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Techniques for strengthening, suppressing delamination, and preventing delamination formation during the drilling of CFRP composites.

[1] 1Suresh Aadepu, [2] DrLachiram, [3] Dr. P. Ramesh Babu
[1] Research Scholar, Mechanical Engineering Department, O. U, Hyderabad, India,[2]DLRL-Scientist-F, Hyderabad, India,[3].Professor, Mechanical Engineering Department Osmania University, Hyderabad, India
[1]adepusuresh97@gmail.com,[2]lachiram@gmail.com, [3] prbmech@yahoo.com

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Abstract: *A simplified framework is adopted to model damagedconfirmed composite structures during drilling, focusing on cutting. This study is divided into two parts. The first part consists of the experimental analysis of drilling applied to unidirectional laminates in carbon/epoxy, examining various angles between the direction of fibers and the tool cutting direction (cutting speed). The second part involves numerical modelling of orthogonal cutting in statics for fibers oriented at 30°,45°& 60°with respect to the tool's cutting direction. The experimental analysis shows that the angle between fiber orientation, cutting speed, and feed greatly influences chip formation and rupture modes. The numerical computation focuses on the fracture process, specifically the energy release rate, computed using the Virtual Crack Extension method. The analysis measures the impact of cutting tool geometry, speed, feed, and fiber orientation on cutting force.*

This paper discusses the problem of drilling-induced delamination when machining carbon fibre-reinforced polymers (CFRPs) and its negative impact on the mechanical properties, surface finish, and accuracy of the machined parts. Specially designed drill bits have shown promise in reducing delamination, but further research is needed to develop novel drill bits that can significantly suppress delamination during the drilling of CFRPs. The research can involve material properties of CFRPs, drill bit geometry, machining parameters, and the drilling process. The use of support plates has shown promising results in reducing push-out delamination, but their applicability is limited to simple and plain geometry CFRP. Further research is required to minimize push-out delamination in complex geometries. Continued efforts in this field will lead to improved machining performance and increased use of CFRPs in various applications.

Background*:The aim of this study is to investigate the damage caused to composite materials by the cutting tool during orthogonal cutting. The study examines the effects of varying the angle θ between the ply direction and cutting speed direction while keeping the geometry of the tool and machining conditions constant. The study uses depths of cut representative of drilling (0.05 mm) and describes the mechanisms of material removal for each experimental condition. To acquire data on forces and temperatures of cut at the tool/test specimen interface, an experimental protocol is proposed. Based on the experimental results, a numerical model of orthogonal cutting is developed for θ = 0°, which calculates the cutting force as a function of various parameters (depth of cut, rake angle, etc.). The model is compared to measurements taken in the experiment and those reported in the literature.*

Materials and Methods: This *paper discusses the problem of drilling-induced delamination when machining carbon fibre-reinforced polymers (CFRPs) and its negative impact on the mechanical properties, surface finish, and accuracy of the machined parts. Specially designed drill bits have shown promise in reducing delamination, but further research is needed to develop novel drill bits that can significantly suppress delamination during the drilling of CFRPs. The research can involve material properties of CFRPs, drill bit geometry, machining parameters, and the drilling process. The use of support plates has shown promising results in reducing push-out delamination, but their applicability is limited to simple and plain geometry CFRP. Further research is required to minimize push-out delamination in complex geometries. Continued efforts in this field will lead to improved machining performance and increased use of CFRPs in various applications.*

Results*: To minimize delamination, the thrust force should be kept as low as possible. In conclusion, the frequency of fiber pull-out at the exit region of the drilled hole increased for the 45° fibre orientation compared to the restricted fiber orientations 30° and 60°.*

Conclusion:*delamination during the drilling of CFRP materials requires a combination of proper drilling techniques, the use of specialized drill bits, coolant, and proper clamping and support of the material.*

Key Word*: Delamination, feed rate, drilling, critical thrust force, torque.*

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I. Introduction

Due to cost considerations, the twist drill is the preferred tool for machining long fiber composite structures made of metal materials. The behaviour of fibers under the influence of the cutting edge, listel, and other tool components strongly affects this machining process. Material removal modes and associated rupture mechanisms differ depending on the relative angle θ between the cutting speed direction Vf (Vc) and the fiber direction (as shown in Fig. 1(a)). Observing these mechanisms in real time is difficult, which makes constructing accurate models challenging. There is limited literature available that describes the physical phenomena governing the interaction between the tool material and composites during drilling. In contrast to metallic materials, the physics of material removal during the drilling of composites with long fibers is complex due to the production of different material removal phenomena and associated damage to the composite part. The angle θ during the drilling of a unidirectional laminated plate changes from one moment to the next and from one point on the cutting edge to another [7]. The nature of material removal mechanisms varies for specific values of θ, such as 30°, 45°, 60°, Additionally, machining conditions depend on various parameters such as cutting force, thrust force, spindle rotation, feed rate of the tool, and tool geometry (rake angle, relief angle) . Previous studies [3], [4], [5] used a plan of experiments based on Taguchi techniques to investigate the influence of cut parameters on specific cutting pressure, power of cut, and delamination factor. These authors found that delamination at the entry and exit of the hole increased with the cutting speed and feed rate of the tool. However, setting up an experimental strategy to investigate the high number of parameters and their coupling can be challenging. To simplify the experimental design while maintaining representative drilling conditions, orthogonal cutting on unidirectional graphite/epoxy laminates was chosen. This approach offers several advantages, such as chip formation occurring in the plane of the laminate, making it easier to observe. The surface quality can be observed directly during and after machining without destroying the test specimen to reach the machined surface. For a given fiber orientation, the phenomenon of chip formation is identical for each point of the part for a fixed depth of cut. The sweep time of the tool during orthogonal cutting is longer than during drilling, allowing for more extended observations of phenomena under specific conditions. Additionally, modelling orthogonal cutting is less challenging than modelling drilling and describes a succession of phenomena encountered during drilling.

In 1980, the first research on orthogonal cutting of composite materials was conducted, focusing on composite materials with thermoplastic matrix and carbon fibers [12]. The study revealed that chip formation is influenced by the orientation of fibers. Additional studies, [11] have shown the relationship between machining conditions, cutting force, and surface quality [2]. Specifically, if the cutting speed aligns with the fiber direction, the relief angle has minimal effect on the wear of the rake face, but it does affect the wear of the flank face. The author proposes a force distribution near the tool point, which applies friction conditions on the relief face rather than on the cutting face, as is the case with metallic materials.

Local stress was examined using photoelasticity during thermoplastic material machining (polyester resin reinforced with carbon fibers). An analytical model was used to calculate cutting forces based on various photoelastic parameters and fiber orientation angles. Composite materials with carbon fibers and epoxy resin have not been widely studied. In [16], a correlation was established between cutting force, chip length, and thickness when the cutting speed direction is perpendicular to the fiber orientation. This correlation is based on beam theory and laminate theory.

Wang et al. and Arola and Ramulu studied orthogonal cutting on carbon/epoxy plates, describing the chip formation mechanisms during machining with a diamond-tipped tool. They studied the influence of tool geometry, wear, fiber orientation on the level of cutting force, and the profile of the machined surface roughness. The authors found that chip formation is due to brittle fracture and have a discontinuous shape, regardless of fiber orientation. The depths of the cut studied varied from 0.13 to 0.38 mm, which are not representative of drilling conditions.

The authors of constructed a numerical model based on their experimental work on unidirectional composite structures. The model is two-dimensional, with the assumption of plane stress. The rupture criteria used were Tsai-Hill and maximum stress. The relative error between measurements and numerical values ranged from 50% for θ = 15° to 12% for θ = 30°. Zhang proposed a two-dimensional numerical model for chip formation under static conditions, assuming the material is orthotropic and using the Tsai-Hill criterion for rupture. However, complete information on the model construction is not available. Additionally, the numerical model was based on different conditions than those of the experiment, with a rake angle of 4.5° compared to 0° and 20° in the tests. The relief angle value is also unspecified.

The aim of this study is to investigate the damage caused to composite materials by the cutting tool during orthogonal cutting. The study examines the effects of varying the angle θ between the ply direction and cutting speed direction while keeping the geometry of the tool and machining conditions constant. The study uses depths of cut representative of drilling (0.05 mm) and describes the mechanisms of material removal for each experimental condition. To acquire data on forces and temperatures of cut at the tool/test specimen interface, an experimental protocol is proposed. Based on the experimental results, a numerical model of orthogonal cutting is developed for $\theta = 0°$, which calculates the cutting force as a function of various parameters (depth of cut, rake angle, etc.). The model is compared to measurements taken in the experiment and those reported in the literature. Ultimately, the study aims to better understand the phenomena of damage caused by the cutting tool on composite materials during orthogonal cutting.

The challenges and complexities of drilling long fiber composite structures using twist drills designed for metallic materials. The behaviour of fibers under the action of the tool and the relative angle between the cutting speed direction and the direction of fibers strongly influence the drilling process. The material removal modes and associated rupture mechanisms vary depending on the angle θ between the cutting speed direction and the direction of fibers. The physical phenomena associated with the drilling of composite long fibers are more complex than those of metallic materials, and there is not much literature available on the topic. The authors propose using the orthogonal cutting on unidirectional graphite/epoxy laminates to study the influence of parameters of cut on the specific cutting pressure, power of cut, and delamination factor. The advantages of using orthogonal cutting are that chip formation is in the plane of the laminate, surface quality is observable during and after machining, and the modelling of the orthogonal cutting presents less difficulty than the modelling of drilling. The passage also briefly discusses previous studies on the orthogonal cutting of composite materials, highlighting the bond between machining conditions and the cutting force, surface quality, and fiber orientation angle.

II. Material And Methods

1. Need for FE Analysis of machining of composite material:

The need for finite element analysis (FEA) in machining composite materials arises from the desire to prevent workpiece damage. This research involves a combination of experimental investigation, empirical and analytical modelling, and numerical modelling, with the latter involving FEA. The experimental investigation is expensive, time-consuming, and poses health and safety risks due to the inhalation of fiber debris. The empirical analysis is limited to the operational window of the experimental setup and fails to account for the process mechanism's effect. The analytical analysis is based on assumptions that may not fully define the problem. In contrast, numerical methods, such as FEA, can simulate the machining process with greater complexity and provide a means of evaluating results that are difficult to measure experimentally, such as stress in the primary or secondary shear zone. However, the scale and accuracy of numerical simulations are constrained by computational costs. Therefore, FEA is necessary to achieve optimal performance in the machining of composite materials.

2. Finite Element modelling Technique:

In the research conducted by Alessandro Abena et.al. [1], it was highlighted that a wide range of parameters must be considered while developing FE simulation of machining composites. The paper presents two modelling techniques - equivalent homogeneous material (EHM) and microscopic simulation methodology - to gain a comprehensive understanding of cutting mechanics. While EHM is relatively straightforward to implement, it lacks in the interaction between fibre-matrix, which is important to understand defect formation and propagation. On the other hand, microscopic simulation methodology provides a more detailed understanding but comes with a higher computational cost. The paper suggests that either of these modelling techniques can be used at a given location depending upon the required level of accuracy. The paper further recommends using dynamic analysis instead of quasi-static analysis and cohesive zone models based on traction-separation law with a small thickness value to evaluate debonding. The analysis is done using ABAQUS/Explicit, where the EHM section of the workpiece is considered anisotropic and homogeneous with pure elastic behaviour, while the interface is modelled as individual phases with different failure models. Mingyang Wu et.al. [2] focuses on the cutting process simulation of composite materials and the analysis of dynamic problems like shock, collision, and forming. The study highlights that the composite material cutting process is a process of elastic-plastic deformation coupling and requires nonlinear finite element analysis to understand it better. The study considers the elastic-plastic stress-strain relationship model, which is highly dependent on strain rate, temperature, and loading. Carbon fiber experiences brittle mode damage and failure is determined by the maximum principal stress criteria. The cutting tool is simulated as a rigid body, and carbon fiber is modelled as strain rate independent due to its lower elastic modulus compared to the matrix. Overall, both studies emphasize the need for finite element analysis to understand the machining process of composite materials and recommend various modelling techniques to achieve the required level of accuracy.

Deform-3D is an industrial simulation system used for analyzing metal forming and heat treatment processes. It allows for the importation of models, meshing, constraint addition, and post-processing steps. Finite Element Simulation (FEM) of machining is a complex process that requires knowledge of the FEM theory, as well as expertise in mechanics to apply simulation software and combine elastic mechanics, fracture mechanics, and plastic mechanics. In this study, the authors used Deform-3D software to simulate the drilling process for carbon fiber composite materials based on the theory of elastic-plastic deformation. However, the material library provided by Deform-3D did not include the necessary carbon fiber composite material models, so a new material model was established with material-related mechanical and physical parameters.

2.1. The finite element mesh:

To reduce the complexity of the drilling process simulation, the size of the established workpiece model was reduced while still meeting the requirements of cutting simulation. The meshing process plays a vital role in establishing the finite element model, as the mesh directly impacts the calculation accuracy and time. The number of mesh elements can be defined based on these two requirements. The drilling process simulation is a highly nonlinear numerical calculation problem that requires strict element requirements. Limited computing environments and larger feed rates can cause fluctuations in cutting force.

The study also showed that the use of UD-CFRP (Unidirectional Carbon Fiber Reinforced Polymer) allowed for modelling each ply separately as an independent UD-CFRP with its own orthotropic elastic properties and material coordinate system. The UD-CFRPs were then stacked up according to the composite stacking sequence. The mesh structure was aligned with fiber orientation to capture the fractures that occur in CFRP machining. The cutter was modelled as a rigid body with meshed solid elements to describe the tool surfaces, and a portion of the tip in contact with the workpiece was given elastic properties of PCD to simulate deformable contact. Full integration, plane strain quadrilateral elements were used in the 2D model. A Lagrangian spatial framework was used, in which the material is fixed to the mesh. Reduced integration elements were advantageous in reducing the time for both the stiffness matrix assembly and stress recovery at each iteration for each of the element integration points. The authors of the study used MSC Marc software, and a Hashin damage model was employed to reduce the stiffness of composite elements based on the fiber and matrix tensile, compressive strengths and interlinear shear strength.

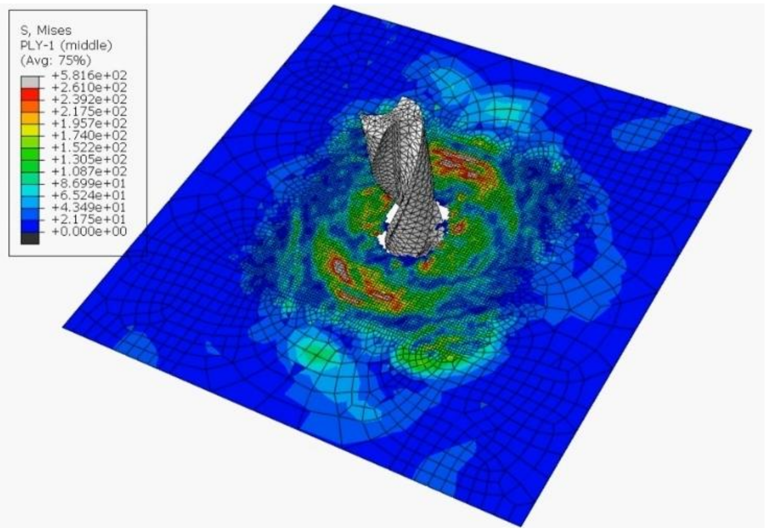
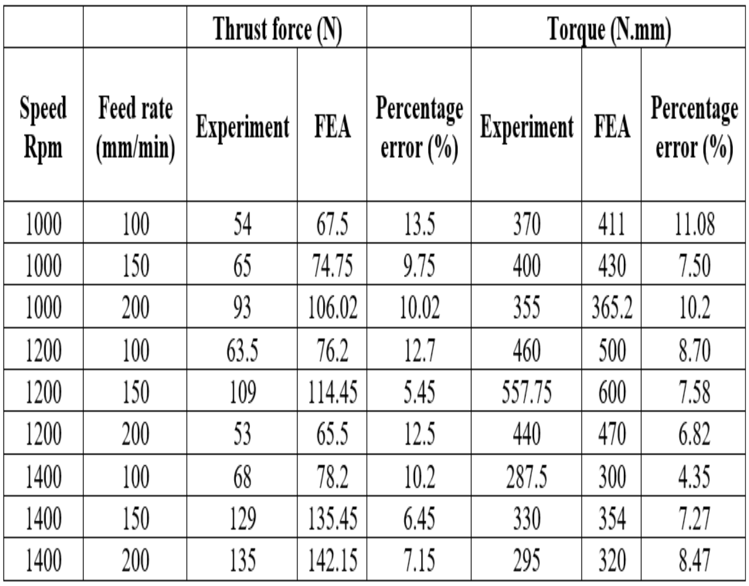


Figure 1: Simulation set-up

III. Results & Discussion:

Table 1. Summary of percentage error for thrust force and torque



		Thrust force (N)			Torque (N.mm)		
Speed Rpm	Feed rate (mm/min)	Experiment	FEA	Percentage error (%)	Experiment	FEA	Percentage error (%)
1000	100	54	67.5	13.5	370	411	11.08
1000	150	65	74.75	9.75	400	430	7.50
1000	200	93	106.02	10.02	355	365.2	10.2
1200	100	63.5	76.2	12.7	460	500	8.70
1200	150	109	114.45	5.45	557.75	600	7.58
1200	200	53	65.5	12.5	440	470	6.82
1400	100	68	78.2	10.2	287.5	300	4.35
1400	150	129	135.45	6.45	330	354	7.27
1400	200	135	142.15	7.15	295	320	8.47

3.Experimental method

Composites are widely used in various applications due to their exceptional mechanical and physical properties such as extraordinary tensile strength, modulus, good corrosion and chemical resistance, elevated adhesion, and dynamic stability. However, the mechanical drilling of nanopolymer composite laminates is significantly different from that of conventional composite laminates. This study provides an overview of the machining of composites (drilling, milling, egse-trimming) and its inhibiting approaches, including sub-surface deformation, surface roughness, and tool wear. Furthermore, it investigates the optimization of machining parameters, drill tool geometry, and tool types. In-depth information about subsurface machining is obtained through FE analysis. To ensure a correlation between experimental and analysis results, different parameters, such as material properties of composites, the element to be used for analysis (modelling technique), and boundary conditions, should be closely monitored. With the knowledge available from FEA, machining parameters can be modified to minimize delamination, fiber cracking, etc. Therefore, to produce defect-free holes and mechanical joining of composite structures, it is essential to monitor the process of machining on CFRP.

3.1. Delaminationsuppression techniques:

Delamination is a common problem that occurs in composite materials, where the layers of the composite separate or peel apart. Delamination can occur due to several factors such as improper manufacturing, impact damage, or fatigue. To prevent delamination in composite materials, the following techniques can be employed:

1)Proper manufacturing: Delamination can be prevented by using proper manufacturing techniques, such as ensuring proper curing and bonding of the composite layers, eliminating voids and air pockets, and using appropriate pressure during the manufacturing process.

2)Material selection: The selection of appropriate materials can also prevent delamination. Materials that have similar thermal expansion coefficients, moisture absorption rates, and stiffness can reduce the risk of delamination.

3)Resin infusion: Resin infusion is a process in which a composite is formed by infusing resin into a dry reinforcement. This process can help to eliminate air pockets, reduce the likelihood of delamination, and improve the strength and durability of the composite.

4)Toughened resin: Toughened resins are resins that have been modified to be more resistant to delamination. These resins have the ability to absorb energy and prevent crack propagation, which can help to prevent delamination.

5)Interleaving: Interleaving involves inserting a layer of material between the composite layers to prevent delamination. The interleaving material can be made of a variety of materials, such as films, fabrics, or thermoplastic polymers.

6)Surface treatment: Surface treatment involves altering the surface of the composite to improve adhesion between the layers. This can be achieved by applying a primer or using plasma treatment.

Overall, preventing delamination requires a combination of proper manufacturing, material selection, and the use of appropriate techniques to improve the strength and durability of the composite.

Delamination is a common problem that can occur in Carbon Fiber Reinforced Polymer (CFRP) materials during drilling. Delamination occurs when the layers of the composite material separate or peel apart, and it can lead to a decrease in strength and performance of the material. To prevent delamination during drilling of CFRP materials, the following techniques can be employed:

1)Use of sharp drill bits: The use of sharp drill bits can help to reduce the likelihood of delamination during drilling. Dull drill bits can cause the composite material to tear, resulting in delamination.

2)Proper drilling speed and feed rate: It is important to use the correct drilling speed and feed rate to prevent delamination. High drilling speeds and feed rates can cause excessive heat buildup and damage the composite material, leading to delamination.

3)Use of specialized drill bits: Specialized drill bits, such as diamond-coated or carbide-tipped drill bits, can help to reduce the risk of delamination during drilling. These drill bits are designed to cut through composite materials without causing damage or delamination.

4)Use of coolant: Coolant can help to reduce heat buildup during drilling, which can lead to delamination. Coolant can also help to lubricate the drill bit and reduce friction, resulting in a cleaner cut and a lower risk of delamination.

5)Clamping and support: Proper clamping and support of the CFRP material can also help to prevent delamination during drilling. Clamping the material firmly in place can prevent movement during drilling, which can cause delamination. Additionally, supporting the backside of the material with a backing plate can prevent delamination by distributing the drilling force evenly across the material.

Overall, preventing delamination during the drilling of CFRP materials requires a combination of proper drilling techniques, the use of specialized drill bits, coolant, and proper clamping and support of the material.

According to research, delamination during the drilling of CFRP composites is influenced by several factors such as thrust force, feed rate, and cone/point angle of the tool. An increase in cone angle of twist drills results in a larger extrusion area on the laminate and a higher thrust force, leading to more pushout delamination. However, a lower point angle of 85° twist drill was found to reduce delamination by 45% at the hole exit. The geometry of the tool also affects delamination, with the core drill being the best at achieving the highest feed rate with minimum delamination, while the trepanning tool is the most effective at reducing thrust and torque. Nano-coated drill bits can also reduce thrust forces and produce smoother hole peripheries. Different types of tools, such as brad-spur, end mill, twist, dagger, and stepped drills, have varying effects on delamination, thrust force, and surface finish. The trepanning or U-shape geometry produces the lowest thrust, while the KTH method yields the highest strength and fatigue life with better machining quality.

3.1.1. Use of support plates:

Industries often use support plates during drilling to reduce delamination, despite the associated higher cycle time and production cost (Capello, 2004). Reducing the area of the last ply from 14 to 6.5 mm can lower the delamination of the last bottom-most layer and its neighbouring layer by 13% and 7%, respectively. To further minimize pushout delamination, an adjustable active-backup force can be set up using an electromagnetic solenoid device to counter the pushout caused by the drill (Tsao et al., 2012). For more complex structures, industries use an electromagnet and a deformable chip colloidal solution of magnetic iron powder in tube-type parts, which can reduce delamination by about 60-80% (Hocheng et al., 2014). A more environmentally safe drilling procedure involves using the expansive internal force of water while freezing to provide backup during the drilling of tubes, which reportedly reduces delamination by 40% (Hocheng et al., 2016). When an aluminium plate is used as backing material at the bottom plies of the laminates, pushout delamination at the hole exit in CFRP laminates is reduced (Davim& Reis, 2003).

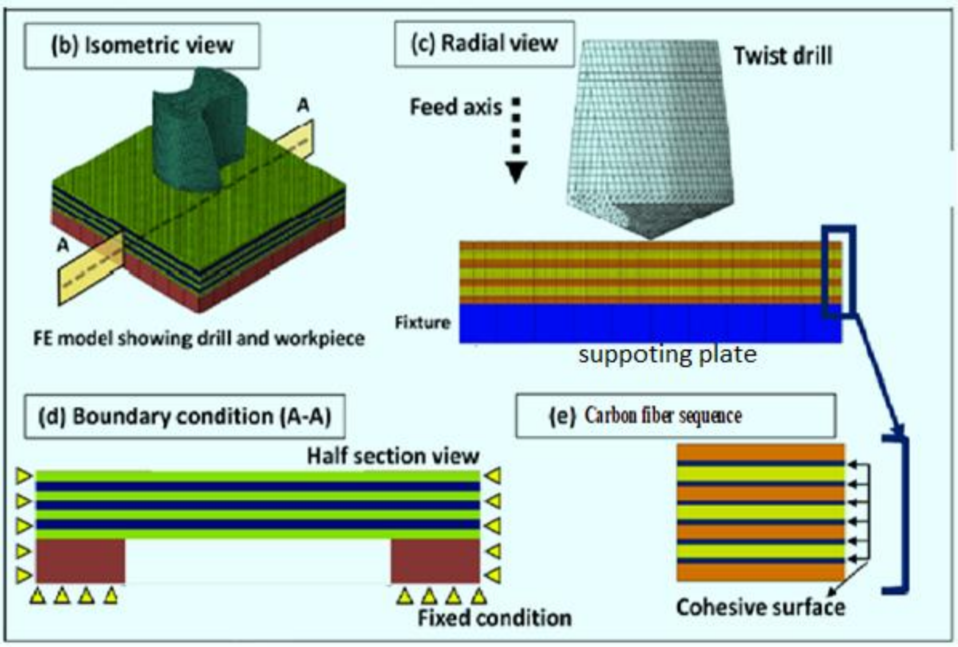


Fig.2.Supporting pate for drilling operation of CFRP material

3.1.2. Use of cooling:

The use of cooling is preferred when machining composites, as wet machining can result in moisture absorption in the FRP, which has a negative impact on the shear fracture toughness of the laminates (Joshi et al., 2018). Cryogenic cooling has been shown to improve hole surface quality, tool life, and reduce delamination in composites, as depicted in Figure 10 (Ahmed, 2004; Joshi et al., 2018; Kumaran, Ko, Li et al., 2017; Morkavuk et al., 2018). Studies have shown that cryogenic drilling with liquid nitrogen can result in lower delamination compared to traditional drilling due to a change in failure mechanism from bending fracture to shear fracture. Moreover, the use of rotary ultrasonic machining technique in a cryogenic setup has been found to reduce peel up delamination, as it increases the shear modulus and transverse strength of the laminate (Kumaran, Ko, Li et al., 2017).

3.1.3. Optimization of drilling parameters

Drilling parameters such as drill diameter, rake angle, chisel edge angle, web thickness, and helix angle, in addition to the type of drill bit used, can influence thrust force, torque, and delamination (Abrao et al., 2008; Murthy et al., 2010). Researchers have explored optimizing drilling parameters using various methods, including Taguchi's method, linear regression analysis, response surface methodology, analytical, numerical, and deep learning techniques (Babu & Philip, 2014; Geng et al., 2019; Genna et al., 2017; Jung & Chang, 2021; Krishnamoorthy et al., 2009; Rao et al., 2017; Saeed et al., 2019). Several studies have investigated the effects of varying drilling parameters on delamination, with experimental results indicating that enhancing the speed of cutting tools during drilling can increase delamination in CFRP composites due to heat generation, which softens the matrix and reduces stiffness (Feito et al., 2018; Krishnaraj et al., 2012; Sorrentino et al., 2018). On the other hand, lowering feed rates and increasing cutting speeds can also result in delamination due to the temperature rise that occurs (Geng et al., 2017; Loja et al., 2018). A high cutting speed (150-200 m/min) and lower feed rate (0.01-0.05 mm/rev) are generally used in industry to reduce delamination and maintain process efficiency, but cutting speeds are usually limited to 4000 m/min to prevent significant temperature increases that can damage the composite (Mkaddem et al., 2013). Increasing the chisel edge length leads to increased thrust force, while decreasing the chisel edge width reduces the extrusion area and the thrust applied (Jain & Yang, 1993; Won & Dharan, 2002). A high ratio of cutting speed to feed rate is optimal for minimizing delamination, and thinning the web can reduce axial thrust by 30 to 35% (Krishnaraj et al., 2010). Studies optimizing drilling parameters have found that minimizing feed rate can lead to minimum peel-up and push-out delamination (Abrão et al., 2007; Aveen et al., 2021; Dandekar & Shin, 2012).

Table 2. Summary of Experimental delamination factor in different orientations

Speed Rpm	Feed mm/min	Fiber Orientation (angle)	Delamination (entry)	Delamination (exit)
1000	100	30	1.068	1.072
1000	150	45	1.315	1.17
1000	200	60	1.558	1.319
1200	100	45	1.328	1.192
1200	150	60	1.562	1.2905
1200	200	30	1.078	1.077
1400	100	60	1.557	1.301
1400	150	30	1.055	1.08
1400	200	45	1.305	1.195

3.1.4. Special tool paths

In addition to optimizing machining parameters, novel machining techniques have been explored and implemented to enhance hole quality in CFRP composites, such as helical milling and wobble milling (Haiyan et al., 2013; Shan et al., 2011; Tonshoff et al., 2000). Helical milling, where the cutting tool moves in a spiral path to produce larger, precise holes, offers advantages such as reduced thrust force, smooth cutting, and improved lubrication and cooling (Amini et al., 2019; B Wang et al., 2018; Wang, Melly et al., 2018). Studies have shown that helical milling can also reduce thrust force, lower workpiece temperature, and decrease delamination with suitable parameters (Wang, Suntoo et al., 2018; J Liu et al., 2014; Qin et al., 2014). Wobble milling is another advanced technology that tilts the cutting tool to minimize axial cutting force and reduce delamination by compressing the composite layers (Pereszlai& Geier, 2020; Schulze &Becke, 2011). Mechanistic models have been developed to study the effects of process parameters on machining force and chip geometry, with wobble milling showing more effective results in minimizing uncut fibers in CFRP (Schulze et al., 2011, 2012; Pereszlai& Geier, 2020).

Drilling-induced delamination is a common problem when machining composite materials, such as carbon fiber-reinforced polymers (CFRPs). Delamination refers to the separation of layers or plies within the composite material. Delamination not only reduces the mechanical properties of the material but also affects the surface finish and accuracy of the machined parts.

Specially developed drill bits have shown promise in reducing delamination during drilling of CFRPs. These drill bits are designed with specific geometries, such as point angles, helix angles, and cutting edge geometries, to improve the drilling performance and reduce delamination.

However, more research is needed to design novel drill bits that can significantly suppress delamination during the drilling of CFRPs. This research can involve studying the material properties of CFRPs, the drill bit geometry, the machining parameters, and the drilling process itself. By understanding the fundamental mechanisms of delamination and how different factors influence it, researchers can design more effective drill bits that can reduce delamination to a minimum.

Overall, the development of novel drill bits for machining CFRPs is an active area of research, and continued efforts in this field will lead to improved machining performance and increased use of CFRPs in various applications.

The use of support plates has demonstrated promising results in reducing push-out delamination, but their applicability is limited to simple and plain geometry CFRP. Hence, additional research is necessary to minimize push-out delamination in complex geometries.

IV. Conclusion and future scope

Carbon Fiber-Reinforced Polymers (CFRP) are increasingly used in various modern applications due to their strength-to-weight ratio and ability to withstand challenging conditions.

Laser drilling is a promising method for producing high-quality holes in CFRP composites with a thickness of less than 3 mm. However, the feasibility of achieving dimensional accuracy and efficiency with a thickness above 10 mm is still unknown, and further research is needed.

Delamination is a common problem in drilling CFRP, with mode I failure being observed in both peel-up and push-out types. Feed rate and spindle speed are critical factors affecting delamination, and proper temperature control is crucial for obtaining good-quality holes.

drill bit designs show promise in reducing drilling-induced delamination, but more research is needed to optimize their performance.

Support plates are effective in reducing push-out delamination but may not be suitable for complex geometries.

Helical milling and wobble milling are expensive but provide excellent surface integrity and minimum defects. Further research is needed to optimize the parameters for drilling CFRP composites using these methods.

References

[1]. D.H. Wang et al.Orthogonal cutting mechanisms of Graphite/Epoxy, composite part II: multi directional laminateInt J Mach Tool Manufacturing. (1995)

[2]. W. König et al.Quality definition and assessment in drilling of fibre reinforced thermosetsAnnal CIRP(1989)

[3]. J.P. DavimStudy of drilling metal–matrix composites based on the taguchi techniquesJ Mater Process Technol(2003)

[4]. J.P. Davim et al.Drilling carbon fibre reinforced plastics manufactured by autoclave experimental and statistical studyMater Des(2003)

[5]. J.P. Davim et al.Study of delamination in drilling carbon fibre reinforced plastics (CFRP) using design experimentsCompos Struct(2003)

[6]. G. Caprino et al.Effect of tool wear on cutting forces in the orthogonal cutting of unidirectional glass fibre-reinforced plasticsComposites: Part A(1996)

[7]. D. Arola et al.Orthogonal cutting of fibre-reinforced composites: a finite element analysisInt J Mach(1997)

[8]. Lachaud F. Délaminage de Matériaux Composites à Fibres de Carbone et à MatriceOrganiques: Etude Numérique et...

[9]. Guegan P. Contribution à la qualification de l'usinage de matériaux composites à matriceorganique. Thèse de doctorat...There are more references available in the full text version of this article.

[10]. Abrão, A. M., Faria, P. E., Rubio, J. C. C., Reis, P., &Davim, J. P. (2007). Drilling of fiber reinforced plas- tics: A review. J Mater Process Technol, 186(1–3), 1–7. https://doi.org/10.1016/j.jmatprotec.2006.11.146

[11]. Abrao, A. M., Rubio, J. C. C., Faria, P. E., &Davim, J. P. (2008). The effect of cutting tool geometry on thrust force and delamination when drilling glass fibre-reinforced plastic composite. Materials & Design, 29 (2), 508–513. https://doi.org/10.1016/j.matdes.2007.01.016

[12]. Ahmed, M. Cryogenic drilling of KevlarTM composite laminates, King Fahd University of Petroleum and Minerals (Saudi Arabia). ProQuest Dissertations Publishing, 2004

[13]. Akman, E., Erdoğan, Y., MÖ, B., Çoban, O., Oztoprak, B. G., & Demir, A. (2019). Investigation of accumulated laser fluence and bondline thickness effects on adhesive joint performance of CFRP composites.Int J AdhesAdhes, 89, 109–116. https://doi.org/10.1016/j.ijadhadh.2018.12.003

[14]. Al-wandi, S., Ding, S., & Mo, J. (2017). An approach to evaluate delamination factor when drilling carbon fiber-reinforced plastics using different drill geome- tries: Experiment and finite element study. The International Journal, Advanced Manufacturing Technology, 93(9–12), 4043–4061. https://doi.org/10.1007/s00170-017-0880-2

[15]. Amini, S., Baraheni, M., & Hakimi, E. (2019). Enhancing dimensional accuracy and surface integrity by helical milling of carbon fiber reinforced polymers. Int J Light Mater Manuf, 2(4), 362–372. https://doi.org/10.1016/j.ijlmm.2019.03.001

[16]. An, Q., Ming, W., Cai, X., & Chen, M. (2015). Study on the cutting mechanics characteristics of high-strength UD-CFRP laminates based on orthogonal cutting method. Compos Struct, 131, 374–383. https://doi.org/10.1016/j.compstruct.2015.05.035

[17]. Anand, R. S., & Patra, K. (2017). Mechanistic cutting force modelling for micro-drilling of CFRP composite laminates. CIRP J Manuf Sci Technol, 16, 55–63. https://doi.org/10.1016/j.cirpj.2016.07.002

[18]. Aurich, J. C., &Dornfeld, D. A. (2009). Burrs-Analysis, Control and Removal: Proceedings of the CIRP International Conference on Burrs (2nd-3rd ed.). April, 2009, University of Kaiserslautern, Germany. Springer Science & Business Media.

[19]. Aveen, K. P., Londe, N. V., Amin, G. G., & Shaikh, I. S. (2021). A review on the effects of input parameters & filler composition on delamination during machining of FRP composites. Mater Today Proc, 46(7), 2607- 2611. https://doi.org/10.1016/j.matpr.2021.02.264

[20]. Azuan, S. A., Juraidi, J. M., & Muhamad, W. M. W. (2012). Evaluation of delamination in drilling rice husk rein- forced polyester composites. Appl. Mech. Mater, 232, 106–110. https://doi.org/10.4028/www.scientific.net/AMM.232.106 Trans Tech Publ.

[21]. Babu, J., & Philip, J. (2014). Experimental studies on effect of process parameters on delamination in drilling GFRP composites using Taguchi method. Procedia Mater Sci, 6, 1131–1142. https://doi.org/10.1016/j.mspro.2014.07.185

[22]. Bagherzadeh, A., Jamshidi, M., &Monemian, F. (2020). Investigating mechanical and bonding properties of micro/nano filler containing epoxy adhesives for anchoring steel bar in concrete. Construction and Building Materials, 240, 117979. https://doi.org/10.1016/j.conbuildmat.2019.117979

[23]. Behniafar, H., &Nazemi, M. K. (2017). Effect of amine-functionalized silica nanoparticles on thermal and mechanical behaviors of DGEBA/IPD epoxy networks. Polym Bull, 74(9), 3739–3749. https://doi.org/10.1007/s00289-017-1928-z analysis: methods for cost-utility analysis.

Suresh Aadepu, et. al. "Techniques for strengthening, suppressing delamination, and preventing delamination formation during the drilling of CFRP composites." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 20(2), 2023, pp. 07-15.