both with varying flute experienced cutting force. T. CHEN (2018)11 .et al represent two number of solid carbide tool in which one of rhombic type and second one is staggered type with varying their different flute angle measured cutting force during machining.
YANG (2016)16 .et al used three different type of solid carbide tool with same diameter but different helix angle as well as type of tooth experienced cutting force three different type tool. EROL (2015)17 .et al experiment by using two number of tools with same diameter with same helix angle but different number of flute and differentiate cutting force generation by them. Shuhan (2014)24 .et al used two number of tools with same diameter but with different type like double spiral compression and multi tooth experienced generation of cutting force.
Rangasamy (2016)35 .et al represent by using three number of different solid carbide tool with same diameter with different type of teeth and helix angle experiment cutting force on CFRP material. HOSOKAWA (2014)38 .et al used two number of tools with same diameter with same number of flute but with different helix angle measured cutting force during machining of material. MADJID (2013)39 .et al using three number of different types of solid carbide tool with same diameter and experienced cutting force by using this all tools. YIGIT (2013)40.et al experienced cutting force by using different diameter of tool with same number of flutes with different helix like double helix and single helix respectively. ONDREJ (2016)50.et al used eight number of different tools with same diameter and different tool type with different angle experienced cutting force during machining CFRP.

Table1 Literature review on cutting force

Authors (Years)	Diameter in mm	No of Flute	Type of Tool	Helix angle	No of Tool	Effect on Cutting Force
R. PRAKASH (2019)[3]	6	12	Solid Carbide Router type end mill two intersecting flute right angle and left angle with 15°		3	By using router tool, surface textured on tool surface so therefore during machining, less impact on machined surface and decrease cutting force. Due to more than one cutting edge engage during machining, less chip thickness produced and lower cutting force.
S. GARA (2018)[8]	8	Left has 6 and right has 12 flute	Solid Carbide Segment Type end mill		1	Segment type solid carbide end mill generate lower cutting force.
T. CHEN (2018)[11]	10		Rhombic cutters have 15° and 40° right and left angle when Staggered cutter have 6° helix		2	During machining in case of tool wear, Rhombic end mill decrease feed force and radial force with slowly increase cutting force than staggered type end mill.
YANG (2016)[16]	6		1. General End mill have 40° helix.		3	Cross flute type and Fine cross flute type end mill generate lower cutting force and suppress more effectively than General End mill.

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			2.Cross flute type have 25° degree right and left 2 flute 3.Fine Cross end mill have 40° left and 15° right 12 teeth			
EROL (2015)[17]	10	3 and 4		30°	2	Cutting force increase in with increase in feed rate but it keeps nearly constant with increase cutting speed for both carbide end mill
Shu han (2014)[24]	10		1.Double Spiral Compression type 2. Multi-tooth		2	Due to multi-tooth geometry during machining chip cut into small piece and reduced tool chip contact area, generate lower cutting force than compression type solid carbide end mill.
Rangasamy (2016)[35]	6		1. Router type 12 flute trapezoidal teeth. 2. Router type pyramid teeth 12 flute 3. 4 flute 30° helix end mill		3	Trapezoidal type cutter generated lower cutting force during machining than other two tools because of the trapezoidal shape of the cutting teeth. Pyramid type teeth generate higher cutting force than other two tools.
HOSOKAWA (2014)[38]	4	2	1. 30° 2. 60°		2	Tangential force and Normal force significantly decrease for Higher Helix End mill than Lower Helix solid carbide end mill.
MADJID (2013)[39]	6		1. Tungsten burr 2. Diamond coated burr. 3.Diamond coated end mill		3	Four flute type solid carbide tool generate lower cutting force than Burr type solid carbide tool.
YIGIT (2013)[40]	10 and 12	4	1.Double Helix type 20° 2.Single Helix 10°		2	Radial force generates more than tangential force due to contact between fibers, tool edge radius and flank face.
ONDREJ (2016)[50]	6		1.Down cut spiral with chip breaker 2.Four flute up cut spiral 3.Cross pitch spiral 4.Cross pitch spiral 5.Up cut spiral with chip breaker 6.Right- and Left-hand spiral 7.Cross pitch Spiral	1.15° 2.10° 3.25° and 27° 4.25° and 27° 5.47° 6.13° 7.10° 8.15°	8	During machining for no 6 tool Right and Left-hand Spiral tool generate lower feed force during slot milling. For no 3. Cross Pitch spiral type coating end mill generate higher feed force and normal force. Tool geometry of tools 1, 2, 5, and 8 are different, but feed force characteristics are identical and almost nearly same for all tools. Second best lower cutting force generate by tool no 4. Cross pitch Spiral type uncoated end mill. For tool 2 and tool 7 seven have different geometry, same helix angle 10°, only different rake angle, although produce higher feed force and lower normal force during machining.

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			8.Three flute up cut spiral			

B. **Surface Roughness**

NORBERT (2018)9.et al used same diameter of two number solid carbide tool with two type coarse teeth and medium teeth and experienced surface roughness with two tools. T. CHEN (2018)11.et al experiences surface roughness by using two number of solid carbide tool with rhombic and staggered type end mill. EROL (2015)17.et al had two number solid carbide tool with same diameter and same helix but number of flutes is different and looked effect on surface roughness. Rangasamy (2016)35.et al using three number different type of solid carbide end mill with same diameter and experience surface roughness after machining CFRP material. ONDREJ (2016)50.et al using eight number of different type of solid carbide end mill with same diameter and experienced surface roughness.

Table2 Literature review on surface roughness

Authors (Years)	Diameter in mm	No of Flute	Type of Tool	Helix angle	No of Tool	Effect on Surface Roughness
NORBERT (2018)[9]	10		1.Compression coarse teeth 2.Compression Medium teeth		2	Surface roughness obtained by Compression medium teeth end mill is better than Compression coarse teeth end mill.
T. CHEN (2018)[11]	10		Rhombic cutters have 15° and 40° right and left angle when Staggered cutter have 6° helix		2	Staggered Helical End mill give better quality machine surface than rhombic milling cutter due to continuous cutting edges.
EROL (2015)[17]	10	3 and 4		30°	2	Four flute end mill give better surface roughness than three flute end mill at higher cutting speed and lower feed.
Rangasamy (2016)[35]	6		1. Router type 12 flute trapezoidal teeth. 2. Router type pyramid teeth 12 flute 3. 4 flute 30° helix end mill		3	The pyramid router type solid carbide end mill gives higher surface roughness due to their sharp cutting edge and four flute type helical end mill give lower surface roughness at all spindle speeds.
HOSOKAWA A (2014)[38]	4	2	1. 30° 2. 60°		2	High helix end mill gives smooth surface finish than lower helix end mill with less delamination and pull out of carbon fiber during machining.
MADJID (2014)[15]	6		1. Tungsten burr 2. Diamond coated burr. 3.Four flute Diamond coated end mill		3	Machining by four fluted end mills with increase feed rate reduced surface roughness.

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	6		1.Down cut spiral with chip breaker 2.Four flute up cut spiral 3.Cross pitch spiral 4.Cross pitch spiral 5.Up cut spiral with chip breaker 6.Right- and Left-hand spiral 7.Cross pitch Spiral 8.Three flute up cut spiral	1.15° 2.10° 3.25° and 27° 4.25° and 27° 5.47° 6.13° 7.10° 8.15°		During side milling best surface roughness maintain by uncoated cross pitch spiral solid carbide end mill and during slotting operation best surface roughness achieved by three flutes up cut spiral solid carbide end mill. Up cut Spiral End mill give highest most unsatisfactory for surface roughness.

C. **Delamination**

SOUHIR (2017)36.et al used same diameter of two number solid carbide tool with three type coarse teeth and medium teeth and experienced on CFRP by controlling end mill machine parameters. Y. CHEN (2019)4.et al experiences CFRP by using two number of flutes with standard helix angle which shows effect of burr length during linear grooves parallel to the main cutting edge. Rangasamy (2016)35.et al using three tools and procedure for machining of router type trapezoidal teeth which shows no delamination present but in helical four flute end mill used produce same due to high axial force. HOSOKAWA (2014)38.et al shows large amount of delamination is observed when milled by the ordinary end mill with helix 30°.

Table3 Literature review on Delamination

Authors (Years)	Diameter in mm	No of Flute	Type of Tool	Helix angle	No of Tool	Effect on Delamination
SOUHIR (2017)[36]	8mm		1.Fine tooth 14nos left helix and 12nos right helix 2.Medium tooth 12nos left helix and 10 no right helix 3.Coarse tooth 6nos left helix and 8 no right helix		3	Fine tooth end mill produce less damage other than medium tooth and coarse tooth end mill. Fine tooth end mill generate larger cutting force. In slotting operation chip formation of CFRP material in multidirectional depend on tool geometry and cutting conditions.
Y. CHEN (2019)[4]	10	2		30°		During machining CFRP surface by NCM tools produce long length of burrs. The rake- face textured tool with liner grooves parallel to the main cutting edge is more effective in reducing the burr length.
Rangasamy (2016)[35]	6		1. Router type 12 flute trapezoidal teeth. 2. Router type pyramid teeth 12 flute 3. 4 flute 30° helix end mill		3	By using Router type trapezoidal teeth and Router type pyramid teeth end mill used no delamination present there but when helical four flute end mill used delamination produced due due high axial force separates top plies and another reason is no of helical flute in helical

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						end mill is one third of the number of flutes in both the router tools.
HOSOKAWA (2014)[38]	4	2	1. 30° 2. 60°		2	The relatively large amount of delamination is observed when milled by the ordinary end mill with helix 30°.

III. PROCESS PARAMETER SELECTION FOR COMPOSITE MATERIAL

A. Cutting Force

Changing different process parameter on composite material effect of force during machining. J. Sui (2019)[1].et al fiber orientation angle which increase cutting force due to increase spindle speed. M.Salamani (2019)[2].et al who control feed rate as per cutting velocity which propagated cutting force at high speed. Prakash, R. (2019)[3].et al reflected in observation that resultant cutting force increase with increase in feed. S. Gara (2018)[8].et al presented cutting force decrease with increase in cutting speed which depend on structure of work piece material. T. Chen (2017)[12].et al observed cutting force increase gradually due to increase of the cutting length. R. Voss (2017)[13].et al presented compared cutting speed and feed rate with lower forces which shows machining quality. EROL (2015)[17].et al, XIAN.W (2016)[18].et al were observed cutting force increased with an increase in the feed rate with constant cutting speed. Chenwai Shan (2013)[20].et al, Weiwei.L (2016)[22].et al, Dong L (2011)[23].et al, Madjid (2013)[26].et al, Yanli H (2017)[30].et al, Guangjun. L (2017)[31].et al, Oğuz .C (2016)[33].et al and Souhir.G (2017)[36].et al were observed different parameter likes feed per tooth, milling depth and milling width, milling force increase which shows some material had given good qualities in senses of operation condition or controlled machining parameters.

Table4 Literature review considering process parameter for composite material due to cutting force

Authors (Years)	Effect on Cutting Force
J. Sui (2019)[1]	When fiber orientation angle larger than 135°, the milling force increases slightly with increase spindle speed.
M.Salamani (2019)[2]	Highest cutting force observed when (VC = 300 m/min and f= 2794 mm/min), and lowest cutting force was generated when (VC =400 m/min and f= 1524 mm/min). The effect of the feed rate on the feed force is less significant than the cutting velocity
Prakash, R. (2019)[3]	It was observed that the resultant cutting force increases with increase in feed. This increase in force due to the geometrical increase in chip thickness as a result of increasing the feed. Low cutting force and surface roughness are achieved at a high cutting speed of 339m/min and low feed of 0.1mm/rev for all three types of routers used.
S. Gara (2018)[8]	Cutting forces decrease with the increase in cutting speed. This is due to the augmentation in cutting temperature and thus the weakening of the structure of the work piece material. Cutting forces increase with increasing in feed per tooth
T. Chen (2017)[12]	With the increase of the cutting length, both the cutting-edge radius and the milling force increase gradually.
R. Voss (2017)[13]	High cutting velocities and feed rates in the range of v_c = 200 m/ min and f = 100 mm/rot generate better machining quality and produce lower forces compared to v_c = 160 m/min and f = 30 mm/rot.
EROL (2015)[17]	Cutting force increased with an increase in the feed rate and remained nearly constant with increase in cutting speed for both end mills.
XIAN.W (2016)[18]	The cutting force increases with the increase of feed rate
Chenwai Shan (2013)[20]	With increase feed per tooth, milling depth and milling width, milling force increase but there is not any effect of milling speed on milling force.
Weiwei.L (2016)[22]	With the increase of cutting depth, the depth of tool cut into the work piece, the friction between tool and work piece, all direction cutting force increased.
Dong. L (2011)[23]	Milling force decreased with the increased cutting speed and feed rate. The width of cut has little effect on the milling force.
Madjid (2013)[26]	With increase feed rate, cutting force increases when in other hand normal forces (F_y) are higher compared to the feed forces (F_x). It is also found that cutting forces decrease with the increasing of cutting speed.

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Yanli H (2017)[30]	When spindle speed increases from 3000 to 5000 rpm, making the feed increase from 120 to 200 mm/min, the feed force and normal forces increase slightly but specific cutting forces decrease with chip thickness but increase slightly with spindle speed at certain ranges.
Guangjun. L (2017)[31]	During down milling, the cutting force increases first and then decreases with the increase in feed per tooth during up milling.
Oğuz .C (2016)[33]	The lowest cutting forces were measured at higher cutting velocities and lower feed rates.
Souhir.G (2017)[36]	Force components increase with increasing in feed per tooth. Cutting forces decrease with the increase in cutting speed.

B. **Surface Roughness**

Changing different process parameter on composite material effect of surface roughness during machining. Table 5 shows effect of surface roughness when controlling different parameters like cutting force, cutting speed, feed rate, type of material and type of tool in specific operation condition show most of reviewers it is dependent on material properties, cutting tool condition and operation condition according parameters control.

Table5 Literature review considering process parameter for composite material due to surface roughness

Authors (Years)	Effect on Surface Roughness
Václav Schorník (2015)[51]	The lowest value of surface roughness is achieved when climb milling with a feed speed of 200 mm/min.
M.Salamani (2019)[2]	Surface roughness (R_a) decreased with an increase in cutting length due to tool wear by more cutting length, material matrix burning, sticking on machined surface.
Prakash, R. (2019)[3]	With increase cutting speed, Ra value increases initially and then decreases. Surface roughness is highest at the medium level of cutting speed and at all feeds.
Sheikh-Ahmad (2002)[49]	Surface roughness generally increased with an increase in feed speed
Souhir.G (2016)[47]	Feed per tooth is highest physical influence on the surface roughness.
Madjid (2013)[39]	With increase of feed speed lower surface roughness achieved. It is also observed that, when trimming is carried out with cutting speeds of 350 m/min and 700 m/min, the measured roughness values are between 10 µm and 15 µm. Surface roughness decreases with increasing milling speed.
Madjid (2012)[34]	Increase of Surface Roughness when varying the cutting distance from 50 cm to 200 cm, Increasing the cutting speed from 700 m/min to 1400 m/min, and when varying feed from 500 mm/min to 125 mm/min. Increasing the cutting speed or decreasing the feed rate leads to an increase of the surface roughness.
M. Konneh (2014)[29]	Minimum surface roughness value was obtained at a combination of the highest spindle speed (35000 rpm), highest feed rate (15 mm/min) and depth of cut (100 µm).
Takayuki (2014)[28]	Surface roughness be higher when machining with small cutting depth.
Weiwei.L (2016)[22]	By increasing cutting speed, machining time of material goes increase, which leads to the increased friction, tool wear and surface roughness values. The surface roughness value increases with the increase of feed rate. When the feed rate is greater than 350 mm/min, the surface roughness rises faster.
Hocheng (1993)[27]	Increase of Surface roughness with increasing speed at lower feed rate.
A. Koplev (1983)[21]	When machining parallel to fiber surface quality achieved good, but when machining perpendicular to fiber surface quality goes to poor.
Madjid (2014)[15]	The cutting speed has no effect on the surface roughness, irrespective of the tool geometry.
H. Sasai (2018)[10]	Four flute solid carbide end-mill has a smaller feed rate per cutting edge than a two flute solid carbide endmill, and good hole quality can be obtained.
Oğuz .C (2016)[33]	The surface roughness values decrease with increasing cutting velocity and decreasing feed rate.
Guangjun.L. (2017)[41]	Feed per tooth has more influence on surface roughness when milling width has least influence on surface roughness. The surface roughness decreases with increasing milling speed. By high speed milling, cutting time of carbon fiber material is reduced, fiber deformation is reduced and

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	so lower the surface roughness. When increase feed per tooth, material cut by tooth is being more, increase machining defects, so resin coating is reduced which increase in the surface roughness.

C. **Delamination**

Changing different process parameter on composite material effect of delamination during machining. Table 6 shows effect of delamination when controlling different parameters like cutting force, cutting speed, feed rate, type of material and type of tool in specific operation condition show most of reviewers it is depend on high cutting force, tool wear, high feed rate.

Table6 Literature review considering process parameter for composite material due to delamination

Authors (Years)	Effect on Delamination
M.Salamani (2019)[2]	The matrix was burned due to high cutting force and high average tool wear and it was difficult to distinguish the machined plies.
Madjid (2013)[39]	During high-speed machining and cutting speeds of 350 m/min and 700 m/min, SEM images show some mechanical damages. Damages are mostly fiber pull out and matrix degradation. With higher cutting speed of 1400 m/min, various damages were observed; the damages are fiber pull outs and matrix degradation.
Sheikh-Ahmad (2017)[48]	Delamination mainly depends on cutting conditions like speed and feed. D90 delamination depth was found to increase with an increase in feed rate, decrease with an increase in cutting speed, and increase with an increase in cutting distance.
Madjid (2012)[34]	With the increase of the cutting speed, from 700 m/min to 1400 m/min, increase in fibers pull out area and with Increasing of the cutting distance leads to increase of the size of the damaged zones.
EROL (2015)[17]	The delamination factor increased with increasing feed rate. As the lowest delamination factor was obtained by feed rate of 100 mm/min, the highest delamination factor was obtained by feed rate of 200 mm/min.
XIAN.W (2016)[18]	Delamination factors decrease with increase no of flute with same cutting parameter.
Takayuki (2014)[28]	When depth of cut was 100 µm, delamination occurred on the upper side of CFRP.
Václav Schorník (2015)[51]	The high value of parameter RSm for feed speed of 350 mm / min can be explained by the extreme increase in the delamination of the fibers at the place of measurement.

IV. CONCLUSION

Conclusion gives a detailed review and discussion of the following: (i) the machinability of CFRP including cutting force, tool wear, surface roughness, delamination and (ii) advanced tool geometries of solid carbide tools and coatings It can be stated that advanced tool geometry of solid carbide tools with specify coating are often necessary in order to effectively and appropriately machine required quality features when working with CFRP composites. Observation shows that different parameter likes feed per tooth, milling depth and milling width, milling force increase which shows some material had given good qualities in senses of operation condition or controlled machining parameters. It shows effect of surface roughness when controlling different parameters like cutting force, cutting speed, feed rate, type of material and type of tool in specific operation condition show most of reviewers it is dependent on material properties, cutting tool condition and operation condition according parameters control. It shows effect of delamination when controlling different parameters like cutting force, cutting speed, feed rate, type of material and type of tool in specific operation condition show most of reviewers it is dependent on high cutting force, tool wear, high feed rate.

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