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An Effective Defect Detection And Optimization In Drilling of Glass Polymer

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SATHYABAMA UNIVERSITY
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AN EFFECTIVE DEFECT DETECTION AND OPTIMIZATION IN DRILLING OF GLASS POLYMER

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Submitted by

A. RAGOTHAMAN
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BONAFIDE CERTIFICATE

Certified that this thesis titled "**AN EFFECTIVE DEFECT DETECTION AND OPTIMIZATION IN DRILLING OF GLASS POLYMER**" is the bonafide work of **Mr.A.RAGOTHAMAN** [Reg. No.2009194102] who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

Glass Fibre Reinforced Plastic (GFRP) composite materials have wide applications in recent times due to their superior properties such as high specific strength and specific stiffness. These materials are most important and economic alternative to conventional materials. The main objective of this research is to analyse the experimental observations during drilling of Glass Fibre Reinforced Plastic composites using helical flute straight shank drill and Brad and Spur drill. Two types of Glass Fibre Reinforced Plastic composites are considered for this study. The Glass Fibre Reinforced Plastic Epoxy composites and The Glass Fibre Reinforced Plastic Polyester composites are taken into consideration for studying the drilling characteristics. The process parameters such as feed rate and cutting speed are considered for the experiment. The performances of drilling process are measured and analyzed in terms of thrust force, torque, delamination and specific cutting pressure. The effects of process parameters on the drilling performances are investigated in this study. It was observed from the analysis that thrust force and torque increases with feed rate, due to their increasing in shear area. Also the delamination factors (peel up & push out) increases with increase in thrust force. Specific cutting pressure during drilling shows the opposite trend to that of thrust force and torque.

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An experimental investigation of full factorial design performed on drilling of Glass Fibre Reinforced plastic laminates using Helical flute straight shank drill and “Brad and Spur” drill by varying the process parameters such as cutting speed and feed rate to find the optimum drilling conditions. The objective is to optimize the drilling process parameters with consideration of multiple performances such as specific cutting pressure, power, peel-up delamination factor and push-out delamination factor. Analysis of variance (ANOVA) was carried out for estimating the percentage contribution of process parameters on drilling performance. Grey relational analysis was used in this multiple objective optimization to get damage free drilling of GFRP composite. Response table and graph are used for this analysis which shows that feed rate is the most significant factor than the cutting speed and also it indicates that delamintation free drilling can be obtained at low feed rate and low cutting speed. The result shows that drilling performance can be enhanced effectively thorough this approach.

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A. RAGOTHAMAN

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LIST OF SYMBOLS AND ABBREVATIONS

Abbreviations

ANOVA	-	Analysis of Variance
CFRP	-	Carbon Fiber-Reinforced Plastics
CFRP	-	Carbon Fibre Reinforced Polymers
FRC	-	Fiber Reinforced Composites
GFRP	-	Glass Fibre Reinforced Polymers
UD-GFRP	-	Uni-Directional Glass Fibre-Reinforced Plastic

CHAPTER 1

INTRODUCTION

1.1 COMPOSITES

Composite materials and its forms have increased growth in usage over the last thirty years. The number of applicability of composite materials has steadily developed, and influenced the present market uncompromisingly. The developed new composite materials are used for all range of engineering applications which include primitive products to highly refined products. The composite materials are used for engineering application since they are known for their weight-saving characteristics and economical considerations. In present years, this characteristics enhanced the application of composite materials for aerospace applications and other marketable uses.

The composite materials constitute of reinforcement which is a high load bearing material and a matrix which is a light material in which the reinforcement is embedded. The reinforcement in a composite material facilitates the increment of the mechanical properties of the system. The organic or inorganic matrix helps to fix the alignment of the reinforcement. The individual constituent of the composite material do not vary in its mechanical and thermal properties but gives combined advantage of its characteristics than incompetent of producing alone.

In olden days, metals were mixed with a certain composition which forms alloy. In present years, the requirement for engineering applications became more challenging. The property of a single material does not accomplish the desired requirement for the static and dynamic requirements. The required properties of the material can be increased by chemical combination of various materials to form a new material but maintaining the change in the individual properties. The combination of two or more materials can be helpful for producing and fulfilling the required properties needed.

The applications of composite materials are unexpected. More metal parts with added weight can be restored by a sole composite material. The increased value of specific modulus or specific stiffness of composite material gives superior strength at major loads. The aircrafts and vehicle part are contrived by light weight materials in order to amplify the fuel efficiency. The maximum stress that can be applied to a material without causing failure of composite material is higher than the metallic materials. The majority of composite materials are made up of plastics or resins since they intrinsically afford resistance to corrosion. The coating is applied over the metallic components to safeguard the metallic materials from corrosion and wear. The minimum value of co-efficient of thermal expansion of the composite material provides the dimensional stability. The reduced manufacturing time and flexibility in fabrication of composite materials in different shapes with smooth surfaces is the advantage over the metallic components. Hence more time can be saved in fabricating multipart and complex components. Composite materials are superior dampers and can diminish shocks and sound since these materials demonstrate high impact properties compared to metals. Hence the composite materials are applied in automobile parts, aircraft components and even in tennis-rackets and golf clubs.

The Composite materials are manufactured specifically with accurate dimensions and specifications by changing the material of fiber, orientation of fiber, the percentage of fiber compared with the matrix and the material of matrix. Carbon- reinforced, Glass-reinforced and Kevlar-reinforced composite materials show very low toxicity, low emission and pollution. Hence these properties give an advantage to construct composite materials for aero planes and automobile parts. The operating process parameters for manufacturing composite materials including pressure and temperature is extremely low compared to metallic components which shows a flexible nature in processing composite materials.

1.2 FIBER REINFORCED COMPOSITES

The Fiber Reinforced Composites (FRC) is a composite material which is produced by mixing the fibers with polymer resin. These Fiber-reinforced composite constitute of fibers with elevated strength, less weight and increased stiffness, entrenched in a matrix with different constituents between them. Similarly composite materials constitute of polymeric material as matrix which is reinforced by usually 3 to 5 microns in diameter unidirectional or a multidirectional fiber is known as Fiber-reinforced polymer (FRP). The fibers are bonded together within the resin material so that the fibers are safeguarded from the atmosphere and also loads are equally distributed between the fibers and the matrix. The FRPs materials have its property as directionally

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dependent (anisotropic), linearly elastic and with a inferior modulus of elasticity but elevated strength compared to many metallic components. The resistance to corrosion, high specific strength, and increased resistance to fatigue, improved dimensional stability and high specific stiffness are the enviable properties of FRPs over steel works. The main drawback of FRP is the vulnerability to humidity and reactive agents such as chemicals, less resistance at high temperatures, and the deformation from ultra-violet light radiations. Fabrication of FRP was underway since the 1940's, where it had several applications, such as chemical dispensation, aerospace, shipbuilding, automotive, etc. However, they had very limited application in civil engineering. In addition to their excellent resistance to corrosion, their high specific strength makes them a desired compound for structural applications. Currently, a variety of FRP compounds are being considered for masonry structures and for repair and retrofit of concrete, Glass Fiber-Reinforced Polymers "GFRP", carbon fiber-reinforced polymers "CFRP", and Aramid Fiber-Reinforced Polymers "AFRP" being a few among them. In many civil engineering applications, glass has been the chief fiber mainly due to its strong characteristics and due to the economical stability of cost. The most general use of the FRP is to retrofit already standing structures in the form of bonded laminates, even though it can be used as a structural stand-alone material such as reinforcement bars for new reinforced concrete structures or structural steel forms. By piling a number of thin fiber layers and matrices, merged into a desired thickness, these laminates can be produced. The orientation of the fiber and the stacking arrangement of each layer are controlled so that the desired mechanical and physical characteristics are generated. The laminates may be used in the form of dry plates or wet

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lay-up of multiple laminates or just a single lamina. Using a suitable adhesive the plates are attached to the surface, whereas the wet lay-up process involves wetting (impregnating) the fabric during installation in-situ with appropriate polymer, the polymer allocation as a binding matrix and also as an adhesive to bond the FRP to the surface of the structure. Strengthening works consists of some important characteristics such as site constraints, predominance of labour and shutdown costs, time and long term durability. Exceptional mechanical properties, improved corrosion resistance, lower installation costs and onsite flexibility are some of the advantages of FRP composites versus conventional materials for strengthening of non-structural and structural elements. This establishes a huge advantage for the FRPs versus traditional strengthening practices. This is because the use of traditional methods may disrupt the aesthetics of building frontages and they may interfere with the usable space adjacent to the strengthened modules. More significantly, from the structural point of view, due to the small addition of stiffness and weight, the dynamic properties of the structure remain unaffected. Any variation to the aforesaid characteristics would naturally result in increased seismic forces. Furthermore, this form of strengthening is attractive to the owner due to the simplicity with which FRP composites can be installed on the structural elements of RC frames, considering both reduced installation cost and down-time.

Conventional substances such as Aluminium and Steel have an isotropic nature whereas fiber reinforced composites display anisotropic characteristics. Most of the fiber reinforced composites being used in the industry are based on polymer matrices. The word polymer denotes a long chain molecule, composed of a large number of repeating entities of matching structure. The function of the matrix is to transfer the load to the fibers, to provide protection against hostile environmental and to shield the surface of fibers from mechanical abrasion.

1.3 FIBER REINFORCEMENTS

Increasing the load bearing capacity of the material is the predominant purpose of reinforcements in the composite materials. It also accounts for the stiffness, tensile strength, and tensile modulus of composites. Furthermore, it regulates the overall performance and cost of composites. Several factors are responsible for the mechanical properties of the composite material such as the type of fiber chosen as the mechanical properties of most reinforcing fibers are superior to the mechanical properties of un-reinforced resin systems. Four ways in which the fiber can contribute to a composite material are interaction between the fiber and the resin, mechanical properties of the fiber itself, amount of fiber in the composite (also known as fiber volume fraction) and the orientation of the fibers.

1.3.1 Glass Fiber

The most universal reinforcement for polymer matrix is the glass fiber in its various forms. Being reinforcement for epoxy, polyester and phenolic resins are some of the major applications of glass fiber. They are commercially available in various compositions and are cheap. The most common variety is silica based and comprises a host of other oxides of calcium, boron, sodium, aluminium and iron. Glass fibers have an isotropic character i.e., the young's modulus and the coefficient of thermal expansion are identical along the axis of the fiber and are perpendicular to it. Glass fiber reinforced polymeric compounds are commonly used in transport, constructions, marine, pressure vessel, chemical industry, and compressor blades.

1.3.2 Carbon Fiber

Carbon fiber reinforced materials are primarily used for high strength structural applications since they yield higher strength modulus. They also have low density and high stiffness. Carbon composites are now extensively used in the automobile and aerospace industries where high stiffness and low weight are necessary. It is one of the strongest and most abrasion resistant materials available. It is usually difficult to machine such composites as they are comparatively more abrasive in nature. These fibers exhibit zero creep and other carbon fiber compounds exhibit zero coefficient of thermal expansion. Carbon fibers having high strength modulus can be manufactured by the carbonization of organic precursor fibers followed by graphitization at high temperatures. The regularly used precursor fibers are polyacrylonitrile (PAN), pitch and viscose rayon. These exhibit several advantages over other fibers and are extensively used in numerous applications.

1.3.3 Kevlar (Aramid) Fibers

Aromatic polyamide fibers are a class of synthetic organic fibers known by a generic name of Aramid fiber. A trade name given to aramid fiber by Dupont, USA is Kevlar. This fiber is used as reinforcement for compounds used in marine structures, aerospace, sports goods, etc. The Kevlar fiber composites are extremely tenacious and possess excellent resistance to ballistic impact and high pressure.

The tensile stress-strain curves for all reinforcement fibers in use are linear up to the point of failure, as shown in Figure 1.1 (Mallick 1993). They display very low strains-to-failure and a brittle failure mode. It makes them susceptible to damage in handling other surfaces even though absence of yielding does not diminish load-carrying capacity of the fibers.

1.4 POLYMER MATRIX MATERIALS

The fibers are bound together by matrix materials and it transfers the load to and from other fibers and shields them from handling and environment. Polymers have been very efficacious in this regard. The polymers are of two principal types, thermosets and thermoplastics. Due to their dielectric properties, low density and comparatively easy process ability a well-bonded three-dimensional molecular structure upon curing, is developed by the thermoset matrix. The two most common thermoset resins are epoxy and polyester. The polyester resin is inexpensive, versatile and is broadly used with glass fiber reinforcement, especially for low performance purposes. Epoxy resins are more expensive than polyester, but their high adhesive properties make them valuable in numerous high performance applications. Epoxy resins also exhibit superior resistance to moisture, minimal shrinkage during curing (around 3%) and properties conducive to good fiber matrix adhesion. Nevertheless, due to stringent environmental considerations, replacements are being found for thermoplastics.

1.5 GLASS FIBER-REINFORCED PLASTICS (GFRP)

The most universal fiber used in Polymer Matrix Composites (PMC) is glass. Low cost, high strength, good insulating properties and high chemical resistance are some of the advantages. On the other hand, the draw backs include poor adhesion in polymers, low elasticity, and sensitivity to abrasion, high specific gravity and low fatigue strength. The major varieties are S-glass and E-glass also known as “fiber glass”. The “E” in E-glass denotes “electrical” as it was considered for electrical purposes. Nonetheless, it is used for many other applications such as structural applications and decorations. The “S” in S-glass denotes higher amount of silica content. Its strength is retained at high temperatures better than E-glass and has the best fatigue strength. It finds applications mainly in the aerospace industry.

1.6 CARBON FIBER-REINFORCED PLASTICS (CFRP)

Of all the composite FRP materials, the exclusive properties and applications of CFRP composites occupy a noticeable position. It has valuable dimensional and functional properties that broaden its scope to various other domains. At present, CFRP composite material is also used. The CFRP composite material is extensively used in a variety of engineering applications. The importance of CFRP composites as compared with other metallic composite alternatives such as aluminium alloys, steel, pinewood and other FRPs in terms of tensile strength, density and specific strength. It is clear from this comparison that CFRP composite is an evolving material that can be optimally matched to any application. The CFRP composite characteristics vary greatly depending on the use of various matrix materials and type of fibers. This allows

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optimal modification to the specific requirements of a constituent. CFRP composite materials are distinctive in regard of critical and demanding high-tech applications that simultaneously require high stiffness and strength along with low weight. The mechanical characteristics of the CFRP composite material are utilized to the fullest in order to overcome the physical limitations of the traditional materials. CFRP composites display excellent static, dynamic, thermal and chemical properties like low density, low weight, high strength modulus, high damping, low coefficient of thermal expansion, high fatigue strength, high thermal shock resistance, high environmental durability, high thermal stability, smooth running through vibration damping, good acoustic emission, bio-compatibility, good corrosion resistance and good wear resistance. The properties of epoxy used in manufacturing CFRP composite includes low viscosity, good chemical resistance, good thermal stability, good dimensional stability, high strength and good impact resistance. Tensile strength is anisotropic in nature, i.e. dissimilar along fiber axis and perpendicular to it. By changing the amount of carbon fiber integrated into the epoxy, the strength and rigidity of CFRP composites can be controlled.

1.7 PROCESSING OF POLYMERIC MATRIX COMPOSITES

Even though there are several advantages in using composite substances, there are also some downsides that need to be taken into consideration. A few of the drawbacks are stated here. Composite materials are more costly to acquire than aluminium and steel. Former techniques of manufacturing composites were sluggish and tiresome resulting in minimal production volumes of the composite materials. One of the disadvantages is the lack of database for composites result in complications in processing and applications. Most matrix materials are polymer based and thus they possess a lower working temperature than most metals. Environment and solvent resistances of composites are polymer/matrix dependent.

Composite materials absorb moisture which disturbs its functional reaction. The Recycling of composites pose a major problem. Despite its several drawbacks, composite materials offer more advantages than metals. The polymer matrix composite material in general comprises of two or more chemically unique macro components, separated by a distinct interface. Obviously one of the fundamental phases is the resin matrix and the another one is the reinforcement. Polymer matrix composite material is manufactured by several methods. The various types of such fabrication processes are open molding, hand layup, spray up, autoclave mostly automated pressure/temperature molding aerospace applications, compression molding, filament winding, pultrusion of extruded composite part, reinforced reaction injection molding (RRIM) – reaction compression, thermoplastic and thermoset molding, resin transfer molding (RTM), structural reaction injection molding (SRIM).

1.7.1 Hand Layup

Hand Layup is a simple technique of treating Polymeric matrix composite material. In this process, the components are placed and fashioned in the mould manually and the squeezing action dispels any trapped air and compacts that part. In the hand layup process, chopped

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strand mat or woven fiber mat is used for development work like prototype fabrication, production of large components and relatively small quantities. First the mould having the desired shape is layered with the mold release which inhibits bonding of the resin matrix material to the mold. If a smooth surface of the part is desired (i.e., boat hulls or aircraft exterior parts), a gel coat is then applied to the mould, followed by a thermosetting polymer resin and the fibers. Then a roller may be used for merging, followed by curing of the polymer resin at the appropriate temperature.

1.7.2 Compression Molding

Compression molding is one of the novel processing techniques for fabricating plastic parts developed at the very commencement of the plastics industry. As a matter of fact, it was broadly used in the baking industry for cake or cookie molding before plastic components. Compression molding is commonly used in fabricating thermoset plastics even though it is applicable to thermoplastics. The raw materials required are usually in the form of putty-like masses, granules, or preforms. Firstly, they are placed in an open, heated mold cavity. After this, the mold is closed and pressure is applied in order to force the material to fill up the cavity. A hydraulically operated ram is often used to generate sufficient force during the molding process. The pressure and heat setting is sustained until the plastic material is cured. Two different types of compounds are present which are most commonly used in compression molding: Bulk Molding Compound (BMC) and Sheet Molding Compound (SMC). SMC is a more expensive process but can be pre-cut to conform to the surface area of the mold. Less flow orientation during the compression stage is resulted from more evenly distributed material over the mold surface and therefore results in more consistent products. Compression molding is frequently used for fabricating electrical components, gears, flatware, buttons, knobs, buckles, electronic device cases, handles, appliance housing, and large container.

1.8 CHARACTERIZATION OF FRP LAMINATES

Fibers of high strength and modulus implanted in a plastics matrix with a unique interface between them, constitute Fiber reinforced plastics (FRP) materials. In general, fibers are the load carrying entities, while the neighboring matrix keeps them in the desired location and orientation, functions as a medium to transfer load between them and guards them from environmental damages. Thermoplastics and thermosetting polymers are polymeric matrices. Laminate is the most universal form in which FRP composites are used in structural applications. It is acquired by piling a number of thin layers of matrices and fibers and combining them into the preferred thickness. Quality testing of the fabricated laminates is performed. The reason for testing is to guarantee quality and performance of composite products. The three main goals of testing are collection of design data and quality control of raw materials, specific understanding of the material and product. The first two types of analysis are more intricate, requiring sophisticated instruments. The third type is routine testing. It is easy to execute and interpret, and is also inexpensive to acquire. Several standards have been evolved for the analysis of raw materials as well as composite products such as IS, BS, ASTM, ASME, SAE, DIN, etc. Optimal design in composite products, a thorough understanding of material properties is essential for quality assessment. Therefore, characterization of compounds experimentally is crucial.

1.9 MACHINING OF COMPOSITES

The machining process involves the elimination of any superfluous or undesirable materials. Turning, drilling and milling are some of the most common machining processes. Composites require different machining techniques as compared to metals i.e., they pose problems/ defects imposed on the work pieces such as faster tool wear and poor surface finish have led to additional study of composite-machining. Dissimilar to metals, composites require distinct tools and working conditions. Although the tools used for machining of metals can be used, care must be taken to sustain optimum levels of thrust force, feed rate, and other factors. The aggressive environment such as force/temperature transients, severe abrasion and the like creates doubts in tool performance. Usually the selection of tools required for the machining of composites is material specific.

One of the major benefits of composites is that an entire component can be fabricated. This reduces the machining of composites. However, including "part integration", sometimes composites have to be combined to form a larger part, indicating that even for composites a certain amount of machining needs to be done. "A typical aircraft wing might have as many as 5,000 holes (Mazumdar 2002)." Therefore, cost is a factor in the machining of composites. A composite might have to go through all or some of the machining procedures like cutting, milling, drilling, etc. In his book (Mazumdar 2002), he points the various functions of machining of composites. These functions include, to form features that cannot be formed during manufacturing/fabrication. Such features can be holes, slots, etc., to maintain tolerance levels in manufactured parts at desired/given values, to eliminate any remaining constituents from the surface of the composite after manufacture so that the finished surface can then be used for adhesion, painting, or any other operation as essential, to obtain a smooth surface and to make smaller pieces of larger material for testing purposes.

Even though the machining of composites seems as simple as machining of metals, it has its own set of difficulties. Some of the trials experienced during machining include issues such as most composites are reinforced with fibers. Machining of composites makes the fibers discontinuous, which affects performance of the composite part. Secondly dimensional accuracy during machining of composites is very hard to predict since the reinforcement and the matrix material have different coefficients of thermal expansion. Furthermore, during machining, the matrix material and the reinforced material are removed, thereby exposing the reinforced material to nature and also to other chemicals, thus making them susceptible to chemical reactions and moisture. For thermoset composites, the cutting temperature cannot be higher than its cure temperature, since a higher temperature can cause disintegration of the material or local stress zones. Also thermoplastic resin-based composites can have very low melting points. While machining, if the temperature at the cutting point is higher than the melting point, then the tool can become clogged as the resin melts. Adding on, most composites are very poor thermal conductors. During machining, heat can build up at the cutting edge of the tool. In order to reduce the heat and protect the composite and the tool, a suitable coolant is needed during machining. Additionally, usage of coolants is necessary while machining, but the selection of the coolant is also very important since the coolant might react chemically with the composite. Hence coolant must be chosen with care. The absorption of coolants by composites can be determined to its performance. It is difficult to get smooth edges after cutting because the fibers are tough and can easily absorb the cutting energy. Hence, when machined, the edges might not be smooth and might have burr surfaces or other surface defects including fiber-projection. Besides, composites are normally abrasive and can reduce the tool life. In addition, in a lay-up sequence, composite and the orientation of reinforcements are very important factors during machining. Knowing these might help reduce delamination at edges during machining. This is mostly observed in, but not limited to, continuous fiber composites.

In the course of the machining of composites, the response of the tool or the material cannot be anticipated, since each composite material has different features. Some general behaviors observed during machining of composites are that some reinforcing materials are brittle, while others are ductile. During machining of aramid fibers, a common mode of failure is the axial splitting of the fiber in the direction transverse to the fiber (orientation) due to weak molecular bonds. Also, weaker molecular bonds mean that they have lower compressive strength, which in turn means that special tools are needed for machining aramid fibers. In addition, ductile materials absorb energy while machining (deformation induced chip formation), which results in poor surface quality. Besides, fibers with lower compressive strength tend to recede into the matrix during machining, which causes burr and fiber kinking during machining.

Conventional machining of FRP is problematic because of the presence of comparatively high volume fraction of hard fibers in the matrix, their orientation and varied fiber and matrix features. Carbon fiber and glass reinforced composites are tough to machine because of speedy tool wear. Although, diamond tools and cemented carbides are most frequently used cutting tool materials. High Speed Steel (HSS) tools are also used in some cases. Apart from resistance to abrasion, the tool must be able to endure high temperature and should have high thermal conductivity. The change in coefficients of thermal expansion between matrix (highly positive) and fiber (slightly negative for carbon and aramid) is favorable for the generation of residual stresses. This makes it hard to attain high dimensional accuracy as well.

1.10 DRILLING OF GFRP COMPOSITES

Composite materials have been used for many applications such as constructional resources, fabrication and joining of different structures. Drilling is one type of machining process to execute above applications. Drilling of polymeric composite materials is an extremely deterministic process due to identical and similar properties in all directions of the composite materials. The conventional drilling methods fail to produce a high quality holes in composite materials. In manufacturing areas drilling a hole is a basic machining operation. It is very difficult to accomplish this machining operation than all other usual machining operations. The non consistent chip deformation, unpredictable cutting speed all along the cutting area, extensive resistance between the material and the tool surfaces and between the drill flank and the work piece are most important key factors which direct to difficulty in twist drilling. Adding to the above problem, the extreme negative value of rake angle, the reduced speed of cutting tool and irregular material removal process cause a low material removal at the chisel edge section of the common function drill bits. Twist drill is the most commonly used drill tools in the drilling of metals and composite materials. The drilling parameters such as tool geometry and tool material are the main sources of delamination. Increased feed rate is the main basis of crack formation on the exit edge of the drilled hole. (Koenig et al., 1985). Hence high spindle speed and a slow feed rate is optimum selection for (Mohd Ariffin et al., 2009).

Hocheng and Tsao (2003) studied effect of chisel length and associated pilot hole on delamination when drilling the composite materials. Delamination was limited by using various twist drills and development of mathematical modeling. Delamination was found at both starting and finishing position in the process of drilling the composite materials. Delamination identified at the starting position of drillind is usually said to be peel up of the material. The delamination identified at the finishing position of drilling when the material is pushed out is said to be fluffing. Placing a back plate at the time of drilling is one of the technique used to diminish delamination at the finishing position. Lachaud et al (2001) determined that the delamination can be reduced by fixing the plates without back plates and by identifying mathematically the thrust force.

1.10.1 Delamination

During machining of materials, many defects were identified out of which delamination is the most important one. Matrix cracking, fiber pullout and fiber breakage are some of the other defects, however delamination can be the cause of decline in the durability of the composite material and can also effect in a drop in the structural integrity of the material and the bearing strength, resulting in questions of performance. The MIL 17 (1999) Handbook for Composite Materials defines delamination as "the separation of the layers of material in a laminate". This phenomenon can occur at any point in the life of a laminate and can be because of several causes and has numerous effects. The tensile strength performance can be affected due to this, liable to the region of delamination. One of the major forms of failure in drilled materials is delamination and is due to the composite's incapability to withstand bending/fiber buckling. This failure can effect in a decline in the compressive capability or rather, the load carrying capacity of the structure. Possible rapid tool and high thrust force wear are some of the major reasons for the occurrence of delamination. Some prior techniques used to avoid delamination have been executed such as to reduce the thrust force by reducing the feed rate, using a back-up plate.

Modern methods have involved vibratory drilling (Arul et al 2006) where a distinct increase in the thrust is observed with the feed rate and it is determined that for the vibratory drilling of woven glass fabric/epoxy laminate of fibre volume fraction 0.4 with HSS tools, the best cutting parameters are 18.85 m/min cutting speed, 0.02 mm/rev.

feed rate, 200 Hz frequency and 15 mm amplitude of vibration for smallest thrust.

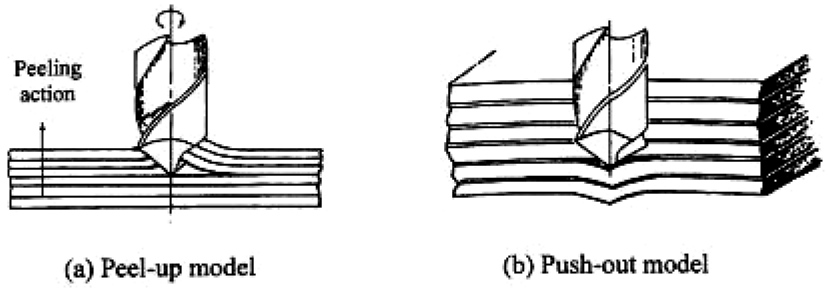

Figure 1.1 Delamination at the entry and exit

Representations of peeling action and push out delamination on laminated specimen are shown in Figures 1.1. Figure 1.2 shows the schematic illustration of delamination. At the commencement of delamination, the drill movement of distance dX is related to the work done by the thrust force FA, which is used to deflect the plate as well as to propagate the interlaminar crack.

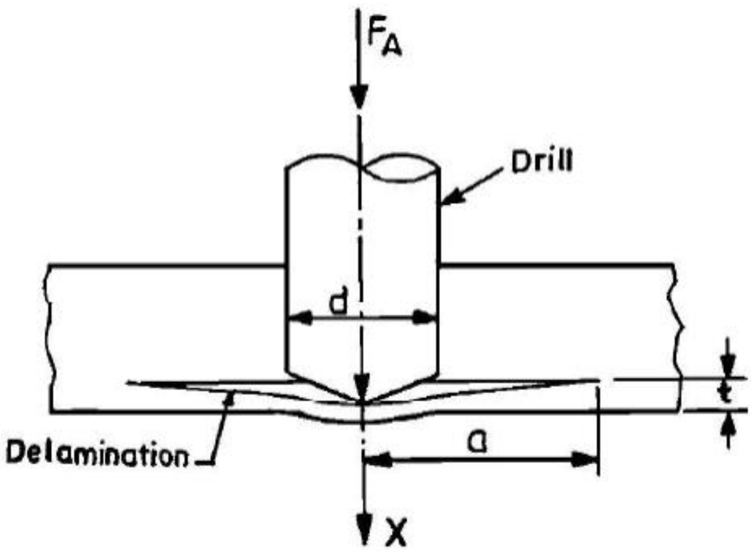

Figure 1.2 Schematic representation of delamination

In the course of drilling, the material in front of the drill point suffers bending and subsequently can experience fiber breakage/pullout and crazing of matrix material. This is mirrored in delamination, debonding and even hole shrinkage. Since composite laminates possess high modulus of elasticity, failure caused due to delamination can be demonstrated by linear elastic fracture mechanics (LEFM) and classical plate bending theory. This model allows the evaluation of the thrust force applied by the drill with regard of the rate of release of critical energy.

Prior research mainly considered delamination found at the free edges of laminates. In order to simplify delamination of composites, it was found that studying of delamination of free edges was too specific a region. The methods of machining have enhanced as the use of composites increased and it was found that more investigation was needed on delamination. As a result, the use of energy method to model the commencement of crack growth was introduced. This method depends on concepts from classical theory in fracture mechanics. Based on the work of Anderson (1994), "the energy approach states that crack extension (i.e., fracture) occurs when the energy available for crack growth is sufficient to overcome the resistance of the material. The material resistance may include the surface energy, plastic work, or other type of energy dissipation associated with a propagating crack". Impact damage in composites includes delamination, matrix cracking, fiber/matrix debonding and fiber failure. Stretching and bending of the laminate are a cause fiber failure. Delamination is because of the mismatch in bending stiffness and transverse shear. The area in between the laminae with the largest difference in ply orientation, is where the largest delamination would be found (Liu 1998). It is mainly due to shear that matrix cracking often occurs. The tensile strength as well the compressive strength of the composite are affected by the combinations of damage types. This growth of the damage is imminent under cyclic loading; hence, it might be essential to specify allowable tolerance (load) of damage in composite. Wang et al (1985) further studied delamination by taking into account the rate of release of energy, which is used to determine the interlaminar fracture toughness of laminates. Anderson (1994) also defined the energy release rate, G, as "the rate of change in potential energy with crack area for a linear elastic material." Bower of Brown University provided the following opinions for use of the energy release rate as a fracture criterion. Crack propagation involves dissipation (or conversion) of energy, regardless of the actual mechanisms involved. Fractional amounts of energy are required to create two new free surfaces (twice the surface energy per unit area of crack advance, to be precise). Additionally, there may be a complex process zone at the crack tip, where the material is plastically deformed, voids may be nucleated and there may be chemical reactions. All the above processes involve transfer of energy. We hypothesize, however, that the process zone remains stable during crack growth. In this case, energy will be transferred at a steady pace during crack propagation. The crack grows only if the rate of change of potential energy is enough to supply this energy. i.e., when the deformation/feed rate in drilling is higher, the energy release will be higher, in relation with crack propagation/ delamination.

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1.10.2 Delamination Factor

GFRP composites, during hole making process, may reveal small amount of geometrical imprecision due to breakage of fibers and fiber pullout resulting in deboning and also matrix crazing. This could contribute to the relaxation of the material and subsequent shrinkage. From Figure 1.3, the delamination factor value (Fd) can be obtained by the following equation (1.1).

$$F_d = D_{max}/D \quad (1.1)$$

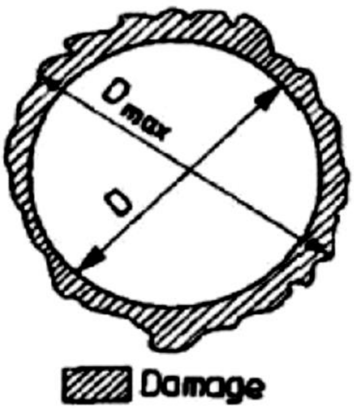

Figure 1.3 Hole Damage portion

\where Dmax is the average maximum diameter of the damage around the hole periphery and D is the diameter of the tool (punch).

1.10.3 Spalling

A detailed study at two kinds of defects during drilling of FRPs – spalling and fuzzing was presented by Zhang et al (2001). Spalling denotes the delamination damage and fuzzing denotes the uncut fibers around the hole. An empirical relationship between the size of the delamination zone and various process parameters was established, with fuzzing damage described quantitatively. Fuzzing and spalling co-exist and both their intensities have comparable variation tendency, i.e. the bigger the spalling, the more severe the fuzzing and vice versa. However, when spalling diminishes to a certain extent, fuzzing fades.

The drilling-induced damage in GFRP was quantified by Bhatnagar et al (2004) and the defect size wad measured by dye-injection and interrelated the damage to process parameters and drill geometry. Their experiments showed that the drilling included damage was lesser for an 8-faceted drill point and a “Jodrill” compared to a standard 4-faceted drill point.

1.10.4 Other Damages

Matrix burning, debonding, fiber pullout was identified as other major sources of damage by Mathew et al (1999). DiPaolo et al (1996) listed three distinguishable mechanisms for damage, viz. crack opening, plate bulge and fiber tearing/twisting. A series of experiments were carried out by Piquet et al (2000), using a conventional twist drill and a specific tool made of micrograin tungsten carbide with a small rake angle. This reduces the usually occurring damages such as plate exit defects, entrance damage, buckling, fiber bending, brittle shear failure, and roundness error. It was detected that the roundness error is because of the material’s anisotropy. A different relative reinforcement direction is present for each angular position of the drill’s cutting edge in regard to fiber orientation. The variation in circularity is indicated in Figure 1.4 along with the practical, real and theoretical diameters. The use of a traditional twist drill is limited when drilling thin composites without a backing plate.

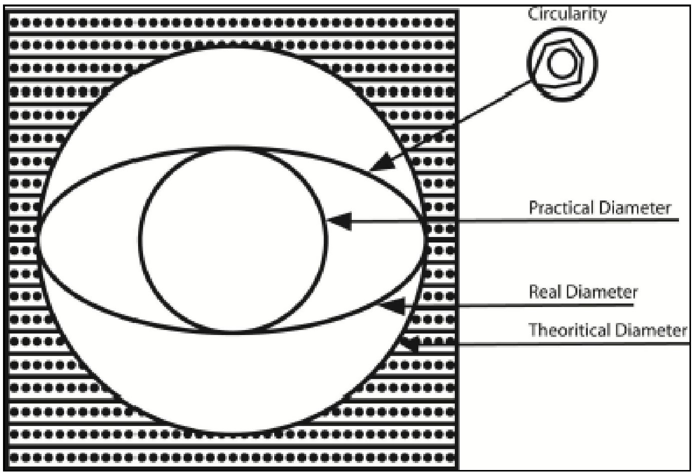

Figure 1.4 Circularity defects of holes

The relatively large range of the non-cutting chisel edge as hypothesized by Roy Meade (1987), was the major drawback of orthodox twist drill in thin plates. Failure of adhesion in the matrix leads to delamination and bending of the remaining plies. Hence appropriate tool geometry is used to enhance composite drilling. Certain alterations have been reported in the drill geometry that can help minimize damage. The effect of geometry of tool on the cutting forces has been studied by Chen (1997). Miller (1987) analyzed drill bit configurations and concluded that for graphite-epoxy laminates, 8-faceted drill gave better results. Higher number of holes to failure was encountered while drilling with carbide drills as reported by Ramulu et al (2001)

Tool wear is one of the major challenges faced during drilling of composite materials because of its highly abrasive nature. A study on drilling of CFRP at high speed was conducted by Lin and Chen (1996),

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and concluded that an increase of the cutting velocity rises the drill wear greatly and thus thrust force rises. Chen (1997) concluded that drilling free of delamination is possible by a suitable selection of drilling parameters and tool geometry. The application of special drill bits, pilot hole, step drilling, backup plate and various non-conventional methods were reviewed by Hocheng and Tsao (2006), so as to reduce the damages. The cutting edge rounding (CER) was studied by Ali Faraz et al (2009), a latent wear characteristic as a measure of sharpness/ bluntness, of uncoated cemented carbide tools during drilling CFRP composite laminates. Four different types of tools were tested to evaluate the applicability and significance of this new wear feature.

The effect of laminate configuration on cutting performance when drilling holes in CFRP composite materials was studied by Shyha et al (2010). Most of the drills tested at the higher feed rate experienced failure in a catastrophic manner. This was attributed to the decrease in strength of the drill due to the smaller diameter of the pilot segment of the tool. The drilled hole diameter was found to be undersized at the end of tool life. Iliescu et al (2010) described the development of a phenomenological model between the thrust force, the drilling parameters and the tool life. A model is designed that predicts the parallel evolution of axial load and tool wear with the different drilling sequences that a tool will face during its life.

1.11 OVERVIEW OF THE RESEARCH

GFRP composites show increased strength, less weight, elevated modulus and outstanding fatigue resistance. These excellent properties of GFRP show usage to many engineering applications. The

GFRP material is extensively used composites in military, aerospace, satellite, nautical, computer applications. Since the applications of the GFRP are numerous, the composite materials are fabricated in different shapes and models. Generally the parts made up of composite materials are much closed to the required one. Hence the working on the composite materials to bring it to the required shape and finish is necessary. The working on composite material includes conventional machining such as drilling, turning, milling, knurling and non conventional machining such as abrasive jet machining, electro chemical machining, water jet machining, electrical discharge machining and ultrasonic machining. Complex constructional structures are formed by joining more than one part. Drilling is basic requisite to fasten together two or more parts by means of bolt and nut joints, screws and rivets.

The GFRP is fabricated by two types of resins. The first type of GFRP is fabricated by using epoxy resin and the second type of GFRP is fabricated by use of polyester resin. The physical and the mechanical properties were determined for the two types of GFRP composite materials. The delamination size and delamination factor were determined for these composite materials. Two types of drill bits, such as helical flute straight shank drill and brad and spur drill are used in the carrying out tests. The five different cutting speeds of 15 m/min, 20 m/min, 25 m/min, 30 m/min, 35 m/min and Feed rates of 0.05 mm/rev, 0.10 mm/rev, 0.15 mm/rev, 0.20 mm/rev, 0.25 mm/rev was chosen. Taguchi’s L25 orthogonal array of experiments is used for the investigation. The trial is performed out on a computerized numerical controlled vertical machining center. The thrust force and

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corresponding torque is determined by piezoelectric dynamometer. The images of maximum diameter of damaged area on drilled holes are taken using a Nikon D 200 camera and is found out from which delamination factor is calculated on both sides of the drilled hole. The effect of the different drilling parameters, cutting speed, feed rate on thrust force, torque, specific cutting pressure, power, delamination is calculated.

The investigational data is studied and the regression models were formulated. The most significant factors and the corresponding relations that influence the output of the investigation are given by Analysis of variance (ANOVA). The grey fuzzy logic method is used to optimize the drilling parameters. This method is used to achieve the most favorable value of the drilling parameters that can decrease the fault of the drilled holes.

1.12 THESIS ORGANIZATION

Chapter 1 presents the introduction to various composite materials that covers classification, characteristics, manufacturing methods and its applications in the field of engineering. The significance of GFRP composite materials among the various composites is explained. Drilling of these composite materials is an important operation in any application. Hence the significance of drilling, and the corresponding problems encountered in these drilling operations are discussed. The basic study of this research is about drilling of GFRP composite materials and hence the various challenges faced in drilling of GFRP composites and their controlling factors are identified. This identification of various controlling factors has turned as a motivation for the present research work. The overview of the research work is explained.

Chapter 2 presents the literature review on GFRP drilling and analysis of drilling parameters. The effect of tool parameters, process parameters and material of work piece (GFRP – Epoxy Resin, GFRP – Polyester Resin plates) on delamination is studied. The effect of process parameters and its interaction effects on the delamination are studied. The theory and the experimental work using ANOVA are explored. The works carried out in drilling using grey relational analysis is presented. Thus the earlier works carried out in this field of study are explored in this chapter. From a detailed study of the literature review, the problem identified for the present research work and the solution proposed is described. The schematic of the research work is also presented.

Chapter 3 describes the experimental work carried out in detail. Two different drilling tools for drilling two different materials used in this research work are described and their details are presented. The fabrication of GFRP composite plates used in the present research work is presented. The experimental setup used in this work is described. The photographs of the drilled plates are shown.

Chapter 4 illustrates the results and discussion of the drilling parameters and the corresponding responses. The effect of spindle speed, feed rate, power, specific pressure on various responses is discussed in detail. A comparison is carried out among the results of the two drill tools and work piece material in order to select the best tool material and the work piece. The experimental plan is described which

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is carried out using Taguchi's L27 approach. The results of the confirmation experiments are presented to validate the obtained models. There are various optimization tools and the algorithms available. However, in the present work, grey fuzzy approach is used. The response table and the ANOVA table is presented for the grey fuzzy reasoning grade obtained with six different inputs viz., thrust force, torque, specific cutting pressure, power, delamination at the entry, delamination at the exit of the holes. The optimum value of the input drilling parameter set is obtained that can be used to minimize the damage of the drilled holes.

Chapter 5 illustrates the conclusion of the drillingparameters and the corresponding responses for drilling of GFRP – Epoxy and GFRP- Polyester Laminates.

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CHAPTER 2

LITERATURE REVIEW

The material technology has identified the composite materials as the emerging material for enormous applications in various engineering domain, due to its mechanical, chemical, structural and functional properties. Though the approximate shape of the composite structure is fabricated during the first phase of fabrication, the dimensional accuracy and the final shape of the composite structure is obtained only through various machining operations. In order to join two different composite structures, drilling is one of the essential machining operations required. The objective of this research work is to minimize the damage due to drilling in GFRP composite materials using optimization of drilling parameters. The study and analysis of damage is carried out using statistical computational method, RSM. The research work carried out in FRP composite materials and especially in GFRP composite is enormous. A review of the literature in the GFRP composite machining, CFRP composite drilling, and analysis of drilling parameters, and optimization techniques is presented in this chapter briefly.

2.1 GFRP DRILLING

The responses of drilling experiments, such as thrust force, torque, delamination, surface roughness, tool wear, tool life depends on the tool parameters and process parameters. Tool parameters include tool material and tool geometry whereas process parameters include spindle speed, feed rate and temperature. A relationship between tool / process parameters (drilling parameters) and the responses are obtained by various researchers either analytically or empirically. These studies are useful in predicting the responses even before the conduct of experimentation so that the damages during drilling can be minimized by carefully select the tool / process parameters.

The presence of delamination reduces the stiffness and strength of a laminate and hence its load carrying capacity. Delamination can often be the limiting factor in the use of composite materials for structural applications, particularly when subjected to compressive, shear and fatigue type of loads and when exposed to moisture and other aggressive environments over a long period of time. Jain and Yang (1994) identified some recommendations for preventing delamination while drilling such as to use variable feed rate for diameters up to 6 mm, when only conventional, standard twist drills are available and to modify tool geometry especially chisel edge in combination with newer, harder materials. HSS drills brazed with PCD bits, and PCD inserts co-sintered with carbide are popular tool materials for machining graphite-epoxy and other abrasive composites. The study has attempted to address and solve the delamination problem associated with drilling laminated composites

U.A. Khashaba (2004) studied the Delamination in drilling GFR-thermoset composites. Delamination is a major problem associated with drilling fiber-reinforced composite materials, in addition to that reducing the structural integrity of the material, also results in poor assembly tolerance and has the potential for long-term performance deterioration. Delamination-free in drilling different fiber reinforced thermoset composites is the main objective of the present paper. Therefore the influence of drilling and material variables on thrust force, torque and delamination of GFRP composites was investigated experimentally. Drilling variables are cutting speed and feed. Material variable include matrix type, filler and fiber shape. Drilling process was carried out of cross-winding/polyester, continuous-winding with filler/polyester, chopped/polyester, woven/polyester and woven/epoxy composites. A simple inexpensive accurate technique was developed to measure delamination size.

The results show that the presence of sand filler in continuous-winding composites not only raised the values of cutting forces and also push-out delamination but also increased their values with increasing cutting speed. In contrast, increasing the cutting speed in drilling cross-winding, woven and chopped composites reduces the push-out delamination as a result of decreasing the thrust force. The thrust forces in drilling continuous-winding composite are more than three orders of magnitude higher than those in the cross-winding composites. Chopped composites have lower push-out delamination than those made from woven fibers. For the same fiber shape, the peel-up and push-out delaminations of woven/epoxy composite are lower than that of woven/polyester composites. Delamination, chipping and spalling damage mechanisms were observed in drilling chopped and continuous-winding composites. In drilling woven composites the delamination was observed at different edge position angles due to the presence of the braids that made by the interlacing of two orthogonal directions of fibers tows (warp and fill). Delamination-free in drilling cross-winding composites was achieved using variable feed technique.

2.1.1 Effect of Tool Parameters on Delamination

Luis Miguel P. Durao et al. (2010) evaluated the Drilling tool geometry for reinforced composite laminates. A comparative study of different drill point geometries and feed rate for composite laminates drilling is presented. For this goal, thrust force monitoring during drilling, hole wall roughness measurement and delamination extension assessment after drilling is accomplished. Delamination is evaluated using enhanced radiography combined with a dedicated computational platform that integrates algorithms of image processing and analysis. An experimental procedure was planned and consequences were evaluated. Results show that a cautious combination of the factors involved, like drill tip geometry or feed rate, can promote the reduction of delamination damage.

C.C. Tsao et al. (2004) analysed the delamination associated with various drill bits in drilling of composite material by Taguchi analysis. This paper presents a prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill. The approach is based on Taguchi's method and the analysis of variance (ANOVA). An ultrasonic C-Scan to examine the delamination of composite laminate is used in this paper. The experiments were conducted to study

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the delamination factor under various cutting conditions. The experimental results indicate that the feed rate and the drill diameter are recognized to make the most significant contribution to the overall performance. The objective was to establish a correlation between feed rate, spindle speed and drill diameter with the induced delamination in a composite laminate. The correlation was obtained by multi-variable linear regression and compared with the experimental results.

C.C. Tsao et al. (2005) studied the effect of eccentricity of twist drill and candle stick drill on delamination in drilling composite materials. Drilling is the most frequently employed operation of secondary machining for fiber-reinforced materials owing to the need for structure joining. Delamination is one of the serious concerns during drilling. Practical experience shows that an eccentric twist drill or an eccentric candle stick drill can degrade the quality of the fiber reinforced material. Comprehensive delamination models for the delamination induced by an eccentric twist drill and an eccentric candle stick drill in the drilling of composite materials have been constructed in the present study. For an eccentric twist drill and an eccentric candle stick drill, the critical thrust force that will produce delamination decreases with increasing point eccentricity. The results agree with industrial experience. The need for control of drill eccentricity during drill regrinding has been proved analytically by the proposed models. A comprehensive analysis for delamination caused by eccentric twist drill and eccentric candle stick drill in drilling of composite materials has been developed in the present study. The analytical results were obtained based on classical elasticity, linear elastic fracture mechanics and energy conservation. For eccentric twist drill and eccentric candle stick drill, the critical thrust force is reduced with increasing eccentricity. The results agree with industrial experience, that the worse drilling quality in use of the same nominal drill can be traced to the various degree of drill eccentricity produced in tool reconditioning process. A lower critical thrust force results if an eccentric twist drill or an eccentric candle stick drill is used so that a lower feed rate has to be used to prevent delamination damage. A guide for drill design and tool regrinding can be developed based on the proposed models, especially when the eccentric ratio affects the critical thrust force. This approach can be extended to examine the similar eccentricity effects of various drills

A.M. Abrao et al. (2008) evaluated the effect of cutting tool geometry on thrust force and delamination during drilling glass fiber reinforced plastic composites. This work is focused on the investigation of the effect of the cutting tool geometry and material on the thrust force and delamination produced when drilling a glass fibre reinforced epoxy composite. Four drills with distinct geometries and composition were tested. Additionally, the influence of the cutting parameters was studied. The drill responsible for the highest thrust force was also responsible for the second smallest delaminated area. Finally, within the cutting range tested the damaged area increased considerably with feed rate and moderately with cutting speed.

H. Hocheng et al. (2008) estimated the effects of special drill bits on drilling-induced delamination of composite materials. Drilling is the most frequently employed operation of secondary machining for fiber-reinforced materials owing to the need for joining structures.

Delamination is among the serious concerns during drilling. Practical experience proves the advantage of using such special drills as saw drill, candle stick drill, core drill and step drill. The experimental investigation described in this paper examines the theoretical predictions of critical thrust force at the onset of delamination, and compares the effects of these different drill bits. The results confirm the analytical findings and consistent with the industrial experience. Ultrasonic scanning is used to evaluate the extent of drilling-induced delamination. The advantage of these special drills is illustrated mathematically as well as experimentally, that their thrust force is distributed toward the drill periphery instead of being concentrated at the center. The allowable feed rate without causing delamination is also increased.

Jose Mathew Investigated (1999) the effect of geometry of a trepanning tool on thrust and torque during drilling of GFRP composites. This paper presents the results of an experimental investigation into the effect of the geometry of a trepanning tool on thrust and torque during the drilling of uni-directional glass fibre-reinforced plastic (UD-GFRP) laminates. It is well-known that the most effective way of achieving good quality holes while drilling fibre-reinforced plastics (FRPs) is by reducing the thrust and torque. Therefore, this investigation was aimed at exploring the possibility of reducing the thrust and torque by using this concept of trepanning. The design considerations and development methodology of the trepanning tool are discussed. The appropriate tool geometry has been determined by using statistically planned experiments and analysis. Orthogonal arrays with analysis of means as well as analysis of variance have been used to assess individual factor and interaction effects and their significance levels. The investigations have revealed that the performance of the trepanning tool is superior to that of conventional twist drills in terms of thrust, torque and hole quality. Low production cost and ease of regrinding are its major additional advantages due to its simple geometry

Davim (2003) studied the behavior of the cemented and tungsten-carbide drilling with distinct geometrics (stub length and brad and spur) when machining a glass fiber reinforced plastics. The results reveal that the thrust force increased with feed rate, however lower values of thrust force were recorded when using the Brad and spur drill, additionally the effect of cutting speed on both thrust force and torque was negligible within the cutting range speed).

K.Palanikumar (2011) investigated and optimised the drilling of GFRP composites. The performances of glass fibre reinforced polymer composite in drilling were studied by conducting various machinability tests using Brad and Spur drill having diameter of 8 mm. it has been noted that high spindle speed and less feed rate is preferred in drilling of GFRP composites using Brad and Spur drill.

G.Z. Keh (2015) studied the Delamination Analyses of GFRP Composites under High Speed Conditions and Various Drill Geometries. The drilling experiment was performed on a 3 axis CNC milling machine with three different tool (twist drill, step drill, brad/spur drill) geometries. Taguchi approach has been proven to be an effective tool in research and industry for solving engineering problems quickly and reliably. Nevertheless, results from Taguchi analyses suggested that the brad/spur drill is not suitable in drilling GFRP due to the smallest value of S/N ratio for delamination factor. This implies that the delamination damage due to the brad/spur type of drill bit was the highest among the three drill bits selected. This could mainly due to the high critical thrust force exerted by the brad/spur drill bit during drilling process. It is to note here that thrust force is defined as the force acting directly into the hole direction as the drill bit started to penetrate with the composite specimen. When the force exceeded the critical thrust force or the inter-laminar strength of the composite specimen, the fibre plies started to separate and delamination damage progressed.

2.1.2 Effect of Process Parameters on Delamination

K. Palanikumar (2011) investigated experimentally and optimised the drilling parameters of GFRP composites. This work extensively presents an effective approach for the optimisation of drilling parameters with multiple performance characteristics based on the Tagugchi's method with grey relational analysis. Taguchi's L16, 4-level orthogonal array has been used for this experimentation. The drilling parameters such as spindle speed and feed rate are optimised with consideration of multiple performance characteristics, such as thrust force, workpiece surface roughness and delamination factor. Response table and response graph are used for the analysis. The analysis of grey relational grade indicates that feed rate is the more influential parameter than spindle speed. The results indicate that the performance of drilling process can be improved effectively through this approach.

E. Kilickap (2010) Optimised the machining parameters on delamination by Taguchi method drilling for GFRP composites. This work investigates the influence of the cutting parameters, such as cutting speed and feed rate, and point angle on delamination produced when drilling a GFRP composite. The damage generated associated with drilling GFRP composites were observed, both at the entrance and the exit during the drilling. Hence it is essential to obtain optimum cutting parameters minimizing delamination at drilling of GFRP composites. Moreover, the application of Taguchi method and analysis of variance (ANOVA) for minimization of delamination influenced by drilling parameters and drill point angle is presented. The optimum drilling parameter combination was obtained by using the analysis of signal-to-noise ratio. The conclusion revealed that feed rate and cutting speed were the most influential factor on the delamination, respectively. The best results of the delamination were obtained at lower cutting speeds and feed rates.

DeFu Liu et al. (2012) studied the mechanical drilling for composite laminates. Composite laminates (CFRP, GFRP, and fiber metal composite laminates) are attractive for many applications (such as aerospace and aircraft structural components) due to their superior properties. Usually, mechanical drilling operation is an important final machining process for components made of composite laminates. However, composite laminates are regarded as hard-to-machine materials, which results in low drilling efficiency and undesirable drilling-induced delamination. Therefore, it is desirable to improve the cost-effectiveness of currently-available drilling processes and to develop more advanced drilling processes for composite laminates. Such improvement and development will benefit from a comprehensive literature review on drilling of composite laminates. This review paper

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summarizes an up-to-date progress in mechanical drilling of composite laminates reported in the literature. It covers drilling operations (including conventional drilling, grinding drilling, vibration-assisted twist drilling, and high speed drilling), drill bit geometry and materials, drilling-induced delamination and its suppressing approaches, thrust force, and tool wear.

N.S. Mohan et al. (2007) analyzed Delamination during drilling process of glass fiber reinforced plastic composite materials. Machining processes are generally used to cut; drill, or contour composite laminates for building products. In fact, drilling is one of the most commonly used manufacturing processes to install fasteners for assembly of laminate composites. The material anisotropy resulting from fiber reinforcement heavily influences the machinability during machining. Machining of fiber reinforced plastic (FRP) components is often needed in spite of the fact that most FRP structures can be made to near-net shape and drilling is the most frequently employed secondary machining process for fiber reinforced materials. Therefore, the precise machining needs to perform to ensure dimensional stability and to obtain a better productivity of the component. The drilling parameters and specimen parameters evaluated were speed, feed rate, drill size and specimen thickness. A series of experiments were conducted using TRIAC VMC CNC machining center to machine the composite laminate specimens at various cutting parameters and material parameters. The measured results of delamination at the entry and exit side of the specimen were measured and analyzed using commercial statistical software MINITAB14. The experimental results indicated that the specimen thickness, feed rate and cutting speed are reckoned to be the most significant factors contributing to the delamination. A signal-to-noise ratio is employed to analyze the influence of various parameters on peel up and push down delamination factor in drilling of glass fibre reinforced plastic (GFRP) composite laminates. The main objective of this study is to determine factors and combination of factors that influence the delamination using Taguchi and response surface methodology and to achieve the optimization machining conditions that would result in minimum delamination. From the analysis it is evident that among the all significant parameters, specimen thickness and cutting speed have significant influence on peel up delamination and the specimen thickness and feed have more significant influence on push down delamination. Confirmation experiments were conducted to verify the predicted optimal parameters with the experimental results, good agreement between the predicted and experimental results obtained to be of the order of 99%

N.S. Mohan et al. (2005) analysed the Influence of process parameters on cutting force and torque during drilling of glass–fiber polyester reinforced composites. This research outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in drilling of glass fiber reinforced composite (GFRC) material. Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. This procedure eliminates the need for repeated experiments, time and conserves the material by the conventional procedure. The drilling parameters and specimen parameters evaluated are speed, feed rate, drill size and specimen thickness. A series of experiments are conducted using TRIAC VMC CNC machining center to relate the cutting parameters and material parameters on the cutting thrust and torque. The measured results were collected and analyzed with the help of the commercial software package MINITAB14. An orthogonal array, signal-to-noise ratio are employed to analyze the influence of these parameters on cutting force and torque during drilling. The method could be useful in predicting thrust and torque parameters as a function of cutting parameters and specimen parameters. The main objective is to find the important factors and combination of factors influence the machining process to achieve low cutting thrust and torque. From the analysis of the Taguchi method indicates that all-significant parameters, speed and drill size are more significant influence on cutting thrust than the specimen thickness and the feed rate. Study of response table indicates that the specimen thickness, and drill size are the significant parameters of torque. From the interaction among process parameters, thickness and drill size together is more dominant factor than any other combination for the torque characteristic.

Vinod Kumar Vankanti et al. (2014) optimized the process parameters in drilling of GFRP composite using Taguchi method. The objective of the present work is to optimize process parameters namely, cutting speed, feed, point angle and chisel edge width in drilling of glass fiber reinforced polymer (GFRP) composites. In this work, experiments were carried out as per Taguchi experimental design and an L9 orthogonal array was used to study the influence of various combinations of process parameters on hole quality. Analysis of variance (ANOVA) test was conducted to determine the significance of each process parameter on drilling. The results indicate that feed rate is the most significant factor influencing the thrust force followed by speed, chisel edge width and point angle; cutting speed is the most significant factor affecting the torque, speed and the circularity of the hole followed by feed, chisel edge width and point angle. This work is useful in selecting optimum values of various process parameters that would not only minimize the thrust force and torque but also reduce the delimitation and improve the quality of the drilled hole.

J. Paulo Davim et al. (2004) studied the drilling of glass fiber reinforced plastics (GFRP) manufactured by hand lay-up. Drilling is a frequently practiced machining process in industry due to the need for component assembly in mechanical pieces and structures. Drilling of composite materials is significantly affected by damage tendency of these materials under action of cutting forces (thrust force and torque). This paper concentrates the cutting parameters (cutting velocity and feed rate) under specific cutting pressure, thrust force, damage and surface roughness in Glass Fiber Reinforced Plastics (GFRP's). A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in a hand lay-up GFRP material. The analysis of variance (ANOVA) was performed to investigate the cutting characteristics of GFRP's using Cemented Carbide (K10) drills with appropriate geometries. The objective was to establish a correlation between cutting velocity and feed rate with the specific cutting pressure, thrust force, damage factor and surface roughness, in a GFRP material.

J. Campos Rubioa et al. (2008) evaluated the effects of high speed in the drilling of glass fibre reinforced plastic. High speed machining is an outstanding technology capable of improving productivity and lowering production costs in manufacturing companies. Drilling is probably the machining process most widely applied to composite materials; nevertheless, the damage induced by this operation may reduce drastically the component performance. This work employs HSM to realize high performance drilling of glass fibre reinforced plastics with reduced damage. In order to establish the damage level, digital analysis is used to assess delamination. A comparison between the conventional (Fd) and adjusted (Fda) delamination factor is presented. The experimental results indicate that the use of high speed machining is suitable for drilling GFRP ensuring low damage levels.

A.M. Abrao et al. (2007) studied about the drilling of fiber reinforced plastics. The use of polymeric composite materials has increased considerably over the last decade and, as a consequence, the number of papers focused on relevant aspects concerning the machinability of such materials has also increased. The principal aim of this work is to present a literature survey on the machining of composite materials, more specifically on drilling of glass and carbon fibre reinforced plastics. Aspects such as tool materials and geometry, machining parameters and their influence on the thrust force and torque are investigated. Additionally, the quality of the holes produced is also assessed, with special attention paid to the delamination damage. The results indicated that despite the fact that some aspects, such as the effect of cutting parameters and tool geometry on the quality of the hole have been extensively studied over the last years, the phenomena associated to shearing of polymeric composite materials require additional studies in order to allow a better understanding of the behaviour of this category of materials when subjected to cutting.

Surinder Kumar (2012) studied the effect of machining parameters on cutting forces (tangential, feed and radial force) for Pultrusion process (UD-GFRP) composite rod in turning operations using (PCD) tool under different cutting conditions (dry, wet and cooled). The experiments were conducted according to the L18 orthogonal array. This paper presents an effective approach for the optimization of turning parameters based on the Taugchi's method with regression analysis. Second order predictive model covering tool nose radius, tool rake angle, feed rate, cutting speed, cutting environment (dry, wet and cooled) and depth of cut has been developed at 95% confidence interval for cutting forces. Minimizing cutting forces is considered as an objective.

Anil Jindal (2011) investigated the Process Parameters in drilling operation using different software technique. This research outlines the Taguchi optimization methodology, which is applied to optimize cutting parameters in drilling of glass fiber reinforced composite (GFRC) material. Analysis of variance (ANOVA) is used to study the effect of process parameters on machining process. This procedure eliminates the need for repeated experiments, time and conserves material by the conventional procedure. The drilling parameters and specimen parameters evaluated speed, feed rate, drill size and specimen thickness. A series of experiments were conducted using Radial Drilling Machine to relate the cutting parameters and material parameters on the cutting thrust and torque. The measured results were collected and analyzed with the help of the commercial software package MINITAB 15. An orthogonal array, signal-to-noise ratio are employed to analyze the influence of these parameters on cutting force and torque during drilling. The method could be useful in predicting thrust and torque parameters as a function of cutting parameters and specimen parameters. The main objective is to find the important factors and combination of factors influence the machining process to achieve low cutting low cutting thrust and torque. From the analysis of the Taguchi method indicates that among the all-significant parameters, speed and drill size are more significant influence on cutting thrust than the specimen thickness and the feed rate. Study of response table indicates that the specimen thickness, and drill size are the significant parameters of torque. From the interaction among process parameters, thickness and drill size together is more dominant factor than any other combination for the torque characteristics.

E. Capello (2010) studied the effect of the drilling on the residual mechanical behavior of glass fiber reinforced plastic (GFRP) laminates when the hole is subjected to bearing load. In the first part, the influence of drilling parameters on the type and extension of the damage is analyzed. The damage was described at the macro level (delaminated area) and at the micro level (cracks, fiber-matrix debonding, etc.). The Design of Experiments and Analysis of Variance techniques are used in order to determine the statistical influence of the drilling parameters on the delamination area. Moreover, the effects of drilling with or without a support beneath the specimens are analyzed and discussed. Push-down delamination was mainly affected by the feed rate, by the presence of support beneath the specimen, and by the twist drill temperature.

G. Caprino (2011) studied to clarify the interaction mechanisms between the drilling tool and material. Drilling tests were carried out on glass-polyester composites using standard HSS tools; drilling was interrupted at preset depths to study damage development during drilling. The specimens, polished by a metallographic technique, were examined by optical microscopy to identify any damage. The results obtained were useful in describing the damage history and to help design drill geometries specifically conceived for composite machining. The qualitative agreement of the observed behavior with the predictions of the model presented in the literature and some of the intrinsic limitations are assessed.

Rajesh Kumar Verma (2015) Studied Machining of Unidirectional Glass Fibre Reinforced Polymers Composites. GFRP have been successfully substituted the traditional engineering materials and widely used in transportation, offshore and marine, spacecraft structures require high specific stiffness and strength but machining of GFRP is significantly different from conventional metals because they are isotropic and non homogeneity in nature which consist of distinctly different phases, so that their machining operation is characterized by uncontrolled intermittent fibre fracture causing oscillating during cutting forces and critical bending stresses, on poor surface finish in terms of fuzzing due to diverse/ crushed fibre. It is not easy for a manufacturer to obtain quantitative and consistent measures but it has been mainly assessed by three parameters including tool wear or tool life, cutting forces or power consumption and better surface finish. Therefore good machinability means less tool wear, low cutting forces and good surface finish. Factors such cutting parameters, vibration, tool wear and fiber orientations should be taken very carefully during machining to obtain favorable environment for best quality as well as productivity. The machining of Glass Fibre Reinforced Polymers (GFRP) is different in many ways from machining of conventional metals and alloys. Due to in homogeneity and isotropic behavior of GFRP composites, different types of problems are faced during machining or cutting of these materials. GFRP material is found suitable for transportation, power generation, offshore and marine, aircraft, spacecraft structures require high specific stiffness and strength (Glass reinforced polymers). Conventional tools are not recommended for machining of composites, cutting tools such as cemented carbides, tungsten carbides, PCD, PCBN are widely used by the manufacturer.

2.1.3 Effect of material of work piece

T.V. Rajamurugan et al. (2013) analysed the delamination in drilling glass fiber reinforced polyester composites. Glass fiber reinforced plastic (GFRP) composite materials are finding increased application in aeronautical, automobile and structural applications. Drilling is a complex process, owing to their tendency to delaminate is used to join the composite structures. In the present work, an attempt has been made to develop empirical relationships between the drilling parameters such as fiber orientation angle, tool feed rate, rotational speed and tool diameter with respect to delamination in drilling of GFR–polyester composites. The empirical relationship has been developed by using response surface methodology. The developed model can be effectively used to predict the delamination in drilling of GFRP composites within the factors and their limits are studied. The result indicated that the increase in feed rate and drill diameter increases the delamination size where as there is no clear effect was observed for fiber orientation angle. The spindle speed shows only little effect on delamination in drilling of GFR–Polyester composites. The experiments are designed through the experimental design method and executed in a vertical machining center. The tool used for the experimentation is Brad and spur drill bit. Second-order polynomial model is developed using the response delamination factor. The four important input variables considered for the present research study is spindle speed, tool feed rate, drill diameter, and fiber orientation angle. The influences of all machining parameters delamination factor have been analyzed based on the developed mathematical model. The results indicated that the delamination factor increases with the increase of feed rate. The delamination factor decreases slightly with the increase of spindle speed. The variation of fiber orientation angle does not show a general trend. Normally the increase of fiber orientation angle almost increases the delamination factor in drilling of GFR–polyester composites. The increase of drill diameter increases the delamination factor in drilling composites materials due to the increase of thrust force. Instead of using bigger holes similar smaller holes may be used. The experimental results indicate that proper selection of cutting parameters improves the performance in drilling. Mathematical relations are established between the cutting parameters and response delamination factor using response surface method. The models are found to be fit at 95% confi- dence level within the levels considered. Tool feed rate is the most influential parameter which influences the delamination factor in drilling composite materials followed by drill diameter.

I. El-Sonbaty et al. (2004) studied the factors affecting the machinability of GFR/epoxy composites. Drilling is an essential operation in the assembly of the structural frames of automobiles and aircrafts. The life of the joint can be critically affected by the quality of the drilled holes. The main objective of the present paper is to investigate the influence of some parameters on the thrust force, torque and surface roughness in drilling processes of fiber-reinforced composite materials. These parameters include cutting speed, feed, drill size and fiber volume fraction. The quasi-isotropic composite materials were manufactured from randomly oriented glass fiber-reinforced epoxy, with various values of fiber volume fractions, using hand-lay-up technique. Two components drill dynamometer has been designed and manufactured to measure the thrust and torque during the drilling process. The dynamometer was connected with a data acquisition, which installed in a PC computer. This set-up enable to monitor and record the thrust force and torque with the aid of a computer program that designed using Lab View utilities. The results indicate that the start point of torque cycle is delayed by few seconds (depending on the value of feed) than the thrust force. This time is consumed to penetrate the specimen by chiseling edge. After the thrust force reached its maximum value is gradually decreased during the full engagement of the drill and goes to zero when both the chisel edge and the cutting lips have exit of the laminate. In contrast the torque was gradually increased up to the end of the cycle and sudden jump to a value about 10 times the peak value. Cutting speed has insignificant effect on the thrust force and surface roughness of epoxy resin. On contrast increasing feed, drill size and fiber volume fractions lead to increase the thrust force and torque. The drilled holes of GFREC with lower Vf ratio at lower feed have greater roughness than that drilled at higher feed. Specimens with high Vf ratio have a contrary behavior. Drill diameter combined with feed has significant effect on surface roughness.

U.A. Khashaba et al. (2010) analysed the machinability in drilling woven GFR/epoxy composites. The present paper deals with the effect of machining parameters (feed, speed and drill diameter) on the thrust force and machinability of woven glass fiber-reinforced epoxy composites. The selected machinability parameters were delamination size, surface roughness, and bearing strength. The results show that, delamination-free in drilling GFRE composites was not observed, in the range of the investigated cutting parameters. Surface roughness instrument can be used as an indication for the position of the internal delamination damage in drilling GFRE composites. The high values of correlation coefficients between thrust force and the machinability parameters confirm the importance of reducing the thrust force to improve the load carrying capacity of the composite structure assembled by rivets or bolted joints. An experimental analysis for thrust force and machinability parameters (delamination size, surface roughness, and bearing strength) associated with drilling woven GFRE composites at various machining variables is presented in this study. The results are summarized as follows: The cutting conditions used in the present work for drilling woven GFRE composites result in thrust force higher than the predicted critical thrust force at the onset of delamination. Therefore, delamination-free in drilling woven GFRE composites was not observed in the present work. Delamination size was increased with increasing feed and drill diameter due to the increasing of thrust force owing to increasing the cross-sectional area of the undeformed chip. The increases of feed results in higher thrust force which in turn increases the resulting delamination damage and subsequently low bearing strength. Drilling at high speeds leads to increases the generated temperature, assisted by a low coefficient of thermal conduction and a low transition temperature of GFRE composites. The accumulated heat around the tool edge destroys the matrix stability and deteriorates the heat affected zone of the machined hole resulting in low bearing strength. The high value of correlation coefficient between thrust force and the machinability parameters confirms the importance of reducing the thrust force in drilling GFRE composites. This will improve the load carrying capacity of composite structure assembled by rivets or bolted joints.

Khairul Ashraf Bin Minhat et al. (2012) studied the effects of drilling induced defects and mechanical properties of GFRE Composites. Glass fiber reinforced epoxy composites become highly demanded on the way to producing parts in various industry uses for example in aerospace and oil and gas fields. Drilling of fiber composites is one type of machining that mostly applied for assembly uses and it can be problematic especially at the drilled holes. Damages occurred at the drilled holes could lead to adverse impact on its functions. The condition of fiber composite which is in homogeneity of the materials per part is one main cause that makes drilling of fiber composite becoming troubles. In this study, GFRE composite was developed using wet hand lay-up technique with 40% fiber volume fraction of woven glass fiber. 9 samples were prepared with geometry from standard ASTM D3039 was referred and each sample was tested by different parameters. Parameters studied are narrowed to focus on the feed rate (0.05 mm/rev, 0.1 mm/rev, and 0.2 mm/rev) and spindle speed (1000, 2000 and 3000 rpm) of drilling process using 10 mm HSS drill bit for each cutting parameter on MTAB Denford CNC Milling Trainer XLMILL machine. Drilled samples were analyzed on its holes in term of damage factor using 3D Noncontact Measuring Machine where delamination of plies ratio with drill bit diameter around the drilled holes was measured.

M.C. Murugesh et al. (2012) studied influence of filler material on glass fiber/ epoxy composite laminates during drilling. The use of polymeric composite materials has increased considerably over the last decade. Drilling is a frequently practiced machining process in industry due to the need for component assembly in mechanical pieces and structures. Machining processes are generally used to cut; drill or contour composite laminates for building products. In fact, drilling is one of the most commonly used manufacturing processes to install fasteners for assembly of laminate composites. The material anisotropy resulting from fiber reinforcement heavily influences the machinability during machining. Machining of fiber reinforced plastic (FRP) components is often needed in spite of the fact that most FRP structures can be made to near-net shape and drilling is the most frequently employed secondary machining process for fiber reinforced materials. The use of filler material like TiO_2 and Graphite have shown that better bonding of the fiber matrix has got its effect on thrust and delamination factor values.

K. Elias George et al. (2012) studied the influence of process parameters on cutting force and torque of drilling of glass fiber reinforced epoxy composites. Drilling is an essential operation in the assembly of the structural frames of automobiles and aircrafts. The life of a joint can be critically affected by the quality of the drilled holes. Drilling of composite materials is significantly affected by damage tendency of these materials under the action of cutting forces (thrust force and torque).Composite laminates of three different types were fabricated by using E-glass fiber and epoxy resin in the laboratory. The trials as per the design of experiments were performed using Taguchi method. The results indicate that composite prepared with a randomly oriented fiber mat (chopped strand mat) gives the best hole with the least value of damage factor at a spindle speed of 450 rpm and at a drill tool angle of 1100. Further, it is found that the peak torque and thrust force required for this combination of their minimum levels. The study shows that a composite reinforced with a randomly oriented fiber mat (chopped strand mat) gives the best hole. Further it is found that the peak torque and thrust required for this is the minimum. The influence of the spindle speed on the damage factor (entry) is higher than that of the drill angle and fiber orientation. The influence of the spindle speed on the damage factor (exit) is higher than that of influence of fiber orientation and drill angle. The influence of the drill angle on the peak thrust force is higher than that of influence of spindle speed and fiber orientation.

B. Ramesh et al. (2013) optimized the ovality on drilling glass fiber reinforced plastic composites with coated tungsten carbide tool. Nonlaminated composites having superior mechanical properties than laminated composites are widely used in ballistic applications. Since literature on the machinability of nonlaminated composites is scarce, an investigation was carried out to study the hole quality in drilling thick nonlaminated Glass Fiber Reinforced Plastic (GFRP) composite rods using coated tungsten carbide twist drill. The GFRP composite rods were made by pultrusion method with high fiber weight fraction. The ovality (hole diameter inaccuracy) of the drilled holes was measured using Coordinate Measuring Machine (CMM). Taguchi's orthogonal array and analysis of variance (ANOVA) were employed to study the influence of process parameters such as feed and spindle speed on ovality of the drilled holes. The optimum level of process parameters towards minimum ovality was obtained to achieve defect controlled drilling of pultruded GFRP composite rods. Correlation for ovality with process parameters was established using a statistical software MINITAB 16. The influence of speed on ovality was insignificant. The influence of feed was significant on ovality of the drilled holes. The optimal process parameter levels within the range of examined was identified as 0.15 mm/rev feed and 1000 rpm speed for pultruded GFRP composite rods using 10 mm diameter twist drill. The influence of process parameters on hole quality in nonlaminated composite rods differs with drill geometry and also differs from the influence of process parameters on hole quality in laminated composites.

K.W. Liew (2014) studied the Minimization of Push-out Delamination in Glass Fiber Reinforced Polyester Using RSM. RSM was employed in this study based on a Central Composite Design to develop a mathematical model that describes the effects of drill diameter, speed and feed rate on the push-out delamination in the GFRP material. A second order regression model was developed and 3D surface plots and contour plots were generated to analyze the two-factor interaction of the parameters. The second order model developed is valid within the ranges of the selected experimental parameters.

ANOVA was done the model test for statistical significance. Based on the experimentations and statistical analyses carried out, it is found that ANOVA shows insignificant lack of fit, validating the second order regression model. Speed and feed rate were significant parameters involved in affecting delamination. Strong interactions between the two variables were noticed. Interactions involving the drill diameter are insignificant. Increasing drilling speed and decreasing feed rate reduces delamination and minimum delamination is achieved when drilling speed is 1420 rpm and feed rate is 83 mm/min, when a nominal drill diameter of 8 mm.

M. Sakthivel (2014) studied the thrust force and torque in drilling of glass fiber reinforced polymer composite. The influence of the machining parameters such as spindle speed, and feed rate over the thrust force and surface roughness has been discussed. Delamination of GFRP composite material is mainly determined by the feed rate and drill tool diameter. All these parameters have major contribution over the quality of the hole, the cutting speed is inversely proportional to the thrust force and torque. This paper have provided a literature review on the drilling of polymer matrix composite machining over the last 10-15 years with a specific focus on the process of conventional drilling. GFRP widely used for aeronautical, manufacturing aircraft and spacecraft structural applications requires an inevitable secondary processing of GFRP machining. As per the work material is concerned, glass fiber reinforced polymer, composites have been equally investigated with conventional high speed steel twist drill which are used in equal to cemented, and tungsten carbide drills. However it seems to be a wide scope availability agreement among the researches on the necessity of developing tools with special geometry to achieve impetus performance with consequent concomitant.

2.2 FABRICATION AND MECHANICAL TESTING OF GFRP COMPOSITES

N. Miskolczi (2013) studied the Polyester resins as a matrix material in advanced fibre-reinforced polymer (FRP) composites. This discusses the use of one type of thermoset polymer, polyester, and its use as a matrix material in fibre-reinforced polymer (FRP) composites. It begins with an overview FRP composites, before explaining why polyester is a particularly suitable material for this application, through discussion of its key properties and structures and the manufacturing processes involved .Composites can offer improved mechanical properties compared with pure polymers at no extra cost, meaning that they are widely used in a variety of applications, including in the transport industry (manufacturing passenger cars and other vehicles), marine and shipping uses, and as structural materials. Some examples of these applications, particularly in civil engineering, are provided in this chapter, along with discussion of potential future trends in the field.

A.R. Chaple (2013) Developed Automatic Lay-Up Process for Manufacturing of FRP Sheets. Hand lay-up process is fabrication process to manufacture of FRP products. FRP or fiberglass corrugated roof sheet also manufactured by hand lay-up process, but some problems has been arise with this method such as, mainly low production rate of sheets; uniform thickness not maintaining; lay-up does not uniformly perform, resin is harmful for human. These problems can be eliminated by hand lay-up process converted into Automatic lay-up process with providing safety environments for works.

S. Pansart (2013) studied the Prepreg processing of advanced fibre-reinforced polymer (FRP) composites. Thermoset resins used in prepregs are always already pre-mixed with their hardeners, which means that they are ready to start their cure reaction once activated by heat. The choice of resin, together with the choice of fibre, will determine the mechanical characteristics of the composite. Of equal importance, though, is the impact of resin choice on the processing characteristics, as well as on the maximum service temperature of the composite and its resistance to environmental influences and fire. Available polyesters (low cost), epoxies (higher mechanical performance), phenolics (good fire, smoke and toxicity properties) and bismaleimides, polyimides and benzoxazines (high service temperatures). In addition, resins can contain fillers or thermoplastic constituents for adjusting and improving various material properties, such as resistance to impact damage

K. Alagarraja et al. (2014) fabricated and tested fiber reinforced polymer composites material. The composite materials are replacing the traditional materials, because of its superior properties such as high tensile strength, low thermal expansion, high strength to weight ratio. The developments of new materials are on the anvil and are growing day by day. Natural fiber composites such as sisal polymer composites became more attractive due to their high specific strength, lightweight and biodegradability. Mixing of natural fiber with Glass-Fiber Reinforced Polymers (GFRPs) is finding increased applications. In this study, sisal – glass fiber reinforced epoxy composites is developed and their mechanical properties such as tensile strength, compression strength, flexural strength and impact strength are evaluated. The interfacial properties, internal cracks and internal structure of the fractured surfaces are evaluated by using Travelling Microscope .The results indicated that the incorporation of sisal fiber with GFRP can improve the properties and used as an alternate material for glass fiber reinforced polymer composites.

Dave Kim et al. (2010) studied the effect of fabrication processes on mechanical properties of glass fiber reinforced polymer composites. Polymer composite materials offer high strength and stiffness to weight ratio, corrosion resistance, and total life cost reductions that appeal to the marine industry. The advantages of composite construction have led to yacht hull structures. In order to construct even larger hull structures, higher quality composites with a lower cost production techniques need to be developed. In this study, the effect of composite hull fabrication processes on mechanical properties of glass fiber reinforced plastic (GFRP) composites is presented. Fabrication techniques used in this study are hand lay-up (HL), vacuum infusion (VI), and hybrid (HL+VI) processes. Mechanical property testing includes: tensile, compressive, and ignition loss sample analysis. Results demonstrate that the vacuum pressure implemented during composite fabrication has an effect on mechanical properties. The VI processed GFRP yields improved mechanical properties in tension/ compression strengths and tensile modulus. The hybrid GFRP composites, however, failed in a sequential manor, due to dissimilar failure modes in the HL and VI processed sides.

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Pathalinga Prasad et al. (2013) Fabricated and Characterized the tensile properties of Laminated Composites. The test specimens were fabricated by simple hand lay-up technique and prepared according to ASTM standards. With a UTM TUE-600 (C) high stroke rate test machine related experiments are carries out to find out the tensile properties of test specimens. Hence using matrix and reinforcement in 65:35 ratios it can be seen that results are good for application like automotive parts manufacturing and few aerospace parts. By using a simple hand lay-up process, E-glass epoxy and carbon epoxy polymer matrix composites have been successfully fabricated. In case of Carbon epoxy polymer matrix composites, the tensile strength of unidirectional plies was found to be 27% greater than quasi-isotropic plies. In case of E-glass epoxy polymer matrix composites, the tensile strength of unidirectional plies was found to be 13% greater than quasi-isotropic plies. In the overall study, the strength of carbon epoxy polymer composites has highest value than that of the E-glass epoxy polymer composites.

S. Prabhakaran (2012) developed the Glass Fiber Reinforced Polymer Composite Ceiling Fan Blade. In the recent world most of the household appliances and industrial appliances are using electric power. Because of the enormous use of Electric power, electricity shortage is the main problem throughout the world. Ceiling fan is the one of the appliance that consumes electric power. This has been minimized by means of reducing the weight of the blade. The best way to reduce the power consumption without sacrificing safety is to employ fiber reinforced composite materials in the fan blades. The objective is to compare the power consumption, cost and weight of composite fan blade with that of aluminium fan blade. In this work the design and fabrication of composite fan blade made up of glass fiber reinforced polymer is carried out by which weight of the fan blade can be reduced. Compared to existing ceiling fan blade, the composite blade saves 30% of power, and 34% less in the cost. From the fabrication it was found that the weight reduction of 28% is achieved using composite material without sacrificing the strength.

M. AnandaRao et al. (2014) fabricated and analyzed the mechanical properties of FRP composites. The main objective of this paper is fabrication and analysis of mechanical properties of FRP composites, comparison of mechanical properties of two test pieces fabricated with and without mixing iron flakes. A Test piece with Glass fibers & Epoxy resin and another test piece with the Glass fiber and Epoxy Resin mixed with iron flakes are fabricated and various mechanical testing is done on both the test pieces and the results have to be compared. The fabrication is done using the dimensions according to the ISO standard. The test pieces are tested using Universal Testing Machine. The main purpose of the paper is to determine the best FRP composite from the two test pieces by comparing the tensile strength, flexural strength and shear strength. Tensile Strength of the Test Piece Epoxy Resin with Glass Fiber FRP is 217.58 MPa; Tensile Strength of Test Piece Epoxy Resin with Glass Fiber with Iron Flakes FRP is 254.27Mpa, which is more than the mild steel. Flexural Strength of Test Piece Epoxy Resin with Glass Fiber FRP is 198.59 MPa and Flexural Strength of Test Piece Epoxy Resin with Glass Fiber with Iron Flakes FRP is 212.74 MPa. Shear Strength of Test Piece Test Piece Epoxy Resin with Glass Fiber FRP is 13.6281 N/mm^2 and Shear Strength of

Test Piece Test Piece Epoxy Resin with Glass Fiber with Iron Flakes FRP is 103.635 MPa. According to ISO standard for composite materials, the tensile strength should be 196.07 MPa, Flexural Strength should be 196.07 MPa and Shear stress should be 73.52 MPa. The result obtained is more than the of ISO standard values, the test pieces are correctly fabricated. So, it can be concluded that Test Piece Test Piece Epoxy Resin with Glass Fiber with Iron Flakes FRP has more mechanical strength than the Test Piece Test Piece Epoxy Resin with Glass Fiber FRP. This gives the scope to use FRP Composite of Epoxy resin and glass fibers with Iron Flakes in place of FRP composite with epoxy resin and glass fiber.

M. S. Ahmadi (2009) studied the mechanical properties of GFRP braid-pultruded composite rods. In this work, a conventional textile braiding machine was modified and added to a pultrusion line in order to produce glass fiber reinforced composite rods by braiding-pultrusion technique. Braid-pultruded (BP) rods were produced with three braid roving linear densities and also with three different braid angles. To study the influence of overbraiding on mechanical properties of pultruded rods, unidirectional (UD) rods, without braided fabric, were produced, as well. All rod types were subjected to tensile, bending and torsion tests. The experimental results showed that BP rods have considerably higher shear modulus, but lower tensile modulus and flexural rigidity than those of UD pultruded rods, when fiber volume fraction is kept constant. Moreover, rods produced with higher braid roving linear densities had better torsional, but lower tensile and flexural properties. The highest shear modulus was observed in BP rods with braid angle of 45°.

Hong-Gang Zhu et al. (2009) studied Durability of GFRP composite made of epoxy/organoclay nanocomposite. With a suitable amount of organoclay introduced into epoxy resin, intercalated/ exfoliated epoxy/organoclay nanocomposite showing improved barrier property and thermal stability can be formed. GFRP composite with epoxy/organoclay nanocomposite matrix has been fabricated in this study. The main purpose of our work is to be investigate the effect of epoxy/organoclay nanocomposite matrix on durability improvement of GFRP composites. GFRP composite laminates with neat epoxy matrix or 3wt% epoxy/organoclay nanocomposite matrix are conditioned in the following environments: (i) standard laboratory condition; (ii) heating for 1h at 40°C, 50°C, and 60°C; (iii) immersion in alkaline solution at 60°C. After predetermined periods of conditioning, aged specimens are tested in uniaxial tension to obtain the tensile strength, tensile modulus and failure strain of GFRP composites. Results show that the tensile strength of aged GFRP composites is reduced to different degrees for different environmental exposure condition. However, the degradation rate is reduced when epoxy/organoclay nanocomposite is used as GFRP matrix. This can be attributed to the improved barrier property and thermal stability of the epoxy/organoclay nanocomposite. When GFRP composites are employed in the rehabilitation of concrete structures, the use of epoxy/organoclay nanocomposite matrix is likely to improve the durability of the rehabilitated structure as well.

A.H.M. Fazle Elahi et al. (2014) studied the mechanical Properties of Glass Fiber Reinforced Polyester Composites. Glass fiber reinforced unsaturated polyester (GFRP) based polymer composite was prepared using hand layup process. Four layers of GF were impregnated by polyester resin and pressed under load of 5kg for a day. Then the fabricated composite were heat treated from 60 degree Celsius to 150 degree for 1 hour and finally taken for mechanical test. Tensile strength, tensile modulus, elongation at break, impact strength, shear strength and hardness of the fabricated composite were measured. The experiment showed that wonderful improvement in the mechanical properties of the fabricated composite resulted from the heat treatment. The maximum tensile strength of 200.6 MPa is found for 900^{o}C heat treated sample. Inverse relationship between heat and mechanical properties of the composite was observed above 1000^{o}C. Finally, the excellent elevated heat resistant capacity of GFRP composite shows the suitability of its application to heat exposure areas such kitchen furniture materials, marine, electric board etc.

Moneeb Genedy et al. (2014) studied the Fatigue Performance of GFRP Composite Using Carbon Nanotubes. Glass fiber reinforced polymers (GFRP) have become a preferable material for reinforcing or strengthening reinforced concrete structures due to their corrosion resistance, high strength to weight ratio, and relatively low cost compared with carbon fiber reinforced polymers (CFRP). However, the limited fatigue life of GFRP hinders their use in infrastructure applications. For instance, the low fatigue life of GFRP caused design codes to impose stringent stress limits on GFRP that rendered their use non-economic under significant cyclic loads in bridges. In this paper, we demonstrate the fatigue life of GFRP can be significantly improved by an order of magnitude by incorporating Multi-Wall Carbon Nanotubes (MWCNTs) during GFRP fabrication. GFRP coupons were fabricated and tested under static tension and cyclic tension with mean fatigue stress equal to 40% of the GFRP tensile strength. Microstructural investigations using scanning electron microscopy (SEM) and Fourier Transform Infrared (FTIR) spectroscopy were used for further investigation of the effect of MWCNTs on the GFRP composite. The experimental results show the 0.5 wt% and the 1.0 wt% MWCNTs were able to improve the fatigue life of GFRP by 1143% and 986%, respectively, compared with neat GFRP.

C.M. Manjunatha (2009) studied the effect of rubber micro-particles and silica nano-particles on the tensile fatigue behaviour of a glass-fibre epoxy composite. It is clear that incorporation of either the CTBN rubber micro-particles or the silica nano-particles alone in the epoxy matrix have almost a similar beneficial effect on the fatigue performance of the GFRP composites. In addition to that raising the fatigue limit by about 15%, these particles enhance the fatigue life of GFRP composite by about two to three times, when com-pared to the neat resin matrix composite. Furthermore, the presence of both rubber and silica particles in the matrix to give a 'hybrid' modified GFRP results in a further enhancement of the fatigue life, particularly at the low stress ranges. Indeed, the fatigue limit was further raised by about 25% due to the presence of both these types of particles. The suppressed extent of matrix cracking and reduced delamination growth rate in the composites based upon the modified matrices appears to be the main reasons for the observed enhancement of the fatigue lives of these GFRP composites

J.R. Correia (2005) studied the Durability of Glass Fibre Reinforced Polyester Pultruded Profiles used in Civil Engineering

Applications. Immersion and condensation environments had a noticeable effect on the flexural properties of GFRP profiles. Strength and strain at failure decreases due to moisture were observed and these effects were accelerated by increased temperature. Nevertheless the degradation is mainly due to physical phenomena, as plasticization of polymeric matrix, since no appreciable chemical degradation was detected by FTIR analysis. For the QUV and Xenon arc experiments, although FTIR analysis shows important chemical degradation in the surface of the material, the synergetic effects of simultaneous exposure to UV radiation, moisture and temperature on the flexural and tensile properties of GFRP profiles were not significant throughout the experiment period. These results seem to confirm that UV radiation has limited influence on the mechanical properties of the material, affecting, above all, the material's surface. The considerable chromatic and gloss changes observed, especially due to UV radiation, cause an aesthetical concern for outdoor applications, where as the use of protective coatings can hardly be avoided.

M.C.S. Ribeiro (2011) analysed Mechanical Behaviour of Polyester Polymer Mortars Modified with Recycled GFRP Waste Materials. In this study the effect of incorporation of recycled glass-fibre reinforced polymer (GFRP) waste materials, obtained by means of milling processes, on mechanical behaviour of polyester polymer mortars was assessed. For this purpose, different contents of recycled GFRP waste powder and fibres, with distinct size gradings, were incorporated into polyester based mortars as sand aggregates and filler replacements. Flexural and compressive loading capacities were evaluated and found better than unmodified polymer mortars. GFRP modified polyester based mortars also show a less brittle behaviour, with retention of some loading capacity after peak load. Obtained results highlight the high potential of recycled GFRP waste materials as efficient and sustainable reinforcement and admixture for polymer concrete and mortars composites, constituting an emergent waste management solution. Compressive strength of GFRP waste admixed polymer mortars increases with increasing additions of waste, and with regard to unmodified mortars. Flexural strength of GFRP waste admixed polymer mortars also increases with regard to unmodified mortars. Different trends were observed for the effect of FPW and CPW recyclates on flexural strength of resultant mortars, whereas flexural strength of FPW admixed mortar increases almost linearly with increasing contents of waste, the addition of higher content (8%) of CPW leads to a lower increase on flexural strength of modified mortar (with reference to unmodified mortars). Nonhomogeneous distribution of waste fibres due to agglomeration and tendency of larger particles to be stress raisers might explained this feature. For the same waste content, CPW admixed polymer mortars present in general improved mechanical behaviour over polymer mortars modified with FPW, showing a superior reinforcing effect. Both types of GFRP waste improve ductility and lead to a less brittle failure of resultant GFRP waste admixed mortars.

K. Naresh Kumar (2013) Experimentally Investigated the Mechanical Properties of Coal Ash Reinforced Glass Fiber Polymer Matrix Composites. Glass fiber reinforced polymer composites are one of the most widely used composite materials. The addition of Coal ash to polymer matrix dramatically increases the overall mechanical strength of the composite material as compared to the polymer composite. In view of this, a method is proposed for mixing coal ash powder (size 52-75 µm) into resin and Ash reinforced polymer composites are fabricated by using hand lay-up technique in different weight percentages of coal ash in polymer such as 0%, 4%, 8%, 12%, 16% and 20%.The mechanical properties such as tensile, flexural, compression and Impact properties are studied as per ASTM standards. From the Experimental analysis, it was observed 20% ash reinforced polymer composite is having better tensile strength in comparison with other ash percentages. Similarly 16% ash reinforced composite is having better flexural strength in comparison with other percentages of ash. Similarly 12% ash reinforced composite is having better compression strength in comparison with others. By conducting impact test it was observed that impact strength of polymer matrix composites without ash is having better impact strength than that of coal ash reinforced polymer matrix composites, it was also found that there is no significant effect on Impact strength with the addition of coal ash to glass fiber reinforced polymer matrix composites. Experimental investigation on tensile, flexural, compression and impact behavior of coal ash reinforced polymer composites with different weight percentages of coal ash have been carried out in the present research work. The conclusions drawn from the present work are, the maximum tensile strength is obtained for 20 % (weight) of coal ash among all the different weight percentages and maximum flexural strength is obtained 16 % (weight) of coal ash among all the different weight percentages. The maximum Compression strength is obtained 12 % (weight) of coal ash among all the different weight percentages. No significant effect is observed in the impact strength values with the increase of coal ash percentage in GFRP composites.

M. Nayeem Ahmed (2013) Studied the Effect of Variation Thickness on Tensile Properties of Hybrid Polymer Composites (Glass fibre-Carbon fibre Graphite) and GFRP Composites. Increase in demand of advanced materials to satisfy the requirements of aerospace and automotive industry viz. high modulus to density ratio, leads to the research in composite materials where an attempt is made to study the properties of composite materials by composing the different materials together to obtain the desired properties by reducing the weight as much as possible. Here an attempt is made to study the behavior and tensile properties of Hybrid polymer composite material by composing E-glass fibres, carbon fibres and graphite with epoxy resin 5052. By the variation of thickness. Tensile strength of hybrid composite is observed for each thickness and is optimized and compared with the properties of standalone glass fibre reinforced composites for the same variation of thickness. The comparison represents the enhancement of tensile strength and the cost effectiveness by the introduction of multiple materials (Hybrid composites). It is found that the Hybrid Composite exhibited more tensile and mechanical properties when compared to the Glass Fibre composites irrespective of their thickness. When the comparison was carried out between - the hybrid & GFRP composites of the different thicknesses, the difference between the tensile strengths of hybrid and GFRP composites of 4mm thickness is less when compared to the difference of strengths of 2mm and 3mm thick composites, which shows the weak bond of 4mm thick hybrid composite lamina, this may be because of starvation of resin or improper molding of lamina. By the addition of graphite powder tensile - strength is enhanced as it mixes up with the resin and acts as the reinforcement within the resin. Addition of graphite in composite enhances the - thermal properties of the composite as graphite is the good conductor. With this study it is concluded that composition - of multiple materials leads to the improvement in mechanical, and thermal properties.

2.3 PROBLEM IDENTIFIED

From the above research motivation, the problem identified is to analyze the major damage during drilling of GFRP composite material – delamination. This analysis is required to be carried out with different tool materials and different tool geometry and the best tool with best geometry is to be suggested for industries. The experimental work need to be properly planned and need to be modeled using either the statistical or empirical approach. Since the optimization of the drilling parameters for minimum damage is not much concentrated in the GFRP drilling scenario with different tool material and different work piece material, an optimization approach is required.

2.4 SCOPE AND OBJECTIVES OF THE PRESENT RESEARCH WORK

- The present research problem is formulated as an experimental investigation, modeling and optimization of machining parameters in drilling of GFRP composite materials. The scope and objectives of the present research work is listed below:

- To conduct drilling experiments on a VMC with the variables set as spindle speed and feed rate. The work piece chosen for drilling is GFRP composite plates manufactured using hand layup technique.
- To use two different drill tool such as helical flute drill and brad and spur drill
- To study different responses such as thrust force, torque, torgue, specific cutting pressure, power, delamination for improving the quality of drilled holes.
- To model the drilling experiments using response surface regression model
- To study parametric influence of various drilling parameters on the responses for identifying the desired drill tool.
- To develop ANOVA table for the identification of influential parameters in drilling of GFRP composite plates.
- To study the interaction effects of drilling parameters on various responses.
- To optimize the drilling parameters using grey relational and grey fuzzy approaches.

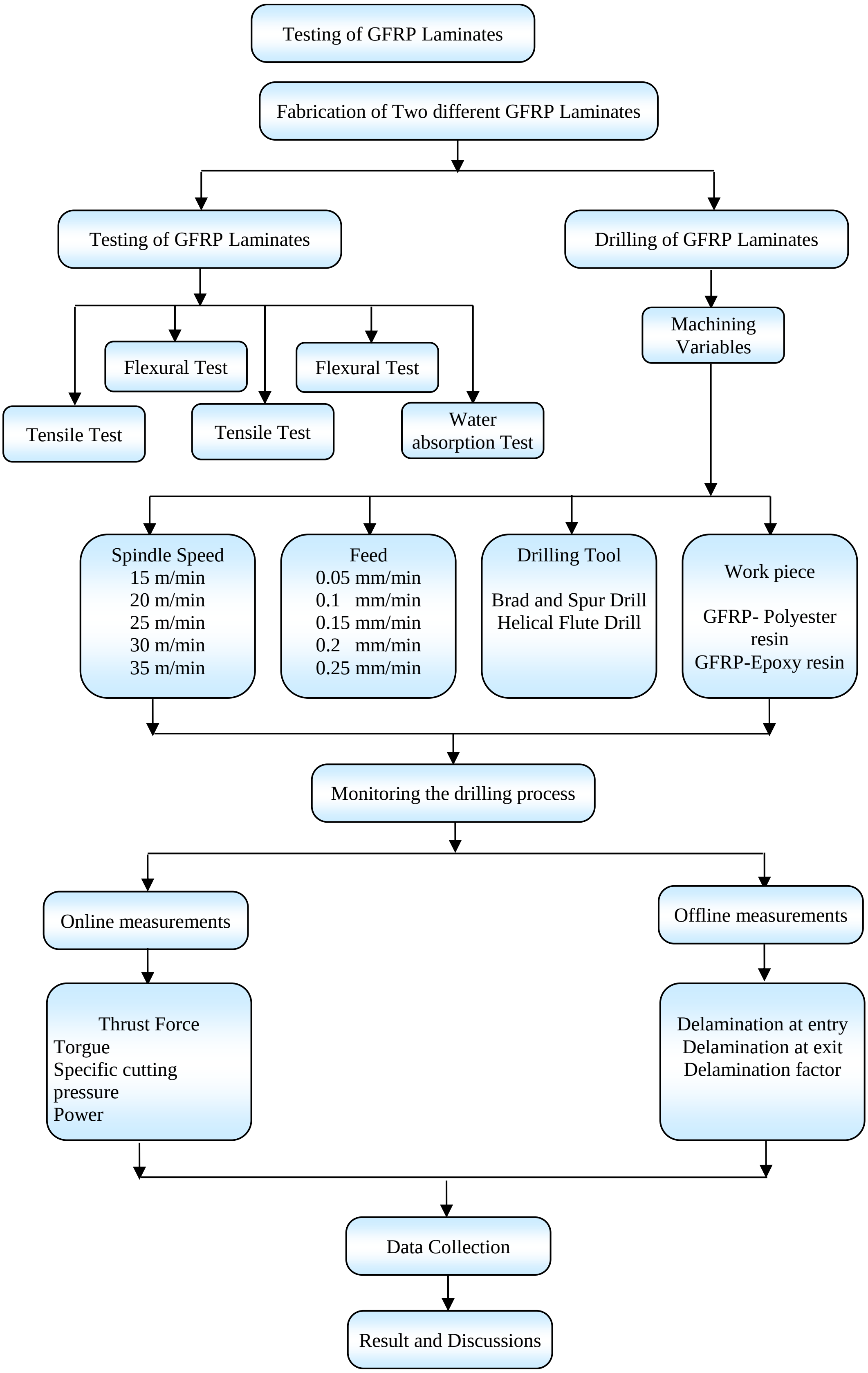

Figure 2.1 Methodology of research work

CHAPTER 3

EXPERIMENTAL WORK

3.1 INTRODUCTION

Composites have gained increased use in aerospace industry because of their excellent mechanical properties, tailorability and its lightweight. A major issue facing the aerospace industry is that effect of service exposure on the performance of graphite/epoxy structural components. It is essential that the components survive extensive cyclic loading and environmental condition of sufficient severity to ensure the necessary confidence for service durability. A lot of work has been done on composite structures to determine their strength capacities and to characterize failure mechanisms, damage tolerance and fatigue behaviour. Any potential problem with failure, damage or fatigue has to be resolved for sufficient confidence to be established to commit to composite materials. To achieve an understanding of composite, investigations of the structural response and integrity of composite laminates are required. This includes physical property evaluation (both static and dynamic), evaluation of functional characteristics and machinability.

Machining performance of a composite material largely depends on the structure property relation of the material. A composite material is influenced by the type of raw material, fabrication process, variables in the material such as fiber orientation, stacking sequence and the number of layers in addition to volume fraction of reinforcement. To assess the performance of machining, knowledge of structure-property relation and its significance on machining is essential. This calls for close monitoring of workpiece fabrication.

Drilling of GFRP composite materials finds widespread applications in many engineering fields. The drilling of FRP composite materials is different from the approach adopted for the conventional materials. Fiber pull-out, spalling, fuzzing, fiber breakage, delamination are some of the problems encountered while drilling these materials. To reduce these defects and to investigate the suitability for many applications, a study of drilling of composite structures is required.

This chapter describes the fabrication of two different types of GFRP composite plates. The properties were studied for the GRPF. Two different drilling tool used in the present study is explained. The various drilling parameters and the responses are explained. A detailed account of the experiments and investigations conducted for defect constrained hole making of glass-epoxy composite laminates is presented in this chapter. The experimental setup and the experimental procedure are discussed. Finally, the experimental results obtained for each tool is tabulated.

3.2 WORK MATERIAL

The work piece material used in the present research work is GFRP composite material made up of epoxy resin and polyester. The significance of GFRP material is already illustrated in chapter 1. The

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advantages of GFRP material include lighter weight, high strength-to-weight ratio, directional strength, corrosion resistance, environmental durability, dimensional stability including low thermal expansion and low thermal conductivity. As illustrated in chapter 1, GFRP composite materials include mainly glass fibers and resins or polyesters. Additionally fillers and additives may be added to suit the requirements.

3.2.1 Fabrication of GFRP – Epoxy Resin Plates

Ethene can be polymerised in slightly different ways to make low-density polyethene (LDPE) and high-density polyethene (HDPE). These polymers have different properties because of the structure of their molecules. Low-density polyethene (LDPE) polymer has side branches. The side branches stop the polymer molecules from lining up regularly. Its structure is not crystalline.

The material has a lower density than HDPE. The forces of attraction between polymer molecules are weakened. The material is less strong, and has a lower melting point, than HDPE. LDPE is low cost polymer and has the impact resistance of - 40°C to 90°C. Low density Poly-Ethylene granules of grade 16MA400 are bought commercially from market. The LDPE granules are shown in Figure 3.1. The properties of Low Density Poly-Ethylene is shown in Table 3.1.

Figure 3.1 Low Density Poly-Ethylene granules

Table 3.1 properties of Low Density Poly-Ethylene

Property	Unit	Value
Melt flow index	Gm/10 min	30
Density (23°C)	Gm/cm^3	0.918
Tensile strength at	MPa	10
Elongation at yield	%	40
Flexural Modulus	MPa	140
Softening point	°C	84

The solid state granules are converted from granules to powder by a suitable organic solvent tetrachloroethylene. The Low Density Polyethylene granules and the organic solvent is taken in the ratio of 1:3 respectively and maintained at a temperature of about 100°C in industrial air heat oven as shown in Figure 3.2 until the low density polyethylene granules are solidified as shown in the Figure 3.3.

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Figure 3.2 Hot air oven

Figure 3.3 Solidified Low density polyethylene

The solidified low density polyethylene is allowed to cool down at room temperature. The low density polyethylene form the liquid form is converted into powder form as shown in Figure 3.4.

Figure 3.4 Powdered Low density polyethylene

Epoxies are thermosetting polymer resins where the resin molecule contains one or more epoxide groups. The chemistry can be adjusted to perfect the molecular weight or viscosity as required by the end use. There are two types of primary epoxies, glycidyl epoxy and non-glycidyl. Glycidyl epoxy resins can be further defined as either glycidyl-amine, glycidyl-ester, or glycidyl-ether. Non-gylcidyl epoxy resins are either aliphatic or cyloaliphatic resins.

One of the most common glycidyl epoxy resins is created using Bisphenol-A, and is synthesized in a reaction with epicholrohydrin. The other frequently used type of epoxy is known as novolac based epoxy resin. Epoxy resins are cured with the addition of a curing agent, which is commonly called a hardener. Perhaps the most common type of curing agent is amine based. Unlike in polyester or vinyl ester resins where the resin is catalyzed with a small (1-3%) addition of a catalyst, epoxy resins usually require the addition of the curing agent at a much higher ratio of resin to hardener, often 1:1 or 2:1. The Epoxy resin grade LY556 and hardener HY 917 is bought commercially. Properties to be considered for epoxy resin is shown in Table 3.2.

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Table 3.2 Properties of Epoxy resin LY 556

Aspect (visual)	Clear, pale yellow liquid
Viscosity at 25 °C	10000 - 12000 [mPa s]
Density at 25 °C	1.15 - 1.20 [g/cm3]
Flash point	> 200 [°C]
Storage temperature	2 - 40 °C

The Epoxy resin grade LY 556 is clear, pale yellow liquid in appearance. The viscosity and density of epoxy resin at 25^{o}C is 1000 – 2000 mPa s and 1.15 – 1.20g/cm^{2} respectively. The flash point for epoxy resin is greater than 200^{o}C. The epoxy resin is stored at a temperature of about 2- 40^{o}C. Properties to be considered for epoxy resin is shown in Table 3.3.

Table 3.3 Properties of Hardener HY 917

Aspect (visual)	Clear liquid
Viscosity at 25 °C	50 - 100 [mPa s]
Density at 25 °C	1.20 - 1.25 [g/cm3]
Flash point	195 [°C]
Storage temperature	2 - 40 °C

The hardener of grade HY 917 is a clear liquid in appearance. The viscosity and density of hardener at 25^{o}C is 50 – 100mPa s respectively. The flash point of hardener is 195^{o}C. The storage temperature of hardener is 2 – 40^{o}C.

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The hand lay-up technique and compression moulding is used in the present work and is involved in the following stages of activities.

- For fabricating the laminates a simple mould was prepared confirming to the required laminate dimensions. The mould involved a Perspex sheet as the bottom plate and steel beadings as the side boundaries.

Figure 3.5 Glass fiber

Figure 3.6 Steel Spacer

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- The beadings were fixed to the bottom plate using an adhesive. To ensure that the laminate can be easily separated from mould, a coating of wax is applied on the surface of the mould. This enabled utilizing the same mould for a number of fabrications.
- A layer of gel coat (resin-rich surface coat) was applied first on the waxed surface of the mould so as to enhance the surface finish of the laminate. This was allowed to cure to an intermediate (or green) stage, so that a good bond will be obtained with the subsequent layers of resin / reinforcement.

Figure 3.7 Magnetic stirrer

- Since curing of resin imposes a constraint on the time available for the consolidation phase, it is essential that materials are prepared before commencement of

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manufacturing. The reinforcement i.e., glass fibers were cut into pieces of 300 mm by 300 mm rectangles. The pieces of glass fibers are weighed as shown in figure 3.5 to prepare the low density polyethylene and resin mixture in 70% and 30% with respect to the weight of the fibers.

- For a laminate thickness of 4 mm, 8 to 10 mats were cut and kept ready. Epoxy resin (cold setting) is weighed out to provide the required resin/glass ration of 2:1 by weight for CSM and 1:1 by weight. To help in the hardening of the resin when used in laminate, a hardener is employed in a ratio of 1:10 by weight of resin. The hardener is mixed with resin thoroughly in a magnetic stirrer as shown in Figure 3.7. While mixing, it is ensured that minimum air bubble is formed.

Figure 3.8 Hand layup process

- The bringing together of resin and reinforcement (fiber) to produce a coherent material with a minimum of air inclusion (i.e. consolidation stage) is perhaps the most critical stage in the production of quality of GFRP products. This process is accomplished by using a brush and a roller as shown in figure 3.8. A glass fiber layer is placed in the mould (on the gel coat) and on it layer of epoxy resin is applied using a brush. To ensure minimum air inclusion and good consolidation, a hand roller is used to spread to resin after application every layer of resin application. This laying process is continued till the required thickness of laminate is achieved. After this, a top plate (Perspex sheet) smeared with wax is placed on the mould so as to obtain good finish even on the other face of the laminate.
- To ensure higher fiber to resin ratio (i.e. to remove excess resin) and better consolidation, the mould is kept under static load of about 100 N in a compression moulding machine as shown in Figure 3.9. To obtain good material properties, the contents are left to cure for about 24 hours at standard conditions.

Figure 3.9 Compression moulding machine

After curing, the laminate is carefully removed from the mould. The laminate thus obtained is trimmed and cut to required dimensions (left specimens). The cured Glass fiber reinforced low density polyethylene composite film is shown in figure 3.10

Figure 3.10 Glass fiber epoxy composite

3.2.2 Fabrication of GFRP – Polyester Resin plates

E-glass woven fabrics and isophthalic polyester thermosetting resin (Camelyaf 266) were purchased to fabricate composite materials. As an accelerator 0.28 wt. % of cobalt naphthenate (CoNAP) and as initiator 1.5 wt. % methyl ethyl ketone peroxide (MEKP) were added to the polyester resins.

Table 3.4 Mechanical properties of polyester resin

Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)
1.2	55	2.4

The composite panels were manufactured using hand lay-up technique. In this technique, dry glass fabrics cut in 300x300 mm dimensions were placed into a mold cavity which were applied the mold release agent (wax-SV8) on the surfaces. After the placement of the fabrics, the mold was closed and clamped tightly, and then the resin was injected into the mold cavity. The laminates were fabricated by placing the one layer of bi woven fabric over the other Polyester resin as a matrix material in between each layer, the tools were used to distribute resin uniformly as explained earlier and a teethed steel roller is used to roll over the fabric before applying resin. Also resin is tapped and dabbed with spatula before spreading resin over fabric layer. This process is repeated till all the 10 layers are placed without applying any kind of external pressure. The surfaces of the laminates were covered MILA film to prevent lay up from external disturbance. After proper curing about 2 days at room temperature the specimens were cut in required sizes per ASTM (ASTM D-790) standards. The cured Glass fiber reinforced polyester composite film is shown in the Figure 3.11.

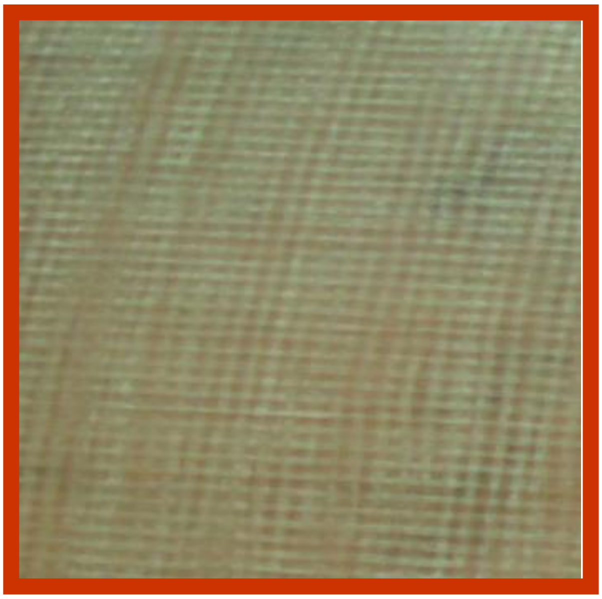

Figure 3.11 Glass fiber polyester composite

3.3 TESTING AND CHARACTERIZATION

3.3.1 Tensile Test

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area.

Figure 3.12 Tensile testing machine

The most common testing machine used in tensile testing is the universal testing machine is shown in the Figure 3.12. This type of machine has two crossheads; one is adjusted for the length of specimen and the other is driven to apply tension to the test specimen. The tensile testing sample (dog bone shape) will be loaded on the crossheads of the tensile machine which is computer operated. A constant pulling load is applied to crosshead until the specimen is fractured. The load at which the specimen breaks is noted as the ultimate tensile strength.

The test specimen for tensile test is been prepared as per the ASTM standard D-638 is shown in Figure 3.16. The test specimen implies the dogbone or dumbbell shape.

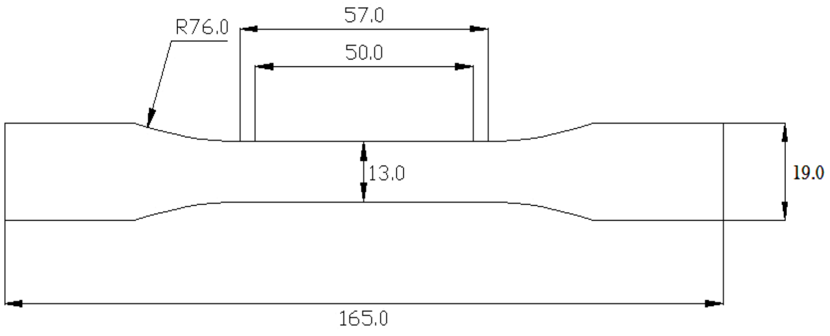

Figure 3.13 Dimensions for Tensile Test Specimen

Tensile test, the specimen dimensions are measured as follows: Width of narrow section=13mm, Length of narrow section=57mm, Overall width=19mm, Overall length of specimen=165mm, Gauge length=50mm, Radius=76mm.

3.3.2 Flexural Test

In the Flexural test the specimen lies on a support span and the load is applied to the center by the loading nose producing three point bending at a specified rate. The three points bending flexural test provides values for the modulus of elasticity in bending, flexural stress, flexural strain and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing.

The test method for conducting the test usually involves a specified test fixture on a universal testing machine as shown in Figure 3.14. The sample is placed on two supporting pins a set distance apart and a third loading pin is lowered from above at a constant rate until the sample failures. The load at which the specimen breaks is noted as the maximum break load for flexural test.

Figure 3.14 Flexural load testing machine

The test specimen for flexural test is been prepared as per the ASTM standard D-790 is shown in Figure 3.15. The test specimen implies a rectangular bar.

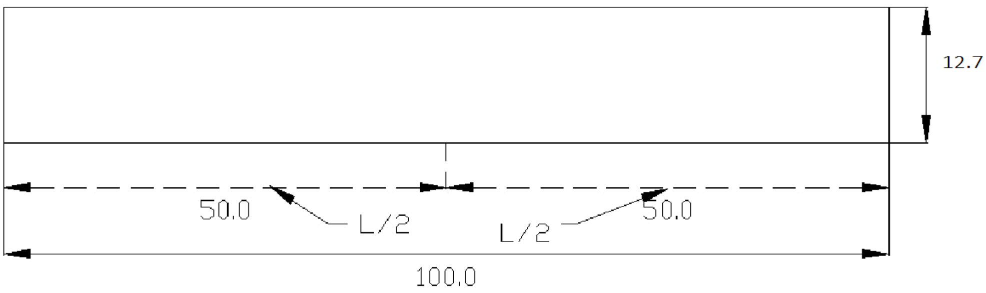

Figure 3.15 Dimensions for Flexural Test Specimen

Flexural test, the specimen dimensions are measured as follows: Width of the specimen=12.7mm, Length of the specimen=100mm.

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3.3.3 Impact Test

The Charpy impact test, also known as the Charpy V-notch test machine is shown in Figure 3.16, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is measure of a given material's notch toughness.

Figure 3.16 Charpy impact test machine

The apparatus consists of a pendulum of known mass (8 kg) is dropped to impact a notched (45^0 angle) specimen material. The impact energy of the specimen absorbed during the failure is transferred to the scale and is noted for each and every composite samples.

The test specimen for impact test is been prepared as per the ASTM standard D-256 is shown in Figure 3.17.

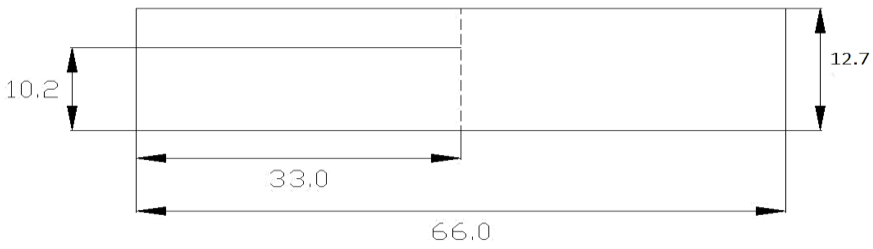

Figure 3.17 Dimensions for Impact Test Specimen

Impact test, the specimen dimensions are measured as follows: Length of the specimen = 66mm, Total width = 12.7mm, Width of specimen after v notch = 10.2mm, Angle for v-notch=45^0.

3.3.4 Hardness Test

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation.

In Wilson hardness testing, the composite specimen experiences a minorload of 10 kgf and major load of 60 kgf for a Dwell time of 5 sec and the hardness values are calculated at three different surfaces of the composite specimen.

Figure 318 Wilson hardness testing machine

The test specimen for hardness test is been prepared as per ASTM standard E10 and as per the machine specification of about 20mm×20mm.

3.3.5 Water Absorption Test

Water absorption is used to determine the amount of water absorbed under specified conditions. For the water absorption test, the specimens are dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then immersed in distilled water for 24 hours. Specimens are removed, patted dry with a lint free cloth, and weighed.

The test specimen for water absorption test is been prepared as per the ASTM D570 is shown in Figure 3.19.

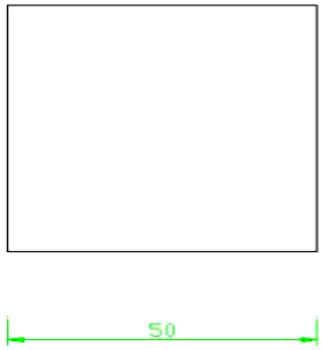

Figure 3.19 Dimension for Water absorption Testspecimen

As per the standard ASTM D 570, water absorption test is used to determine the amount of water absorbed under specified conditions. For the water absorption test, the specimens are dried in an oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then immersed in distilled water for 24 hours. Specimens are removed, patted dry with a lint free cloth, and weighed.

The mathematical equation for calculating the water absorption percentage is

$$WA(t) = \frac{\mathrm{Wt} - Wo}{\mathrm{Wo}}$$

Where, WA (t) is the percentage co-efficient of water absorbed.

W_t is final weight of composite immersed in dilled water at time t.

W_0 is initial dry weight of composite material.

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Factors affecting water absorption include: type of plastic, additives used, temperature and length of exposure. The data sheds light on the performance of the materials in water or humid environments.

3.4 DRILLING TOOL

Drill bits are cutting tools used to create cylindrical holes, almost always of circular cross-section. Drill bits come in many sizes and have many uses. Bits are usually connected to a mechanism, often simply referred to as a drill, which rotates them and provides torque and axial force to create the hole. The drill tools used in the present research work are Brad and spur drill and Helical Flute drill.

3.4.1 Brad and Spur Drill

The lip and spur drill bit is a variation of the twist drill bit which is optimized for drilling in plastics. It is also called the brad point bit or dowelling bit.

Figure 3.20 Brad and spur drill

The centre of the drill bit is given not the straight chisel of the twist drill bit, but a spur with a sharp point and four sharp corners to cut the wood. The sharp point of the spur simply pushes into the soft wood to keep the drill bit in line.

3.4.2 Helical Flute Drill

The twist drill comprises cutting point at the tip of a cylindrical shaft with helical flutes; the flutes act as lift swarf out of the hole. The original method of manufacture was to cut two grooves in opposite sides of a round bar, then to twist the bar to produce the helical flutes. A special tool grinder is available for sharpening or reshaping cutting surfaces on twist drill bits in order to optimize the bit for a particular material.

Figure 3.21 Helical Flute drill

3.5 DRILLING PARAMETERS

The identification of the drilling parameters is based on the extensive literature survey and the initial experiments conducted. The drilling parameters identified the process parameters that include cutting speed and feed rate. The drilling parameters chosen for this experimentation is cutting speed and feed rate.

3.5.1 Spindle Speed

It is understood from the literature survey that higher cutting speed produces low thrust force and better surface finish. However, excessive speed leads to tool wear and a rough surface finish of the work piece. Hence, the spindle speed chosen in the present study are 15 m/min, 20 m/min, 25 m/min, 30 m/min and 35 m/min.

3.5.2 Feed Rate

The speed with which the drill tool is pushed down towards the work piece is called as feed rate. Higher feed rates result will increased thrust force and a rough surface finish whereas lower feed rates result will more heat generated in the work piece and the lower material removal rate. Hence a reasonable feed rate is preferred in drilling of GFRP composites. The feed rate chosen for the present experimentation is 0.05, 0.1, 0.15, 0.2 and 0.25 mm/min.

Drill diameter is also another important parameter that accounts for the damage during drilling operation. However, the drill diameter depends on the size of the hole that is required for the specific application. Hence the drill diameter is fixed as 6 mm in the present experimental study. The experiments were carried out of drill diameters of size 6 mm and thrust force, torque and delamination analysis were carried out.

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3.6 EXPERIMENTAL SETUP

The schematic arrangement of the experimental setup and the analysis made with the drilled holes is shown in Figure 3.22. A computer numerical control (CNC) vertical machining center, ARIX VMC 100, is used to set the prefixed drilling conditions, viz. the speed at which the spindle rotates and the rate at which the drill advances (feed rate). The specification of the CNC vertical machining center is specified in Table 3.5. A Kistler make piezoelectric dynamometer is used to observe the thrust force and torque while machining is carried out. The work table was covered with polythene paper in order to protect the machine from carbon dust arising due to drilling operation. The experimental setup is shown in Figure 3.23. The tool designed with a specific point angle is fixed in the drill chuck.

Table 3.5 Specifications of Vertical Machining Center

Specifications	**Unit**	
Clamping area	mm × mm	450 × 90
Max. safe load on table	kg	500
X-axis	mm	600
Y-axis	mm	450
Z-axis	mm	500
Feed rates	mm/min	1- 10,000
Speed	rpm	Upto 6000

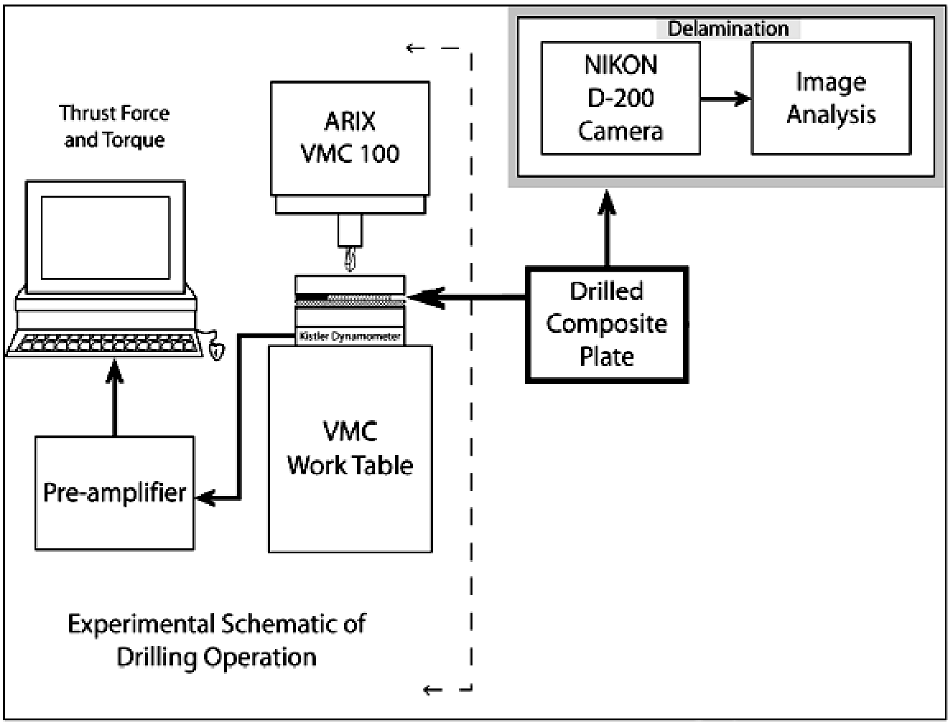

Figure 3.22 Schematic of the experimental setup

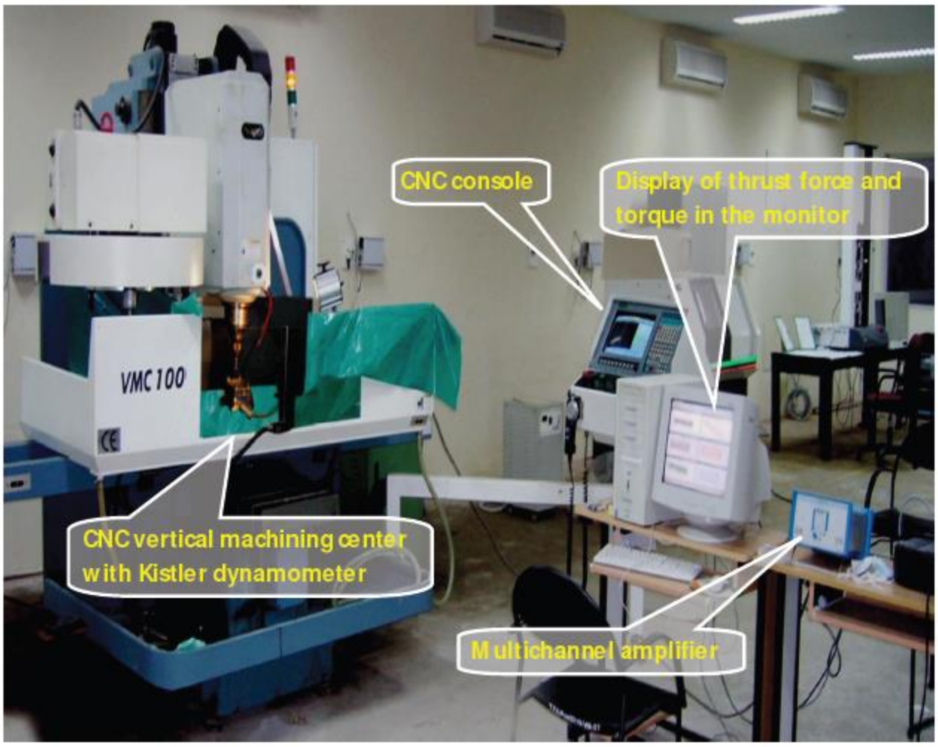

Figure 3.23 Drilling Equipment setup

The drilling operation is carried out with the prefixed cutting condition and the thrust force and the torque has been measured using Kistler make piezo electric dynamometer.

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CHAPTER 4

RESULTS AND DISCUSSION

The composite materials are widely used in different fields due to their excellent properties. GFRP composite plates are used in many applications such as aerospace, defense, biomedical, sports, automobiles, structural members and so on, especially in light weight applications that require a high stiffness and rigidity. The varying structures of these applications require different stages of manufacturing in order to bring it to a near-net shape. Drilling is one such manufacturing process that joins different structures rigidly. However, drilling induces various damage in GFRP composites that need to be minimized. Hence a detailed study on drilling of GFRP composites is required. In the present study, the process parameters and tool parameters that influence the damage on the drilled holes are to be analyzed so that a proper selection of these parameters will minimize the damage encountered during drilling operation.

4.1 INTRODUCTION

In the present study, GFRP composite plates are manufactured through hand lay-up technique and the mechanical properties are measured. The drilling experiments are carried out on a CNC machine under varying levels of the process parameters such as spindle speed and feed rate. Since, it is evident from the literature survey that the tool parameters including tool geometry plays a vital role in producing good quality holes, two different tools were chosen viz. Brad and spur drill and Helical Flute drill. The spindle speed chosen in the present study were 15 m/min, 20 m/min, 25 m/min, 30 m/min and 35 m/min. The feed rate chosen for the present experimentation was 0.05, 0.1, 0.15, 0.2 and 0.25 mm/min and experiments were carried out based on Taguchi's L27 orthogonal array of experiments.

There are several responses that characterize the quality of holes including thrust force, torque, delamination, eccentricity, surface roughness and so on. In the present study, six responses are observed to study the performance of drilling operation to achieve good quality holes. The responses include thrust force, torque, power, specific cutting pressure, delamination size and delamination factor. The results and discussion based on this experimental study are presented in this chapter. GFRP composite structures are widely used in a variety of applications owing to their superior mechanical properties and hence machining of GFRP is of prime importance. In spite of the fact that in general, composites are produced to near-net shape, an additional machining operation is often required. Out of various additional machining operations, drilling is indispensable and is used to fasten structures of different assemblies. However, drilling GFRP composites is a challenging operation, as it faces numerous problems such as delamination, spalling, fuzzing, fiber pull-out and matrix cracking.

4.2 MECHANICAL BEHAVIOR OF GFRP

The main objective of the mechanical testing of composite is the determination of mechanical parameters such as strength, stiffness, flexibility and hardness that will be later used on the design of a composite structure.

4.2.1 Tensile Test

Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure occurs.. Specimens for tension test were carefully cut from the laminate and finished to required size using emery paper. Tests were conducted using Shimadzu make testing machine (Model: AG-IS 50 KN, Capacity: 5 Tonnes and Accuracy: 0.2%) at a cross head speed of 5mm/min as per ASTM D638. Five specimens with identical dimensions for each composite material were tested as per ASTM standards and average result was determined. The Photographic view of GFRP-polyester after tensile test is shown in Figure 4.1.

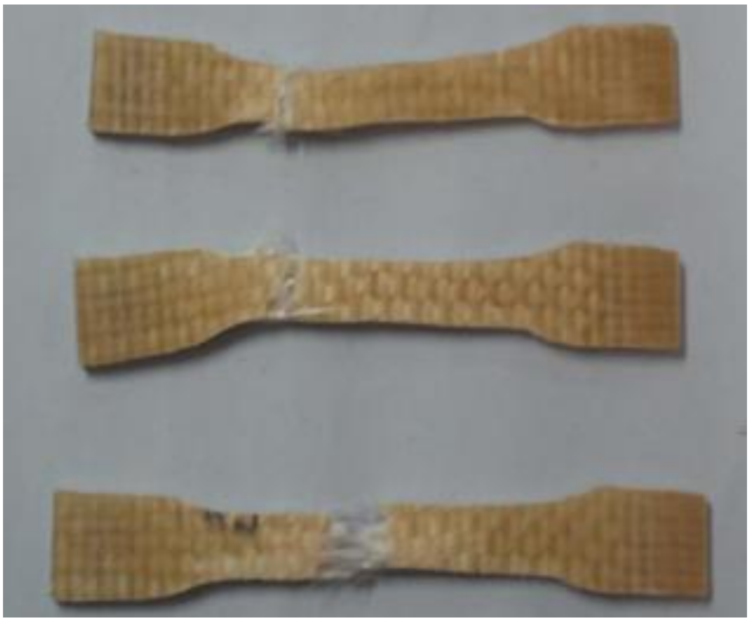

Figure 4.1 Photographic view of GFRP-polyester after tensile test

Figure 4.2 Photographic view of GFRP-epoxy after tensile test

Table 4.1 Comparison of Ultimate Tensile Strength for composite fibers

Different LDPE Fiber Composites	Ultimate Tensile Strength (Mpa)
GFRP-Epoxy	298.67
GFRP-Polyester	95.2

In this work, it was observed that the higher tensile strength for the Glass fiber reinforced plastics-Polyester composites as shown in Table 4.1. GFRP-Epoxy has higher tensile strength and GFRP-Polyester has lower tensile strength. GFRP-Epoxy has improved tensile strength nearly four times of the GFRP-Polyester due to the better bonding strength between fiber and epoxy resin.

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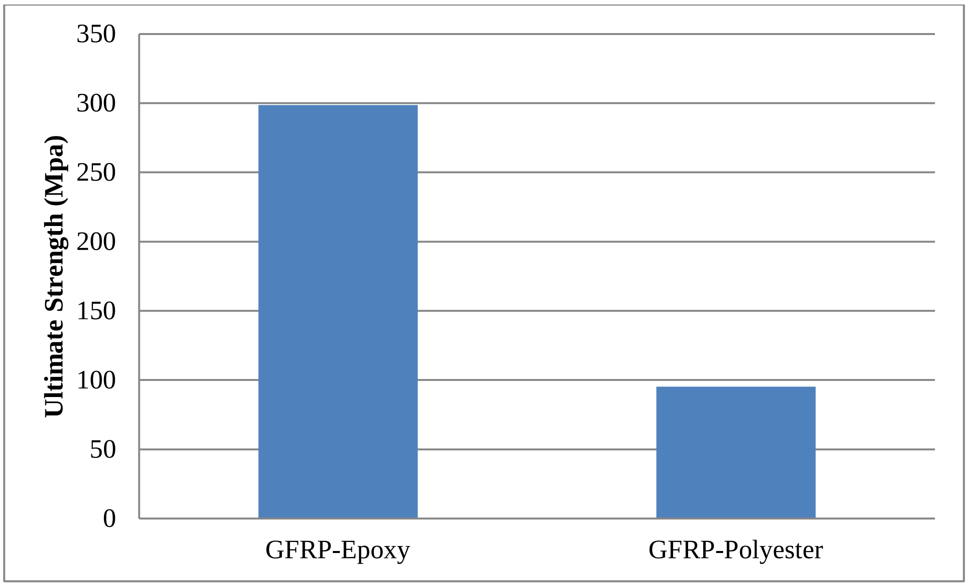

Figure 4.3 Variation of Ultimate Tensile Strength for composite fibers

4.2.2 Flexural Test

Flexural strength is also known as modulus of rupture, bending strength or fracture strength. Flexural test was conducted as per ASTM D 790. The test was conducted on the Instron machine (Model: 3382) with Series IX software using a load cell of 10 kN at 2.8 mm/min rate of loading. Testing conditions of 23±2^{o}C temperature and relative humidity of 50 ±5 % were followed.

The Photographic view of GFRP-polyester after flexural fracture is shown in Figure 4.4. The Photographic view of GFRP-epoxy after flexural fracture is shown in Figure 4.5.

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Figure 4.4 Photographic view of GFRP-polyester after flexural fracture

Figure 4.5 Photographic view of GFRP-polyester after flexural fracture

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Table 4.2 shows the comparison of flexural values of GFRP-Epoxy and GFRP-Polyester composites. From this table it is observed that the flexibility of GFRP-Epoxy composite is greater due to its flexible property.

Table 4.2 Comparison of Flexural Break Load for Different GFRP Composites

Different LDPE Composites	Break Load in kN
GFRP-Epoxy	1.372
GFRP-Polyester	0.5

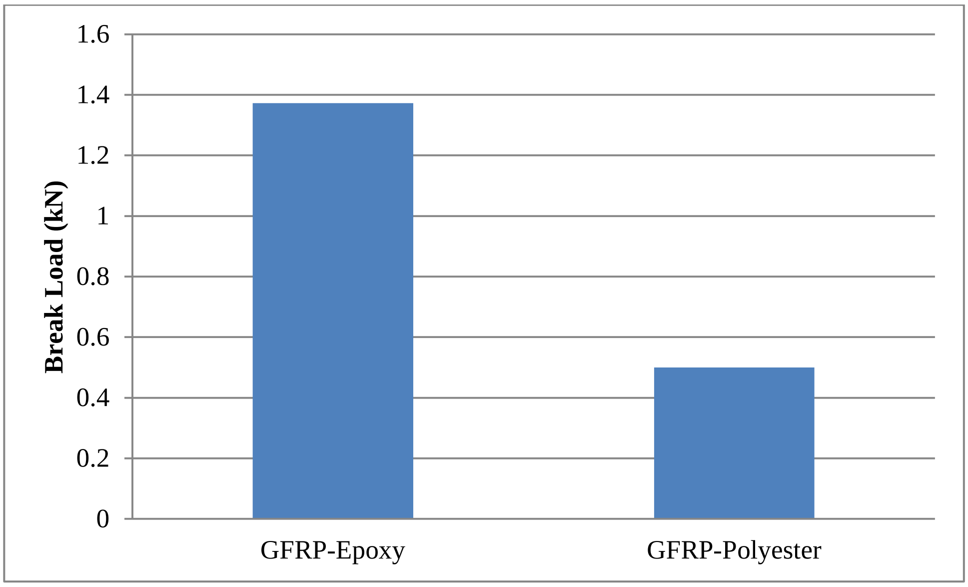

Figure 4.6 Variation of Flexural Break Load of GFRP-Fiber composites

The variation of flexural break load for different GFRP composites is shown in Figure 4.6. From the graph it is seen that the flexural strength GFRP-Epoxy is found to have higher performance when compared GFRP- polyester composite.

4.2.3 Impact Test

The term “impact strength,” as well as the term “impact energy,” is also applied to the amount of energy absorbed before fracture. The impact strength of the samples was measured using an Izod impact test machine as per ASTM D256-05 standards.

The test specimen was supported as a vertical cantilever beam and broken by a single swing of a pendulum in ATS FAAR Impact tester (Model: 16.1& Capacity up to 25 J). In each case, a total of five specimens were tested and all the tests were carried out at room temperature (23±2^{o}C). The photographic image of tested specimens after impact testing is shown in Figure 4.7.

Figure 4.7 Photographic view of GFRP-epoxy after impact fracture

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Figure 4.8 Photographic view of GFRP-epoxy after impact fracture

Table 4.3 Comparison of Impact energy Values for Different GFRP Composites

Different LDPE Composite	Impact Energy in joules
GFRP-Epoxy	8.6
GFRP-Polyester	3.2

The above Table 4.3 shows the comparison of impact energy values for different GFRP composites. The impact energy value of GFRP-Epoxy seems to be greater than the GFRP-Polyester composites.

From the Figure 4.9 we conclude that the impact value of GFRP-Epoxy seems to be greater than GFRP-Polyester. This resembles that the GFRP-Epoxy composite material is superior to GFRP-Polyester composites.

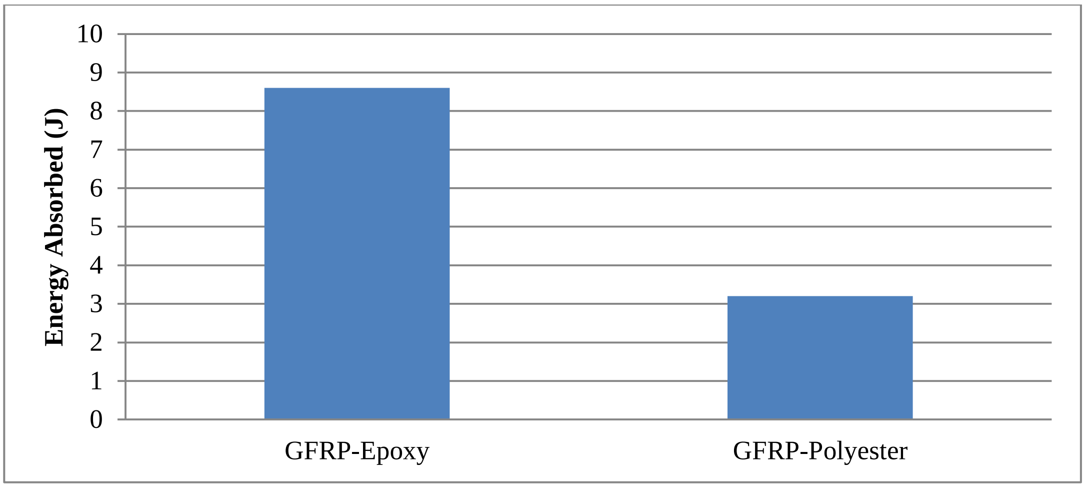

Figure 4.9 Variation in Impact Energy of GFRP composites

4.2.4 Wilson Hardness Test

In Wilson hardness testing, the composite specimen experiences a minor load of 10 kgf and major load of 60 kgf for a Dwell time of 5 sec and the hardness values are calculated at three different surfaces of the composite specimen.

Table 4.4 Comparison of Hardness values for Different GFRP composites

Different LDPE Composites	Hardness Values
GFRP-Epoxy	86.24
GFRP-Polyester	107.03

From Table 4.4 it is seen that the hardness value for GFRP-Polyester is high. This is due to the decreased tensile property GFRP-Epoxy. For a material tensile strength is always inversely proportional to hardness.

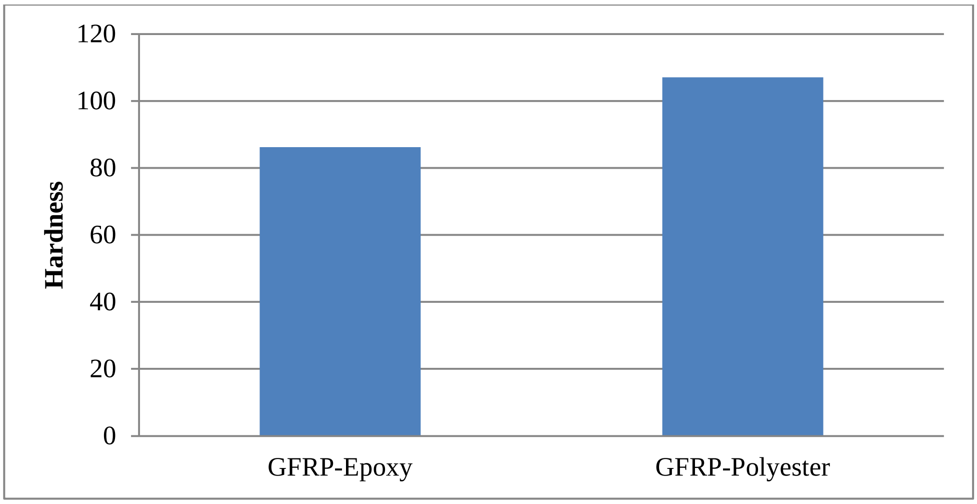

Figure 4.10 Variation in Hardness values of GFRP composites

From the Figure 4.10 it can be concluded that the hardness values for GFRP-Polyester composites seems to be greater than GFRP-Epoxy composite.

4.2.5 Water Absorption Test

From the data shown in Table 4.5, it is concluded that, the composites with GFRP- Polyester has high water absorption coefficient while the composite with GFRP-Epoxy has low water absorption coefficient.

Table 4.5 Comparison of Water absorption values for Different GFRP composites

Different LDPE Composites	Absorption Co-efficient in %
GFRP-Epoxy	0.034
GFRP-Polyester	0.051

This is probably due to the high toughness of the polymer composites. This is due to the adhesive bonding of epoxy resin with the glass fiber. As the bonding is strong the water absorption coefficient is too low for GFRP-Epoxy composite.

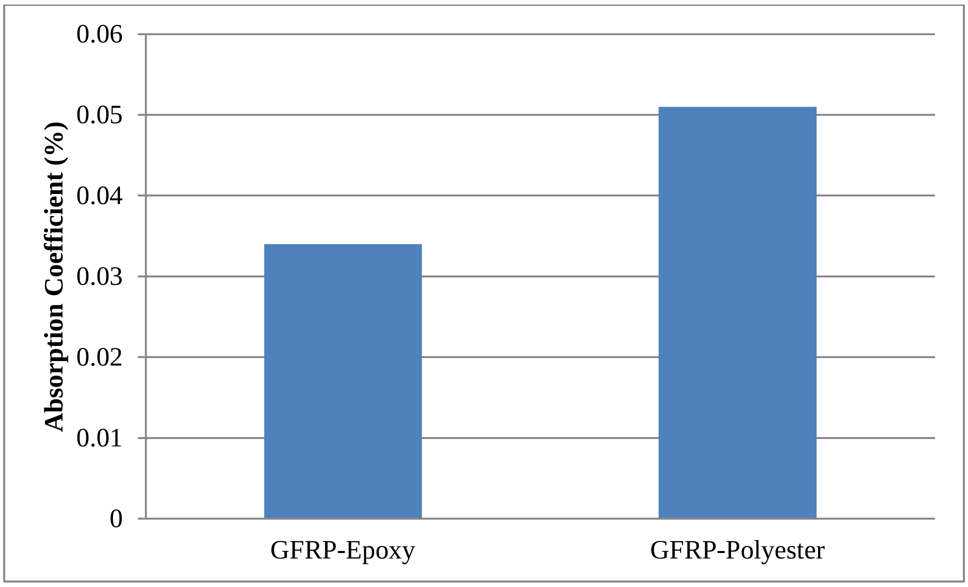

Figure 4.11 Variation in Water absorption co-efficient of GFRP composites

The Figure 4.11 represents that the GFRP-Epoxy shows a least absorption co-efficient as compared with GFRP-polyester composite.

4.3 MECHANISM OF DRILLING IN GFRP COMPOSITES

Fiber Reinforced Composites essentially consist of a hard reinforcing phase embedded in a soft and tough polymer matrix phase. Mostly, Fiber Reinforced Composites are produced to near-net shape during the fabrication stage itself. However, additional machining is unavoidable to achieve the desired surface quality and dimensional tolerance for assembly purposes. Among the machining processes, drilling is the most widely used machining process, since laminated composites are mostly used in structural applications. Several hole production processes, including conventional drilling, ultrasonic drilling, laser drilling and water-jet drilling have been tried for a variety of economic and quality reasons, but conventional drilling is still the most widely used technique in the industries today. This is mostly attributable to differences in thermal and related properties of the matrix and reinforcement, as well as poor electrical conductivity posing serious constraints to nontraditional machining. Machining of Fiber Reinforced Composites differs significantly from machining conventional metals and their alloys. The cutting tool continuously encounters alternate matrix and fibre materials, whose response to machining environment can vary greatly, while experiencing force fluctuations and consequent deterioration in performance.

Apart from force fluctuations, cutting tools also experience severe abrasion wear on the flank surface, due to hard and abrasive glass fibre. This necessitates complex requirements for the cutting tool material. Further, during machining of fibre reinforced laminated composites, the work material can also experience delamination, fibre breakage, matrix crazing and related ones. Delamination is a type of defect frequently met with composite materials, described as the separation of a layer or group of layers from their adjacent ones, due to failure of the internal bonding between the layers. Delamination can be either local or covering a wide area. It can occur either during the curing phase of the resin in the manufacturing stage or during the subsequent service life of the laminated part. Delaminations constitute a severe discontinuity, because they do not transfer interlaminar shear stresses and, under compressive loads, they can cause rapid and catastrophic buckling failure. Hence, utmost care is to be exercised to attain defect controlled machining performance. Composite materials behave in a complicated manner due to macroscopic anisotropic effects and other coupling effects. Also, the experimental characterization is more complicated than conventional homogeneous isotropic material.

4.3.1 Evaluation of Thrust Force and Torque

Drilling experiment was conducted on a three-axis CNC vertical milling machine. To neglect the effect of drill wea,r only one set of experiments were conducted using new helical flute straight shank and 'Brad and Spur' drills with 6mm diameter.

Figure 4.12 Drilled GFRP - Polyester Laminates

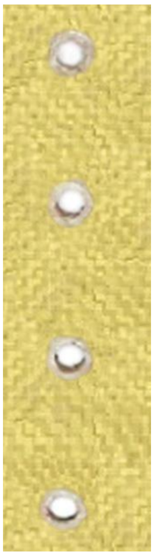

Figure 4.13 Drilled GFRP Epoxy Laminates

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The two axis dynamometer is mounted on a table provide with a fixture to hold a composite laminate specimen for the drilling experiment. Thrust force and torque during machining were measured by piezoelectric dynamometer. The charge amplifier converts the resulting charge signals, which are proportional to the force, to voltage and managed through the data acquisition system. Experimental conditions were repeated for three times to get consistent value.

The thrust force and Torgue obtained under two different drilling conditions is tabulated with respect to spindle speed and feed rate in Table 4.6 to Table 4.10. The thrust force obtained under two different drilling conditions is plotted with respect to spindle speed and feed rate in Figure 4.14. It shows the variation of thrust force with respect to spindle speed and. feed rate. The variations are plotted for the experiment conducted with the two drill tools. The variations showed that thrust force is low for high spindle speed condition. This is due to the fact that there is an increase of heat produced at high spindle speed that assists drilling operation. A low coefficient of thermal conduction and low transition temperature of plastics in combination with increase of heat leads to a low value of thrust force at high speed of 35 m/min in the present study. An increasing cutting speed will certainly increase production rate. It is also observed that the experiments conducted with brad and spur drill tool produced lowest thrust force as compared to that of helical flute SS drill.

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Table 4.6 Thrust force and Torque for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.05	44.32	12.31	194.52	298.39
20	0.05	40.34	11.21	182.43	279.85
25	0.05	36.72	10.20	170.63	261.75
30	0.05	32.82	9.12	158.43	243.03
35	0.05	28.52	7.92	146.45	224.65

Table 4.7 Thrust force and Torque for the drilled holes in GFRP-Epoxy laminates at feed rate 0.1mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.1	83.43	23.18	237.64	364.54
20	0.1	79.75	22.15	226.53	347.5
25	0.1	76.54	21.26	216.72	332.45
30	0.1	73.25	20.35	205.53	315.28
35	0.1	70.93	19.70	195.32	299.62

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Table 4.8 Thrust force and Torque for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15 mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.15	131.21	36.45	271.32	416.20
20	0.15	128.32	35.64	265.32	407.00
25	0.15	125.21	34.78	260.54	399.67
30	0.15	122.32	33.98	254.23	389.99
35	0.15	119.15	33.10	249.65	382.96

Table 4.9 Thrust force and Torque for the drilled holes in GFRP-Epoxy laminates at feed rate 0.2 mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.2	152.53	42.37	285.12	437.37
20	0.2	145.32	40.37	278.43	427.11
25	0.2	139.54	38.76	272.43	417.91
30	0.2	133.27	37.02	266.27	408.46
35	0.2	127.74	35.48	260.23	399.19

Table 4.10 Thrust force and Torque for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25 mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.25	159.25	44.24	307.84	472.23
20	0.25	155.46	43.18	297.47	456.32
25	0.25	152.56	42.38	287.23	440.61
30	0.25	149.25	41.46	277.34	425.44
35	0.25	146.47	40.69	267.54	410.41

Table 4.6 shows the variation of thrust force and torque for the drilled holes in GFRP- Epoxy laminates at feed rate 0.05 mm/rev. The thrust force and torque decreases with increase in cutting speed irrespective of drill tool. It was found that thrust force was larger when using the helical flute SS drill bit than the brad and spur drill bit.

Table 4.6 to Table 4.10 shows the Influence of drilling variables on peak thrust force and torque, respectively for GFRP – Epoxy composites. The results indicate that, the thrust force and torque were increased with increasing feed. This fact was due to the increasing the cross-sectional area of the undeformed chip. The increase in hardness and cutting resistance of the material, also may results in wear in the cutting edges of the drill through drilling one hole. Therefore the thrust force and torque are increased with increasing cutting speed.

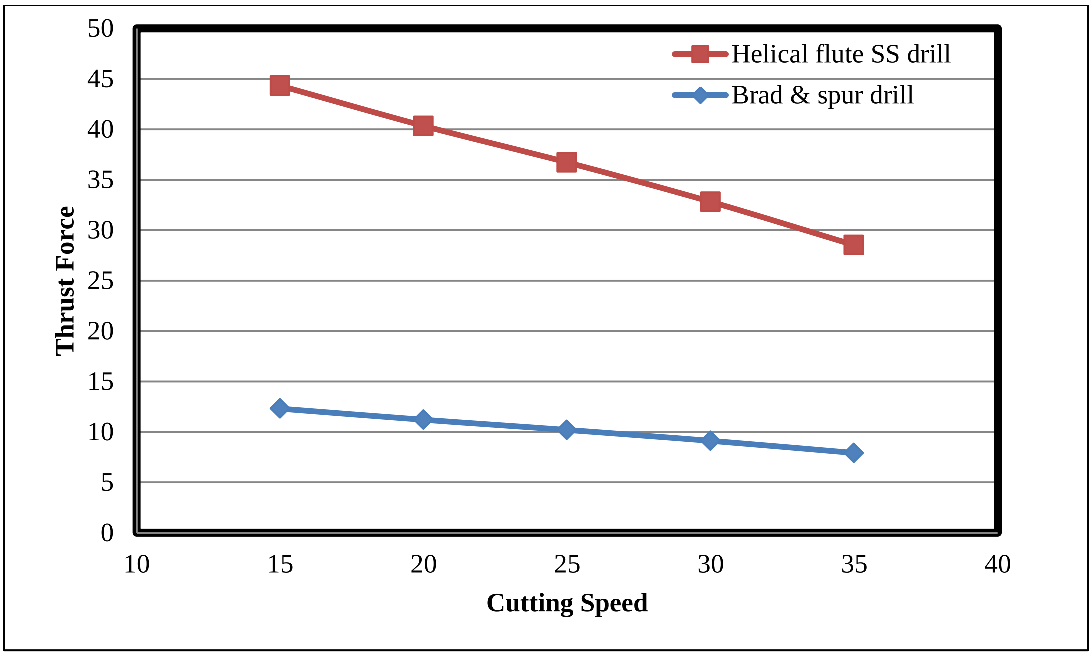

Figure 4.14 Thrust force for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

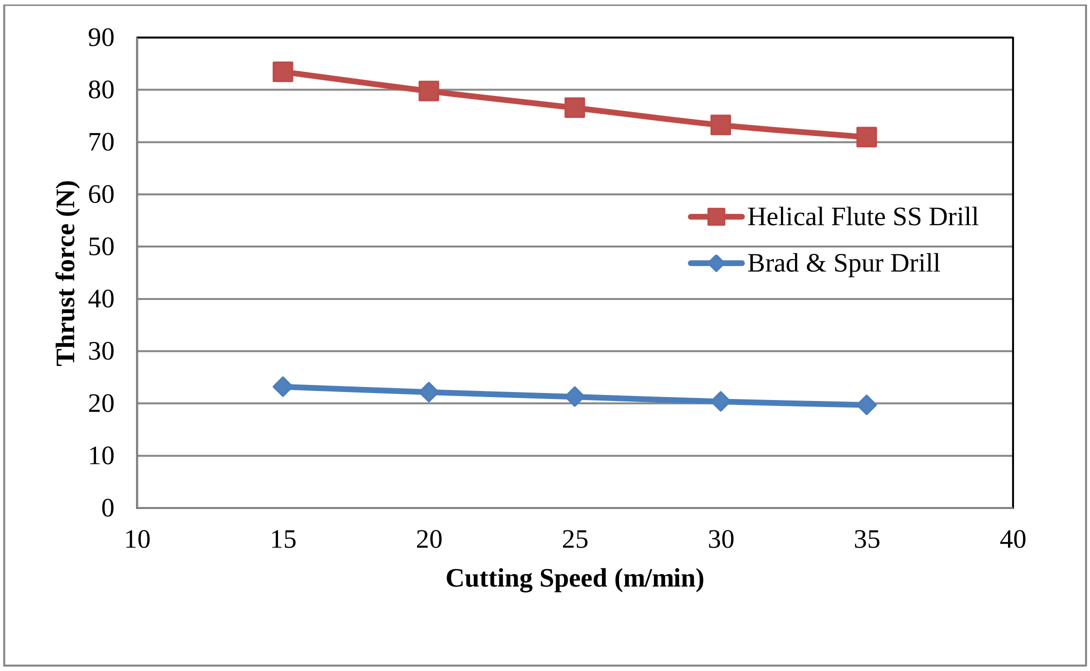

Figure 4.15 Thrust force for the drilled holes in GFRP-Epoxy laminates at feed rate 0.1mm/rev

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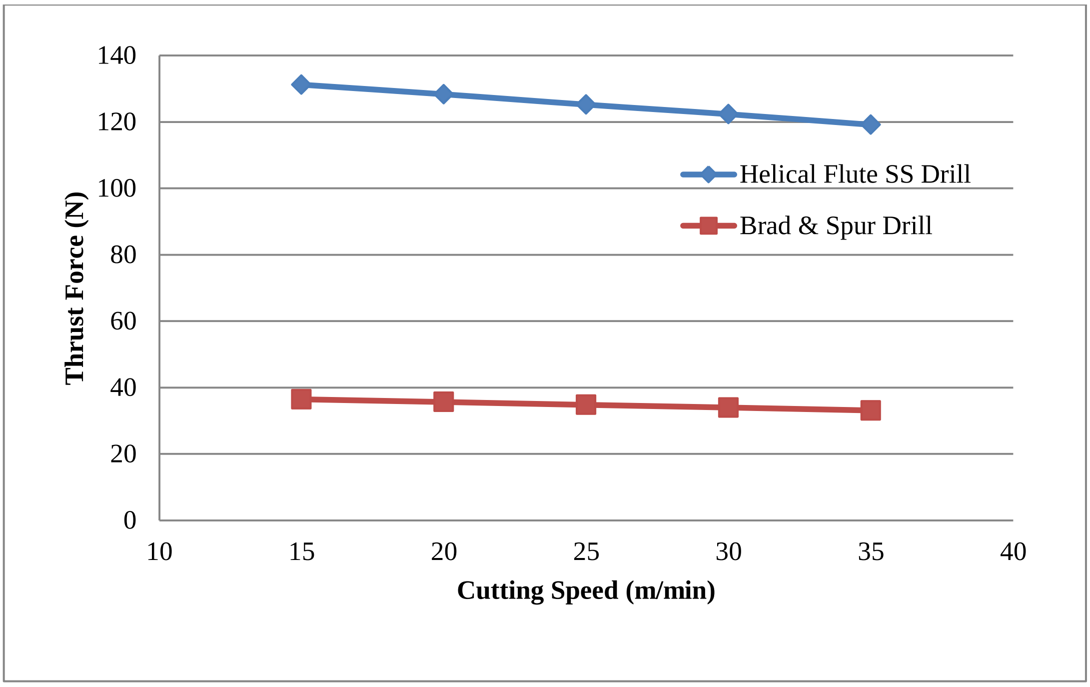

Figure 4.16 Thrust force for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15mm/rev

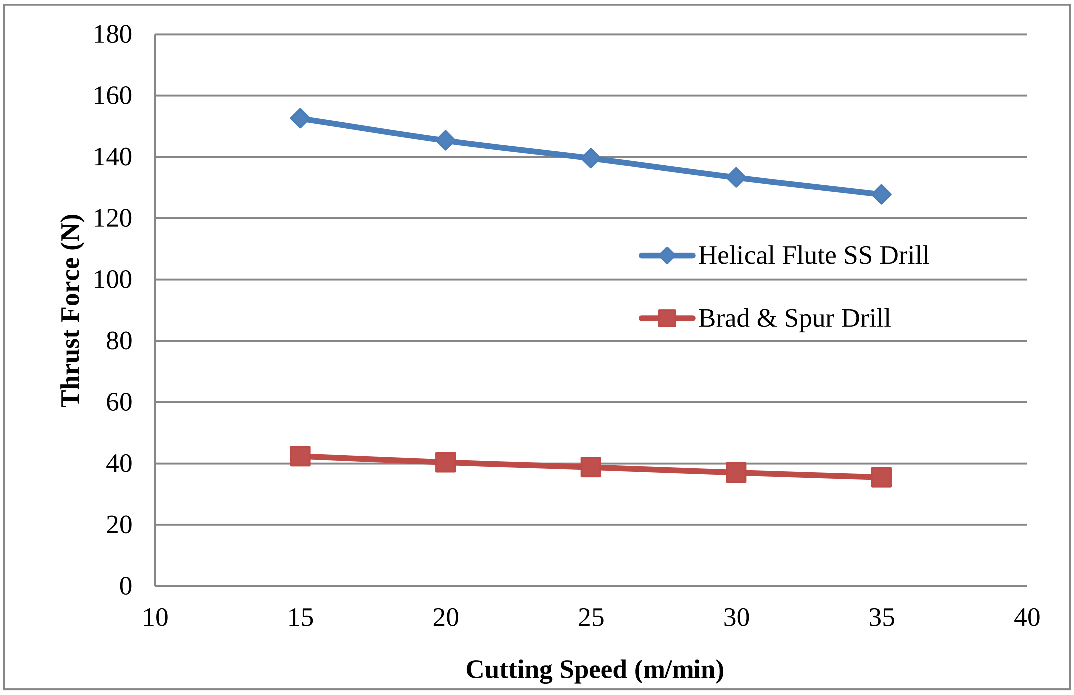

Figure 4.17 Thrust force for the drilled holes in GFRP-Epoxy laminates at feed rate 0.2mm/rev

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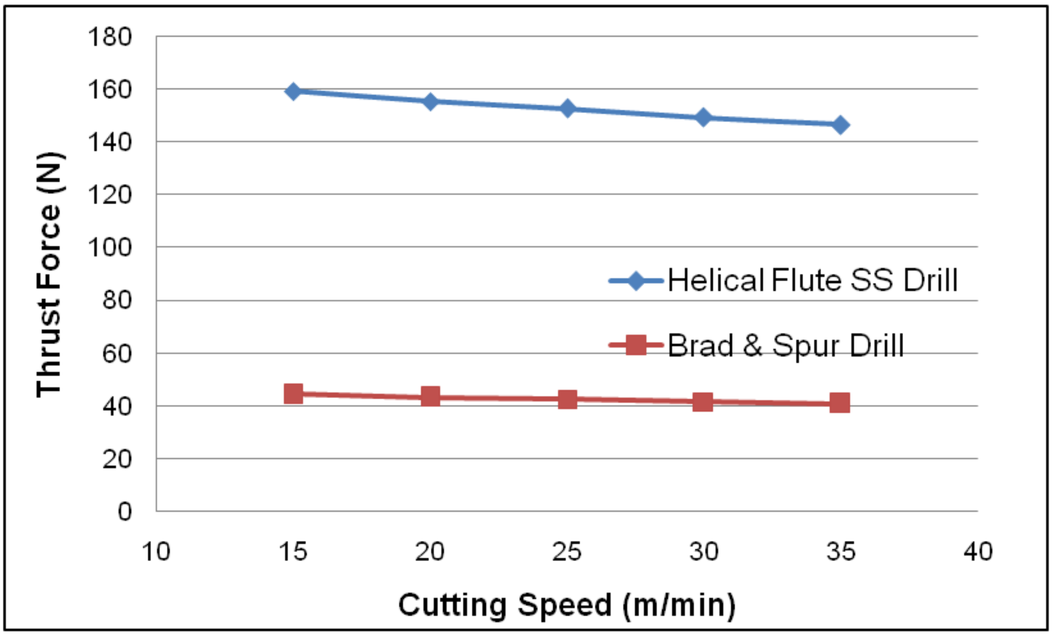

Figure 4.18 Thrust force for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

Figure 4.14 to Table 4.18 shows the Influence of drilling variables on peak thrust force for GFRP – Epoxy composites. The thrust forces are low for brad and spur drill as compared to helical flute SS drill.

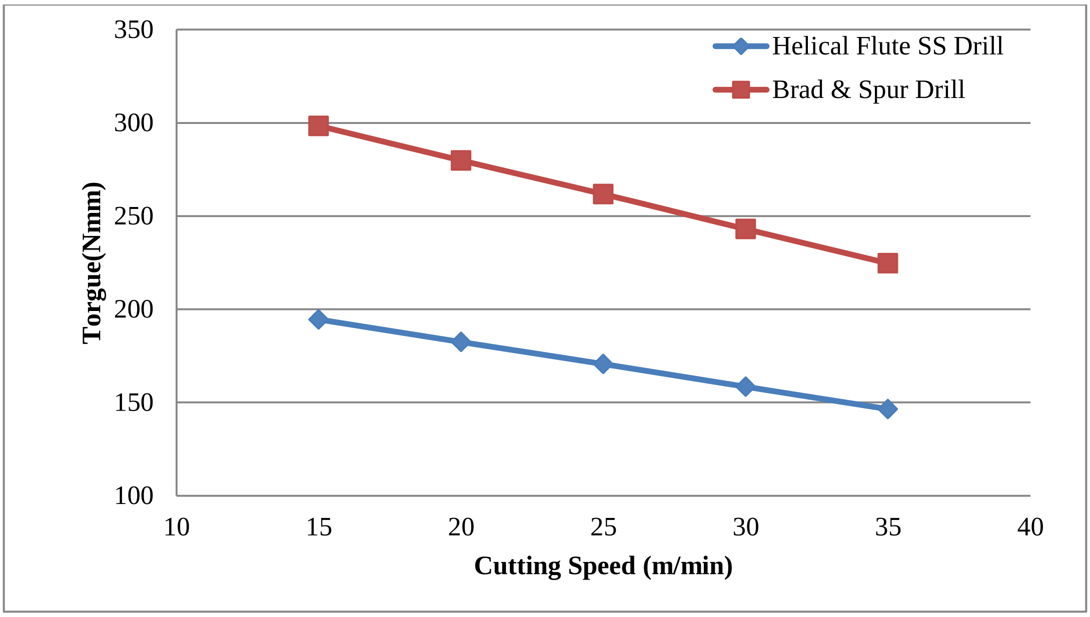

Figure 4.19 Torgue for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

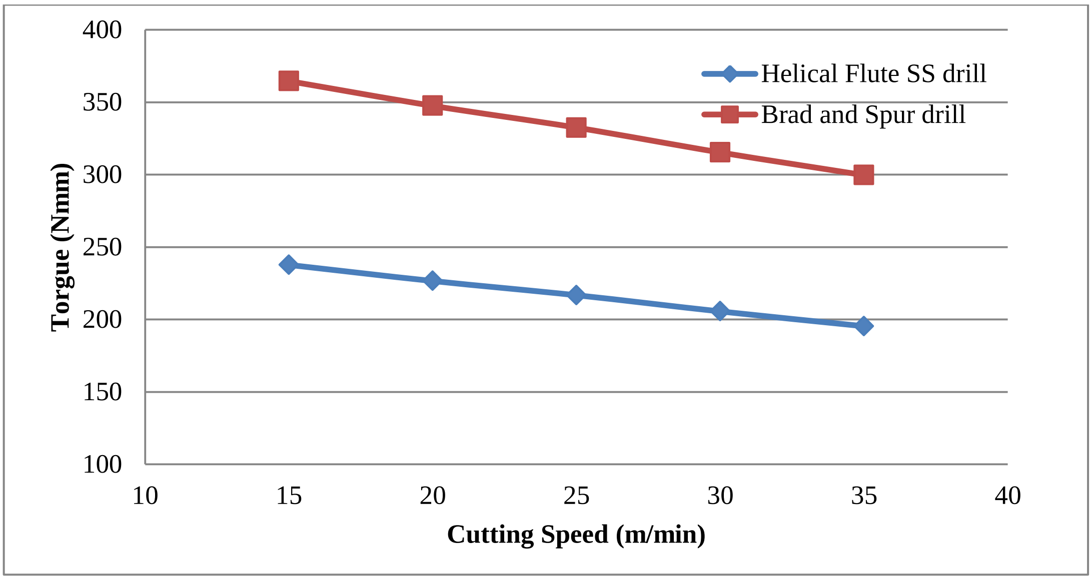

Figure 4.20 Torgue for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15mm/rev

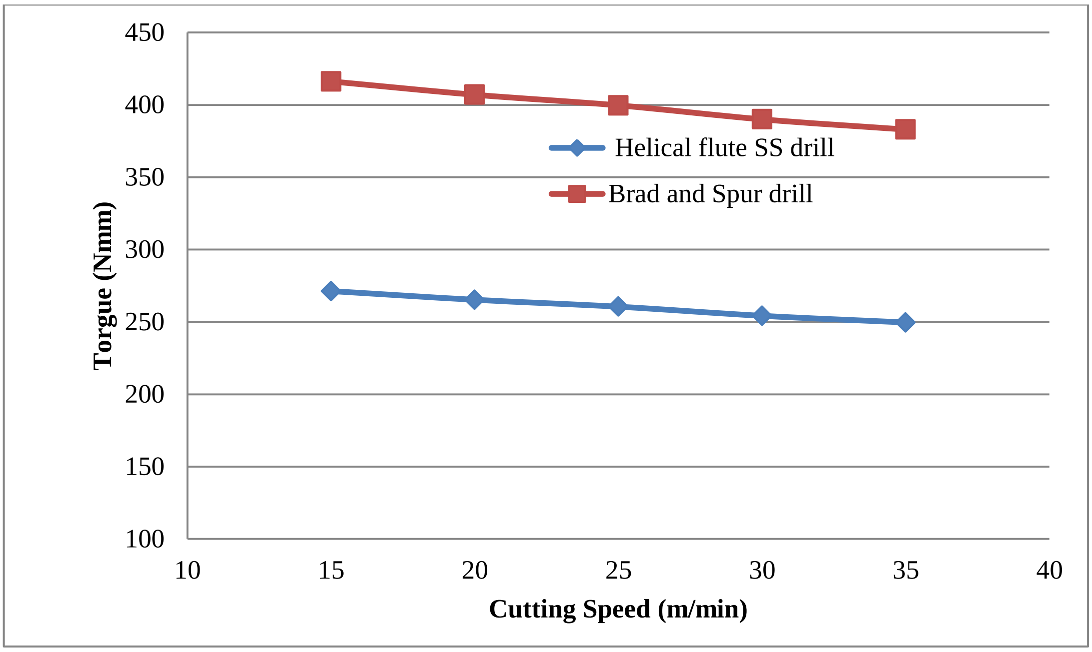

Figure 4.21 Torgue for the drilled holes in GFRP-Epoxy laminates at feed rate 0.2mm/rev

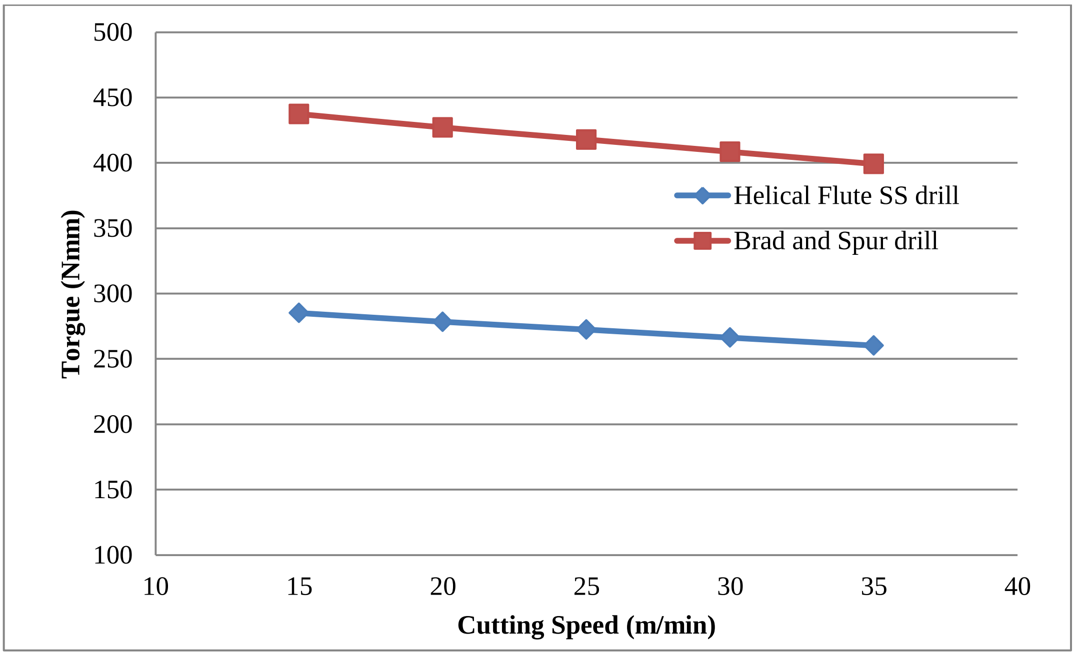

Figure 4.22 Torgue for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

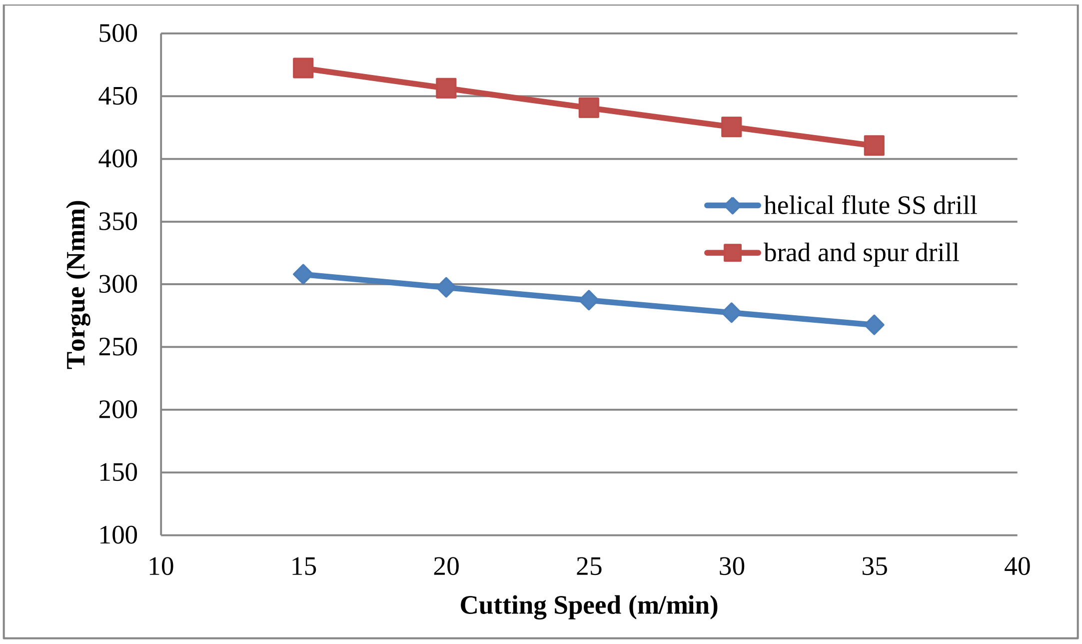

Figure 4.23 Torgue for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

Figure 4.19 to Figure 4.23 shows the Influence of drilling variables on torgue for GFRP – Epoxy composites. The torgue is found to be low for helical flute SS drill as compared to brad & spur drill.

4.3.2 Evaluation of Specific Cutting Pressure

Table 4.11 shows the variation of specific cutting pressure for the drilled holes in GFRP - Epoxy laminates at feed rate of 0.05 mm/rev. The specific cutting pressure decreases with increase in cutting speed irrespective of drill tool. It was found that specific cutting pressure was larger when using the brad and spur drill bit than the helical flute SS drill bit.

Table 4.11 to Table 4.15 shows the Influence of drilling variables specific cutting pressure for GFRP – Epoxy composites. The results indicate that, the specific cutting pressure were decreased with increasing feed. Figure 4.24 to Figure 4.28 shows the Influence of drilling variables on Specific cutting pressure for GFRP – Epoxy composites. The Specific cutting pressure is found to be low for helical flute SS drill compared to Brad & spur drill.

Table 4.11 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.05	864.53	1326.19
20	0.05	810.80	1243.77
25	0.05	758.36	1163.32
30	0.05	704.13	1080.14
35	0.05	650.89	998.46

Table 4.12 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.1mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.15	401.96	616.60
20	0.15	393.07	602.96
25	0.15	385.99	592.10
30	0.15	376.64	577.76
35	0.15	369.85	567.35

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Table 4.13 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.1	528.09	810.09
20	0.1	503.40	772.22
25	0.1	481.60	738.77
30	0.1	456.73	700.63
35	0.1	434.04	665.82

Table 4.14 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.2mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.2	316.80	485.97
20	0.2	309.37	474.57
25	0.2	302.70	464.34
30	0.2	295.86	453.84
35	0.2	289.14	443.55

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Table 4.15 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.25	273.64	419.76
20	0.25	264.42	405.62
25	0.25	255.32	391.65
30	0.25	246.52	378.17
35	0.25	237.81	364.81

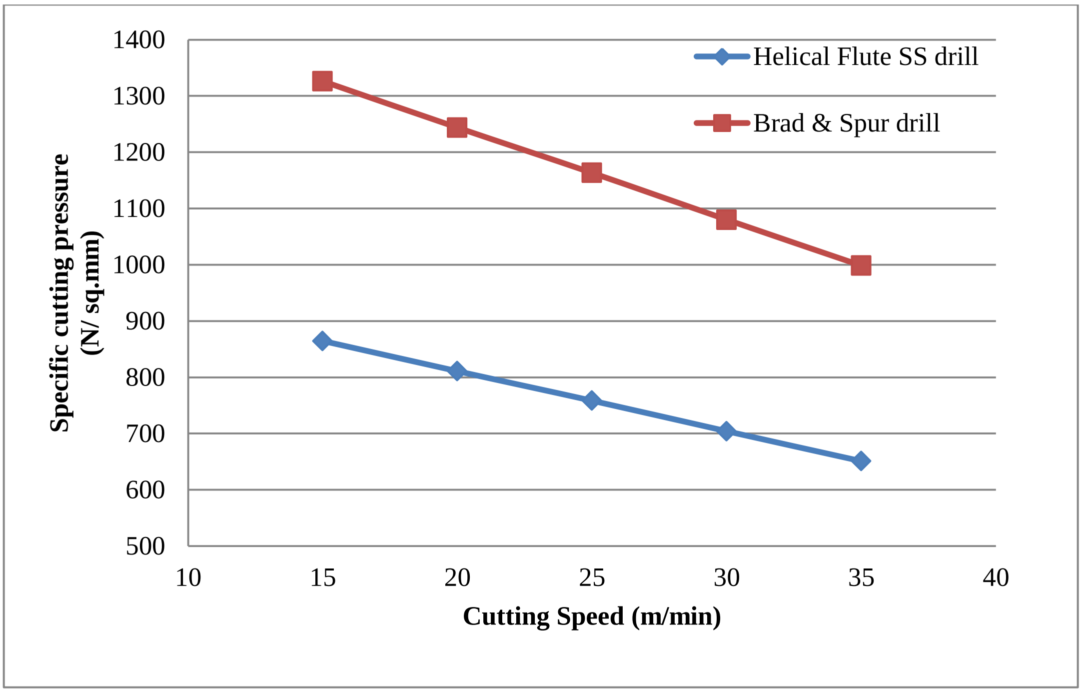

Figure 4.24 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

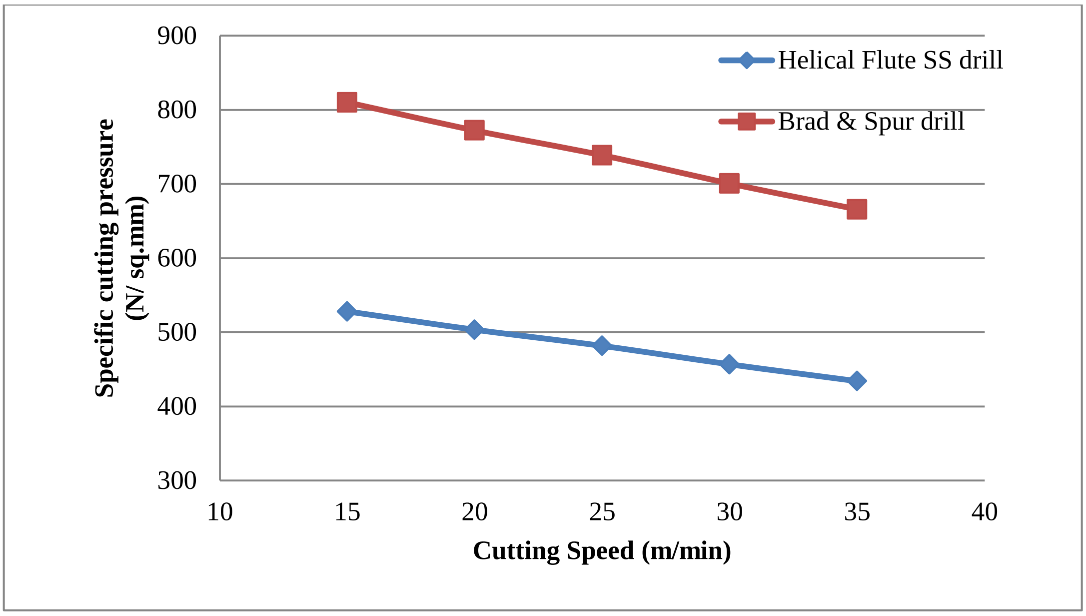

Figure 4.25 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.1mm/rev

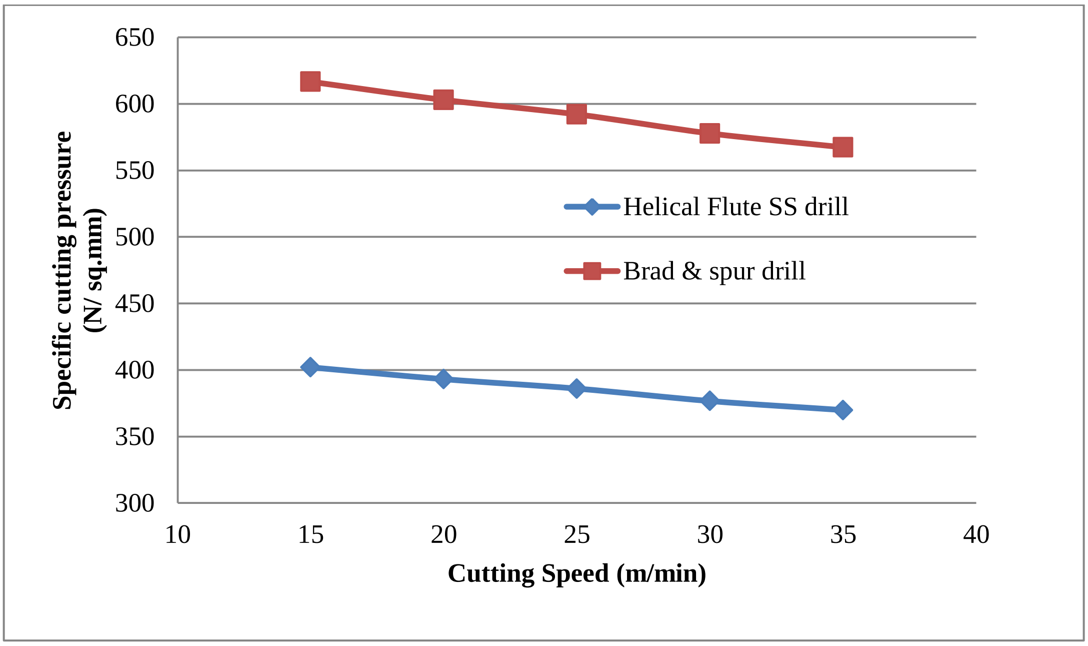

Figure 4.26 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15mm/rev

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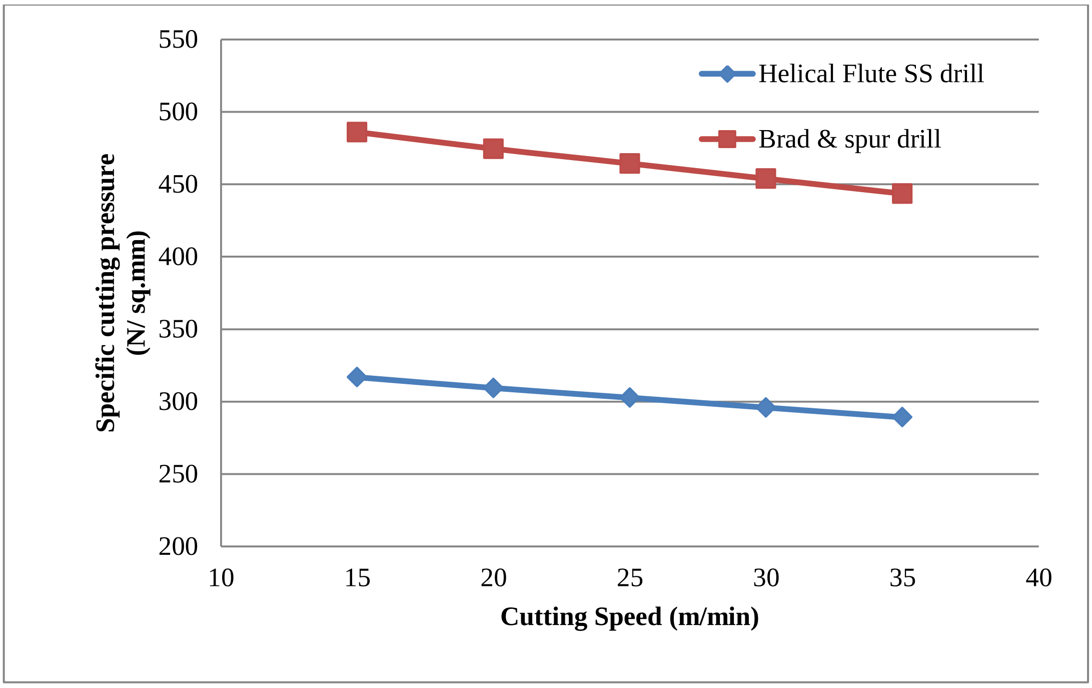

Figure 4.27 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.2mm/rev

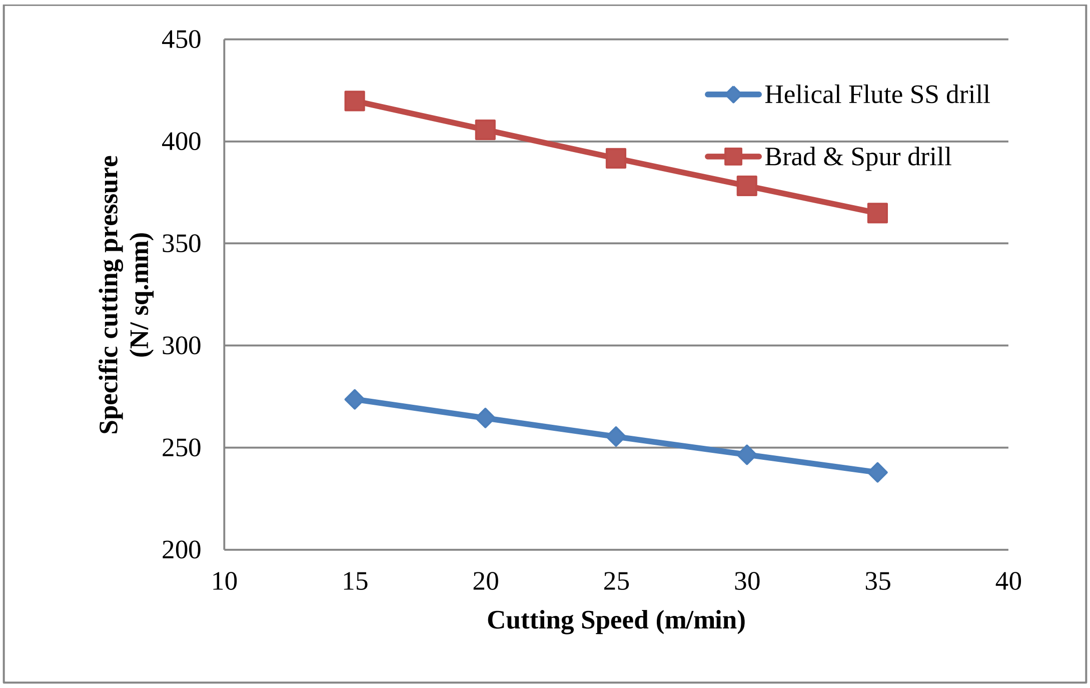

Figure 4.28 Specific cutting pressure for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

Table 4.16 shows the variation of thrust force and torque for the drilled holes in GFRP- Polyester laminates at feed rate 0.05 mm/rev. The thrust force and torque decreases with increase in cutting speed irrespective of drill tool. It was found that thrust force was larger when using the helical flute SS drill bit than the brad and spur drill bit.

Table 4.16 to Table 4.20 shows the Influence of drilling variables on peak thrust force and torque, respectively for GFRP – Polyester composites. The results indicate that, the thrust force and torque were increased with increasing feed. This fact was due to the increase in the cross-sectional area of the undeformed chip. The increase in hardness and cutting resistance of the material may also result in wear in the cutting edges of the drill through drilling one hole. Therefore the thrust force and torque were increased with increasing cutting speed.

Table 4.16 Thrust force and Torque for the drilled holes in GFRP- Polyester laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.05	58.43	16.23	205.52	315.27
20	0.05	54.52	15.14	198.72	304.84
25	0.05	51.23	14.23	192.23	294.88
30	0.05	47.52	13.2	186.45	286.01
35	0.05	44.34	12.32	180.34	276.64

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Table 4.17 Thrust force and Torque for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.1	104.83	29.12	251.23	385.39
20	0.1	95.53	26.54	239.23	366.98
25	0.1	87.26	24.24	228.53	350.57
30	0.1	78.45	21.79	217.34	333.4
35	0.1	70.23	19.51	206.86	317.32

Table 4.18 Thrust force and Torque for the drilled holes in GFRP-Polyester laminates at feed rate 0.15 mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.15	128.23	35.62	314.43	482.34
20	0.15	124.63	34.62	305.45	468.56
25	0.15	120.72	33.53	296.13	454.26
30	0.15	116.23	32.29	287.37	440.83
35	0.15	112.74	31.32	279.36	428.54

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Table 4.19 Thrust force and Torque for the drilled holes in GFRP-Polyester laminates at feed rate 0.2 mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.2	145.45	40.4	355.23	544.92
20	0.2	140.25	38.96	353.23	541.85
25	0.2	135.53	37.65	352.45	540.66
30	0.2	130.72	36.31	350.23	537.25
35	0.2	126.34	35.09	349.23	535.72

Table 4.20 Thrust force and Torque for the drilled holes in GFRP-Polyester laminates at feed rate 0.25 mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Thrust Force (N)		Torgue (N-mm)	
		Helical flute SS drill	Brad & spur drill	Helical flute SS drill	Brad & spur drill
15	0.25	164.32	45.64	448.23	687.58
20	0.25	159.34	44.26	430.87	660.95
25	0.25	154.43	42.9	413.24	633.91
30	0.25	149.54	41.54	396.28	607.89
35	0.25	144.23	40.06	379.45	582.08

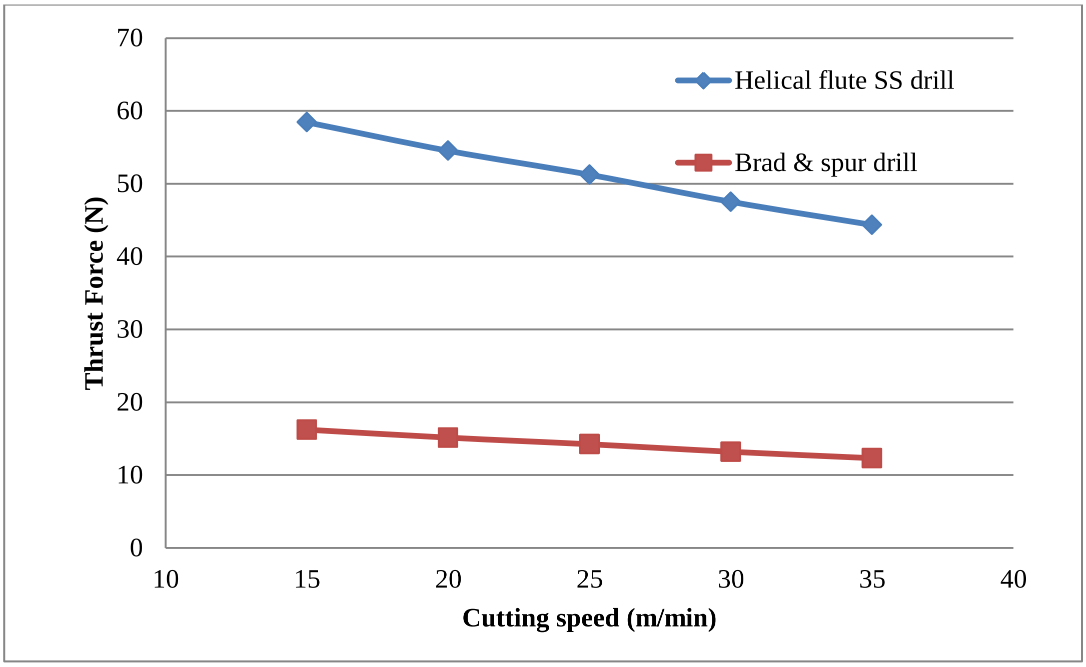

Figure 4.29 Thrust force for the drilled holes in GFRP-Polyester laminates at feed rate 0.05mm/rev

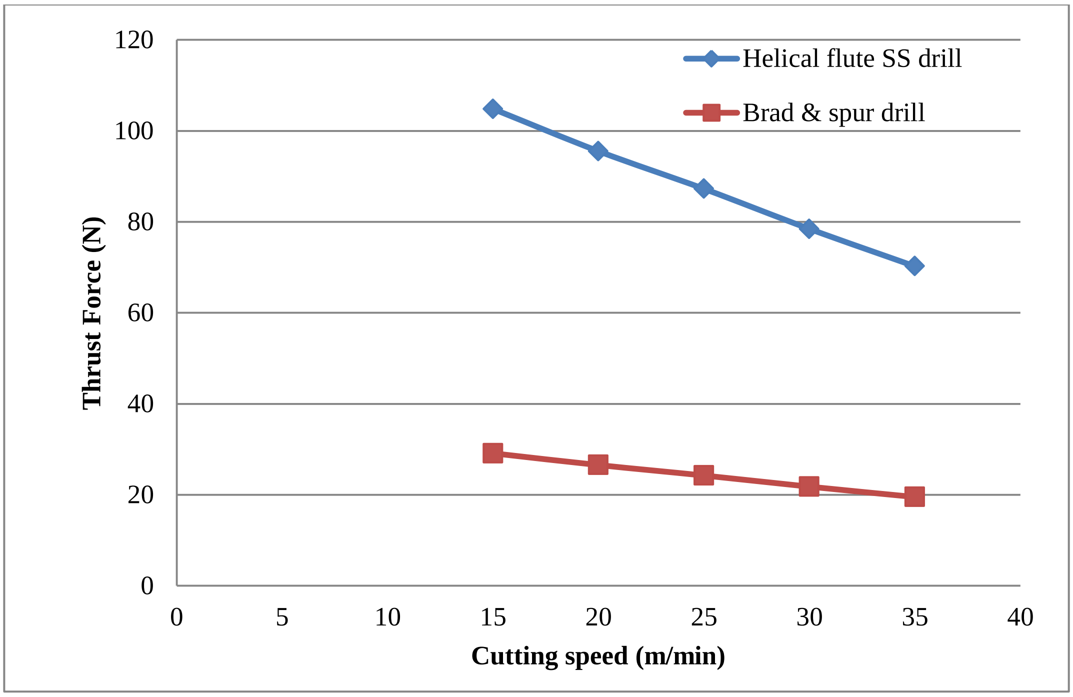

Figure 4.30 Thrust force for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

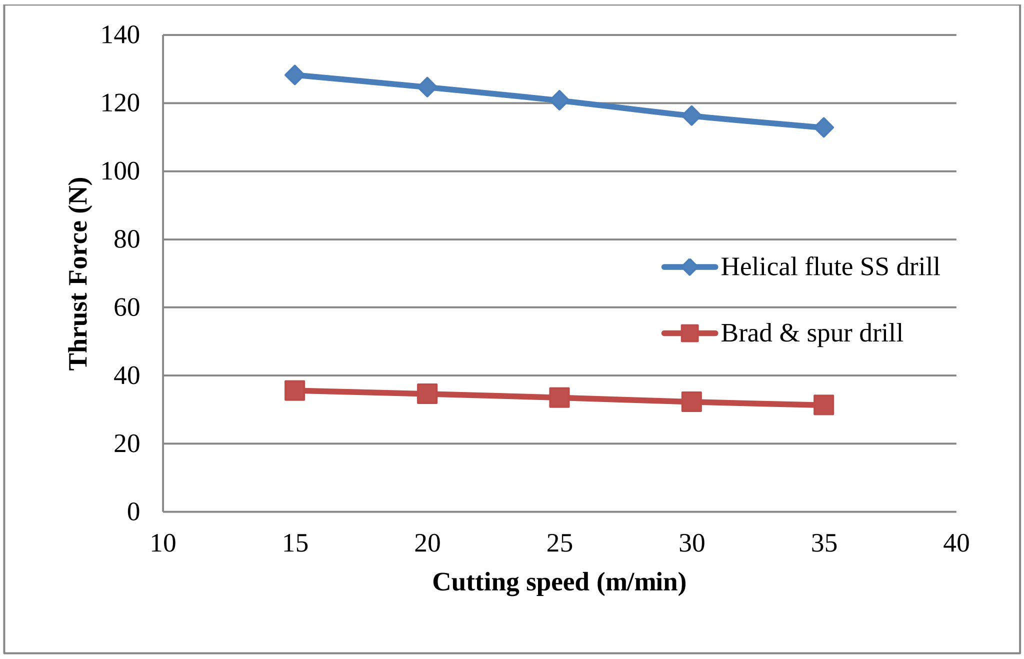

Figure 4.31 Thrust force for the drilled holes in GFRP- Polyester laminates at feed rate 0.15mm/rev

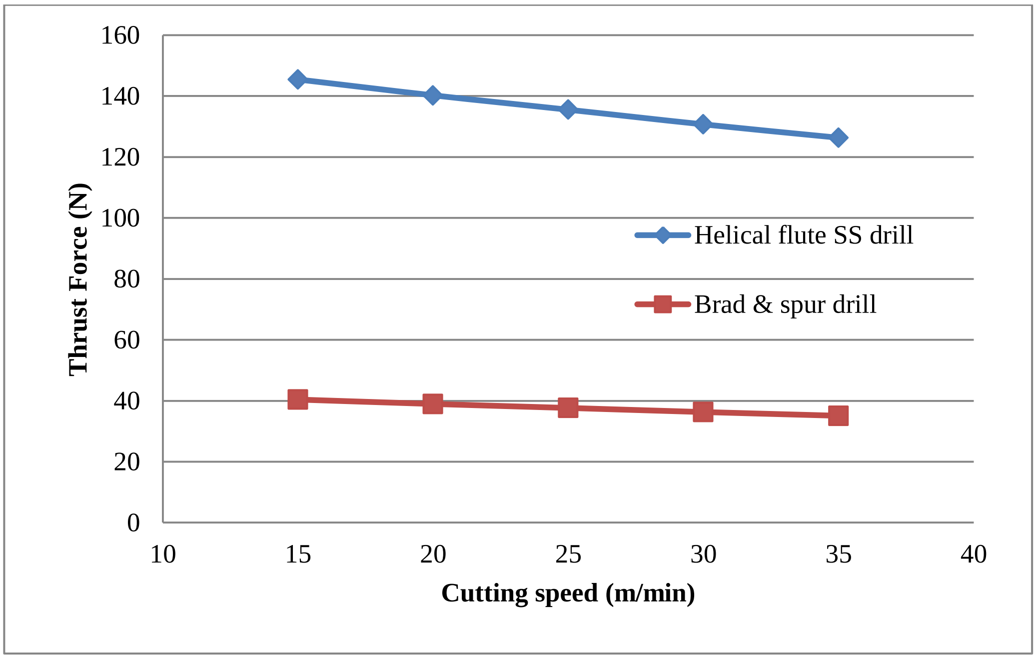

Figure 4.32 Thrust force for the drilled holes in GFRP-Polyester laminates at feed rate 0.2mm/rev

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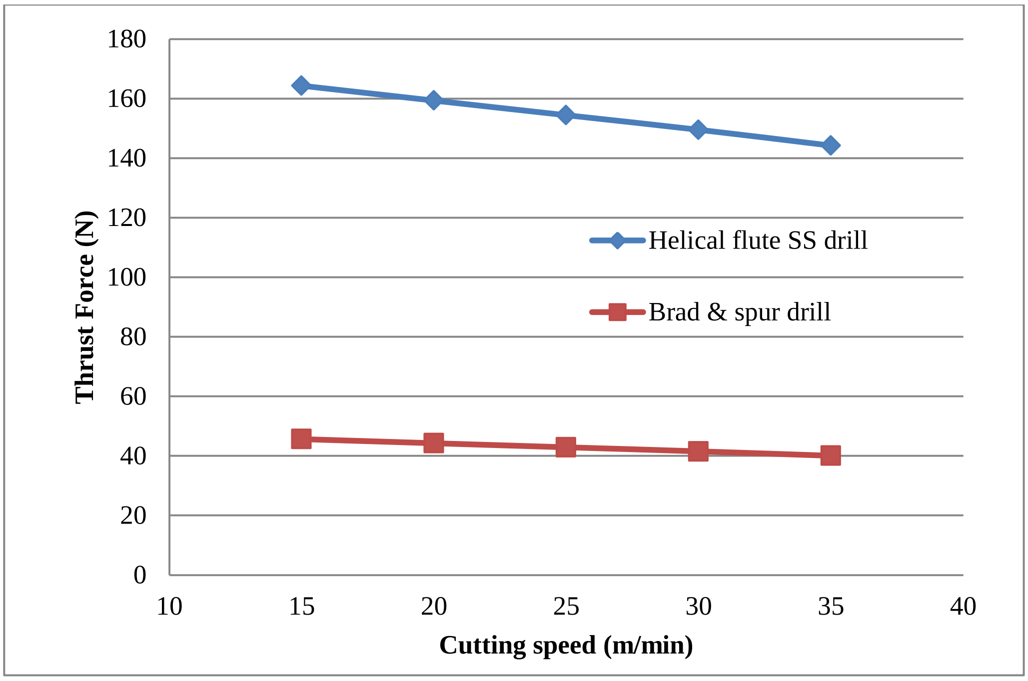

Figure 4.33 Thrust force for the drilled holes in GFRP-polyester laminates at feed rate 0.25mm/rev

Figure 4.29 to Table 4.33 shows the Influence of drilling variables on peak thrust force for GFRP – Polyester composites. The thrust forces are low for brad and spur drill as compared to helical flute SS drill.

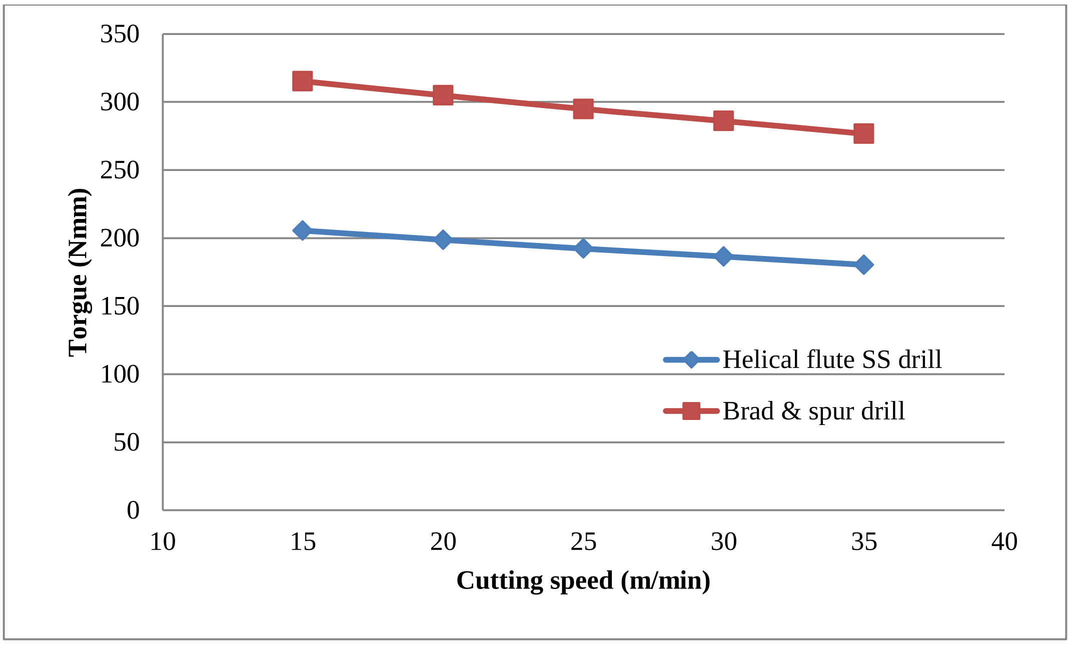

Figure 4.34 Torgue for the drilled holes in GFRP-Polyester laminates at feed rate 0.05mm/rev

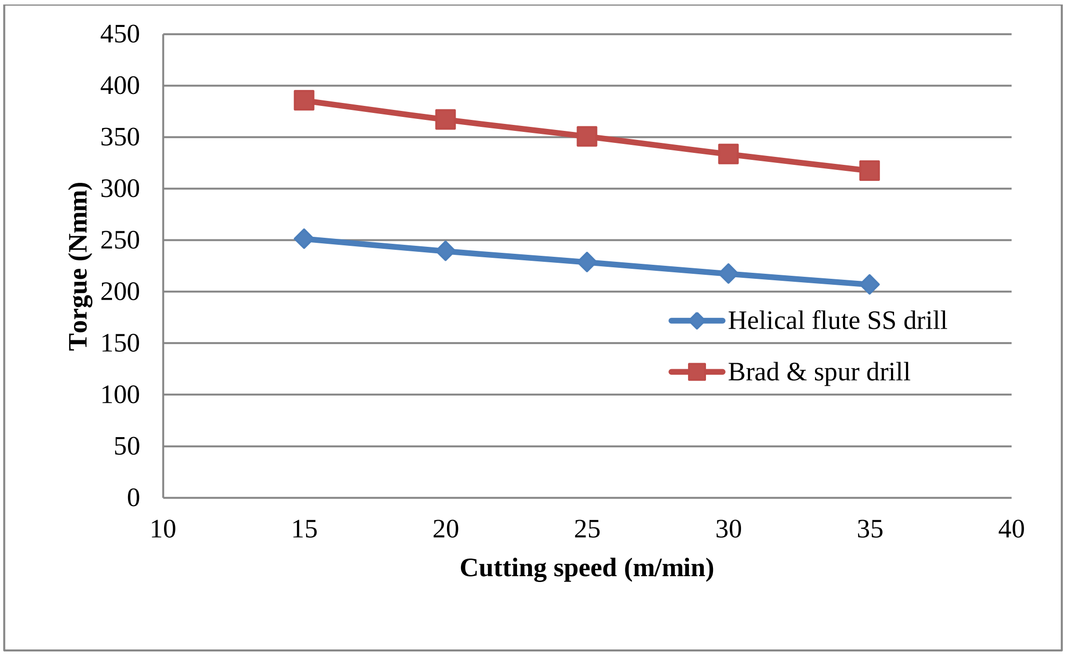

Figure 4.35 Torgue for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

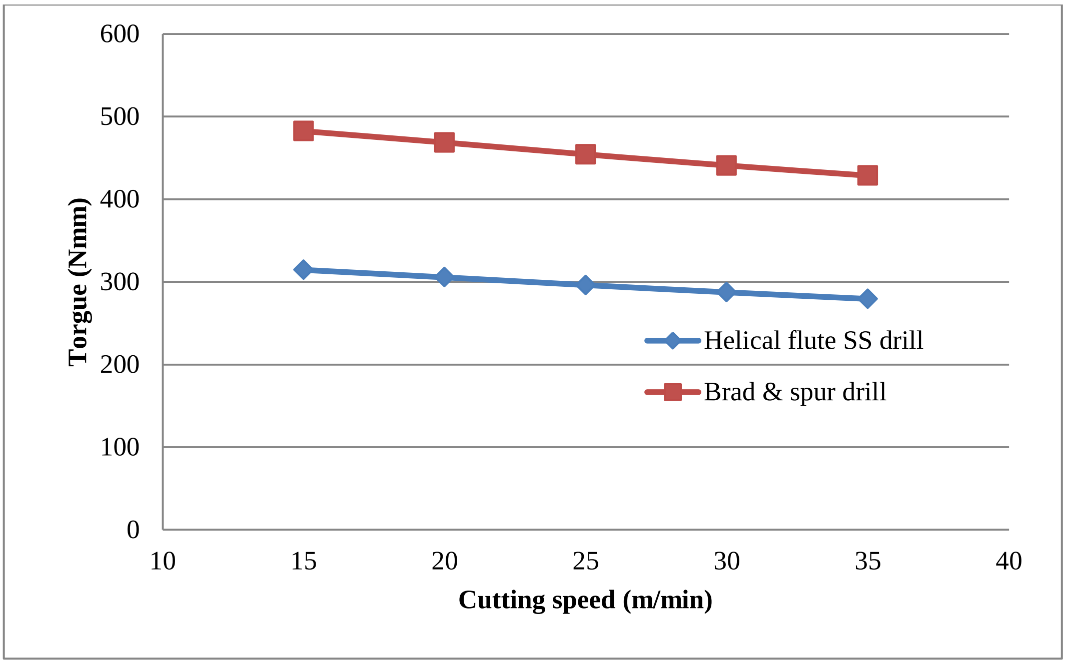

Figure 4.36 Torgue for the drilled holes in GFRP-Polyester laminates at feed rate 0.15mm/rev

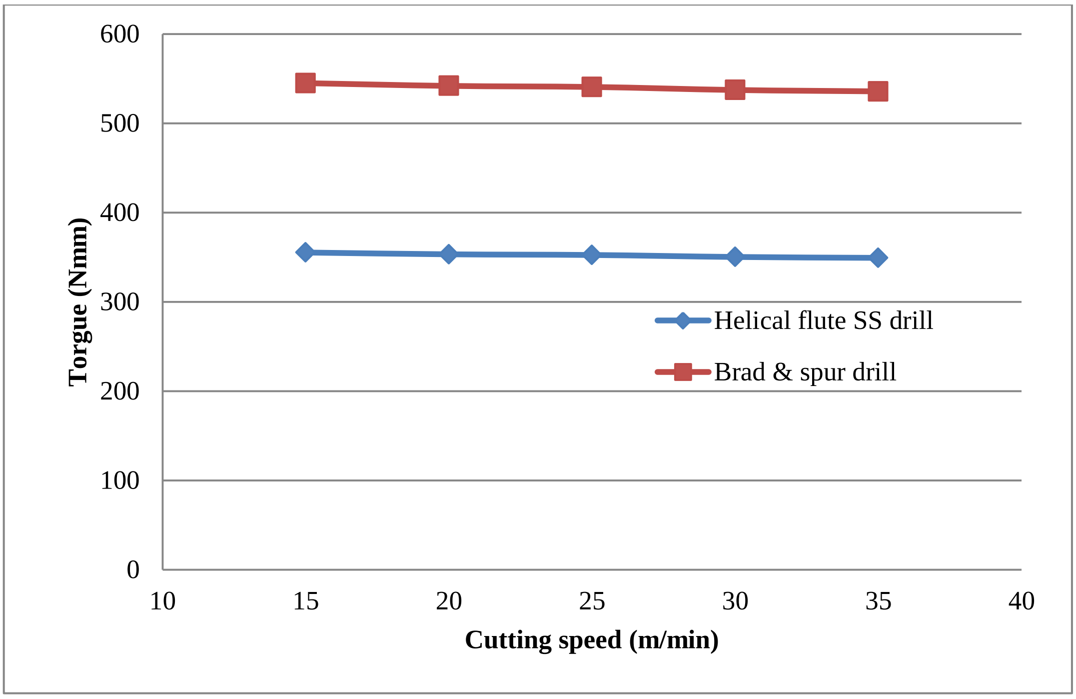

Figure 4.37 Torgue for the drilled holes in GFRP-Polyester laminates at feed rate 0.2mm/rev

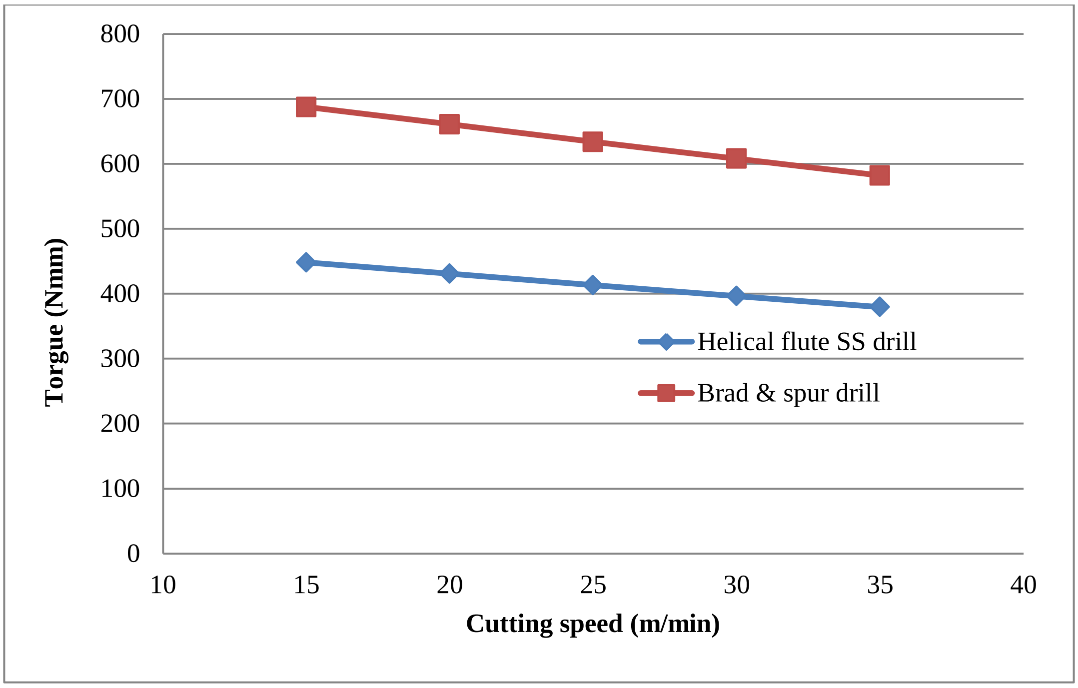

Figure 4.38 Torgue for the drilled holes in GFRP-Polyester laminates at feed rate 0.25mm/rev

Figure 4.34 to Figure 4.38 shows the Influence of drilling variables on torgue for GFRP – Polyester composites. The torgue is found to be low for helical flute SS drill compared to Brad and spur drill.

Table 4.21 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.05	913.42	1401.19
20	0.05	883.2	1354.83
25	0.05	854.36	1310.58
30	0.05	828.67	1271.17
35	0.05	801.51	1229.52

Table 4.22 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.1	558.29	856.42
20	0.1	531.62	815.51
25	0.1	507.84	779.03
30	0.1	482.98	740.89
35	0.1	459.69	705.16

Table 4.23 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.15mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	**Specific cutting pressure (N/mm^2)**	
		Helical flute SS drill	Brad & spur drill
15	0.15	465.82	714.57
20	0.15	452.52	694.16
25	0.15	438.71	672.98
30	0.15	425.73	653.07
35	0.15	413.87	634.87

Table 4.24 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.2mm/rev

Cutting Speed V(m/min)	**Feed rate f (mm/rev)**	**Specific cutting pressure (N/mm^2)**	
		Helical flute SS drill	**Brad & spur drill**
15	0.2	394.7	605.47
20	0.2	392.48	602.06
25	0.2	391.61	600.73
30	0.2	389.14	596.95
35	0.2	388.03	595.24

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Table 4.25 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.25mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Specific cutting pressure (N/mm^2)	
		Helical flute SS drill	Brad & spur drill
15	0.25	398.43	611.19
20	0.25	383	587.52
25	0.25	367.32	563.48
30	0.25	352.25	540.35
35	0.25	337.29	517.4

Table 4.21 shows the variation of specific cutting pressure for the drilled holes in GFRP- Polyester laminates at feed rate of 0.05 mm/rev. The specific cutting pressure decreases with increase in cutting speed irrespective of drill tool. It was found that specific cutting pressure was larger when using the brad and spur drill bit than the helical flute SS drill bit.

Table 4.21 to Table 4.25 shows the Influence of drilling variables specific cutting pressure for GFRP – Polyester composites. The results indicate that, the specific cutting pressure were decreased with increasing feed.

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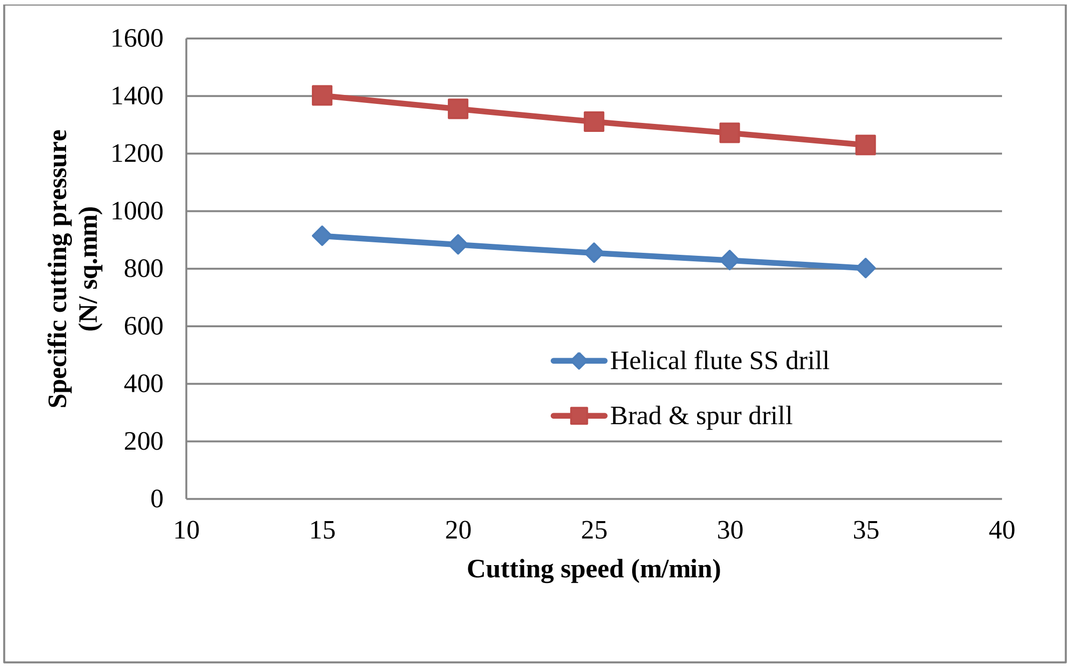

Figure 4.39 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.05mm/rev

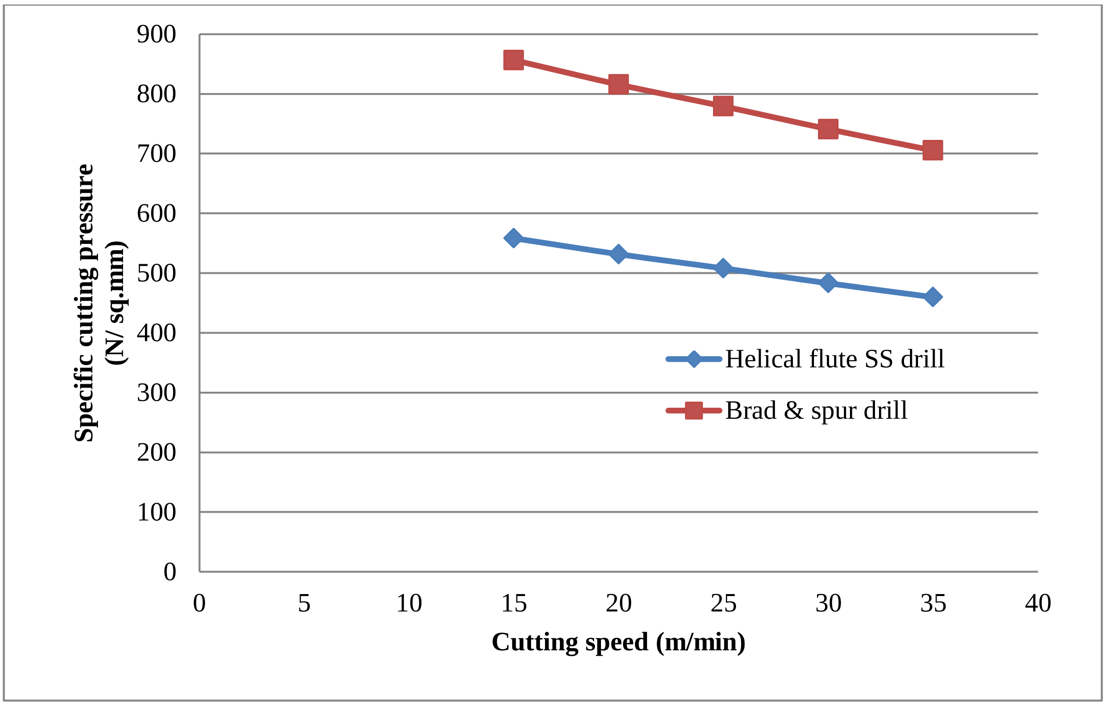

Figure 4.40 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

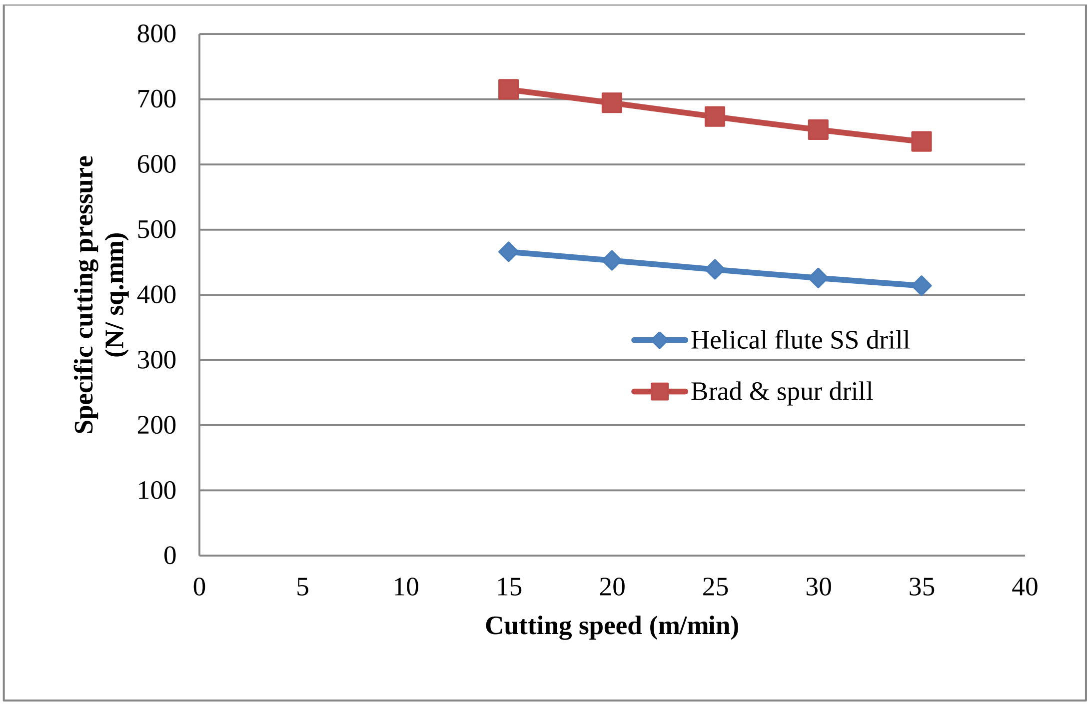

Figure 4.41 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.15mm/rev

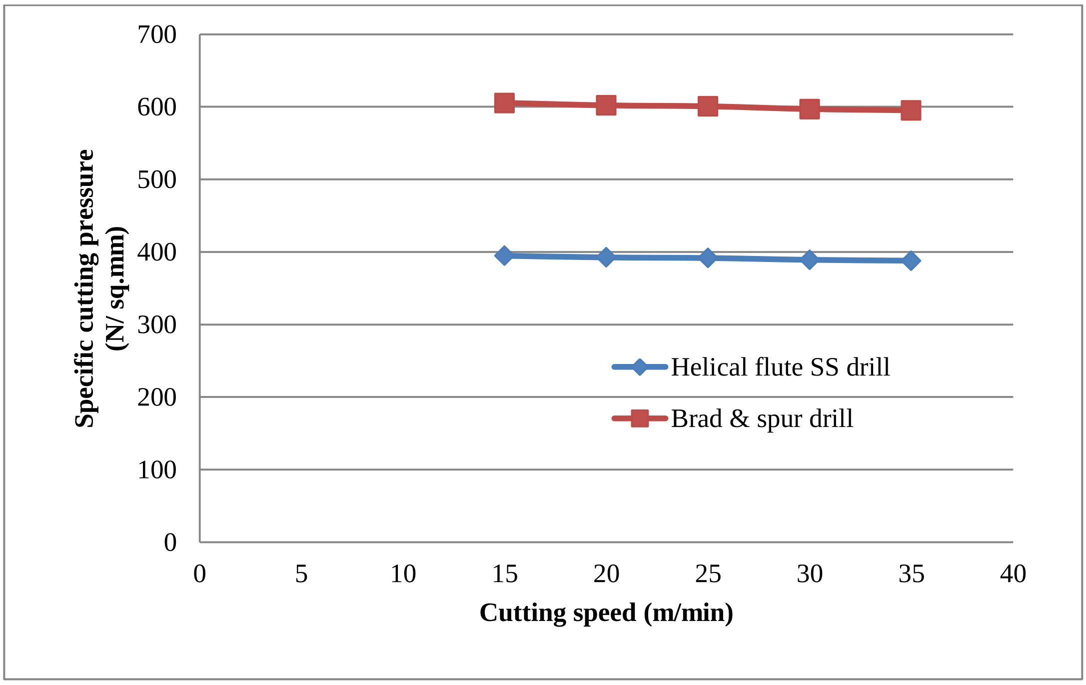

Figure 4.42 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.2mm/rev

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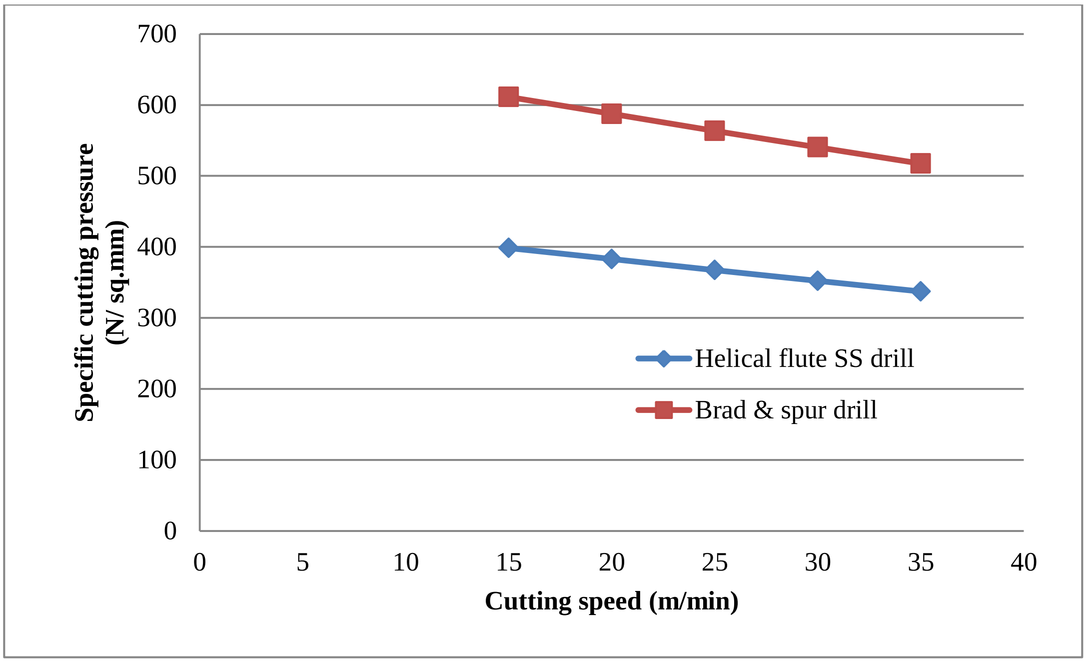

Figure 4.43 Specific cutting pressure for the drilled holes in GFRP-Polyester laminates at feed rate 0.25mm/rev

Figure 4.38 to Figure 4.43 shows the Influence of drilling variables on Specific cutting pressure for GFRP – Polyester composites. The Specific cutting pressure is found to be low for helical flute SS drill as compared to Brad and spur drill.

4.3.3 Computation of Delamination

The specimen was placed directly on the glass plate of the flat bed scanner. The image of the drilled specimen was obtained. Shadow zone was clearly observed around the drilled hole due to the transmitted light through it by using the CorelDraw software. The shadow zone indicates the delamination size.

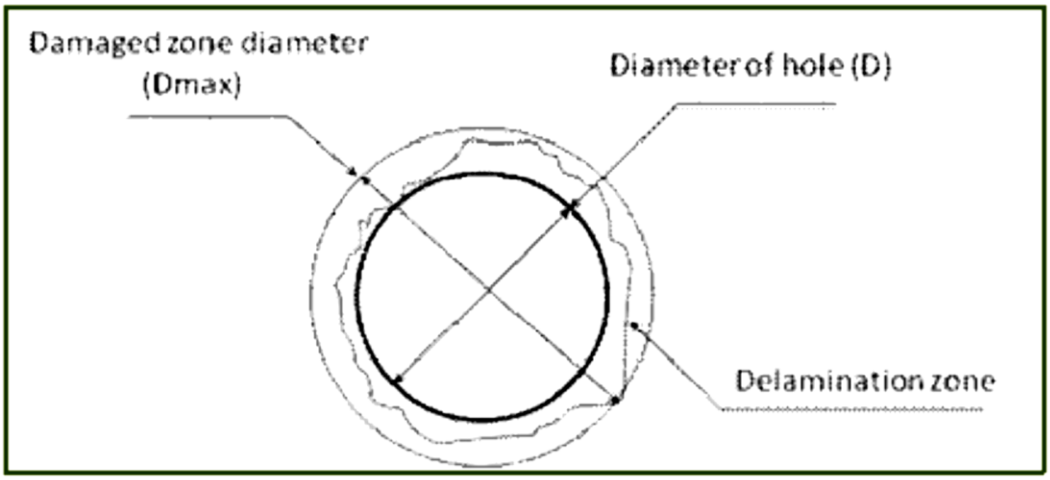

Figure 4.44 The scheme of delamination

Delamination at entrance (peel up) and at exit (push out) can be determined. The damage of hole was denoted by the delamination factor Fd. The scheme of the delamination is shown in Figure 4.44.

The value of delamination factor (Fd) can be obtained by the following formula;

$$Fd = Dmax/D$$

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Table 4.26 Photographs illustrating pullout and push out in GFRP-Epoxy laminates

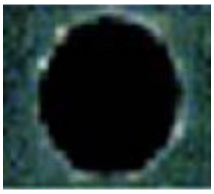
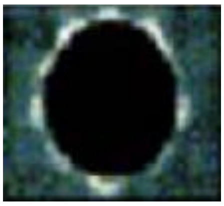
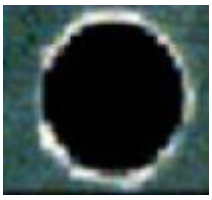
Feed	Pull out lamination	Push out lamination
0.05mm/rev		
0.1 mm/rev		
0.15 mm/rev		
0.2 mm/rev		
0.25 mm/rev		

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Table 4.27 Photographs illustrating pullout and push out in GFRP-Polyester laminates

Feed	Pull out lamination	Push out lamination
0.05mm/rev		
0.1 mm/rev		
0.15 mm/rev		
0.2 mm/rev		
0.25 mm/rev		

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Table 4.28 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.05	0.182	0.762	0.051	0.012	1.061	1.254	1.017	1.004
20	0.05	0.202	0.752	0.070	0.031	1.067	1.251	1.023	1.010
25	0.05	0.222	0.742	0.089	0.050	1.074	1.247	1.030	1.017
30	0.05	0.242	0.732	0.108	0.069	1.081	1.244	1.036	1.023
35	0.05	0.262	0.722	0.128	0.089	1.087	1.241	1.043	1.030

Table 4.29 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.1mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.1	0.264	0.943	0.129	0.090	1.088	1.314	1.043	1.030
20	0.1	0.304	0.991	0.168	0.129	1.101	1.330	1.056	1.043
25	0.1	0.344	1.039	0.206	0.167	1.115	1.346	1.069	1.056
30	0.1	0.383	1.086	0.244	0.205	1.128	1.362	1.081	1.068
35	0.1	0.423	1.134	0.282	0.243	1.141	1.378	1.094	1.081

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Table 4.30 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.15	0.463	1.256	0.320	0.281	1.154	1.419	1.107	1.094
20	0.15	0.478	1.270	0.334	0.295	1.159	1.423	1.111	1.098
25	0.15	0.493	1.284	0.349	0.310	1.164	1.428	1.116	1.103
30	0.15	0.507	1.298	0.363	0.324	1.169	1.433	1.121	1.108
35	0.15	0.522	1.312	0.377	0.338	1.174	1.437	1.126	1.113

Table 4.31 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.2	0.512	1.426	0.367	0.328	1.171	1.475	1.122	1.109
20	0.2	0.560	1.408	0.413	0.374	1.187	1.469	1.138	1.125
25	0.2	0.493	1.284	0.349	0.310	1.164	1.428	1.116	1.103
30	0.2	0.655	1.371	0.504	0.465	1.218	1.457	1.168	1.155
35	0.2	0.702	1.352	0.549	0.510	1.234	1.451	1.183	1.170

Table 4.32 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.25	0.523	1.521	0.378	0.339	1.174	1.507	1.126	1.113
20	0.25	0.581	1.497	0.433	0.394	1.194	1.499	1.144	1.131
25	0.25	0.639	1.474	0.488	0.449	1.213	1.491	1.163	1.150
30	0.25	0.696	1.450	0.544	0.505	1.232	1.483	1.181	1.168
35	0.25	0.754	1.426	0.599	0.560	1.251	1.475	1.200	1.187

Table 4.33 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.05mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.05	0.321	0.816	0.184	0.016	1.107	1.208	1.061	1.005
20	0.05	0.411	0.768	0.271	0.103	1.137	1.224	1.09	1.034
25	0.05	0.502	0.72	0.357	0.189	1.167	1.24	1.119	1.063
30	0.05	0.592	0.672	0.444	0.276	1.197	1.256	1.148	1.092
35	0.05	0.682	0.624	0.53	0.362	1.227	1.272	1.177	1.121

Table 4.34 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.1	0.726	1.212	0.572	0.404	1.242	1.342	1.191	1.135
20	0.1	0.79	1.165	0.634	0.466	1.263	1.357	1.211	1.155
25	0.1	0.854	1.119	0.695	0.527	1.285	1.373	1.232	1.176
30	0.1	0.918	1.072	0.756	0.588	1.306	1.388	1.252	1.196
35	0.1	0.982	1.025	0.818	0.65	1.327	1.404	1.273	1.217

Table 4.35 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.15mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.15	1.264	1.402	1.088	0.92	1.372	1.414	1.315	1.259
20	0.15	1.227	1.362	1.053	0.885	1.384	1.428	1.327	1.271
25	0.15	1.19	1.323	1.017	0.849	1.397	1.441	1.339	1.283
30	0.15	1.153	1.283	0.982	0.814	1.409	1.454	1.351	1.295
35	0.15	1.116	1.243	0.946	0.778	1.421	1.467	1.363	1.307

Table 4.36 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.2mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.2	1.312	1.516	1.134	0.966	1.437	1.475	1.378	1.322
20	0.2	1.339	1.494	1.16	0.992	1.446	1.483	1.387	1.331
25	0.2	1.367	1.471	1.186	1.018	1.456	1.49	1.395	1.339
30	0.2	1.394	1.449	1.213	1.045	1.465	1.498	1.404	1.348
35	0.2	1.421	1.426	1.239	1.071	1.474	1.505	1.413	1.357

Table 4.37 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.25mm/rev

Cutting Speed V(m/min)	Feed rate f (mm/rev)	Delamination size Sd (mm)				Delamination factorFd			
		Helical flute SS drill		Brad & spur drill		Helical flute SS drill		Brad & spur drill	
		Peel up	Push out	Peel up	Push out	Peel up	Push out	Peel up	Push out
15	0.25	1.303	1.526	1.126	0.958	1.434	1.493	1.375	1.319
20	0.25	1.33	1.514	1.152	0.984	1.443	1.497	1.384	1.328
25	0.25	1.358	1.502	1.178	1.01	1.453	1.501	1.393	1.337
30	0.25	1.385	1.49	1.204	1.036	1.462	1.505	1.401	1.345
35	0.25	1.412	1.478	1.23	1.062	1.471	1.509	1.41	1.354

Delamination at entrance (peel up) and at exit (push out) was determined for GFRP-Epoxy and GFRP-Polyester laminates. The delamination factor was determined for the composite laminates and the drilling was performed by Helical flute SS drill and Brad and spur drill with various cutting speed and feed rate as shown in Table 4.28. The delamination increases with cutting peed and feed rate irrespective of the type of the drilling tool and GFRP composites as shown in Table 4.30. The delamination factor is found to be low when Brad and spur drill tool is used for drilling. It is found from the Table 4.31 that the delamination factor is less for GFRP-Epoxy laminates when the Brad and spur drill tool is used.

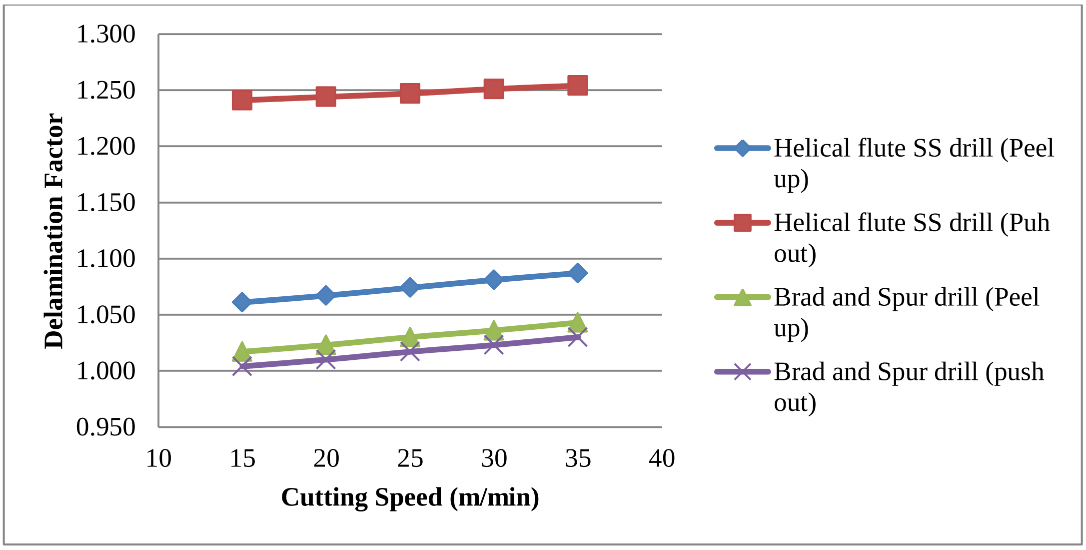

Figure 4.45 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.05mm/rev

The delamination is found to be low when the Brad and spur drill tool is used compared to helical flute SS drill as shown in Figure 4.45. The delamination gradually increases with cutting speed. The helical flute SS drill gives high delamination size in push out condition.

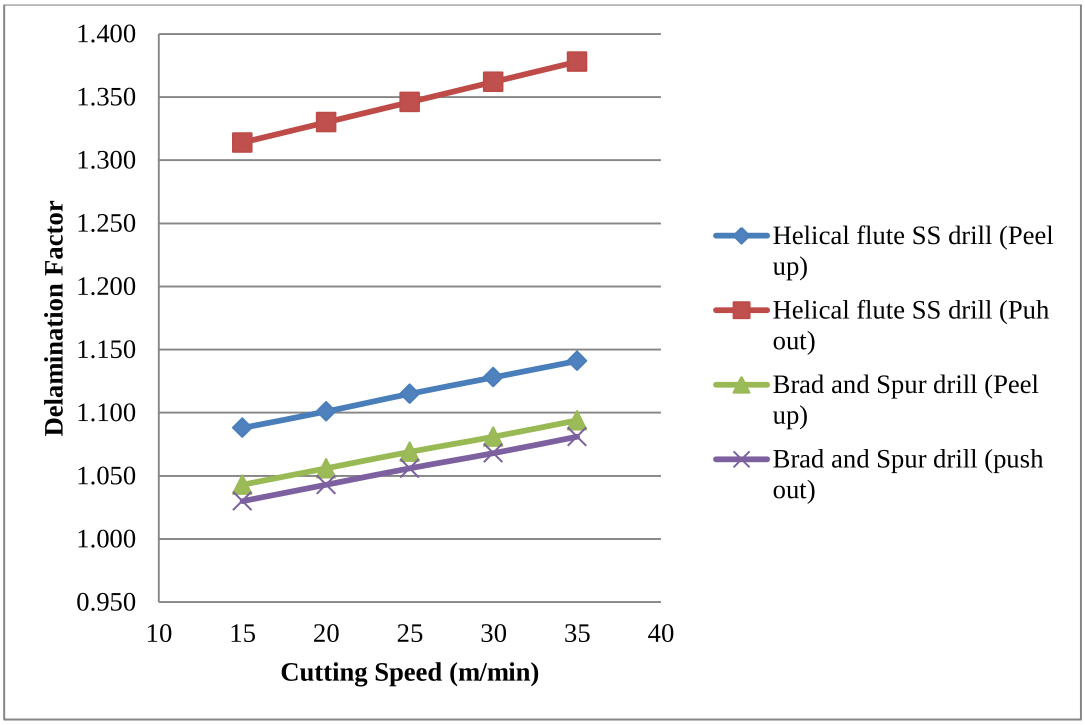

Figure 4.46 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.1mm/rev

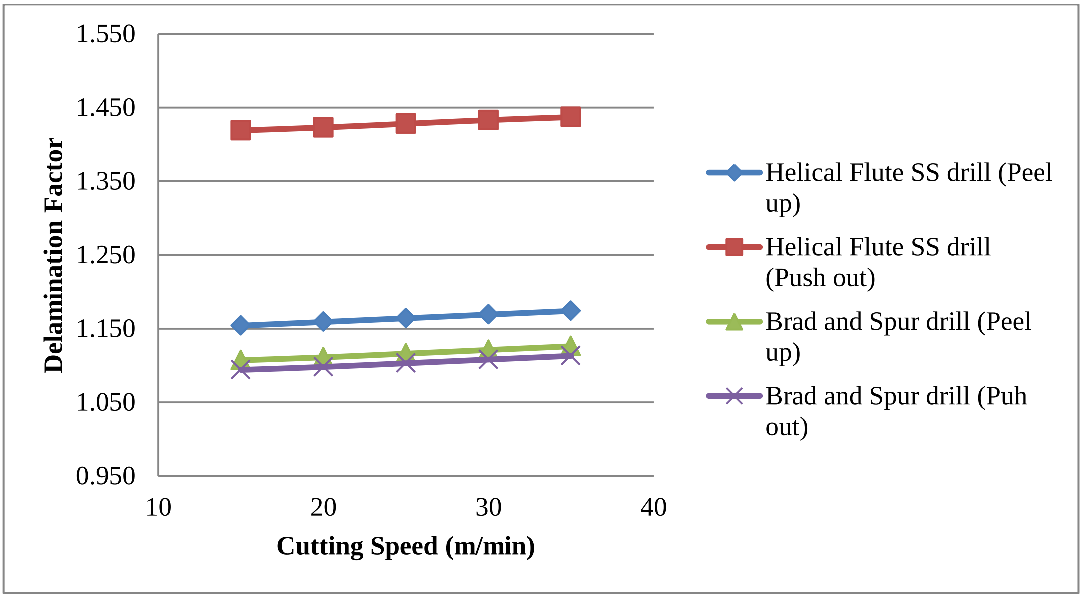

Figure 4.47 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.15mm/rev

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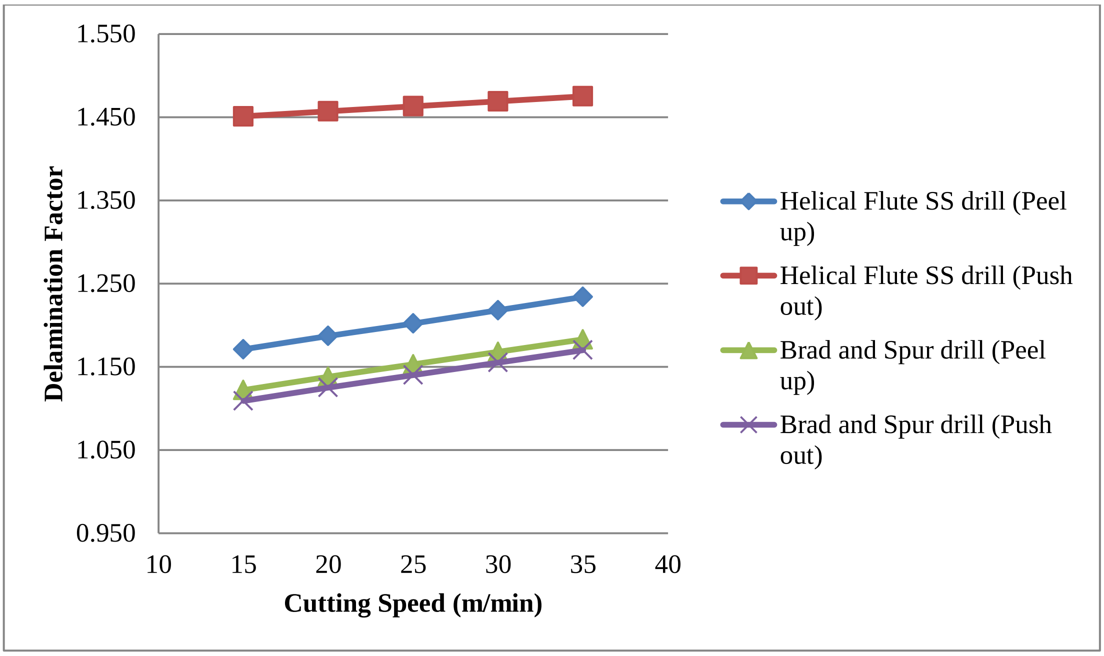

Figure 4.48 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.2mm/rev

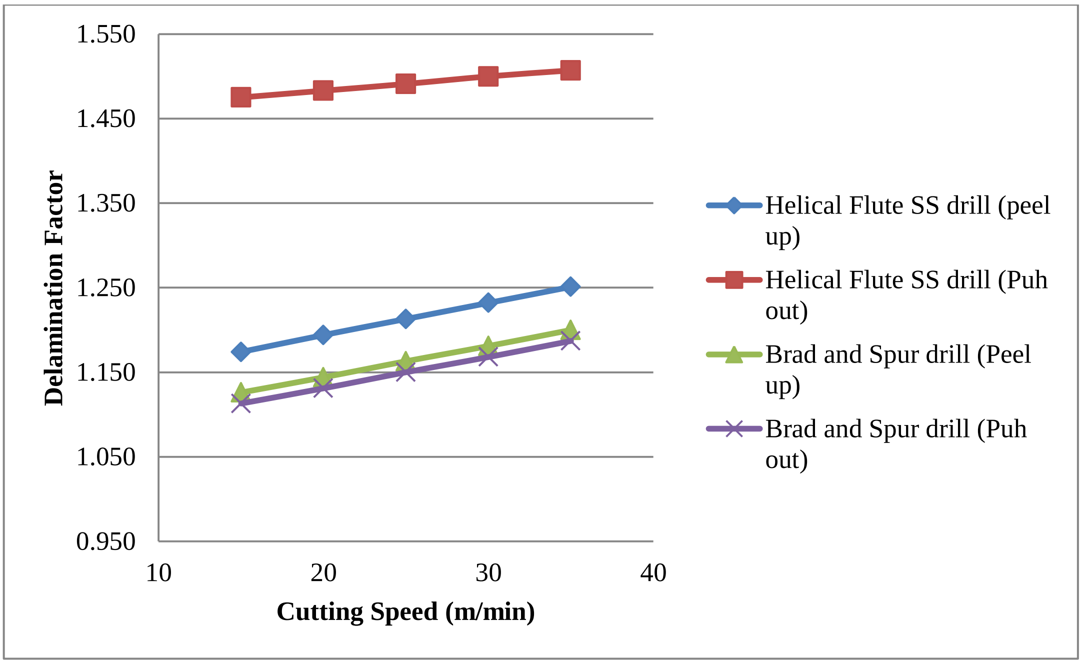

Figure 4.49 Delamination factor for the drilled holes in GFRP-Epoxy laminates at feed rate 0.25mm/rev

The delamination factor for drilled holes in GFRP-Epoxy laminates by Brad and spur drill and helical flute SS drill increases with feed rate. This increament of delamination is not found to be drastic with increase in feed rate as shown in Figures 4.45 to 4.49.

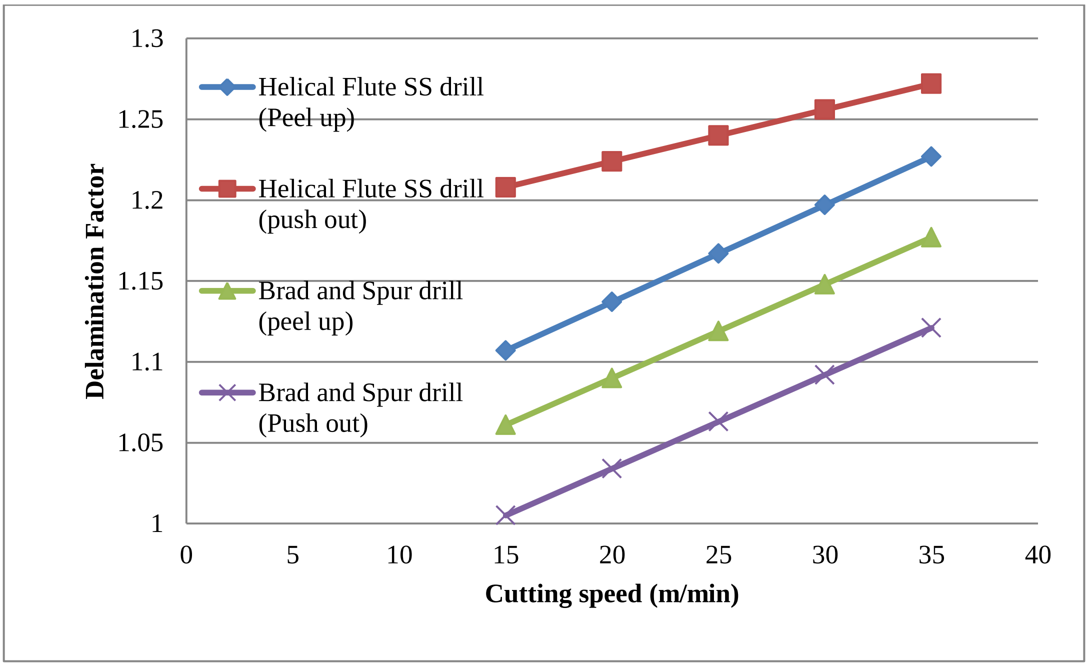

Figure 4.50 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.05mm/rev

The delamination is found to be low when the Brad and spur drill tool is used compared to helical flute SS drill as shown in Figure 4.50. The delamination gradually increases with cutting speed. The helical flute SS drill gives high delamination size in push out condition.

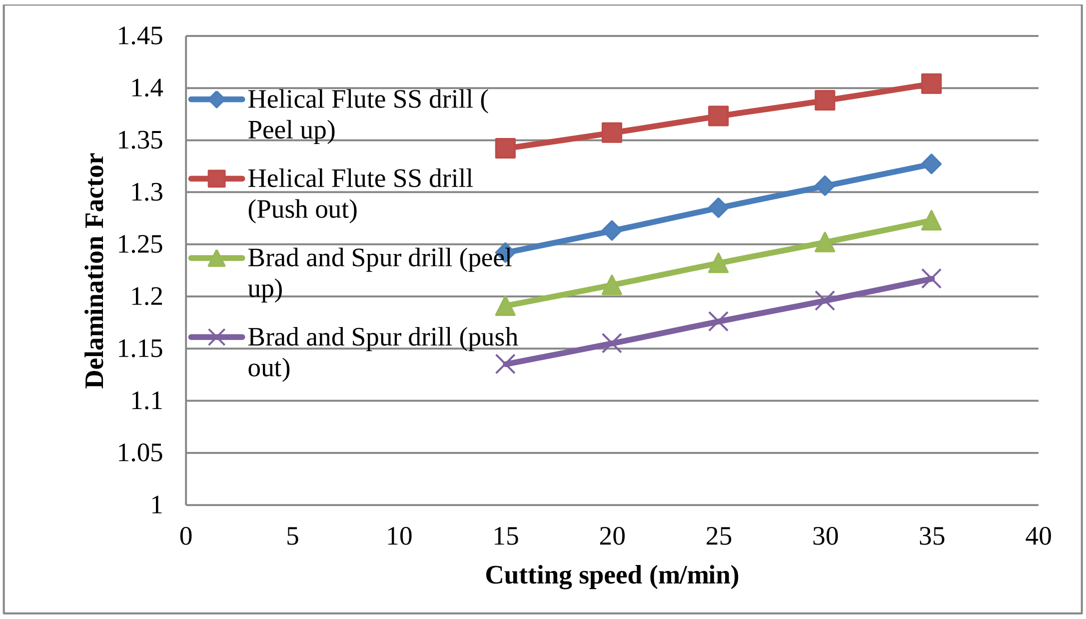

Figure 4.51 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.1mm/rev

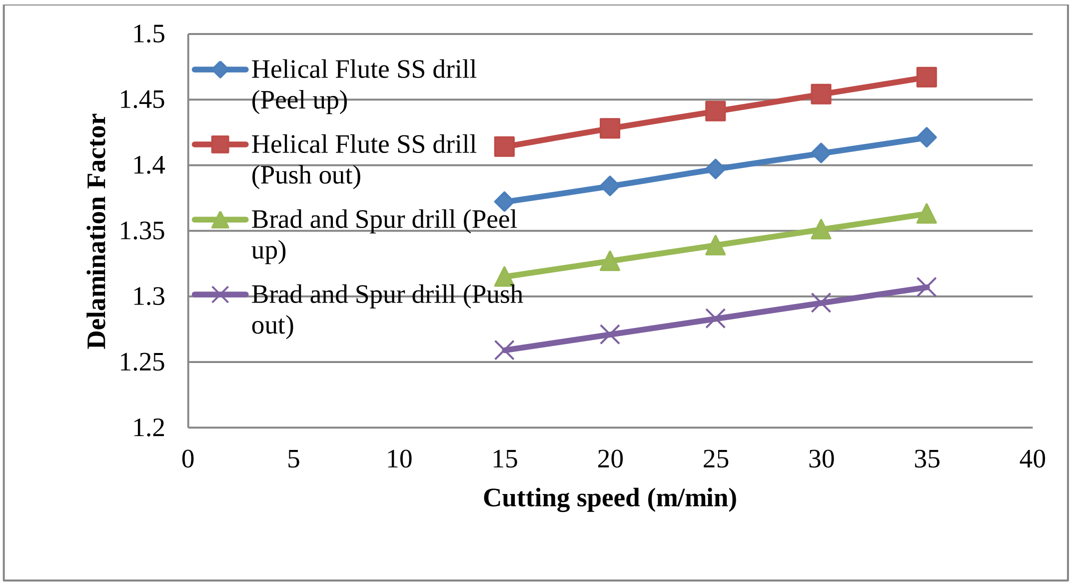

Figure 4.52 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.15mm/rev

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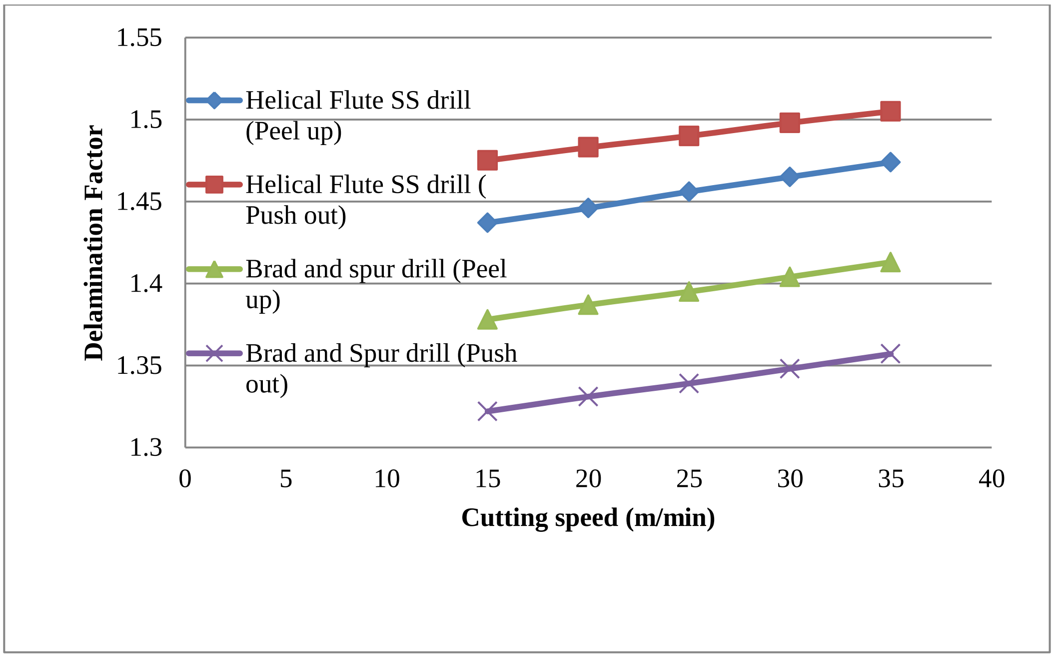

Figure 4.53 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.2mm/rev

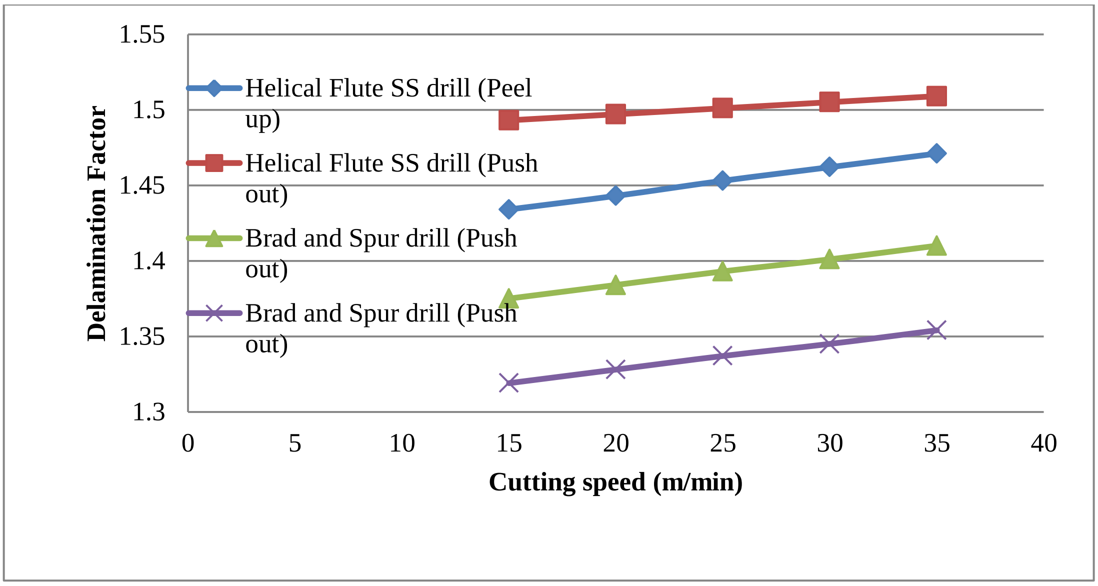

Figure 4.54 Delamination factor for the drilled holes in GFRP-Polyester laminates at feed rate 0.25mm/rev

The delamination factor for drilled holes in GFRP-Polyester laminates by Brad and spur drill and helical flute SS drill increases with feed rate. This increment of delamination is not found to be drastic with increase in feed rate as shown in Figures 4.50 to 4.54.

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CHAPTER 5

GREY RELATIONAL ANALYSIS

5.1 INTRODUCTION

Experiments were conducted at full factorial design. The performance of GFRP composite in drilling were studied by conducting various drilling experiments using Helical flute straight shank and 'Brad and Spur' drill. To analyse the presence of any nonlinearity in the machining experiment, five levels were considered. Although many factors affect the drilling process, the machining parameter such as cutting speed, feed rate and drill diameter are the important parameters. For this work, only cutting speed and feed rate were considered at five levels. Table 5.1 shows the process parameters considered for drilling the composites.

Table 5.1 Process parameters for drilling the composites

Control factor	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting speed	15	20	25	30	35
Feed rate	0.05	0.1	0.15	0.2	0.25

In the grey relational analysis, the normalized experimental results were found to calculate the grey relational coefficient. From the normalized experimental data, the relationship between the desired and actual experimental data can be calculated. Data pre-processing is normally required, since the range and unit in one data sequence may differ from others. Then the grey relational grade was calculated by averaging the grey relational coefficient corresponding to each process response. The overall evaluation of the multiple process response is based on the grey relational grade. The Taguchi based Grey method integrates the algorithm of Taguchi method and grey relational analysis are used to determine the optimum process parameters with multiple performance characteristics. The need of Taguchi method is to find controllable factors and levels, to get best factor level through orthogonal array and to reduce quality loss and costs. Taguchi method recommends the use of the loss function to measure the performance characteristic deviation from the desired value. This is converted to S/N ratio.

5.2 GREY RELATIONAL ANALYSIS FOR GFRP-EPOXY DRILLING

The experimental values of output parameters for helical flute drill and Brad and Spur drill conducted for L25 orthogonal array and normalized values of S/N ratios are presented in Table 5.2. The S/N ratio for the output parameter is calculated using Equations. The S/N ratios were normalized. The deviation sequences were also calculated for the output parameters and listed in Table 5.3. The Grey relation coefficients for L25 array was calculated and listed for both the drills in Table 5.4 and corresponding Grey Relational Grades (GRG) were calculated. The output parameters found out are C-Specific Cutting

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pressure in N/mm^2; D – Power in W ; E – Peel up delamination factor; F – Push out delamination factor

Table 5.2 L_{25} Orthogonal array – Input and Output Parameters

Expt. No.	Parameters Input		Normalised S/N ratio - Helical Flute Drill				Normalised S/N ratio – Brad & Spur drill			
	A	B	C	D	E	F	C	D	E	F
1	15	0.05	0	1	1	0.9511	0	1	1	1
2	15	0.1	0.5368	0.8997	0.8578	0.7255	0.5368	0.8955	0.8579	0.8579
3	15	0.15	0.738	0.8216	0.5105	0.3308	0.738	0.8139	0.5081	0.5081
4	15	0.2	0.8739	0.7895	0.421	0.1203	0.8739	0.7805	0.4262	0.4262
5	15	0.25	0.9428	0.7364	0.4052	0	0.9428	0.7256	0.4043	0.4043
6	20	0.05	0.0857	0.8863	0.9684	0.9624	0.0857	0.8815	0.9672	0.9672
7	20	0.1	0.5762	0.7495	0.7894	0.6654	0.5762	0.739	0.7868	0.7868
8	20	0.15	0.7522	0.6292	0.4842	0.3157	0.7522	0.6137	0.4863	0.4863
9	20	0.2	0.8858	0.5884	0.3368	0.1428	0.8858	0.5713	0.3387	0.3387
10	20	0.25	0.9575	0.5293	0.3	0.03	0.9575	0.5099	0.306	0.306
11	25	0.05	0.1694	0.7908	0.9315	0.9774	0.1694	0.7822	0.9289	0.9289
12	25	0.1	0.611	0.6122	0.7157	0.6052	0.611	0.4191	0.7158	0.7158
13	25	0.15	0.7635	0.4422	0.4578	0.2969	0.7635	0.3712	0.459	0.459
14	25	0.2	0.8964	0.3961	0.2578	0.1654	0.8964	0.3113	0.2568	0.2568
15	25	0.25	0.972	0.3389	0.2	0.0601	0.972	0.7036	0.2021	0.2021
16	30	0.05	0.2559	0.7155	0.8947	0.9887	0.2559	0.4754	0.8961	0.8961
17	30	0.1	0.6506	0.4963	0.6473	0.5451	0.6506	0.2397	0.6502	0.6502
18	30	0.15	0.7784	0.2699	0.4315	0.2781	0.7784	0.1813	0.4316	0.4316
19	30	0.2	0.9073	0.2138	0.1736	0.1879	0.9073	0.1277	0.1748	0.1748
20	30	0.25	0.9861	0.1624	0.1	0.0902	0.9861	0.6431	0.1038	0.1038
21	35	0.05	0.3408	0.6574	0.8631	1	0.3408	0.3668	0.8579	0.8579
22	35	0.1	0.6868	0.3922	0.5789	0.4849	0.6868	0.0596	0.5792	0.5792
23	35	0.15	0.7893	0.0971	0.4052	0.2631	0.7893	0	0.4043	0.4043
24	35	0.2	0.918	0.0396	0.0894	0.2105	0.918	0.1481	0.0928	0.0928
25	35	0.25	1	0	0	0.1203	1	0.1481	0	0

The highest GRG indicates the optimal experimental conditions. The optimal conditions for both the drills are: feed =0.05mm/rev and cutting speed= 15m/min. Low feed rate and low

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cutting speed results in good drilling performance for both the drills. The S/N ratio of performance characteristic for different feeds, cutting speeds and drill types are shown in table. Normalized S/N ratio value closer to 1 gives the better performance.

Table 5.3 Deviation sequences

Expt. No.	Deviation sequences - Helical Flute Drill				Deviation sequences – Brad & Spur drill			
	C	D	E	F	C	D	E	F
1	1	0	0	0.0488	1	0	0	0
2	0.4631	0.1002	0.1421	0.2744	0.4631	0.1044	0.142	0.142
3	0.2619	0.1783	0.4894	0.6691	0.2619	0.186	0.4918	0.4918
4	0.126	0.2104	0.5789	0.8796	0.126	0.2194	0.5737	0.5737
5	0.0571	0.2635	0.5947	1	0.0571	0.2743	0.5956	0.5956
6	0.9142	0.1136	0.0315	0.0375	0.9142	0.1184	0.0327	0.0327
7	0.4237	0.2504	0.2105	0.3345	0.4237	0.2609	0.2131	0.2131
8	0.2477	0.3707	0.5157	0.6842	0.2477	0.3862	0.5136	0.5136
9	0.1141	0.4115	0.6631	0.8571	0.1141	0.4286	0.6612	0.6612
10	0.0424	0.4706	0.7	0.9699	0.0424	0.49	0.6939	0.6939
11	0.8305	0.2091	0.0684	0.0225	0.8305	0.2177	0.071	0.071
12	0.3889	0.3877	0.2842	0.3947	0.3889	0.4038	0.2841	0.2841
13	0.2364	0.5577	0.5421	0.703	0.2364	0.5808	0.5409	0.5409
14	0.1035	0.6038	0.7421	0.8345	0.1035	0.6287	0.7431	0.7431
15	0.0279	0.661	0.8	0.9398	0.0279	0.6886	0.7978	0.7978
16	0.744	0.2844	0.1052	0.0112	0.744	0.2963	0.1038	0.1038
17	0.3493	0.5036	0.3526	0.4548	0.3493	0.5245	0.3497	0.3497
18	0.2215	0.73	0.5684	0.7218	0.2215	0.7602	0.5683	0.5683
19	0.0926	0.7861	0.8263	0.812	0.0926	0.8186	0.8251	0.8251
20	0.0138	0.8375	0.9	0.9097	0.0138	0.8722	0.8961	0.8961
21	0.6591	0.3425	0.1368	0	0.6591	0.3568	0.142	0.142
22	0.3131	0.6077	0.421	0.515	0.3131	0.6331	0.4207	0.4207
23	0.2106	0.9028	0.5947	0.7368	0.2106	0.9403	0.5956	0.5956
24	0.0819	0.9603	0.9105	0.7894	0.0819	1	0.9071	0.9071
25	0	1	1	0.8796	0	0.8518	1	1

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It was observed that the S/N ratios of specific cutting pressure are closer to 1 at higher feeds for both the drill types irrespective of cutting speeds whereas S/N ratios of power, peel up delamination and push out delamination are observed to be closer to 1 at lower feeds for both the drill types and at all cutting speeds.

Table 5.4 Grey relational coefficients and Grey Relational Grades (GRG)

Expt. No.	Deviation sequences - Helical Flute Drill					Deviation sequences – Brad & Spur drill				
	Grey relational coefficients				GRG	Grey relational coefficients				GRG
	C	D	E	F		C	D	E	F	
1	0.3333	1	1	0.9109	0.811	0.3333	1	1	1	0.8333
2	0.5191	0.833	0.7786	0.6456	0.6941	0.5191	0.8272	0.7787	0.7787	0.7259
3	0.6562	0.737	0.5053	0.4276	0.5815	0.6562	0.7287	0.5041	0.5041	0.5983
4	0.7986	0.7037	0.4634	0.3623	0.582	0.7986	0.6949	0.4656	0.4656	0.6062
5	0.8973	0.6548	0.4567	0.3333	0.5855	0.8974	0.6456	0.4563	0.4563	0.6139
6	0.3535	0.8148	0.9405	0.93	0.7597	0.3535	0.8084	0.9384	0.9384	0.7597
7	0.5412	0.6662	0.7037	0.599	0.6275	0.5412	0.657	0.7011	0.7011	0.6501
8	0.6686	0.5742	0.4922	0.4222	0.5393	0.6687	0.5642	0.4932	0.4932	0.5548
9	0.814	0.5485	0.4298	0.3684	0.5402	0.8141	0.5384	0.4305	0.4305	0.5534
10	0.9217	0.515	0.4166	0.3401	0.5484	0.9217	0.505	0.4187	0.4187	0.566
11	0.3757	0.7051	0.8796	0.9568	0.7293	0.3757	0.6966	0.8755	0.8755	0.7059
12	0.5624	0.5632	0.6375	0.5588	0.5805	0.5624	0.5532	0.6376	0.6376	0.5977
13	0.6789	0.4726	0.4797	0.4156	0.5117	0.678	0.4626	0.4803	0.4803	0.5255
14	0.8284	0.4529	0.4025	0.3746	0.5146	0.8284	0.4429	0.4021	0.4021	0.5189
15	0.947	0.4306	0.3846	0.3472	0.5273	0.9471	0.4206	0.3852	0.3852	0.5345
16	0.4019	0.6373	0.826	0.9779	0.7108	0.4019	0.6278	0.828	0.828	0.6714
17	0.5887	0.4981	0.5864	0.5236	0.5492	0.5887	0.488	0.5884	0.5884	0.5633
18	0.6929	0.4064	0.4679	0.4092	0.4941	0.6929	0.3967	0.468	0.468	0.5064
19	0.8437	0.3887	0.3769	0.381	0.4976	0.8437	0.3791	0.3773	0.3773	0.4943
20	0.9729	0.3738	0.3571	0.3546	0.5146	0.9729	0.3643	0.3581	0.3581	0.5133
21	0.4313	0.5934	0.7851	1	0.7024	0.4313	0.5835	0.7787	0.7787	0.643
22	0.6149	0.4513	0.5428	0.4925	0.5254	0.6149	0.4412	0.543	0.543	0.5355
23	0.7035	0.3564	0.4567	0.4042	0.4802	0.7035	0.3471	0.4563	0.4563	0.4908
24	0.8592	0.3423	0.3544	0.3877	0.4859	0.8592	0.3333	0.3553	0.3553	0.4758
25	1	0.3333	0.3333	0.3623	0.5072	1	0.3698	0.3333	0.3333	0.5091

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The average of grey relational grades for control factors based on their levels is calculated and presented in Table 5.5 for both the drill types. It was noticed that highest grey relational grade was obtained at low feed and low cutting speeds for the both the drill types. This also supports to the argument of optimal drilling performance based on individual grey relational grades.

Table 5.5 Response table for Grey relational grade

Control Factors	Helical flute drill					Brad and Spur drill			
	Levels					Levels			
	1	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**
A	0.6508	0.603	0.5726	0.5532	0.5402	0.7426	0.5953	0.5213	0.524
B	0.6755	0.6168	0.5765	0.5497	0.5308	0.7226	0.6145	0.5351	0.5297

Table 5.6 ANOVA

Testing Parameters	Degrees of Freedom	Helical flute drill			Brad and Spur drill		
		Sum of squares	Mean Sum of Squares	Contribution	Sum of squares	Mean Sum of Squares	Contribution
A	4	0.039	0.0097	0.1816	0.0666	0.0166	0.3314
B	4	0.1752	0.0438	**0.8148**	0.1332	0.0333	**0.6628**
Error	16	0.003	0.0001	0.0035	0.0045	0.0002	0.0056
Total	24	0.2173			0.2044		

ANOVA was done for the L25 array experiments in order to determine which control factors contribute more to the drilling performance. It was found that feed rate contributes more to the drilling performance followed by cutting speed. The detail of ANOVA is presented in Table 5.6. Confirmation tests were also done for the optimal level of control factors and observed closer results. Taguchi based grey relational analysis was done for L25 orthogonal experimental design and found that least feed rate and least cutting speed resulted in best drilling performance. This approach converted multiple performance characteristics into GRG and therefore simplified the analysis. The influencing control factors on drilling performance found by ANOVA are feed rate (81.48%) followed by cutting speed (18.16%) for Helical flute drill whereas cutting speed (33.14%) followed by feed rate (66.28%) for “Brad and Spur” drill.

5.3 GREY RELATIONAL ANALYSIS FOR GFRP-POLYESTER DRILLING

The experimental values of output parameters for helical flute drill and Brad and Spur drill conducted for L25 orthogonal array and normalized values of S/N ratios are presented in Table 5.7. The S/N ratio for the output parameter is calculated using Equations. The S/N ratios were normalized. The deviation sequences were also calculated for the output parameters and listed in Table 5.8. The Grey relation coefficients for L25 array was calculated and listed for both the drills in Table 5.8 and corresponding Grey Relational Grades (GRG) were calculated. The output parameters found out are C-Specific Cutting pressure in N/mm^2; D – Power in W ; E – Peel up delamination factor; F – Push out delamination factor

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Table 5.7 Normalised values of S/N ratios

Expt. No.	Input Parameters		Normalised S/N ratio - Helical Flute Drill				Normalised S/N ratio – Brad & Spur drill			
	A	B	C	D	E	F	C	D	E	F
1	15	0.05	0	1	1	0.7873	0	1	1	1
2	15	0.10	0.6164	0.9327	0.6321	0.3488	0.6164	0.9328	0.6306	0.999990203
3	15	0.15	0.7769	0.8397	0.1444	0.1395	0.7769	0.8398	0.1420	0.999977242
4	15	0.20	0.9003	0.7797	0.1008	0.0132	0.9003	0.7799	0.0994	0.999976112
5	15	0.25	0.8938	0.6431	0.1089	0	0.8938	0.6431	0.1079	0.999976338
6	20	0.05	0.0524	0.9122	0.9182	0.8405	0.0524	0.9124	0.9176	0.999997815
7	20	0.10	0.6626	0.8328	0.5749	0.4019	0.6626	0.8329	0.5738	0.999988696
8	20	0.15	0.7999	0.7030	0.1771	0.1827	0.7999	0.7030	0.1761	0.999978146
9	20	0.20	0.9042	0.6093	0.0762	0.0365	0.9042	0.6093	0.0738	0.999975433
10	20	0.25	0.920	0.4570	0.0844	0.0132	0.9206	0.4570	0.0823	0.999975659
11	25	0.05	0.1025	0.8309	0.8365	0.8936	0.1025	0.8310	0.8352	0.999995629
12	25	0.10	0.7039	0.7420	0.5149	0.4518	0.7039	0.7420	0.5142	0.999987114
13	25	0.15	0.8239	0.5763	0.2098	0.2259	0.8239	0.5764	0.2102	0.99997905
14	25	0.20	0.9057	0.4383	0.0490	0.0631	0.9057	0.4383	0.0511	0.99997483
15	25	0.25	0.9478	0.2892	0.0572	0.0265	0.9478	0.2893	0.0568	0.999974981
16	30	0.05	0.1471	0.7538	0.7547	0.9468	0.1471	0.7539	0.7528	0.999993444
17	30	0.10	0.7471	0.6629	0.4577	0.5049	0.7471	0.6631	0.4573	0.999985607
18	30	0.15	0.8464	0.4572	0.2452	0.2691	0.8464	0.4572	0.2443	0
19	30	0.20	0.9100	0.2722	0.0245	0.0863	0.9099	0.2724	0.0255	0.999974152
20	30	0.25	0.9740	0.1369	0.0326	0.0398	0.9740	0.1370	0.0340	0.999974378
21	35	0.05	0.1942	0.6832	0.6730	1	0.1942	0.6833	0.6704	0.999991258
22	35	0.10	0.7875	0.5922	0.4005	0.5548	0.7875	0.5923	0.3977	0.999984024
23	35	0.15	0.8670	0.3433	0.2779	0.3156	0.8670	0.3434	0.2784	0.999980859
24	35	0.20	0.911	0.1037	0	0.1129	0.9119	0.1037	0	0.9999
25	35	0.25	1	0	0.0081	0.0531	1	0	0.0085	0.9999737

Table 5.8 Deviation sequences

Expt. No.	Deviation sequences - Helical Flute Drill				Deviation sequences – Brad & Spur drill			
	C	D	E	F	C	D	E	F
1	1	0	0	0.2126	1	0	0	0
2	0.3835	0.0672	0.3678	0.6511	0.3835	0.0671	0.3693	9.79654E-06
3	0.2230	0.1602	0.8555	0.8604	0.2230	0.1601	0.8579	2.27581E-05
4	0.0996	0.2202	0.8991	0.9867	0.099	0.2200	0.9005	2.38885E-05
5	0.1061	0.3568	0.8910	1	0.1061	0.3568	0.8920	2.36624E-05
6	0.9475	0.0877	0.0817	0.1594	0.9475	0.0875	0.0823	2.18538E-06
7	0.3373	0.1671	0.4250	0.5980	0.3373	0.1670	0.4261	1.13037E-05
8	0.2000	0.2969	0.8228	0.8172	0.2000	0.2969	0.8238	2.18538E-05
9	0.0957	0.3906	0.9237	0.9634	0.0957	0.3906	0.9261	2.45667E-05
10	0.0793	0.5429	0.9155	0.9867	0.0793	0.5429	0.9176	2.43406E-05
11	0.8974	0.1690	0.1634	0.1063	0.8974	0.1689	0.1647	4.37076E-06
12	0.2960	0.2579	0.4850	0.5481	0.2960	0.2579	0.4857	1.28862E-05
13	0.1760	0.4236	0.7901	0.7740	0.1760	0.4235	0.7897	2.09495E-05
14	0.0942	0.5616	0.9509	0.9368	0.0942	0.5616	0.9488	2.51696E-05
15	0.0521	0.7107	0.9427	0.9734	0.0521	0.7106	0.9431	2.50188E-05
16	0.8528	0.2461	0.2452	0.0531	0.8528	0.2460	0.2471	6.55614E-06
17	0.2528	0.3370	0.5422	0.4950	0.2528	0.3368	0.5426	1.43934E-05
18	0.1535	0.5427	0.7547	0.7308	0.1535	0.5427	0.7556	1
19	0.0899	0.7277	0.9754	0.9136	0.0900	0.7275	0.9744	2.58478E-05
20	0.0259	0.8630	0.9673	0.9601	0.0259	0.8629	0.9659	2.56217E-05
21	0.8057	0.3167	0.3269	0	0.8057	0.3166	0.3295	8.74153E-06
22	0.2124	0.4078	0.5994	0.4451	0.2124	0.4076	0.6022	1.59759E-05
23	0.1329	0.6566	0.7220	0.6843	0.1329	0.6565	0.7215	1.91409E-05
24	0.0880	0.8962	1	0.8870	0.0880	0.8962	1	2.6526E-05
25	0	1	0.9918	0.9468	0	1	0.9914	2.62999E-05

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Table 5.9 Grey relational coefficients and grey relational grades (GRG)

Expt. No.	Helical Flute Drill					Brad & Spur drill				
	Grey relational coefficients				GRG	Grey relational coefficients				GRG
	C	D	E	F		C	D	E	F	
1	0.3333	1	1	0.7016	**0.7587**	0.3333	1	1	1	**0.8333**
2	0.5658	0.8814	0.5761	0.4343	0.6144	0.5658	0.8815	0.5751	0.9999	0.7556
3	0.6914	0.7573	0.3688	0.3675	0.5462	0.6914	0.7574	0.3682	0.9999	0.7042
4	0.8338	0.6942	0.3573	0.3363	0.5554	0.8338	0.6943	0.3569	0.9999	0.7212
5	0.8249	0.5835	0.3594	0.3333	0.5253	0.8249	0.5835	0.3591	0.9999	0.6918
6	0.3454	0.8507	0.8594	0.7581	0.7034	0.3454	0.8510	0.8585	0.9999	0.7637
7	0.5971	0.7495	0.5405	0.4553	0.5856	0.5971	0.7495	0.5398	0.9999	0.7216
8	0.7142	0.6273	0.3779	0.3795	0.5247	0.7142	0.6274	0.3776	0.9999	0.6798
9	0.8392	0.5613	0.3511	0.3416	0.5233	0.8392	0.5613	0.3505	0.9999	0.6877
10	0.8630	0.4794	0.3532	0.3363	0.5079	0.8630	0.4794	0.3527	0.9999	0.6737
11	0.3577	0.7473	0.7535	0.8246	0.6708	0.3577	0.7473	0.7521	0.9999	0.7143
12	0.6281	0.6596	0.5076	0.4770	0.5680	0.6281	0.6597	0.5072	0.9999	0.6987
13	0.7396	0.5413	0.3875	0.3924	0.5152	0.7396	0.5413	0.3876	0.9999	0.6671
14	0.8413	0.4709	0.3446	0.3479	0.5012	0.8413	0.4709	0.3450	0.9999	0.6643
15	0.9055	0.4129	0.3465	0.3393	0.5011	0.9055	0.4129	0.3464	0.9999	0.6662
16	0.3695	0.6700	0.6709	0.9039	0.6536	0.3695	0.6701	0.6692	0.9999	0.6772
17	0.6641	0.5973	0.4797	0.5025	0.5609	0.6641	0.5974	0.4795	0.9999	0.6852
18	0.7651	0.4794	0.3984	0.4062	0.5123	0.7651	0.4795	0.3981	0.3333	0.4940
19	0.8474	0.4072	0.3388	0.3537	0.4868	0.8474	0.4073	0.3391	0.9999	0.6484
20	0.9506	0.3668	0.3407	0.3424	0.5001	0.9506	0.3668	0.3410	0.9999	0.6646
21	0.3829	0.6121	0.6046	1	0.6499	0.3829	0.6122	0.6027	0.9999	0.6494
22	0.7018	0.5507	0.4547	0.5289	0.5590	0.7018	0.5508	0.4536	0.9999	0.6765
23	0.7899	0.4322	0.4091	0.4221	0.5133	0.7899	0.4323	0.4093	0.9999	0.6578
24	0.8502	0.3581	0.3333	0.3604	0.4755	0.8502	0.3581	0.3333	0.9999	0.6354
25	1	0.3333	0.3351	0.3455	0.5035	1	0.3333	0.3352	0.9999	**0.8333**

ANOVA was done for the L25 array experiments in order to determine which control factors contributes more to the drilling performance. It was found that feed rate (89.93%) contributes more to the drilling performance in case of helical flute drill whereas cutting speed (54.81%) contributes more for "Brad and Spur" drill. The details of ANOVA are presented in Table 5.10. Confirmation tests were also done for the optimal level of control factors and observed best results which are shown in Table 5.11.

Table 5.10 ANOVA

Testing parameters	Degrees of Freedom	Helical Flute Drill			Brad & Spur drill		
		Sum of Squares	Mean Sum of Squares	Contribution	Sum of Squares	Mean Sum of Squares	Contribution
A	4	0.0122	0.0030	0.0942	0.0472	0.0118	0.5481
B	4	0.1166	0.0291	0.8993	0.0306	0.0076	0.3559
Error	16	0.0033	0.0002	0.0064	0.0330	0.0020	0.0959
Total	24	0.1322			0.1109		

Table 5.11 Confirmation Test

Optimum control factors		Output Parameters Helical Flute Drill				Output Parameters Brad & Spur drill			
A	B	C	D	E	F	C	D	E	F
15	0.05	913.42	17.12	1.10	1.27	1401.19	26.27	1.061	1.005

Taguchi based grey relational analysis was done for L25 orthogonal experimental design and found that least feed rate and least cutting speed resulted in best drilling performance. This approach converted multiple performance characteristics into GRG and therefore simplified the analysis. The influencing control factors on drilling performance found by ANOVA are feed rate (89.93%) followed by cutting speed (9.42%) for Helical flute drill whereas cutting speed (54.81%) followed by feed rate (35.59%) for “Brad and Spur” drill.

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CHAPTER 6

CONCLUSION

6.1 INTRODUCTION

The present research work is focused on drilling of GFRP composite plates. The GFRP composite plates are manufactured by hand lay method. The composite plates are of two types. They are GFRP-Epoxy and GFRP-Polyester composites. The physical properties are determined for the two types of GFRP composites. The drilling operation on GFRP composite plates are performed by using Helical Flute Drill and Brad and Spur drill. The experiment was planned using Taguchi's L27 orthogonal array. The experiments were carried out on a CNC vertical machining center with two drilling parameter, viz. spindle speed and feed rate at five different levels. The quality of the drilled holes was observed with six responses of interest, viz. thrust force, torque, delamination, Power, specific cutting pressure. In order to obtain a good quality of the drilled holes, an optimal drilling condition is identified.

6.2 CONCLUSION

A multiple performance optimization approach is used to identify the optimal drilling conditions that produce a good quality hole in drilling of GFRP composite plates using Helical Flute Drill and Brad and Spur drill. Grey fuzzy approach is used to reduce the uncertainty and vagueness in the grey relational grade. The conclusion drawn in the present study is as follows:

1. It is found that all response values viz. thrust force, torque and specific cutting pressure decreases with increase in cutting speed. The delamination size at push out and peel up, are higher as cutting speed increases as obtained from parametric analysis of the responses with respect to drilling parameters.
2. It is found that all response values viz. thrust force, torque and specific cutting pressure decreases with increase in feed rate. The delamination size at push out and peel up, are higher as feed rate increases as obtained from parametric analysis of the responses with respect to drilling parameters.
3. It is found that the Brad and Spur drill showed good performance in delamination at push out and peel up and other response values viz. thrust force, torque and specific cutting than Helical Flute Drill.
4. It is found that the GFRP- Epoxy showed very good drilling performance than GFRP- polyester irrespective of the drilling tool Brad and Spur drill and Helical Flute Drill due to its elevated mechanical properties.
5. It is found from Taguchi based grey relational analysis, the least feed rate and least cutting speed results in best drilling performance. This approach converted multiple performance characteristics into GRG and therefore

simplified the analysis. The influencing control factors on drilling performance found by ANOVA are feed rate followed by cutting speed for Helical flute drill whereas cutting speed followed by feed rate for "Brad and Spur" drill.

6.3 SCOPE FOR FUTURE WORK

This drilling investigation on the glass fiber reinforced composites made up of Epoxy and polyester resins has given insight into the effect of cutting speed and feed rate on response values viz. thrust force, torque specific cutting pressure, power and delamination at push out and peel up. Further investigations on the drilling properties of glass fiber reinforced composites and its behaviour at various conditions are required to understand the reinforced composites. Therefore based on present investigation, the following suggestions are made for further research on the topics:

1. The surface roughness and the roundness of the drilled hole can be investigated in order to improve the quality of holes.
2. The effect of coolant systems on cutting parameters can be considered for better cutting quality.
3. The effect of process parameters can be assessed with different tool types and cutting inserts.
4. The effect of process parameters can be assessed with different thickness of GFRP composite plates.
5. Different data analysis methods can be used for further exploration.

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