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Effect of Machining Parameters on Delamination and Surface Roughness in Composite Materials: A Review

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Abstract: *The drilling of natural fiber-reinforced polymer composites (NFRCs) and their hybrid composites is a critical machining operation for facilitating parts assembly, with strict dimension tolerance requirements. Due to the comparable specific properties, eco-friendliness, and accessibility of NFRCs, they have gained significant attention in recent years compared to synthetic fiber-based composites. This review article presents an overview of past and present research studies on the drilling behavior of NFRCs and their hybrids, investigating various drilling techniques and performance parameters, analyzing drill bit geometry and materials, residual strength, and methods of improving drilling properties. Additionally, future work is proposed for developing an AI-basedprediction model that identifies the delamination factor and surface roughness for a given drill toolpoint angle, cutting speed, and feed rate on thrust force. The challenges and recommendations forresearchers are also highlighted to advance this research field.*

Keywords: composite materials, drilling, delamination, surface roughness machining parameters, mechanical properties

I. INTRODUCTION

Composite materials typically consist of two phases: a reinforcing phase (such as fibers, sheets, or particles) and a matrix material. The matrix material can be a metal, ceramic, or polymer, while the reinforcing material is typically a low-density, high-strength, or high-toughness material [1]. Composite materials are gaining increasing attention in modern applications, particularly in engineering structures and constructions, due to their lightweight nature and increased strength compared to conventional materials [2]. The addition of fiber reinforcement enhances various properties of the matrix, including stiffness, tensile strength, heat resistance, chemical resistance, conductivity, corrosion resistance, and matrix interaction of polyester/sisal fiber matrices and composites [3]. Natural fibers are commonly used as reinforcement material in research, with sisal fiber being a readily available, renewable, and high-strength material [4, 5]. Hybridization of glass with pineapple and sisal fibers has been shown to enhance the mechanical properties of composites, with the hybrid composites reinforced with sisal fiber at the outer surface exhibiting good strength [6].

Drilling is a hole-making process required for the assembly of several composite components, as natural fiber-reinforced polymer composites (NFRP) are commonly made in near-net shape. However, drilling of NFRP composite materials differs from drilling metallic materials due to their nonhomogeneous and anisotropic properties [7]. The drilling process can cause significant structural damage in laminated composites, such as delamination, debonding of fiber-matrix, micro-cracks, and thermal damage, which can compromise the structural integrity and mechanical performance of the composites [8]. Drilling factors, such as drill bit geometry and drilling conditions play a predominant role in producing delamination during drilling [9].

Previous studies have recommended various drilling parameters to minimize delamination, such as lower feed rates and higher spindle speeds [10, 11]. Recent developments in natural fiber- reinforced polymer composites have led to advancements in conventional drilling techniques. Therefore, this review article aims to provide an overview of NFRP composites drilling in the last ten years, including a detailed analysis of different drilling conditions and parameters (such as thrust force, drill geometry, speed, and feed) and post-drilling analysis of delamination, thermal damage, and surface roughness [12]. By exploring the effect of different machining processes on delamination of polyester composites, this review article can aid in choosing better machining processes to reduce delamination during drilling.

II. LITERATURE REVIEW

Drilling of FRP composites is an important area of research, as these materials are commonly used in a range of industrial applications. In recent years, conventional drilling has been the most popular method for drilling FRP composites. However, there are still challenges to be addressed in this area, particularly with respect to chip formation and delamination. A number of studies have investigated the factors that influence chip formation and delamination in GFRP composite drilling. For example, it has been found that the reinforcement of glass fibers has a greater influence on chip formation than the resin material. Additionally, the delamination factor (DF) tends to increase at the hole exit due to the increase in feed and flute number, while a decrease is seen at the hole entry. Both the point angle and feed values have an immediate effect on DF on both the entry and exit sides of the hole. Table 1 provides a summary of some of the literature works that have investigated these issues in recent years. By examining these studies in more detail, we can gain a better understanding of the challenges and opportunities in FRP composite drilling, and identify areas for future research. Few of the notable research ananlysis we can put out as follows.

Rezghi et Al.[13] in his work on Jute epoxy material utilizing drills namely Two facet twist drill, HSS drill, CoroDrill (854, 856) with Speed-750, 1250, 1750 rpm, Feed- 0.05, 0.1, 0.15 mm/rev. finds out that the thrust forces were generated more with CoroDrill 854 drill than HSS and Coro Drill 856 drill. Whereas the delamination size was less with the HSS tool than the other two. Jute fibers' coarse structure in the JFRP composite resulted in the smallest possible delamination size. This was attributed to less contact of fibers with the drill than the matrix.

Ameur et al.[14] while working with Quasi-isotropic CFRP laminate with drills namely HSS, WC and WC-TiN twist drill with Ø:118^0 with D: 6 mm & Speed 3000, 6000, 9000 rpm.with Feed 60, 120, 180 mm/min finds out that Minimal thrust force, torque, exit delamination factor and cylindricity error attained at low feed, low speed by using WC-TiN drill.

Phadnis et al.[15] drilled UD cross-ply CFRP laminate material with the help of TiN-coated jobber carbide twist drill of D: 3 mm with speed of 40, 150, 600, 1300, 2500, 5000 rpm feed with 16, 40, 80, 150, 300, 600 mm/min. finds that Low feed rates (<150 mm/min) and high spindle speed (>600 rpm) are the most effective drilling condition.

Wang et al.[16] worked with CFRP laminate using Carbide, diamond-like coated and polycrystalline diamond twist drill with Ø: 140^0 & D: 5 mm on speed 1200, 2400, 3600 rpm with feed 5,10, 20 mm/min reported that lowest exit delamination factor for stack sequence (0/0/0/45/0/0/−45/0) 2s using diamond coated twist drill at high speed, low feed rate.

Tsao et al.[17] worked on BD woven CFRP composite material for drilling with HSS candle stick material with D: 6, 8,10 mm & speed S: 800, 1000, 1200 rpm with feed rate of 0.01, 0.03, 0.05 mm/rev founds out that Drill diameter (63.5%) & feed rate (26.4%) are significantly influencing on thrust force. Surface roughness affected by feed rate (40.1%) & spindle speed (26.5%).

Gaitonde et al.[18] noted that BD woven CFRP composite material when drilled with WC twist drill with felix angle: 25 ^{0} D: 5 mm. & Vc: 60, 120, 600 m/ min. with the feed rate of 1, 3, 6 mm/min. having Ø: 85^0, 118^0, 135^0, Lowest peel-up delamination factor recorded at higher speed, lower feed and lower level point angle.

Cadorin et al.[19] in his work with 3D woven CFRP composite drilling with Diamond-coated carbide three lips twist drill with speed of 750–10000 rpm, feed with 0.01–0.3 mm/ rev. D: 8.57 mm founds out that delamination initiation and drill hole-wall roughness are extremely reliant on feed and mode of lubrication used. Fiber pull-out, delamination cracks appear when the relative angle between reinforcement and tool is −45° or 90°. The optimal conditions attained at feed (0.075 mm/rev) and spindle speed (5000 rpm) with internal lubrication.

On material focused research Angadi et al.[20] used Cenosphere carbide drill with D: 6,8,10 mm. F:50,150,300 mm/min & S:2000,3000,4000 rpm founds out that the quality of drilled hole mainly depends on wt% cenosphere.

Belaadi et al.[21] with his jute fabrics reinforced epoxy matrix bio composites material drilled with HSS_TiN, HSS and Brad & Spur drills with speed of 355, 710 and 1400 rev/min, with feed rate f: 50, 108 and 190 mm/min and d: 5, 7 and 10 mm find out that the feed rate had a significant contribution on spindle speed and diameter. The optimum conditions obtained for the Fd factor were a feed rate of 51 mm/min, a spindle speed of 1160 rev/min and a drilling diameter of 5 mm. Microcracks may occur during drilling.

Ramesh and Gopinath [22] while study with sisal-glass fiber reinforced polymer composites material used carbide drill with feed rate of 0.04,0.06,0.08 mm/rev and speed for 1000,2000,3000 rpm & 6,9,12 founds out that the high spindle speed, low feed rate and drill diameter are preferred to improve the performance but it affected the surface roughness quality

Yallew et al.[23] while working on woven jute fabric-reinforced polymer composites with the radial drill machine speed range from 90 to 4500 rpm and Feed range from 0.03 to 0.3 mm/rev with D: 8 mm & Ø: 118^0 stated that the main cause of delamination is the thrust force and parabolic drill shows better cutting behaviour than the Jo and twist drill

Sakthivel et al[24] worked with basalt and sisal material with radial drilling machine configured at D: 3,4,5 mm; f:0.1,0.2,0.3 mm/rev; S: 300,600,900 rpm. The analysis reveals the optimized parameter to control thrust force and delamination factor in basalt/sisal fibre is Drill bit diameter at 3mm, speed at 300 rpm and feed rate at 0.1mm/rev.

Aravindh, S., and K. Umanath [25] use Jute fiber material in drilling study with HSS drill tools on various feed rate on same spped and other configuration founds out that Feed rate is significant parameter to improve the quality of drilled hole.

Arputhabalan et al.[26] in his study with Kenaf, sisal, and aloe vera composite material with drilling with HSS Twist drill D:8mm; f:0.02, 0.04 mm/rev; S: 500, 800 rpm founds out that process Increase the delamination for polyvinyl chloride than that of other, decreased Spindle speed is suggested to drill vinyl ester polymer.

Ramesh et al.[27] study on composite material made up of matrixed Sisal, glass/Polyester resin drilled with the Solid carbide, TiN coated solid carbide, and HSS brad and spur drill with the setup of D:12mm; f:0.04, 0.08 mm/rev; S: 1860 rpm stated that Increase in Feed rate Maximum Thrust force and delamination. at HSS drill bit.

III. RESEARCH SUMMARY AND OUTCOME

Based on the reviewed literature, it can be inferred that the drilling conditions such as spindle speed, feed rate, and tool material have a significant influence on the quality of drilled holes in FRP composites. The optimal drilling conditions vary depending on the type of composite material and the type of drill used. The reviewed literature also suggests that the quality of drilled holes is influenced by the fiber orientation, matrix properties, and the percentage of reinforcement in the composite material. Furthermore, microcracks, fiber pull-out, and delamination can occur during drilling, and the relative angle between the reinforcement and the tool also plays a crucial role in determining the quality of drilled holes. Future research can focus on developing advanced drilling techniques and tools that can effectively drill different types of FRP composites. The effect of various drilling parameters on the quality of drilled holes can also be studied in detail. Additionally, the development of sustainable composite materials and the study of their machinability can be another area of future research.

Research Challenges identification

The machining of NFRCs is a complex and challenging process that requires careful consideration of various parameters and factors. Further research is needed to fully understand the machinability of NFRCs and to address issues like delamination as well as other quality parameters such as surface roughness. Developing an AI-based prediction model to identify the delamination factor and surface roughness for a given drill tool point angle, cutting speed, and feed rate on thrust force could potentially help address some of these challenges and lead to more effective and efficient machining of NFRCs. There are several challenges associated with identifying the delamination factor and surface roughness for a given drill tool point angle, cutting speed, and feed rate on thrust force in the drilling of natural fiber-reinforced polymer composites (NFRCs) and their hybrid composites. Some of these challenges include:

• Complex material behavior: The drilling behavior of NFRCs is highly dependent on their unique properties, such as fiber orientation, fiber volume fraction, and matrix properties. These material properties make it difficult to develop a simple analytical model to predict the drilling behavior accurately.
• High-dimensional parameter space: The drilling process involves multiple parameters, such as the drill tool point angle, cutting speed, and feed rate on thrust force. Optimizing these parameters for improved drilling properties requires exploring a large parameter space, which is challenging to do using traditional experimental methods.
• Time-consuming and expensive experiments: Conducting experiments to evaluate the effect of various drilling parameters on the delamination factor and surface roughness is time-consuming and expensive. Therefore, there is a need for a more efficient and cost- effective approach to identify optimal drilling conditions.
• Limited understanding of the underlying mechanisms: The underlying mechanisms responsible for delamination and surface roughness in NFRC drilling are not fully understood. Therefore, it is challenging to develop accurate models for predicting the drilling behavior.

An AI-based prediction model can address some of these challenges by leveraging machine learning algorithms to develop predictive models that can identify the optimal drilling parameters for minimizing delamination and surface roughness. By training the model on large datasets of experimental data, it can learn the underlying relationships between drilling parameters and the resulting delamination factor and surface roughness, providing a more efficient and cost-effective approach for optimizing the drilling process.

IV. CONCLUSION AND FUTURE SCOPE

This review paper presented a comprehensive overview of the past and present research studies of the drilling behavior of NFRCs and their hybrid composites. Firstly, various drilling techniques used for NFRCs were investigated, and an overview of the various drilling parameters and key aspects of drilling performance parameters were presented. A study on drill bit geometry and materials, residual strength, and the challenges involved in improving the drilling properties for natural fiber-reinforced polymer composites and their hybrid was analyzed. Future research in this field should focus on the development of an AI-based prediction model for identifying the delamination factor and surface roughness for a given drill tool point angle, cutting speed, and feed rate on thrust force. Additionally, more attention should be given to other quality parameters such as surface roughness, residual stresses, and roundness of the produced hole. The proper selection of machining parameters and cutting tools used should take into account the type of fiber used as reinforcement or filler in a composite, and the cutting mechanism should be thoroughly understood to analyze the machinability of NFRCs.

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