# Experimental Investigation of Process Parameters in drilling operation using different software technique

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***Abstract :*** *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 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 characteristic.*

***Keywords:*** *Drilling, factorial setting, design of experiment, Grey Taguchi, delamination.*

## 1. Introduction

Composite structure materials have successfully substituted the traditional materials in several lightweight and high strength applications. These material structures are synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. The objective of having two or more constituents is to take advantage of the superior properties of both materials without compromising on the weakness of either. In a glass fiber reinforced composite structures, the glass fibers carry the bulk load and the matrix serves as a medium for the transfer of the load. Applications of such structures are observed in aircraft components, offshore and marine, industrial, military and defense, transportation, power generation, radomes, etc. Machining of these structures involves cutting, drilling, or contouring GFRP laminates for the assembly into composite structures. In fact, drilling is one of the most common manufacturing processes used in order to install fasteners for assembly of laminates. In machining processes, however, the quality of the component is greatly influenced by the cutting conditions, tool geometry, tool material, machining process, chip formation, work piece material, tool wear and vibration during cutting, etc. Therefore, a precise machining needs to be performed to ensure the dimensional stability and interface quality. For these reasons there have been research developments with the objective of optimizing the cutting conditions to obtain a better productivity in drilling process. Productivity involves the higher, metal removal rate and Tool life result in the less rejection of the components. Thus, in material removal processes, an improper selection of cutting conditions will result in rough surfaces and dimensional errors. Possibly a dynamic phenomenon due to auto excited vibrations may appear. Therefore, it is necessary to understand the relationship among the various controllable parameters and to identify the important parameters that influence the quality of drilling. Moreover, it is necessary to optimize the cutting parameters to obtain an extended tool life and better productivity, which are influenced by cutting thrust and torque. Design of experiment [DOE] is a statistical-based approach to analyze the influence of known process variables over unknown process variables. The present work is envisaged with the aim of harnessing the features of DOE for process optimization in drilling of GFRP composites.

## 2. Literature Review

The metal cutting process involves plastic deformation, fracture, impact continuous and intermittent multi contact points and friction. Direct visual inspection is never possible since workpiece and chip obstruct the view therefore sensors are used to observe the failure. To get desired quality cutting parameters should be selected in a proper way. Wardany et al. (1996) reported that drilling is a complex operation when compared to other machining operation as the two points of the drill wear alternately till they both have zero clearance at the margin, and become lodged within work piece. Kanai and Kanda (1978) suggested that different types of drill wear could be recognized as outer corner wear, flank wear, margin wear, crater wear, chisel wear and chipping at the lip. Bonifacio and Dinz (1994), Rao (1986) suggested that the wide tool failure modes are flank wear, fracture, crater wear and plastic deformation . Nouari et al. (2003) provided necessary information about the main factors affecting the hole quality i.e. cutting speed, temperature, feed rate, geometrical parameters as well as the influence of the cutting conditions and the temperature on the tool life in drilling. They suggested that improvement of surface quality and dimensional accuracy of the holes can be got at large cutting speed and a weak feed rate.

Many scientists have used Taguchi methods for their design experiments. Taguchi method systematically reveals the complex cause and effect relationship between design parameter and performance. Taguchi methods are most recent additions to the tool kit of design, process, and manufacturing engineers and quality assurance experts. In contrast to statistical process control which attempt to control the factors that adversely affect the quality of production. A considerable amount of research has been conducted on the effects of drilling on composite materials. Most has been targeted toward the study of delamination. There has been research on the quality of the holes drilled during research as well. Surface roughness is a major matter of concern over the last few years as industries desperately try to excel in quality and reduce the price simultaneously. It is indicated as an important design feature in many situations such as parts subject to fatigue loads, precision fits, and aesthetic requirements. In addition to tolerances, surface roughness imposes one of the most critical constraints for the selection of machines and cutting parameters in process planning. Drill wear is an important issue since wear on drill affects the whole quality and tool life of the drill. Direct visual inspection of cutting edge of tool and measurement of roughness of the drilled hole in a transfer line is not feasible and therefore indirect methods using sensory feed back during drilling have been used to compute the roughness of drilled hole and the wear of the drill Standardized methods were suggested by DOE for each of steps which has been used comprehensively in this work to significantly reduce the number of experiments and form the rule box. Three input parameters and eighteen rules have been taken depending upon standard L18 Orthogonal array based on Taguchi Design. The degree of significance of each of the factors on the process response has been deduced by using ANOVA.

**Dipaolo g, kapoor G and devor [1]** studied the crack growth phenomenon that occurs while drilling fiber-reinforced composite materials (FRCM), specifically unidirectional (UD) carbon fiber/epoxy resin. It used an experimental setup that exploits the technology of video to understand the complete crack growth phenomenon as the drill emerges from the exit side of the workpiece. Significant damage mechanisms are observed and defined, and correlations between the average exit drill forces and the crack tip position are shown. Instantaneous forces as they vary along the orientation of the cutting edges are identified in terms of their contribution to the crack propagation.

**Wen-Chou Chen [2]** studied the concept of delamination factor *F*d (i.e. the ratio of the maximum diameter Dmax. in the damage zone to the hole diameter *D*) is proposed to analyze and compare easily the delamination degree in the drilling of carbon fiber-reinforced plastic (CFRP) composite laminates. Experiments were performed to investigate the variations of cutting forces with or without onset of delamination during the drilling operations. The effects of tool geometry and drilling parameters on cutting force variations in CFRP composite materials drilling were also experimentally examined. The experimental results shown the delamination-free drilling processes may be obtained by the proper selections of tool geometry and drilling parameters.

**S. C. Lin, I. K. Chen [3]** studied the effects of increasing cutting speed on drilling characteristics of carbon fiber-reinforced composite materials. The effects of increasing cutting speed ranging from 9550 up to 38650 rev min”1 (from 210 to 850 m min”1) on average thrust force, torque, tool wear and hole quality for both multifacet drill and twist drill are studied. It was found that increasing cutting speed will accelerate tool wear. And the thrust force increases as drill wear increases. Although tool geometries change quickly due to the fast development of tool wear and the thrust force increases drastically as cutting speed increases, an acceptable hole entry and exit quality is maintained. This is because relatively small feeds are used in these tests. It was concluded that tool wear was the major problem encountered when drilling carbon fiber reinforced composite materials at high speed.

**R. Stone and K. Krishnamurthy [4]** studied the linear-elastic fracture mechanics theory which proposed critical cutting and thrust forces in the various drilling regions that can be used as a guide in preventing crack growth or delamination. Using these critical force curves as a guide, a thrust force controller was developed to minimize the delamination while drilling a graphite epoxy laminate. A neural network control scheme was implemented which re network identifier to model the drilling dynamics and a neural network controller to learn the relationship between feed rate and the desired thrust force. Experimental results verifying the validity of this control approach as well as the robustness of the design are presented. Visual measurements of the delamination zones were used to quantify the benefits of the thrust force controlled drilling process versus the conventional constant feed rate drilling process.

**J. Mathew, N.Ramakrishnan and N. K. Naik [5]** studied that thrust is a major factor responsible for delamination and it mainly depends on tool geometry and feed rate. Trepanning tools, which were used in this study, were found to give reduced thrust while making holes on thin laminated composites. In this work the peculiarities of trepanning over drilling of unidirectional composites has been emphasized. The models for prediction of critical thrust and critical feed rate at the onset of delamination during trepanning of uni-directional composites based on fracture mechanics and plate theory also have been presented. Mathematical models correlating thrust and torque with tool diameter and feed rate have been developed through statistically designed experiments and effect of various parameters on them have been discussed. It is observed that sub-laminate thickness is the most decisive parameter from the viewpoint of critical feed rates.

## Cutting force

Cutting force can be an indication of how difficult a material is machined (Colligan, 1994; Kim et al., 2005; Lambert, 1979). Usually, a smaller cutting force is desired. An increase in the cutting force can cause the spindle axis to vibrate, causing poor quality of machined surfaces. It can also cause premature failure of drills and reduce the drill life. Large torque, which often indicates more friction between the drills and workpiece, can produce a large quantity of heat, causing higher temperature at the tool-workpiece interface.

### Cutting temperature

During drilling process, about 90% of the work of plastic deformation is converted into heat, producing very high temperatures in the deformation zones and the surrounding regions of the interfaces between the chip, tool and workpiece (Bayoumi and Xie, 1995; Ezugwu, 1997; Li, 2007; Shahan and Taheri, 1993). The heat partition between the cutting tool and workpiece depends on the thermal properties of both materials. Because of Ti's poor heat conductivity (which is about 1/6 of that for steels) (Anonymous, 1993), a larger portion (as high as 80%) of heat generated in Ti drilling will be absorbed by the tool (Konig, 1979; Li, 2007). In comparison, 50% to 60% of the heat generated when drilling steel is absorbed by the tool (Child and Dalton, 1965). High cutting temperature is an important reason for the rapid tool wear commonly observed when drilling Ti (Ezugwu, 1997).

### Tool wear and tool life

Ti chips can easily weld to the cutting edges of the tool (a.k.a., built-up-edge, or, BUE). It is particularly so once tool wear begins (Barish, 1988; Trucks, 1981). BUE usually leads to chipping and premature failure of the tool. When machining Ti, the tool wear progresses rapidly because of high cutting temperature and strong adhesion between the tool and workpiece (Narutaki and Murakoshi, 1983). And the high stresses developed at the cutting edge of the tool may cause plastic deformation and/or accelerate the tool wear (Dearnley and Grearson, 1986; Dornfeld et al., 1999; Ezugwu, 1997; Konig, 1979; Sharif and Rahim, 2007; Yang and Liu, 1999).

### Hole quality

Hole quality in drilling Ti is evaluated in terms of hole diameter and cylindricity, surface roughness, and burr (Kim et al., 2001). Ti is generally used for parts requiring the great reliability and resistance of wear, and therefore high hole quality must be maintained. Higher surface roughness can possibly lead to severe wear, catastrophic fatigue, and lower ability to resist corrosion. However, the surface of Ti is easily damaged during machining operations (Child and Dalton, 1965; Konig and Schroder, 1975). Damage appears in the form of micro cracks, plastic deformation, heat-affected zones, and tensile residual stresses (Kahles et al., 1985; Koster, 1973; Narutaki and Murakoshi, 1983).

## Chip type

In twist drilling and vibration assisted twist drilling, the Ti chip could be entangled around two flutes of the drill and bent by the tool holder. This chip entanglement will cause difficulty for smooth chip ejection (Li et al., 2007). The characteristic of the chip formation in twist drilling of Ti is different from other metals (Kim and Ramulu, 2005; Yang and Liu, 1999). Yang and Liu (1999) categorized the Ti chips into three types: continuous chip, continuous chip with built-up edge, and discontinuous chip. The distinctive features of Ti chip can be described as serrated, shear-localized, discontinuous, cyclic, and segmented (Bayoumi and Xie, 1995; Hou and Komanduri, 1995; Machado 1990). There are two main shapes of chip morphology: spiral cone chip and folded long ribbon chip. It has reported that the spiral cone chip is easier to be ejected so the length of spiral cone chip can be considered as a scale to evaluate the difficulty for chip evacuation in drilling.

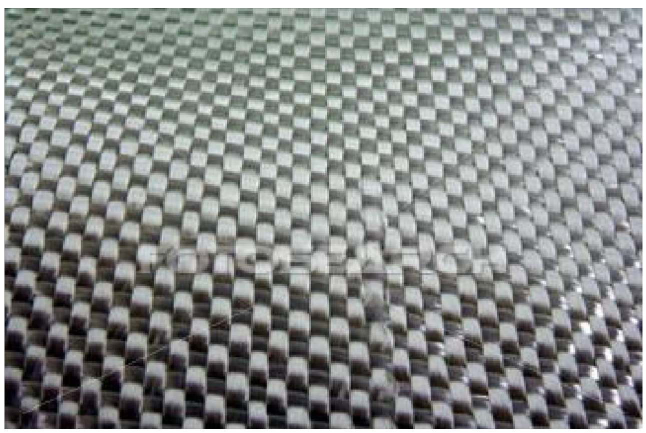

*Fig. 1 Glass Fiber Composite*

## Effects of feedrate

The most significant parameter of a drilling process affecting the cutting force is feedrate. It has been consistently reported that an increase in feedrate would increase the thrust force (Kim and Ramulu, 2005, Kim et al., 2005; Lambert, 1979; Ramulu et al., 2001; Rao et al., 1990) and the torque (Kim et al, 2005; Lambert, 1979; Rao et al., 1990)

**Effects of cutting speed**

It was reported that an increase in cutting speed would reduce the thrust force and torque when drilling Ti (Kim et al, 2005; Kim and Ramulu, 2005; Lambert, 1979; Li, 2007; Li et al., 2007; Rahim and Sharif, 2006).

**Effects of coolant**

Li et al. (2007) reported that the external coolant supply had no obvious effect on the thrust force and torque, but internal coolant supply could slightly increase the thrust force (likely caused by the hydrodynamic force) and the consumed energy during the drilling process.

**Effects of other factors**

Kim and Ramulu (2005) reported that typical thrust force and torque profiles varied with cutting depth as the drill penetrated the composite material when drilling Ti/composite stacks. Thrust force increased proportionally to an optimal depth then it dropped to a lower level for higher depth of cut. The thrust force was the maximum as the drill penetrated Ti and the maximum torque occurred when the drill lips cut both composite and Ti simultaneously. Lambert (1979) reported that the drilling force could be influenced significantly by the drilling time. Increased drilling time resulted in increased thrust force.

Drilling-induced delamination occurs both at the entrance and the exit planes of the workpiece. Investigators have studied analytically and experimentally cases in which delamination in drilling have been correlated to the thrust force during exit of the drill. A significant portion of the thrust force is due to the chisel edge, as has been shown in increasing the chisel edge length results in an increase in thrust force. The candle stick drill and saw drill have a smaller center than the twist drill; thus, a smaller extent of the last laminate is subjected to a bending force. Experiments indicate that there exists a critical thrust force below which no delamination occurs. Above that level, matrix cracks are generated by interface delamination growing from the crack tips. The first analytical model to determine the critical thrust force of the twist drill was formulated by Hocheng and Dharan. They employed linear elastic fracture mechanics and solved for the critical thrust force that relates the delamination of composite laminates to drilling parameters and composite material properties. Hocheng and Tsao developed a series analytical model of special drills (candle stick drill, saw drill, core drill and step drill) for correlating the thrust force with the onset of delamination. Enemuoh et al. developed an approach combining Taguchi's method and multi-objective optimization criterion to obtain the optimum drilling conditions for delamination-free drilling in composite laminates. Davim and Reis also presented a similar approach using Taguchi's method and the analysis of variance (ANOVA) to establish a correlation between cutting velocity and feed rate with the delamination in a CFRP laminate.The rate of penetration (ROP) or drilling rate is the speed at which a drill bit breaks the rock under it to deepen the borehole. Since drilling rate prediction is essential for drilling parameters determination and drilling cost optimazation, it has been a great concern for drilling engineers during last decades (Kaiser, 2007; Bourgoyne et al., 2003). Rate of penetration is affected by many parameters such as hydraulics, weight on bit, rotary speed, bit type, mud properties etc (Akgun, 2007). Due to the uncountable uncertain factors influencing the drilling rate, unfortunately, there exists no exact mathematical relation between drilling rate and its parameters. Furthermore, their relationship to each other and to drilling rate is nonlinear and complex (Ricardo et al., 2007). However, experts have suggested some simplified models for mapping important variables of drilling on drilling rate (Kaiser, 2007). One of them is Bourgoyne and Young Model (BYM), which is used widely in practice (Bourgoyne and Young, 1974). Bourgoyne and Young succeed to model the effect of different drilling parameters involving drilling rate as eight mathematical functions. For instance, the first function represents the effect of formation strength, bit type, mud type and solid content. In this model, there are some unknown parameters or coefficients which must be determined based on previous drilling experiences in the field. Bourgoyne and Young, (1974) suggested multiple regression method for this task. However, this method does not guarantee reaching physically meaningful coefficients (Bahari et al., 2008). To clarify, computed coefficients using multiple regression method can be negative or zero. Negative or zero coefficients are not physically meaningful. For instance, if the weight on bit coefficient be negative, it illustrates that increasing the weight on bit decreases the penetration rate; or if this value be zero, it means that increasing the weight on bit has no effect on the drilling rate. To reach meaningful results, some other methods such as non-linear least square data fitting with trust-region (Bahari and Baradaran, 2007) have recently been applied. Although extensions of BYM yield physically meaningful coefficient, they do not represent desired prediction accuracy.

*Fig. 2 Radial Drilling Machine*

On the other hand, soft computing methods have been successfully applied to different applications in the field of petroleum industry such as reservoir characterization (Zellou and Ouenes, 2007), optimum bit selection (Yilmaz et al., 2002), trap quality evaluation (Shi et al., 2004), and drilling rate prediction (Bahari and Baradaran, 2009) during past decades. In fact, these intelligent methodologies have many features that make them attractive to use in these problems. Among these, however, the ability to deal with ill-defined and noisy real signals and datasets are the most important one. Hole making is one of the most important process in manufacturing (Serope Kalpakjian, 2001). One of the methods to make a hole is by drilling operation (Osawa et al, 2005). Drills basically have high length to diameter ratios, thus they are capable to produce a deep holes (Serope Kalpakjian, 2001). However, the friction will occur when the drills touches the surface of the work piece (Serope Kalpakjian, 2001). This situation will make the rpm of the motor decreasing and this will make the hole making less accurate as it should be from theoretically. There are several type of drilling which are gun drilling, twist drill, and trepanning.

Abrao et al. have focused the investigation on the effect of cutting tool geometry and material on thrust force and delamination produced while drilling GFRP composites. Durao et al. have studied the effect on drilling characteristics of hybrid carbon + glass/epoxy composites. They validated the influence of delamination in bearing stress of drilled hybrid carbon + glass/epoxy quasi-isotropic plates. They conducted the experiments with five different drill bits viz., HSS twist drill, carbide twist drill, carbide brad, carbide dagger and special step drills. Dandekar et al. carried out a experimental study of comparing the drilling characteristics of E-glass fabric reinforced polypropylene composite and aluminum alloy 6061-T6. Mohan et al. have studied the influence of cutting parameters, drill diameter and thickness while machining GFRP composites and analyze the delamination. Paulo Davim et al. have studied the influence of cutting parameters (cutting velocity and feed) while machining GFRP with two different matrixes in order to study its influence along with those parameters on delamination. Khashaba et al. have studied the influence of material variables on thrust force, torque and delamination while drilling of GFRP composites with different types of fiber structures. They have carried out the experiment with cross winding /polyester, continuous winding/polyester, woven polyester and woven /epoxy. Among all it seems woven epoxy came out with best results in terms of torque, thrust force. Tsao et al. have studied the drilling of CFRP composite. Here the approach carried was carried out based on Taguchi techniques and analysis of variance. The main focus of this work is to have a correlation between drill diameter, feed rate and spindle speed .The experiments were carried out at 3 levels .The phenomenon of interaction was not considered and the results indicated that the drill diameter have a significant contribution to the overall performance. From the above literature, it has been known that the delamination due to thrust force and torque produced in drilling are important concern and is to be modeled. For modeling thrust force and torque in drilling of composite materials fuzzy logic approach is used in this work. Artificial intelligence tools are playing an important role in modeling and analysis. Fuzzy logic is relatively easier to develop and require less hardware and software resources. Fuzzy logic controller is the successful application of fuzzy set theory and was introduced by Zadeh in 1965 as an extension of the set theory by the replacement of the characteristic function of a set by a membership function whose value range from 0 to 1. A considerable amount of investigations have been directed towards the prediction and measurement of thrust forces. The thrust force generated during drilling have a direct influence on the cutting of material. Wear on the tool, accuracy of the workpiece and quality of the hole obtained in drilling are mainly depends on thrust force. Balazinski and Jemielnaik introduced the fuzzy decision support system for the estimation of the depth of cut and flank wear during the turning process. Arghavani et al. used fuzzy logic approach for the selection of gaskets in sealing performance. Yue jiao et al. used fuzzy adaptive networks in machining process modeling. They have used fuzzy logics for surface roughness prediction in turning operations. Palani kumar et al. used fuzzy logic for optimizing the multiple performance characteristics. Recently Latha and Senthil kumar have successfully applied fuzzy logic for the prediction of delamination in drilling of glass fibre reinforced plastics. In the present work a user friendly fuzzy logic based system has been designed for the prediction of thrust force and torque in drilling of glass fiber reinforced plastic composites. The experiments are conducted on computer numerical control machining centre. L18 orthogonal array is used for experimentation. Special multi-facet drill is used for the investigation. The results indicated that the fuzzy logic model can be effectively used for the drilling of composites.

**Capello E**, **Tagliaferri V [6]** 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 and V. Tagliaferri studied [7]** 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 their intrinsic limitations are assessed.

**R. Piquet et. al [8]** studied the drilling with a twist drill and a specific cutting tool of structural thin backing plates in carbon/epoxy. The possibility to manufacture carbon/epoxy with a conventional cutting tool was analysed and the limits of the twist drill were shown. Consequently we defined a specific cutting tool. Series of comparative experiments were carried out using a conventional twist drill and this specific cutting tool. The results shown the capabilities of the 18 specific cutting tool because several defects and damages usually encountered in twist drilled holes were minimised or avoided (entrance damage, roundness and diameter defects and plate exit damage).

**E.-S. Lee [9]** studied the machinability of GFRP by means of tools made of various materials and geometries was investigated experimentally. By proper selection of cutting tool material and geometry, excellent machining of the workpiece is achieved. The surface quality relates closely to the feed rate and cutting tool. When using glass fibre reinforced plastics (GFRP) it is often necessary to cut the material, but the cutting of GFRP is often made difficult by the delamination of the composite and the short tool life.

**L-B Zhang, L-J Wang and X-Y Liu [10]** studied the analysis for multidirectional composite laminates is based on linear elastic fracture mechanics (LEFM), classical bending plate theory and the mechanics of composites. This paper presents a general closed-form mechanical model for predicting the critical thrust force at which delamination is initiated at different ply locations. Good correlation is observed between the model and the experimental results.

**E. Ugo. Enemuoh et. al [11]** studied new comprehensive approach to select cutting parameters for damage-free drilling in carbon fiber reinforced epoxy composite material is presented. The approach is based on a combination of Taguchi's experimental analysis technique and a multi objective optimization criterion. The optimization objective includes the contributing effects of the drilling performance measures: delamination, damage width, surface roughness, and drilling thrust force. A hybrid process model based on a database of experimental results together with numerical methods for data interpolation are used to relate drilling parameters to the drilling performance measures. Case studies are presented to demonstrate the application of this method in the determination of optimum drilling conditions for damage-free drilling in BMS 8-256 composite laminate.

**J. Paulo Davim and Pedro Reis [12]** studied the cutting parameters (cutting velocity and feed rate) on power (*P*c), specific cutting pressure (*K*s), and delamination in carbon fiber reinforced plastics (CFRPs). A plan of experiments, based on the techniques of Taguchi, was established considering drilling with prefixed cutting parameters in an autoclave CFRP composite laminate. The analysis of variance was preformed to investigate the cutting characteristics of CFRPs using cemented carbide (K10) drills with appropriate geometries. The objective was to establish a correlation between cutting velocity and feed rate with the power (*P*c) specific cutting pressure (*K*s) and delamination factor (*F*d) in a CFRP material. Finally, this correlation was obtained by multiple linear regressions.

**C. C. Tsao,H. Hocheng [13]** studied 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 carbon fiber-reinforced plastic (CFRP) laminate is used in this paper. The experiments were conducted to study 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 CFRP laminate. The correlation was obtained by multi-variable linear regression and compared with the experimental results.

**U. A. Khashaba studied the [14]** Delamination-free in drilling different fiber reinforced thermoset composites was the main objective of research. Therefore the influence of drilling and material variables on thrust force, torque and delamination of GFRP composites was investigated experimentally. Drilling variables were cutting speed and feed. Material variable include matrix type, filler and fiber shape. Drilling process was carried out on 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 thrust forces in drilling continuous-winding composite are more than three orders of magnitude higher than those in the cross-winding composites. Delamination, chipping and spalling damage mechanisms \

**Velayudham A, Krishnamurthy R and Soundarapandian T [18]** studied the dynamics of drilling of high volume fraction glass fibre reinforced composite. At high fibre volume, fibres do not show much relaxation and normal hole shrinkage associated with polymeric composites was not observed during drilling. Peak drilling thrust, dimension of holes drilled and vibration induced during drilling are observed to correlate with each other. Vibrations study has been attempted through wavelet packet transform and the results demonstrated its capability in signal characterisation.

**N.S. Mohan, S.M. Kulkarni and A. Ramachandra [19]** studied the drilling parameters and specimen parameters evaluated were speed, feed rate, drill size and specimen thickness on FRP. 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 was 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.

**C.C. Tsao and H. Hocheng [20]** studied the effects of backup plate on delamination in drilling composite materials using saw drill and core drill. The critical drilling thrust force at the onset of delamination is calculated and compared with that without backup. Saw drills and core drills produce less delamination than twist drills by distributing the drilling thrust toward the hole periphery. Delamination can be effectively reduced or eliminated by slowing down the feed rate when approaching the exit and by using back-up plates to support and counteract the deflection of the composite laminate leading to exit side delaminations. The use of the back-up does reduce the delamination in practice, which its effects have not been well explained in analytical fashion.

**I. Singh and N. Bhatnagar [21]** studied to correlate drilling-induced damage with drilling parameters. Tool point geometry is considered a major factor that influences drilling-induced damage. Experiments were conducted and drilling-induced damage was quantified using the digital image processing technique. The results also reestablished the cutting speed to feed ratio as an important variable that influences drilling-induced damage. Mathematical models for thrust, torque, and damage are proposed that agree well with the experiments.

**S. Arul et. al [22]** studied the drilling of polymeric composites which aimed to establish a technology that would ensure minimum defects and longer tool life. Specifically, the authors conceived a new drilling method that imparts a low-frequency, high amplitude vibration to the workpiece in the feed direction during drilling. Using high-speed steel (HSS) drill, a series of vibratory drilling and conventional drilling experiments were conducted on glass fiber-reinforced plastics composites to assess thrust force, flank wear and delamination factor. In addition, the process status during vibratory drilling was also assessed by monitoring acoustic emission from the workpiece. From the drilling experiments, it was found that vibratory drilling method is a promising machining technique that uses the regeneration effect to produce axial chatter, facilitating chip breaking and reduction in thrust force.

**H. Hocheng and C.C. Tsao [23]** studied the critical thrust force at the onset of delamination, and compares the effects of these different drill bits. The results confirm the analytical findings and are consistent with the industrial experience. Ultrasonic scanning is used to evaluate the extent of drilling-induced delamination in fiber-reinforced materials. 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. The analysis can be extended to examine the effects of other future innovative drill bits.

**J. Rubioa et. al [24]** studied HSM to realize high performance drilling of glass fibre reinforced plastics (GFRP) 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 HSM carried out for drilling GFRP ensuring low damage levels. 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.

**V. Krishnaraj, S. Vijayarangan and A. Ramesh Kumar [25]** studied the damage generatedduring the drilling of Glass Fibre Reinforced Plastics (GFRP) which was detrimental for the mechanical behaviour of the composite structure. This work was focused on analysing the influence of drilling parameters (spindle speed and feed) on the strength of the GFR woven fabric laminates and further to study the residual stress distribution around the hole after drilling. Holes were drilled at the centre of the specimens in a CNC machining centre using 6 mm diameter micrograin carbide drill for various spindle speeds (1000 4000 rpm) and feed rates (0.02, 0.06, 0.10 and 0.20 rev/min). Degree of damage depends on the feed rate and spindle speed. Experimental results indicate that failure strength and stress concentration are related to the drilling parameters and a drilling parameter (3000 rpm and 0.02 mm/rev), which gives better mechanical strength.

**U.A. Khashaba M.A. Seif and M.A. Elhamid [26]** studied the effects of the drilling parameters, speed, and feed, on the required cutting forces and torques in drilling chopped composites with different fiber volume fractions. Three speeds, five feeds, and five fiber volume fractures are used in this study. The results show that feeds and fiber volumes have direct effects on thrust forces and torques. On the other hand, increasing the cutting speed reduces the associated thrust force and torque, especially at high feed values. Using multivariable linear regression analysis, empirical formulas that correlate favorably with the obtained results have been developed. These formulas would be useful in drilling chopped composites. The influence of cutting parameters on peel-up and push-out delaminations that occurs at drill entrance and drill exit respectively the specimen surfaces have been investigated. No clear effect of the cutting speed on the delamination size is observed, while the delamination size decreases with decreasing the feed. Delamination-free in drilling chopped composites with high fiber volume fraction remains as a problem to be further investigated.

**Redouane Zitoune, Vijayan Krishnaraj and Francis Collombet [27]** studied the parametric influences on thrust force, torque as well as surface finish, the experimental results shown that the quality of holes can be improved by proper selection of cutting parameters. This is substantiated by monitoring thrust force, torque, surface finish, circularity and hole diameter. For the CFRP, the circularity is found to be around 6 lm at low feed rates, when the feed is increased the circularity increases to 25 lm. The wear tests carried out show that, during first 30 holes, thrust force in CFRP undergoes a more important increase (90%) than thrust force of aluminium (6%).

**I.S. Shyha et. al [28]** studied the effect of drill geometry and drilling conditions on tool life and hole quality. Main effects plots and percentage contribution ratios (PCR) are detailed in respect of response variables and process control factors. More conventionally, tool wear and cutting force data are plotted tabulated, together with micrographs of hole entry/exit condition and internal hole damage. Drill geometry and feed rate ingeneral had the most effect on measured outputs. Thrust force was typically below 100 Nattestcessation; however, drill wear progression effectively doubled the magnitude of force from test outset. Entry and exit delamination factors (Fd) of 1.3 were achieved while the maximum number of drilled holes for a tool life criterion VBB max of r 100 mm was 2900 holes using a stepped, uncoated drill with a feed rate of 0.2 mm/rev.

**S.R. Karnik et.al [29]** studied the delamination behaviour as a function of drilling process parameters at the entrance of the CFRP plates. The delamination analysis in high speed drilling is performed by developing an artificial neural network (ANN) model with spindle speed, feed rate and point angle as the affecting parameters. A multilayer feed forward ANN architecture, trained using error-back propagation training algorithm (EBPTA) is employed for this purpose. Drilling experiments were conducted as per full factorial design using cemented carbide (grade K20) twist drills that serve as input–output patterns for ANN training. The validated ANN model is then used to generate the direct and interaction effect plots to analyze the delamination behavior. The simulation results illustrate the effectiveness of the ANN models to analyze the effects of drilling process parameters on delamination factor. The analysis also demonstrates the advantage of employing higher speed in controlling the delamination during drilling.

**L.M.P. Durao et.al [30]** studied to minimization of axial thrust force during drilling reduces the probability of delamination onset, as it has been demonstrated by analytical models based on linear elastic fracture mechanics (LEFM). A finite element model considering solid elements of the ABAQUS software library and interface elements including a cohesive damage model was developed in order to simulate thrust forces and delamination onset during drilling. Thrust force results for delamination onset are compared with existing analytical models.

**Redouane Zitoun and Francis Collombe [31] s**tudied a numerical FE analysis is proposed to calculate the thrust forces responsible for the defect at the exit of the hole during the drilling phase of long-fibre composite structures, within a quasi-static framework. This numerical model compared with the analytical models studied in the literature – takes into account the tool point geometry as well as the shear force effects in the laminate.

## 3. Conclusions

From the analysis of result in the drilling using conceptual *S/N* ratio approach, Taguchi method provides a simple, systematic and efficient methodology for the optimization of the process parameters and this approach can be adopted rather than using engineering judgement. Furthermore, the multiple performance characteristics such as tool life, cutting force, surface roughness and the overall productivity can be improved by useful tool of Taguchi method. In this work, it is observed that specimen thickness, feed rate, speed and diameter are significant parameters of cutting thrust.

Further by the observation interaction among the parameters, the combined effect of thickness and drill size, feed and drill size are more significant than any other combination influence on average *S/N* response for cutting thrust. Among the thrust significant parameters, speed and drill size are more significant than the specimen thickness and the feed rate. The selection of the highest speed on the lowest thickness specimen with the smallest drill size and lowest feed rate result the best combination to get the lower the cutting thrust during drilling within the range of experiment. Using the response table for *S/N* ratio, for the optimum cutting conditions resulted in the estimated torque of 2.97 N and from the experiment the value of cutting thrust is found to be 2.826 N, confirming within the 95.15% of confidence. Interaction plot [data means] for *S/N* ratio indicates that change in level of thickness causes the corresponding change in one direction of feed rate and speed. Surface response plot indicates that thrust force minimum observed in the higher speed range. It is also observed that the minimum thrust force falls in the smaller drill size region. The main effects plot for S/N ratio for torque indicates the selection of central feed rate, highest speed, lowest specimen thickness (3 mm) and lowest drill size (3 mm) result the best combination to get the lowest the torque during drilling within the selected range of experiment.

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