

# MACHINING OF COMPOSITES – A REVIEW

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**ABSTRACT:** Composites are materials widely used in many goods and components due to their superior properties. The machining of these materials is inevitable although they are manufactured to near net shape. This becomes more important when new product designs and shapes pose tougher dimensional and performance constraints like surface finish, dimensional tolerances & material removal rate etc. Thus many researchers in the past have attempted to study machining of composite materials to know the effect of various process parameters on the quality of machining characteristics. In this paper an attempt has been made to review the work of some researchers who conducted experimental studies on machining of composite material. Literature review reveals that current research focuses on nontraditional machining of metal matrix and ceramic matrix composites and also on traditional machining of glass fiber reinforced plastics and carbon fiber reinforced plastics to reduce or eliminate the problem of delaminating.

**KEYWORDS:** Glass Fiber Reinforced Plastic (GFRP), Delamination, Metal Matrix Composites, MRR

## 1 INTRODUCTION

Composite materials are continuously replacing normal engineering materials due to their outstanding properties such as high strength to weight ratio, high specific stiffness, improved fatigue resistance and creep resistance. A composite material is a combination of two or more chemically distinct and insoluble phases. The word composite in the term composite materials signifies that two or more than two materials are combined on macroscopic scale to form a useful third material whose properties and structural performance are superior to those of the constituents acting independently. Composite materials have found increasingly wider applications in aircraft, space vehicles, offshore structures, piping, electronics, automobiles, boats and sporting goods. Generally, one phase of the composite materials is matrix phase or continuous phase which can be plastic, metal or ceramic and other phase is dispersed phase or reinforcing phase which can be glass, graphite, boron, aramids and various other oxides, carbides and nitrides. Matrix Phase is usually more ductile and less hard phase whereas dispersed phase is usually stronger than the matrix.

Dispersed phase is generally in the form of particles or fibers. When more than one type of fiber is used in a matrix then the composite is known as hybrid. Although in many applications, composites are manufactured to final shape but machining is generally required particularly at product assembly stage.

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Many traditional machining methods like turning, drilling and milling are widely used to machine composite materials. Due to matrix-fiber two phase structure, many difficulties are encountered in machining of composites e.g. delamination and fiber splitting.

Delamination is defined as “the separation of the layers of material in a laminate.” Delamination can occur at any time in the life of a laminate for various reasons and has various effects. It can affect the tensile strength performance depending on the region of delamination. Among the various defects that are caused by drilling, delamination is recognized as the most critical. Many researchers over the past years have tried to study the machinability of composites using traditional machining methods and reported considerable improvement in dimensional and performance characteristics like surface roughness, hole quality and tolerance. However, due to advancements in product designs and advent of new high cost materials, rigorous surface finish and tolerance requirements pose a challenge in machining of composites.

Therefore, to meet these challenges various researchers have utilized advance machining methods like electric discharge machining, ultrasonic machining and hybrid machining methods to successfully machine composite materials, fulfilling stringent dimensional and performance constraints. In this paper, an attempt has been made to review the research work related to machining of composite materials using both traditional as well as nontraditional machining methods.

## 2 TRADITIONAL MACHINING OF COMPOSITES

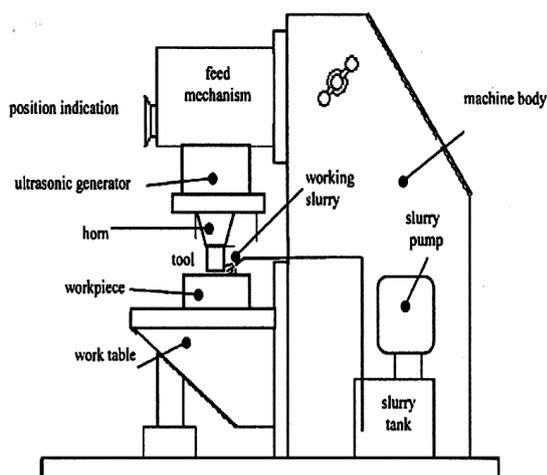
Latha B and Senthilkumar V.S. conducted an experimental study on drilling of Glass fiber reinforced Plastic composites to predict thrust force using fuzzy logic. They developed a fuzzy rule based model and compared it with the response surface model. The machining operations were carried out as per  $L_{27}$  experimental design. The process parameters considered for the experiments were spindle speed, feed rate and drill diameter. The results revealed that feed rate and drill diameter are the factors that influence the thrust force in drilling of GFRP composites. Spindle speed shows only very limited effect on thrust force. Palanikumar K. et al. used taguchi method with fuzzy logic to optimize machining parameters in turning GFRP composites using a carbide tool. The process parameters viz. fiber orientation, cutting speed, feed rate, depth of cut and machining time were optimized with consideration of multiple performance characteristics viz. material removal rate, tool wear and surface roughness. Results showed that fiber orientation and machining time were the significant parameters in machining of GFRP composites. Sarma P.M.M.S. et al. correlated surface roughness values obtained from turning GFRP composites with average grey scale values obtained from the images of specimens taken by a CCD camera. The GFRP pipes were turned using a polycrystalline diamond tool. The effect of cutting speed, feed rate, depth of cut and fiber orientation angle on surface roughness was studied and it was found that feed rate is the most significant parameter. Gaitonde V.N. et al. developed a second order mathematical model using response surface methodology in turning metal matrix composite material by a PCD tool. The effect of cutting speed and feed rate on machining force, cutting power and specific cutting force was studied while machining Aluminium alloy reinforced with 20% Silicon carbide particles. Results concluded that machining force and cutting power increase with feed rate while specific cutting force decreases for a given value of cutting speed. Krishnamoorthy A. et al. drilled carbon fiber reinforced composites to analyze delamination. In this work, response surface methodology was used for modeling the drilling parameters viz. spindle speed, feed rate and drill diameter for delamination in drilling CFRP composites. Results reported that feed rate is the main drilling parameter which influences delamination followed by drill diameter. High speed and low feed rate is suitable for minimum

delamination in drilling of CFRP composites. It was concluded that by using proper tool geometry and drill size, the delamination can be reduced. In another study, Mohan N.S. et al. conducted drilling tests on glass fiber-reinforced plastic composite GFRP laminates using a CNC milling center. Machining parameters such as drill size, feed rate, and cutting speed were observed for damage-free drilling of GFRP materials. A series of drilling experiments were conducted on glass fiber-reinforced polyester laminates and the responses experienced such as thrust force and torque as functions of feed rate and drill size were characterized to develop a semi empirical relationship which correlated well with an established model in terms of cutting parameters. Results indicated that experimental values correlated better with the model of thrust for 6 mm drill size than for 10 mm and torque correlated better for lower feed ranges than for the higher feed ranges. Tsao C.C. used a core saw drill for drilling CFRP composite materials to analyze the effect of feed rate, spindle speed and diameter ratio on mean thrust force and delamination. Taguchi method was used to optimize process parameters. Feed rate and spindle speed showed major influence on thrust force and delamination. Mathew J. et al. 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 were emphasized. The models for prediction of critical thrust and critical feed rate at the onset of delamination during trepanning of unidirectional composites based on fracture mechanics and plate theory were also presented. Mathematical models correlating thrust and torque with tool diameter and feed rate were developed through statistically designed experiments. It was observed that sub-laminate thickness is the most decisive parameter from the viewpoint of critical feed rates. S. Arul et al. 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 work piece 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 work piece. 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. S. C. Lin and I. K. Chen studied the effects of increasing cutting speed on drilling characteristics of carbon fiber-reinforced composite materials. The effects of increasing cutting speed on average thrust force, torque, tool wear and hole quality for both multi facet drill and twist drill were studied. It was found that increasing cutting speed will accelerate tool wear. E. S. Lee studied the machinability of GFRP by means of tools made of various materials and geometries were investigated experimentally. It was observed that by proper selection of cutting tool material and geometry, excellent machining of the work piece is achieved. The surface quality relates closely to the feed rate and cutting tool. Tosun Gul drilled Al/SiCp metal matrix composites and used analysis of variance to study the effect of spindle speed, feed rate, drill type, point angle of drill and heat treatment on surface roughness. Feed rate and drill type were the main significant factors effecting surface roughness.

### 3 NON TRADITIONAL MACHINING OF COMPOSITES

Hocheng H. and Hsu C. C. conducted an experimental study on ultrasonic drilling of carbon fiber reinforced plastic composites. The figure 1 shows the schematic of ultrasonic machining process. The research depicted the effect of slurry



**Figure 1: Schematic of ultrasonic machining process**  
concentration, abrasive size, feed rate and electric current on material removal rate, surface roughness and hole clearance.

It was concluded that surface roughness is independent of feed rate of the tool and no delamination occurs at the hole edge. Li Z.C. et al. studied rotary ultrasonic machining of ceramic matrix composites. A 23 full factorial design was used for the experiments with two replications. Effect of three process parameters viz. spindle speed, feed rate and ultrasonic power on material removal rate, cutting force and hole quality was studied. Results revealed that all the three input parameters have significant effects on MRR. Feed rate has the most significant effect on cutting force. Jianxin and Taichiu investigated the effect of properties and microstructure of work material on MRR in USM of alumina based ceramic composites. MRR was reported to be low while machining composites of higher fracture toughness such as whisker-reinforced composites. The particle reinforced composites yielded higher values of MRR on account of their low fracture toughness. The composites of higher flexural strength demonstrated better surface integrity while machining with USM.

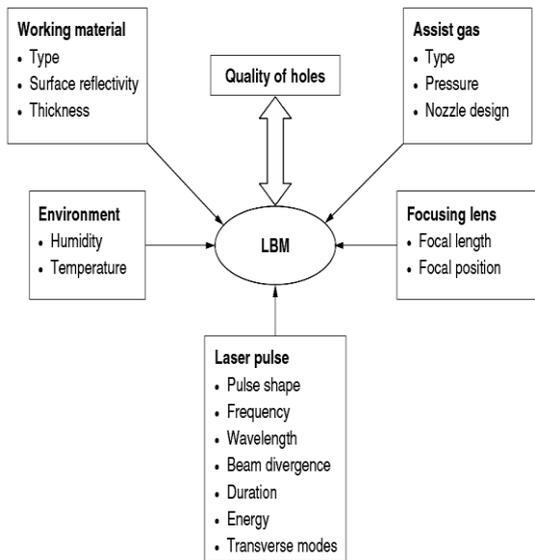
Karthikeyan et al. worked on mathematical modeling for electric discharge machining of aluminium-silicon carbide metal matrix composites. They studied the effect of SiC percentage, current and pulse duration on material removal rate, tool wear rate and surface roughness. The mathematical models were developed to predict the same within the operating region. Results revealed that MRR increases with increase in the current and decrease with an increase in the percent volume of SiC and the pulse duration. The tool wear rate increases with an increase in the current and the percent volume of SiC, but decreases with an increase in the pulse duration. Surface roughness increases with an increase in the current, percent volume of SiC and the pulse duration.

The figure 2 shows the electric discharge machining process used for the machining of hard materials suitable for the dies used in molding purposes. Narender Singh et al. worked on optimization by gray relational analysis of machining parameters in electric discharge machining of Al-10%SiCp composites. Orthogonal array with gray relational analysis was employed to optimize the multi response characteristics of machining of Al-10%SiCp composites.



**Figure 2. Presentation of electric discharge machining process**

The experimental result for the optimal setting showed that there was considerable improvement in the process. The application of this technique converts the multi-response variable to a single-response gray relational grade and, therefore, simplifies the optimization procedure. The effect of various process parameters involved in laser beam machining process are shown in figure 3.



**Figure 3. Effect of process parameters in laser beam machining process**

#### 4 DISCUSSION

Machining of composites is quite different from normal engineering materials because composites are anisotropic and inhomogeneous. Literature review highlights that many researchers have attempted to study and thus optimize the process parameters in traditional machining of

composite materials particularly of glass fiber reinforced plastics and carbon fiber reinforced plastics. Main focus of this research is to eliminate or reduce the problem of delamination in machining of composites. Metal matrix composites and ceramic matrix composites are very costly and difficult to machine by traditional methods. Thus studies have been conducted on machining of these materials by non traditional methods like ultrasonic machining and electric discharge machining etc. Objective of each study is almost same that is to improve the quality of the machined product in terms of surface roughness, hole quality and MRR.

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