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Review Article

DRILLING OF GLASS FIBER REINFORCED POLYMER COMPOSITE (GFRP): A REVIEW

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ABSTRACT

The use of fiber reinforced polymer (FRP) composite material has increased significantly in current scenario due to its superior properties like higher strength to weight ratio, higher stiffness, lower thermal expansion. Number of papers focusing on machining characteristic of GFRP composite have been increased since last decades. Drilling is most common process for assembling component made from glass fiber reinforced polymer (GFRP) composite. This paper is attempt to review the various drilling Performed on GFRP. Effect of cutting parameters, drill geometry, drill material and fiber content on delamination, thrust forced and surface roughness has been reviewed. It is intended to support readers to achieve a complete view on drilling of SFRPC for selecting the damage free drilling process and conditions.

INTRODUCTION

Composite materials are engineered from two distinct materials in order to improve the performance of product and reduce the cost of manufacturing[1]. Due to considerable advantage of fiber reinforced polymer composite, they are mainly used as replacement of conventional materials in industries such as aerospace, defense, chemical industry which demand materials having superior properties such as higher specific strength[2]. All the FRP composite undergo some machining process in their fabrication process to match with its specific engineering application. In machining FRP composite, a finishing compared to metals cannot be achieved because special characteristic such as non- homogeneity and anisotropic behavior and highly abrasive fibers. Some non-conventional machining process such as laser beam machining and abrasive water jet machining provide satisfactory results for Kevlar fiber composite but on other hand also rise the unacceptable damage in carbon and glass fiber reinforced composite. In fact, no new technology seems to offer alternative to conventional drilling in terms of cost and availability[3]. As joining of composite materials to other structures are mainly carried out by means of riveted and bolted joints, Drilling is extensively used working operation for secondary machining of FRP composite materials[4]. FRP composites have excellent performance characteristic but machining of FRP composites has always been difficult because of number of difficulties come across. several of them are listed below[5].

1. Surface delamination: Separation of layers at the entry and exit side of drill.
2. Internal delamination: Separation of layers that occur between layers.
3. Fiber/ resin pull out: Tearing away of fiber/ resin from machined edge.

Due to drilling induced damage, 60% parts are rejected in aircraft industry in final assembly[6]. Delamination between sub surfaces of specimen is another important drilling induced damage when drilling FRP composite laminates. So Delamination and sub-surface deformation damage has to be reduced to improve quality of drilled holes and structural integrity and this can be achieved by proper selection of cutting parameters (cutting speed, feed rate), drill materials and drill geometry [7] [8]. Delamination in FRP composites were witnessed both at entry and exit of drilled hole in the form of peel up delamination and push out delamination. Results shows that push out delamination is more severe than peel up delamination due to reduced thickness of laminate to resist the deformation [9]. This paper is attempt to review drilling operation for GFRP and this will provide assistance to choose better drilling conditions to reduce drilling induced damage.

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Drilling of GFRP

The focus of researchers on improvement of mechanical drilling on GFRP composites had been mainly on cutting forces, cutting parameters, drill geometry, drill material, tool wear, delamination mechanism and its preventing approaches. Drilling induced delamination influenced by input parameters such as cutting speed, feed rate, drill point angle, drill diameter and chisel edge [10]. In addition to these parameters fiber orientation, fiber fraction (weight fraction, volume fraction) also effect the delamination [11]. This all parameters contribute to the thrust force, torque and quality of the drilled hole.

Effect of Cutting parameters

Ogawa *et al*[12]investigated the effect of cutting parameters on surface roughness and thrust force in small diameter drilling for GFRP. The thrust force was divided into two components in this study namely static thrust force and dynamic thrust force. Surface roughness of the drilled hole which was measured by scanning electron microscopy (SEM) was more affected by the feed rate and dynamic thrust force than cutting speed. Therefore, it is effective to reduce the feed rate to improve the drilled hole quality. Sonbaty *et al* [13] studied the effect of cutting speed, feed rate and drill size on thrust force and torque while drilling of GFR/Epoxy composite. The thrust force and torque were found to be decreased with increasing cutting speed and found to be increased with increasing feed and drill diameter. The holes drilled with lower feed rate have better surface roughness compared to holes drilled at higher feed. Sonbaty *et al* [14] investigated the effect of feed rate, cutting speed and drill diameter on machinability of GFRE composite. The result show that the surface roughness increase with feed rate but no convincing effect of cutting speed was observed.

For drilling chopped glass reinforced polyester composite using HSS twist drill of standard point angle the optimal conditions are cutting speed (240m/min), feed rate (0.1mm/rev) and drill diameter (8.5mm) [15]. Though lower feed rate decreases the axial thrust force and possibility of delamination, when the productivity is considered as general priority in industry lower feed rate is not suitable because the risk of thermal degradation of matrix at higher temperature [16]. I. Singh *et al* [18] tried to correlate drilling induced damage with drilling parameters. They proved that delamination factor was highly depend on ratio of cutting speed to feed rate and increased with higher ratio. Delamination zone was successfully measured by image segmentation and thresolding principle. Regression model was developed for thrust force, torque and damage with 10% error for 8-facet drill, joe drill, parabolic drill and 20% error for 4-facet drill. Gaitonde *et al* [17] tried to predict the delamination factor measured as a function of cutting speed, feed rate and point angle with the use of second order non-linear mathematical model. The results proved that increase of feed rate results in increase in thrust force along with hole damage. High speed machining (HSM) is an outstanding technology capable of improving productivity and lowering production costs in manufacturing companies. Rubio *et al*[19] found the effect of high speed in the drilling of glass fiber reinforced plastic. The experimental results indicate that to obtain larger material removal rates associated with minimal delamination, higher spindle speeds should be used when drilling GFRP. At a spindle speed of 40 000 rpm, delamination is minimal, irrespectively of the feed speed employed. Within the cutting range tested, delamination decreases as the spindle speed is elevated, probably owing to the fact that cutting temperature is elevated with spindle speed, thus promoting the softening of the matrix and inducing less delamination. At high spindle speeds drill produced less delamination compared to the twist drills with 115° and 85° point angle, owing to the fact that drill acts similarly to a trepanning tool, promoting lower shear area and, consequently, lower thrust force values.

Effect of drill material

The hardness of the glass fibers results in a high level of tool wear in drilling operations so material of drill dominates the selection of drill for drilling of GFRP. Carbide tools, coated carbide tools and PCD tools have better results in case of tool wear and tool life while the drilling of GFRP[20]. Reddy *et al* [21] made the comparison of solid carbide and HSS drill for drilling of general purpose resin reinforced with glass fiber. Result confirmed that quality of drilled hole is also assisted by drill. It was also reported that the delamination and thrust force in case of solid carbide drill is lower than for HSS drill. Ferit Ficci *et al* [22] used three different drill (HSS, TiN coated HSS, Carbide) for investigating drilling characteristic of high performance PPA (polyphthalamide) matrix composite reinforced with 30% glass fiber. The result showed same phenomenon for all drills tested in terms of delamination which is reduction of delamination with increasing cutting. Carbide tools had Lowest surface roughness values in drilling operations. HSS drill has shown higher thrust force and much more delamination than that of Tipped carbide drill but the variation of thrust force with cutting speed is steady in case of Iso Phthalic glass with 50% volume fraction. M. Mudhukrishnan *et al*[23]examined the influence of drill tool material (HSS twist drill, Tipped carbide drill, solid carbide drill) and machining parameters (feed rate, spindle speed) on GFR-PP composite with focus on surface roughness. Regression model was developed using experimental data for estimating surface roughness and oversize. Result concluded that the surface roughness increased with increase in feed rate and decreased with increase in spindle speed. The solid carbide drill was observed to had better drilling performance compared to others. Finally, it was concluded that the performance of suitable drill for better drilling performance is in order of solid carbide, tipped carbide and HSS due to high hardness and better rigidity of solid carbide drill.

Effect of drill geometry

The drill geometries suchlike drill diameter, helix angle point angle, rake angle, chisel edge affects the thrust force, torque, surface roughness and delamination while drilling FRP composites. Figure 1 represents the effect of different tool geometries on the delamination factor. Jose Mathew *et al* [24] tried to reduce thrust force and torque using trepanning tool and compared results with traditional twist drill. They successfully reduced thrust force about 50% and torque about 10% in comparison with twist drill. Vinod Kumar *et al* [25] used HSS twist drill to study the effect of feed rate, cutting speed, chisel edge width and point angle while drilling of glass fiber reinforced polymer composite. For thrust force, the optimum process parameters were obtained as cutting speed (500rpm), feed rate (0.04 mm/rev), point angle (90º) and chisel edge width (0.8mm). for torque.

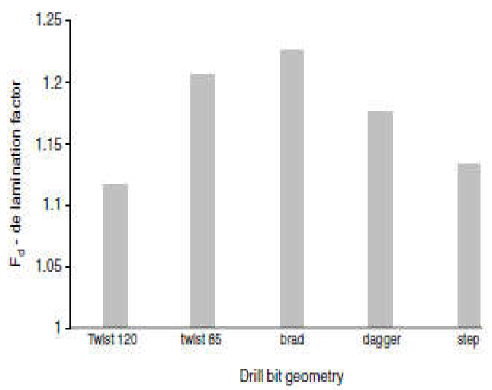

Fig 1 Effect of various drill geometry on delamination factor.

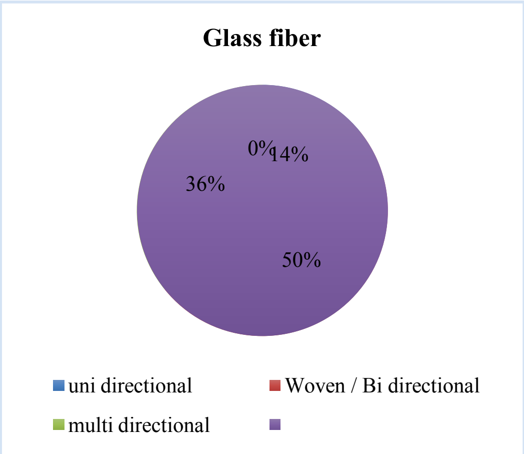

Fig 2 Different form of fibers used in literature

Cutting speed (500 rpm), feed rate (0.06 mm/rev), point angle (95º) and chisel edge width (1.6 mm). for surface roughness, cutting speed (500 rpm), feed rate (0.04 mm/rev), point angle (95º) and chisel edge width (0.8 mm). for the circularity, cutting speed (1500 rpm), feed rate (0.06 mm/rev), point angle (90º) and chisel edge width (0.8 mm).Carbide tipped drill with straight shank (K20) was used to drill asymmetric GFRP laminate by Dhiraj Kumar *et al* [26] because of its ability to dissipate heat rapidly. Except of this advantage, results revealed that the drilling induced delamination and surface roughness were more than that were in the solid carbide eight-facet drills. values of surface roughness fluctuating in a wide range from 0.794 to 2.769µm.Bhatnagar *et al* [27] have attempted to quantify and propose regression model in term of cutting speed and feed rate and study the effect of various drill geometry namely 4 faceted drill, 8 faceted drill, parabolic drill and jodrill on drilling induced damage in drilling of GFRP composite. They concluded that drilling induced zone in case of [(0/90)/0] laminate was smaller as compared with UD-laminate and 4 faceted drill was not suggested for drilling GFRP as highest thrust force was recorded for this drill. On contrary general results, highest thrust damage was not measured for 4 faceted drill. Ramkumara *et al*[28] studied effect of work piece vibration on drilling of glass/epoxy (GFRP) laminates using three types of drill, e.g. tipped WC, 2-flute solid carbide and 3-flute solid carbide. A UD-GFRP laminate of 4mm thickness was prepared and drilling was carried out using a vertical drilling machine. The result indicates that (I) Giving small amplitude low frequency vibration to work piece results in much better drill performance in drilling of GFRP laminates. (II) The number of holes that can be drilled with vibrating work piece before drill performance deteriorates is much larger than for conventional drilling. (III) Hole quality is improved and delamination reduced when work piece is given a small amplitude low frequency vibration. (IV) Among the three types of drills used, e.g. tipped WC, 2-flute solid carbide and 3-flute solid carbide, 3-flute solid carbide drill performs the best.

Effect of fiber content

The increase in fiber content results in poor surface finish as pull out of fiber increase with increase of fiber volume fraction. S. Sivrajan *et al* [29]used 30% and 50% volume fraction of high performance Iso phthalic polyamide glass fiber and concluded that The variation of thrust force with cutting speed is steady in case of Iso Phthalic glass with 50% volume fraction but in case of Iso phthalic glass composite with 30% volume fraction the thrust force fluctuates with cutting speed. The occurrence of delamination is less when drilling Iso phthalic glass composite with 50 % volume fraction. Increasing fiber content results in an excessive toll wear because of more interaction with highly abrasive of fiber. To study the effect of fraction of fiber content in drilling of GFRP Ahmed *et al* [30] carried out drilling experiments on five specimens with different fiber content (5-25%) using standard HSS twist drill. Minimum surface roughness was observed for specimen with 5% fiber content. Combination of highest spindle speed, lower feed rate, low fiber content resulted in better quality of drilled hole.

CONCLUSION

The following conclusion can be drawn from the literature.
In conventional drilling, among all the driving parameters for drilling induced damage, feed rate is most important parameter followed by drill geometry and spindle speed. Best results can be obtained from PCD tools but due to cost factor some other drill materials like TiN and TiAN coated drill may be proved alternative. Use of High speed drilling is suitable to achieve low damage levels and it can also improve productivity and reduce the production cost but tool wear is major issue to drill at higher speed and feed. There is a need to focus on High speed drilling and vibration assisted drilling for future scope.

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