# A Review Study on the Traditional Machining of Composite Materials

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**Abstract:** Composite materials are widely used materials in many industrial applications due to their superior properties. Machining of composite materials is difficult to carry out due to the anisotropic and non-homogeneous structures of composites and are mostly prepared in laminate form before undergoing the machining process. Machining of these materials is inevitable although they are manufactured to near net shape. This becomes more important when new product designs and shapes poses tougher dimensional and performance constraints like surface finish, dimensional tolerances & material removal rate etc. Thus many researchers in the past have attempted to study the machining of composite materials to know the effect of various process parameters upon the quality of machining characteristics. In this paper an overview of the various issues involved in the machining of the main types of composite materials is presented. Literature review reveals that current research focuses on the traditional machining of glass and carbon fiber reinforced plastics to reduce or eliminate the problem of delamination and dimensional accuracy.

**Keywords:** Machining, Turning, Grinding, Drilling, Composite Material.

## 1. INTRODUCTION

Machining is one of the basic operations necessary to cut things to size and to finish off edges, dimensions and other aspects of a finished assembly part. Machining involves the removal of material from the workpiece by means of a certain processes in order to get the desired size and shape as per the specifications. Machining of the composite materials differs significantly in many aspects with the machining of conventional metals and their alloys [1]. In the machining of composites, the material behavior is not only non-homogeneous and anisotropic, but it also depends on the diverse reinforcement and matrix properties, and the volume fraction of matrix and reinforcement. The tool encounters alternatively matrix and reinforcement materials, whose response to machining can be entirely different. Thus, there are a number of problems associated with the machining of fiber reinforced composite materials [2]. The varying material properties and the degree of anisotropy causes difficulty in predicting the behavior of the material through its machined. This can lead to a specific problems of FRP machining. Some of these problems can be describe as follows: The delamination due to the local dynamic loading caused by different stiffness's of the fiber and matrix. Also, the dimensional accuracy during machining of the composite is very hard to predict since the reinforcement and matrix have different coefficient of thermal expansion. Cutting tools may also be damaged by abrasive fibers rounding the cutting edges prematurely. The differences in the hardness between the fiber and matrix may lead to edge chipping of the tool. In addition, the tool may be clogged by melted matrix material. Some of the most common traditional machining processes are drilling, turning, and milling. Earlier composites were machined like metals, but poor surface finish and faster tool wear led to the further study of composite machining [2].

In this paper, an elaborated review on the problems encountered in the traditional machining of composite materials has been done and narrated.

## 2. TRADITIONAL MACHINING OF COMPOSITE MATERIALS

Traditional machining techniques are those processes, which involve cutting action by physical contact between tool and work piece having relative motion between the same. They are: grinding, milling, turning and drilling etc. [3]. They were adopted to machine composite materials in view of the availability of equipment and experience. As it is mentioned before, machining of composite material is not easy task due to its two phase structure. Many difficulties are encountered in machining of composite materials like delamination and fiber splitting.

### 2.1. Turning Machining of Composite Materials

Manna and B. Bhattacharyya [4], investigated on machinability of silicon carbide particulate aluminum metal matrix composite during turning with fixed

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rhombic tools. They experimented on the cutting speed, depth of cut on the cutting force and surface finish criteria. They also investigated on the combined effect of cutting speed and feed on flank wear and influence of cutting speed, feed rate and depth of cut on the tool wear. Formation of the chip and BUE (Build of edge) also they analyzed during their experimentation. They selected Al/SiC-MMC of 80mm diameter bar as a work piece and they used T-Max-U Positive rhombic insert type tool and it's specification CCGX-90-T3-04-Al-H10. The tool material is uncoated tungsten carbide (WC) (HWK10) [11]. They used in their experiments, the Turret Lathe with cutting speed rang of 20 to 225m/min, feed rate range 0.14 to1.00 mm/rev and the depth of cut range 0.25 to1.5mm. During the turning operation, the cutting force and the feed rate measured was by Kistler Piezoelectric Dynamometer of Kistler type 5501 with load amplifier of Kistler type 5007 [4]. During the machining of Al/SiC-MMC, they observed that flank wear rate is high at low cutting speed due to the generation of high cutting force and formation of BUE. Cutting speed zone between 60 and 150 m/min is recommended for machining Al/SiC-MMC, and the generation of BUE increase the actual rake angel at low cutting speed. They also found that the increment of cutting force which may in turn increase the cutting tool wear and they also they found that feed rate is less sensitive to the flank wear as compare to the cutting speed. They also concluded that for better surface finish, high speed, low feed and low depth of cut are recommended. A. K Sahoo *et al.* [5], discuss the machinability assessment in turning operation on MMC with carbide insert. In their experiment, they were used Al reinforced in SiCp metal matrix composite as work piece and as a tool they were used TiN coated carbide tool for turning operation, this operation done in dry condition. After machining, the researchers observed the chips which were metallic partial blue, and built up edge formation, they also observed the variable flank wear. Feed was found to be the most significant parameter in surface roughness. The tool wear is very important for any kind of machining because, it reduced the tool life. During the drilling operation, the error in the size of drill hole create a various problems in assembling. Taskesen *et al*. [6], studied the optimum cutting parameters that reduce the tool wear, and drill hole size error. In their experiments, they used Taguchi's L27. They found that in drilling operation, the abrasive wear and built of edge both were effected the drill tool and this were mostly depends upon the particle mass fraction, which was related by the feed rate, drill hardness and spindle speed. In their experiment the TiA1N coated carbide drills showed best performance. As a result, they revealed that optimal combination of the drilling parameters can be used to obtain both minimum tool wear and diametric error. G. Belingardi *et al*. [7], observed that, during the drilling of ply wood and glass fiber reinforced polymer specimens, the holes were damaged. Therefore; in their experiment, a comprehensive notch-edge damage analysis were performed with the help of recording test video, digital microscope, polariscopic and layer by layer SEM analysis. As an experimental observation they observed that the effectiveness of finding damaged zone was dependent on the damage observation technique. Predicted damaged zone by numerical solution are in good agreement with experimental observations. Tool wear also a problem in machining of fiber reinforce polymeric composites. This problem mainly cause of hardness and abrasive nature of synthetic fibers. Umar Nirmal *et al*. [8], concluded that, T-BFRP composite caused less damage on testing equipment compared to CSM-GFRP composite, with surface roughness of stainless steel counter face being lower by about 5%.

### 2.2. The Grinding of Composite Materials

Grinding operation is used in large scale for surface finish than general conventional machining in industries. In grinding operation the metal removal rate (MRR) is very low than other conventional machining and surface finish is very good than other. The grinding wheel removed microchips from work piece by sharp abrasive grids with very high cutting velocity. The sharp abrasive grids are strongly held in grinding wheel by suitable bond material [9]. Like other materials, the composite materials needed the grinding operation to obtain a good surface finish. A proper process such as grinding operation makes the surface free from a surface damage like a cracking, splintering and pulling out of reinforced particles. Z Zhong *et al*. [10], studied how to reduce the surface damages such as cracking, subsurface damaging, pulling of reinforced materials etc. In their experiment, they used 2618/Al2O3 10% and 2618/ Al2O3 with 2618 aluminum alloy matrix. They used a grinding wheels with Sic grain two types: one for rough grinding and the other for fine grinding. As a result, they found that through the rough grinding, the surface finish value Ra were scattered but in the case of fine grinding, there is no cracks and defects on the ground surface and the sub –surface damage, rate of rare cracked particle were also be reduced.

### 2.3. Drilling of Composite Materials

Drilling operation is a commonly used machining process for making cylindrical hole, making a tapering hole and finish the existing holes. The tool uses for making the hole called a drill bit, the drill bit available in various shapes and size, various material and application. Commonly HSS twist drill with two flutes is used for machining and other types of drill bit are also be used as respect the job piece design requirement. Other drill bits likes as center drills, step drills, taper drills, spade drills, straight-shank small drills, long or deep-hole drills, slot drills, carbide drills, gun drill etc. [11]. In the drilling of a composite reinforced material, delamination is the very serious concern. Navid Zarif Karimi *et al*. [12], studied the effect of drilling parameters upon the delamination factor and compressive residual strength of drilled laminates. The delamination factor is just the ratio of diameter of drilled hole diameter or drill bit diameter and the damage hole diameter. The drill hole diameter denoted ‘D0’ and the damaged hole diameter denoted as ‘Dmax’ and the delamination factor denoted as ‘Fd’ and it is write as ‘ Fd=Dmax/D0’[12]. They used the Taguchi method, and the work-piece was made by the hand-lay-up technique through mixing the resin reinforced with uni-directional E-Glass fiber. The composite samples were made of 6mm thickness, 13plies and had 50% fiber volume fraction. The plate area is 100mm X150mm. In the experiments, they used the machine tool FP4M vertical machining center with maximum rpm 2500, and the feed rate 200mm/min. The drill bit used standard HSS twist drills of 5mm diameter and 30° helix angle. During the experiments, it was not used the coolant media, so to avoid the wear of the tool, a drill bit was changed after each five experiments. The thrust force was measured by Kistler 9255B piezoelectric dynamometer. The acoustic emission software AWE in a data acquisition system (PAC) PCI-2 with a sampling rate of 1MH was used for recording of AE events. The researchers were selected three base factors in their study, the factors were drill point angle, cutting velocity, and feed rate. They conclude that, the feed rate can be affected on the thrust force when the other two factors (cutting velocity and drill point angle) are negligible while, they found that the drill point angle and the feed rate felled significant effect upon the adjusted delamination. The drill point angle and the cutting speed were negligible. Whereas, the feed rate affected on the compressive residual strength and it is better obtained when the feed rate was lower. There was a qualitatively linear relation between compressive residual strength and damaged area. Different feed rate showed the delamination factor depend on thrust force during drilling. The delamination factor really a serious problem to drill composite work-piece, it is actually depends on the thrust force during drilling by the twist drill bit [12]. It was found that the size of the delamination zone has been shown how the thrust force developed during the drilling operation [13]. The numerous studies have examined the delamination during the drilling process [14-17]. It was found in all the previous studies that the thrust force depends on the cutting conditions (cutting speed, feed rate). To minimized the delamination factor, the researchers try so many practices to reduce the feed rate and increase the spindle speed. But H. Hocheng *et al*. [18] tried to find out a different ways to reduce the thrust force and delamination factor. In their work, they used a special types of drill bits such as saw drill, candle drill, core drill and step drill. They also, tried to compare the effect of critical thrust force and delamination factor during the drilling process by these special types of drill bits. They used composite laminates made of woven WFC200 fabric carbon fiber for their experiment. The laminates were cured in an autoclave at 150°C and 600KPa, the dimensions of the composite plate specimens was 60mm×66mm×6mm. This experiment was carried out using a vertical machining center and the mean thrust force was measured by K9273 four component piezoelectric, and Kistler 5007 charge amplifier. Then, reading values were stored by the TEAC DR-F1 DEGITAL RECORDER. A twist drill with 10 mm diameter made of high speed steel, saw drill, candle stick drill, step drill were used in the machining process. The drilling operation conducted in totally dry condition. The step drill diameter ratio was 0.2, the core drill diameter plated with diamond. The drill diamond grit size #60 at the front end. For the experiment they selected spindle speed 900 and 1000rpm, the selected feed rate for this experiment were 0.003, 0.005, 0.008, 0.0088, 0.009, 0.01, 0.011, 0.0111, 0.012, 0.0122 and 0.0133 mm/rev. After drilling the holes are scanned by ultrasonic C-Scan and produced images and they observed that the delamination factor increased with thrust force. They also watched that traditional twist drill provide low threshold of the compared to special drill [18]. And also they found the correlation between thrust force and feed rate for various drills, and watched in selected feed rate twist drill showed highest thrust force than saw drill and core drill. And candle stick drill and step drill showed lowest thrust force compare with twist drill in selected feed rate. This proved that the twist drill has more delamination factor than types of other types of drill bit. After their experiment they compare their results with theoretical prediction of critical thrust force at the onset of delamination. In their experiment they used various types of drill bits with different geometry and different level of thrust force. At last of their experiment they conclude that the traditional twist drill shows high delamination factor in higher feed rate, but compare with twist drill the among five drills the core drill, candle stick drill, saw drill and step drill, makes holes with higher feed rate than twist drill and the delamination factor is almost low than twist drill. That means, the core drill, candle stick drill, saw drill, step drill makes delamination free hole with high feed rate, which is not possible in twist drill. This is shorter cycle time of drilling operation without delamination [19-23]. The delamination factor obviously depends on the thrust force of drilling, to measure or minimized the delamination factor the thrust force must be calculated. The magnitude of thrust force can help to obtain the delamination factor and manufacturer easily done the delamination free holes. The different nature of damage harms the lifespan of the assemblies. In the literature [24] according to three zones of appearance: at the entry of the hole – by the peeling oh the higher plies of laminate, on the wall of the hole- by the fiber wrenching and the resin degradation and at the exit of the hole by the delamination of the last plies (mainly due to thrust force of the cutting tool) [25, 26]. The authors in [27] shows the defects induced by the choice of machining conditions have a large influence on the ultimate strength of bored tubes requested in fatigue. Similarly, the absolute cutting modulus is inversely proportional to the defect severity linked to the choice of machining parameters [28]. Zitoune *et al*. [29] studied on how the thrust force which can control delamination in their study. Within their study they use two types of UD prepared in carbon/ epoxy. These raw materials of laminated structure made by Hexcel composites and respectively under Hex ply T2H 268 150 EH25 NS 35% with 59% fiber with 0.25mm thickness. And other sample content 34% Hexply T700 GC 268 M21 with 58% fiber and the thickness was 0.26mm. These two types of plies were named the first one T2H-EH25, and another one named T700-M21. The second type job piece (T700-M21) content 20μm diameter thermoplastic nodules, which represent about13% matrix mass rate. These nodules are improved the damage tolerance of the sample, and also controlled the crack propagation within the laminate. The blind drilling hole was done by NC machine. For their machining they used tungsten carbon micro grain tool with grade K20. And the tool diameter was 4.8mm; the point angle was 118° the tool had also three-slopes sharpen. For their experiment they used machining parameter 0.001mm/rev and 1500mm/rev feed rate. To avoid the delamination in blind hole machining a wooden plate was supported under the lower face of job piece. After blind hole drilling the delamination and the cracks are observed by visual inspection. After the experiment they analysis the drilling condition of long-fiber composite structure. And they made a numerical model based on fracture mechanics. By this model the thrust force criteria can be calculated which caused of fracture. The conformation between critical thrust force and analytical model can be numerically obtained. From this experiment they achieved the thrust force depends on tool feed rate. After their experiment they proposed the critical thrust force analytical model taking into account a crack presence in the vicinity of chisel edge. The integration of shear effects in that analytical model which they proposed also be planed [30-34].

## 3. CONCLUSIONS

In the study of machining of composite materials, some areas still need to be enlightened more clearly. It was shown from the literature survey that: One of the areas where there is still much scope of work is necessary to be done is the hole making of woven glass fiber reinforced polyester composite materials as less work was done on this material among all the fiber reinforced composite materials. With regard to the quality of machined hole, the principal drawbacks are related to surface delamination, fiber/resin pullout, out of roundness, dimensional accuracy, and inadequate surface roughness of the hole wall.

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