# Drilling of Glass Fibre Polymer Composites by the Application of Taguchi Method and ANOVA Analysis for Optimization of Machining Parameters

[1.] N. Satheshkumar
P.G, Department of mechanical engg, C.M.S College of Engineering,Namakkal

[2.] G. Kumaresan
Asso.prof/ Department of mechanical engg C.M.S College of engineering,Namakkal

[3.] Dr.K.G.Muthuraja
Sr.prof, Department of mechanical Engg
V.M.K.V Engineering college,Salem

***Abstract*— The objective of the present work is to The purpose of this paper is to study the effect of process parameters such as spindle speed and feed, drill diameter and point angle, and material thickness on thrust force and torque generated during drilling of Glass Fiber Reinforced Polymer (GFRP) composite material using solid carbide drill bit. Full factorial Design of Experiments (DOE) has been adopted and the results indicate that spindle speed is the main contributing parameter for the variation in the thrust force and drill diameter is the main contributing factor for variation in torque. The optimum combination of process parameter settings has been found out using the integration of Taguchi method and Response Surface Methodology. Investigated the trepanning tool is to reduce the thrust force and torque during drilling glass fiber reinforced plastic (GFRP) laminates. Only in recent years the cutting tool manufacturers have started developing tool geometries specifically for drilling of composite materials. Four-facet, eight-facet, inverted cone and carbide tipped drills are some of the widely used tool designs in drilling of composite materials. Some of the researchers have tried to minimize the thrust force by selecting various combinations of independent parameters and also tried to optimize the process by different Design of Experiment (DOE) techniques such as Taguchi's technique.**

## I. INTRODUCTION

Fibre reinforced plastics find wide application in all manufacturing fields due to their distinct properties such as low weight, high strength and stiffness1. Although composite components are produced to near-net shape, machining is often needed to fulfill the requirements related to tolerances of assembly needs. Among all machining processes, drilling is the most indispensable method for the fabrication of products with composite panels. The performance of these products is mainly dependant on surface quality and dimensional accuracy of the drilled hole. The quality of the hole drilled is influenced by the cutting conditions, tool material and geometry. The material anisotropy resulting from fibre reinforcement considerably influences the quality of the drilled hole.

Much of the literature reported on drilling of FRP material by conventional tools has shown that the quality of the cut surface is strongly dependent on the cutting parameters, tool geometry, tool material, work piece material, machining process, etc. An improper selection of these parameters can lead to unacceptable material degradation, such as fiber pullout, matrix catering, thermal damage and dispread delaminating. Palanikumara and Paulo Davim investigated the influence of cutting parameters namely cutting speed, fiber orientation angle, depth of cut and feed rate on tool flank wear and the results indicated that cutting speed has a greater influence on tool flank wear followed by feed rate. Taguchi proposed that the engineering optimization of a process should be carried out in three step approach: the system design, the parameter design and the tolerance design.

The Taguchi method uses orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments. The orthogonal arrays reduce the number of experimental configurations to be studied. Furthermore, the conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and their settings. Orthogonal arrays are not unique to Taguchi. However, Taguchi has modified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects. The experimental results are then transformed into a signal-tonoise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values.

Murthy et al. studied the effect of process parameters like speed, feed, drill diameter, point angle and material thickness on thrust force and torque generated during drilling of GFRP composites using solid carbide drill bit and found the optimum process parameter settings using Taguchi method and response surface methodology. The results revealed that the spindle speed is the main contributing process parameter for the variation in thrust force and drill diameter for torque. The phenomenon of delamination during drilling was identified and analyzed by Hocheng and Tsao. They developed a mathematical model to predict the critical thrust force using various drill bits. Khashaba et al. studied the effect of machining parameters in the drilling of GFR/epoxy composites and they developed a model to predict the critical thrust force during drilling. Mohan et al. optimized cutting process parameters in drilling of glass fiber reinforced composite (GFRC) material and found that speed and drill size are more significant influence factors in cutting thrust than the specimen thickness and the feed rate.

Kilickap investigated the influence of cutting parameters, such as cutting speed, feed rate and point angle on delamination produced when drilling a GFRP composite and concluded that feed rate and cutting speed are the most influential factor on the delamination, respectively. A significant amount of research was carried out to find the influence of machining parameters on the delaminating of composite laminates using Taguchi and analysis of variance techniques.

In this work, process parameters are optimized in drilling of GFRP composites using Taguchi design of experimental technique and the results are analyzed using ANOVA technique to know the percentage contribution of each parameter on thrust force, torque, surface finish and circularity of the hole. The main objective of the present work is to optimize the process parameters in the drilling of GFRP composite using Taguchi method design and to find the significance of each process parameter using ANOVA. In the present work, statistical analysis software MINITAB 15 was used for the design and analysis of experiments to perform the Taguchi and ANOVA analysis and also to establish regression models.

## II. DRILLING

Drilling is a cutting process that uses a drill bit to cut or enlarge a hole of circular cross-section in solid materials. The drill bit is a rotary cutting tool, often multipoint. The bit is pressed against the work piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work piece, cutting off chips from the hole as it is drilled.

Exceptionally, specially-shaped bits can cut holes of non-circular cross-section; a square cross-section is possible.

### *A. PROCESS*

Drilled holes are characterized by their sharp edge on the entrance side and the presence of burrs on the exit side (unless they have been removed). Also, the inside of the hole usually has helical feed marks. Drilling may affect the mechanical properties of the work piece by creating low residual stresses around the hole opening and a very thin layer of highly stressed and disturbed material on the newly formed surface. This causes the work piece to become more susceptible to corrosion at the stressed surface. A finish operation may be done to avoid the corrosion. Zinc plating or any other standard finish operation of 14 to 20 µm can be done which helps to avoid any sort corrosion.

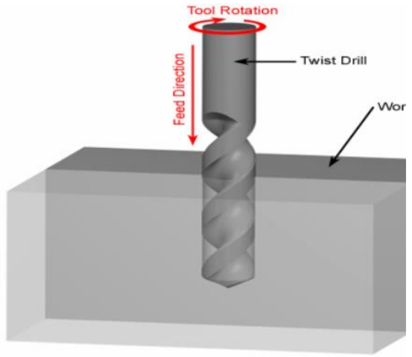

*Fig. No A. Drill Process*

For fluted drill bits, any chips are removed via the flutes. Chips may be long spirals or small flakes, depending on the material, and process parameters. The type of chips formed can be an indicator of the machinability of the material, with long gummy chips reducing machinability.

When possible drilled holes is should be located perpendicular to the work piece surface. This minimizes the drill bit's tendency to "walk", that is, to be deflected, which causes the hole to be misplaced. The higher the length-to-diameter ratio of the drill bit, the higher the tendency to walk. The tendency to walk is also preempted in various other ways, which include:

Establishing a centering mark or feature before drilling, such as by:

- Casting, molding, or forging a mark into the work piece
- Center punching
- Spot drilling (i.e., center drilling)
- Spot facing, which is facing a certain area on a rough casting or forging to establish, essentially, an island of precisely known surface in a sea of imprecisely known surface

Constraining the position of the drill bit using a drill jig with drill bushings

Surface finish in drilling may range from 32 to 500 micro inches. Finish cuts will generate surfaces near 32 micro inches, and roughing will be near 500 micro inches. Cutting fluid is commonly used to cool the drill bit, increase tool life, increase speeds and feeds, increase the surface finish, and aid in ejecting chips. Application of these fluids is usually done by flooding the work piece or by applying a spray mist.

In deciding which drill(s) to use it is important to consider the task at hand and evaluate which drill would best accomplish the task. There are a variety of drill styles that each serves a different purpose.

The subland drill is capable of drilling more than one diameter. The spade drill is used to drill larger hole sizes. The index able drill is useful in managing chips.

### B. SPOT DRILLING

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

### C. CENTER DRILLING

The purpose of center drilling is to drill a hole that will act as a center of rotation for possible following operations. Center drilling is typically performed using a drill with a special shape, known as a center drill.

### D. DEEP HOLE DRILLING

Deep hole drilling is defined as a hole depth greater than ten times the diameter of the hole. These types of holes require special equipment to maintain the straightness and tolerances. Other considerations are roundness and surface finish.

Deep hole drilling is generally achievable with a few tooling methods, usually gun drilling or BTA drilling. These are differentiated due to the coolant entry method (internal or external) and chip removal method (internal or external). Using methods such as a rotating tool and counter-rotating workpiece are common techniques to achieve required straightness tolerances.[5] Secondary tooling methods include trepanning, skiving and burnishing, pull boring, or bottle boring. Finally a new kind of drilling technology is available to face this issue: the vibration drilling. This technology consists in fractionating chips by a small controlled axial vibration of the drill. Therefore the small chips are easily removed by the flutes of the drill.

A high tech monitoring system is used to control force, torque, vibrations, and acoustic emission. The vibration is considered a major defect in deep hole drilling which can often cause the drill to break. Special coolant is usually used to aid in this type of drilling.

### E. GUN DRILLING

Another type of drilling operation is called gun drilling. This method was originally developed to drill out gun barrels and is used commonly for drilling smaller diameter deep holes. This depth-to-diameter ratio can be even more than 300:1. The key feature of gun drilling is that the bits are self-centering; this is what allows for such deep accurate holes. The bits use a rotary motion similar to a twist drill; however, the bits are designed with bearing pads that slide along the surface of the hole keeping the drill bit on center. Gun drilling is usually done at high speeds and low feed rates.

A drill bit enters the work piece axially and cuts a blind hole or a through hole with a diameter equal to that of the tool. A drill bit is a multi-point tool and typically has a pointed end. A twist drill is the most commonly used, but other types of drill bits, such as a center drill, spot drill, or tap drill can be used to start a hole that will be completed by another operation

*Fig No.E GUN DRILLING*

## III. HYPOTHESIS TESTING

Seeking the significance of relationship between the process variables and the cutting energy consumption in composite drilling has been an active area of research since several decades. Marques et al. found that as the feed rate increases, the thrust force increases, whereas, as the speed increases the thrust force decreases up to a certain value beyond which it increases.

Madhavan et.al. Postulate that as the spindle speed increases, the cutting torque will decrease for a value of speed beyond which it increases. Wen-Chou-Chen found that as point angle increases, the thrust force increases and the cutting torque decreases.

Mansheel Cheong et al. found that as the drill diameter increases, both the thrust and torque forces will increase16. Panda et al. investigated that increase in drill diameter will increase the thrust force.

Abrao et al. observed an increment in the amount of thrust force generated with the increase in thickness of the composite work material. Based on the contemporary research, a number of exogenous factors have been indentified, which are supposed to influence the thrust force and torque, which determines the cutting energy required in drilling. The list includes: material thickness, volume fraction of fiber, type of fiber, tool diameter, drill point angle, speed, and feed. As the research focus is to find the significance of influence of these exogenous factors on the drilling process, the following two hypotheses have been formulated.

### A. THRUST FORCE (H1)

Ho1: There is no significant influence of exogenous factors on thrust force. Ha1: There is a significant influence of exogenous factors on thrust force.

### B. TORQUE (H2)

Ho: 2 there is no significant influence of exogenous factors on cutting torque. Ha2: There is a significant influence of exogenous factors on cutting torque. Material and Methods Machine: The experiment has been carried out on the TRIAC CNC vertical machining centre which enables high precision machining. The laminate composite specimen was rigidly held by the fixture which is attached to the dynamometer mounted on the machine table. The thrust force generated during cutting was measured with the help of KISTELER dynamometer. The data collected was transferred to a computer for analysis. Solid carbide drills have been used for the present experimental study because they offer better heat and wear resistance properties and are widely used in machining GFRP composites.

Technical specifications of TRIAC CNC are as follows: Tool Type (ATC)..... BT30, Tool holding capacity, (ATC) 8 tools, spindle speed (programmable) 100 – 4000 rpm. Maximum feed rate on X and Y axis...2500 mm/min. Maximum feed rate on Z axis.....1000 mm/min. Figure-1 Experimental set-up Work piece: Drilling experimentation has been carried out on GFRP composite material which is manufactured by hand layup method. Chopped strand mat made of E-glass fiber having the density of 2590 kg/ m3 and modulus of elasticity of 72.5 GPa is used as reinforcement material. Matrix system consists of general purpose polyester resin [GP] and a room temperature curing accelerator catalyst is used. The hardener used is the methyl ethyl ketone peroxide (MEKP). The polyester resin is used owing to the advantages such as: low cost, ease of handling, good mechanical and electrical properties. The density and modulus of elasticity of the general purpose polyester resin are 1350 Kg/m3 and 3.25 GPa respectively.

## IV. CUTTING CONDITIONS AND EXPERIMENTAL PROCEDURE

Considering the seven exogenous factors, the number of experiments, N = LF = 37 = 2187. To reduce the number of experiments there are several approaches, Taguchi method being the most common. However, in the present case, Volume fraction and Fibre types (chopped strands of random orientation type and oven mat type) are two factors which mainly influence the property of the composites. In general, the thrust and torque parameters will mainly depend on the machining conditions employed such as: cutting speed, feed rate, tool geometry, machine tool and cutting tool rigidity.

### A. *TAGUCHI METHOD:*

Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given below. Smaller the better: It is used where the smaller value is desired.

$$\text{S/N ratio}\,(\eta) = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n} y_i^2$$

- Where yi = observed response value and n = number of replications. Nominal the best: It is used where the nominal or target value and variation about that value is minimum.

$$\text{S/N ratio}\,(\eta) = -10\log_{10}\frac{\mu^2}{\sigma^2}$$

- Higher the better: It is used where the larger value is desired.

  Where, yi = observed response value and n = number of replications. Taguchi suggested a standard procedure for optimizing any process parameters.

The steps involved are:
• Determination of the quality characteristic to be optimized.
• Identification of the noise factors and test conditions.
• Identification of the control factors and their alternative levels.
• Designing the matrix experiment and defining the data analysis procedure.
• Conducting the matrix experiment.
• Analyzing the data and determining the optimum levels of control factors.
• Predicting the performance at these levels

## V. CONCLUSION

Thrust force is significantly influenced by spindle speed, and they are inversely proportional. Hence, while working on Glass Fiber Reinforced Composites by using Solid Carbide drills, higher spindle speed are recommended for process parameter ranges under consideration. Cutting torque is significantly influenced by drill diameter. Higher the drill diameter, larger will be the thrust force and cutting torque required. Thrust force increases, whereas, cutting torque decreases with the increase in drill point angle. Both thrust force and cutting torque increase with the increase in feed rate and material thickness. Integrating Taguchi method and RSM can be very effective in process parameter optimization, as combining of the results of the two methods can not only optimize the parameters, but also, indicate the values of response, through which, process parameter selection can be refined and results justified. The results are based on the preselected range of values of speed, feed, material thickness, drill diameter and drill point angle, and hence, the inferences drawn cannot be completely generalized. However, statistical procedures very clearly reveal significant influence of all the process parameters on the thrust force and torque.

## VI. FUTURE WORK

As the objective of this research has been mainly on optimization of the process parameters, deeper analysis on the significance of influence has not been carried out for a wide range of process parameters including volume fraction and fiber type. This opens up ample scope for future work in this area. The inferences drawn through this study can be of great significance to the practitioners, in minimization of tool wear and cutting energy, as Solid carbide tool is being widely used in machining GFRP.

## REFERENCES

[1] Bhatnagar N, Ramakrishnan N, Naik NK, Komanduri R. On the machining of fiber reinforced plastic (FRP) composite laminates. Int J Mach Tools Manufact 1995;35: 701–6.
[2] Teti R. Machining of composite materials. CIRP Ann Manufact Technol 2002;51:611–34
[3] Manna A, Bhattacharyya B. Taguchi method based optimization of cutting tool flank wear during turning of PR-Al/20 vol.% SiC-MMC. Int J Mach Mach Mater 2006;14:488–99.
[4] Abrao AM, Faria PE, Campos Rubio JC, Paulo Davim J. Drilling of fiber reinforced plastics: a review. J Mater Process Technol 2007;186:1–7.
[5] Gopalsamy B, Mondal B, Ghosh S. Taguchi method and ANOVA. An approach for process parameters optimization of hard machining while machining hardened steel. J Sci Ind Res 2009;68:686–95.
[6] Palanikumara K, Paulo Davim J. Assessment of some factors influencing tool wear on the machining of glass fiber-reinforced plastics by coated cemented carbide tools. J Mater Process Technol 2009;209:511–9.
[7] Taguchi G. Introduction to quality engineering, Asian Productivity Organization. Dearborn, MI: Distributed by American Supplier Institute Inc.; 1986
[8] Phadke SM. Quality engineering using robust design. Englewood Cliffs, N.J: Prentice Hall; 1989.
[9] Bendell A. Introduction to Taguchi methodology. In: Taguchi methods: proceedings of the 1988 European Conference. London, England: Elsevier Applied Science; 1988. p. 1–14.
[10] ASI. Taguchi methods: implementation manual. Dearborn, MI, USA: American Supplier Institute Inc. (ASI); 1989.
[11] Murthy BRN, Rodrigues LR, Anjaiah D. process parameters optimization in GFRP drilling through integration of Taguchi and Response surface methodology. Res J Recent Sci 2012;1:7–15.

.