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Machining of Unidirectional Glass Fibre Reinforced Polymers (UD-GFRP) Composites -A Review

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Abstract

This present a past research on machining of UD-GFRP composites, their properties, application and mainly the machining problems faced out by the manufactures. Fiber glass reinforced plastic, commonly known as fiberglass, was developed commercially during World War II; fiberglass was developed as a replacement for the molded plywood used in aircraft radomes (fiberglass being transparent to microwaves). In 21st century, GFRP have been successfully substituted the traditional engineering materials and widely used in transportation, power generation, offshore and marine, aircraft, spacecraft structures require high specific stiffness and strength (Glass reinforced polymers) As there are many properties in reinforced composites but machining of GFRP is significantly different from conventional metals because GFRP materials are isotropic and non homogeneity in nature which consist of distinctly different phases, so that their machining operation is characterized by uncontrolled intermittent fibre fracture causing oscillating cutting forces and critical bending stresses, poor surface finish in terms of fuzzing due to diverse/crushed fibre or resin pull out. It is not easy for a manufacturer to obtain quantitative and consistent measures but it has been mainly assessed by three parameters including tool wear or tool life, cutting forces or power consumption and better surface finish. Therefore good machinability means less tool wear, low cutting forces and good surface finish. Machinability may also be assessed by the type of chips produced and the cutting temperatures since there is a correlation between the types of chip produced and surface finish. On the other hand, cutting temperatures, cutting forces and surface finish are directly or indirectly related to tool wear. Therefore, tool life tests are most commonly used to assess machinability. In GFRP, Minimizing the surface roughness which highly affects the quality of the products is critical challenge for the industry and academia alike. Factors such cutting parameters, vibration, tool wear and fiber orientation end tool geometries/materials should be taken very carefully during machining operations to obtain favorable environment for best quality as well as productivity.

1. Introduction

Composite materials refer as bonding of two or more homogeneous materials with different material properties to derive a final product with certain desired material and mechanical properties. It can also be defined as "a matrix of polymeric material that is reinforced by fibers or other reinforcing material". It consists of mainly two phases:

- Matrix phase: The primary phase having a continuous character is called matrix. Matrix is usually more ductile and less hard. It consists of any of three basic material types' polymers, ceramics or metals. The matrix forms the bulk part.
- Reinforcement: The secondary phase is embedded in the matrix in a discontinuous form arrangement into particulate reinforced (random, preferred orientation) and fibre reinforced (continuous, discontinuous, aligned, random).This dispersed phase is usually harder and stronger than the continuous phase and is called reinforcement. It serves to strengthen the composites and improves the overall mechanical properties of the matrix. Much of the strength of FRP/Composites is due to the type, amount and arrangement of the fibre reinforcement.

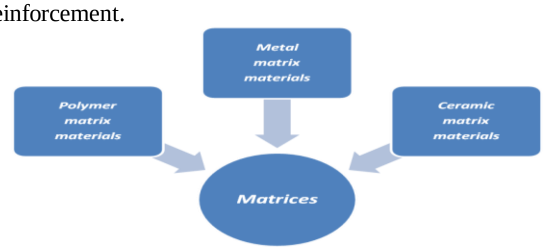

Fig: 1. Different types of Matrix

1.1 Glass Fibre

Any polymer, metal or ceramic that has been drawn into long and thin filament is termed as fibre. Some of the fibres used as reinforcements are glass fibres, carbon fibres & aramid fibres.Glass fibres are the most common of all reinforcing fibres for polymer matrix composites, main advantages of glass fibres is low cost, ease of manufacturing, high value of stiffness and strength. Their

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low density, chemically resistive, insulating features are other bonus characteristics, although the one major disadvantage in glass is that it is prone to break when subjected to high tensile stress for a long time. However, it remains break-resistant at higher stress-levels in shorter time frames. This property mitigates the effective strength of glass especially when glass is expected to sustain loads for many months or years continuously. Period of loading, temperature, moisture and other factors also dictate the tolerance levels of glass fibers.

1.2 Forms of Glass Fibre

- Chopped-Strand Mat and Continuous Mat.
- Fibre Glass Roving.
- Woven Roving and yarns.
- Surface Mat.

It is to be noted that there is no one-material-fits-all solution in the engineering world. Also, the above factors may not always be positive in all applications. An engineer has to weigh all the factors and make the best decision in selecting the most suitable material(s) for the project at hand. Table 1.1 shows few applications of composite material in different industry.

Table: 1. Application of Composites

Industry	Examples	Comments
Aircraft	Door, elevators	20-35% Weight savings
Aerospace	Space Shuttle, Space stations	Great weight savings
Automotive	Body frames, engine components	High stiffness and damage tolerance
Chemical	Pipes, Tanks, Pressure vessels	Corrosion resistance
Construction	Structural and decorative panels, fuel tanks	Weight savings, portable

2. Prior State of Art

In this section literature review on machining of GFRP is presented for study the machining of composites which are under transition phase. Lu et. al. (2002) applied fuzzy rule based inference system for optimization of multiple response or performance characteristics and take advantage of coupled system of Taguchi method and fuzzy rule. This coupled techniques become useful for solving Multi Performance Characteristics Index (MPCI). Several case studies is done for application of this technique. Gordon et. al. (2003) presents a brief review of research on the cutting of Fibre reinforced polymer (FRP) composites and medium-density fibreboard (MDF) and some recent research on the prediction of cutting g forces for MDF is also presented. Palanikumar et. al. (2003) study the experimental investigation on tool wear, surface roughness, on cutting tool and forces developed during machining of GFRP composites and found that surface finish and surface integrity are the most important factor for surface sensitive parts subjected to fatigue and creep. Sobanty et.al (2004) investigate the influence of some parameters include cutting speed, feed, drill size and fibre volume fraction. The quasi isotropic composites materials were manufactured from randomly oriented GFR epoxy composites, with various value of fibre volume fraction, using hand lay-up technique and found that drill diameter combined with feed has a significant effect on surface roughness. Palanikumar et.al (2004) optimized the machining parameters for minimum surface roughness in turning of GFRP composites using design of experiments. The machining parameters considered were speed, feed, depth of cut and work piece (fibre orientation) and analyzed that the machining of FRP is different from that of metal working in many respects, because the metal behavior is not only non-homogeneity , but also depend upon types of fiber and matrix properties, fibre orientation and types of weave. Davim et. al. (2004) studies the cutting parameters (Cutting velocity and feed rate) under specific cutting pressure, thrust force, damage and surface roughness in Glass fibre reinforced plastics. A plan of experiments, based on the taguchi techniques applied on drilling processes with prefixed cutting parameters in a hand lay-up GFRP material. Hu et. al. (2004) investigates the grinding performance of epoxy matrix composites reinforced by unidirectional carbon fibres, using an alumina grinding wheel. Emphasis was placed on understanding the effect of fibre orientations and grinding depths on the grinding force and surface integrity, and on understanding the grinding mechanisms, with a comparison to orthogonal cutting. Davim et al. (2005) presents an optimisation study of surface roughness in turning FRPs tubes manufacture by filament winding and hand layup techniques, with the use of PCD cutting tool and obtained a optimal setting of surface roughness and material removal rate by using multiple regression analysis (MRA). Mohan et al. (2005) conducted series of experiments using TRIAC VMC CNC machining centre to relate the cutting parameters and materials parameters on the cutting thrust and torque. With the help of software MINITAB 14 analysed all the parameters and found that the interactions among process parameters, thickness and drill size together is more dominant factor than any other combination for the torque characteristic. Davim et. al. (2005) proposed a new machinability index in turning of fibre reinforced plastics FRP’s using polycrystalline diamond tools and trace the evolution of the cutting force according to various parameters such as depth of cut, rate angle. Zitoune et. al. (2005) study the experimental analysis of the orthogonal cutting applied to unidirectional laminates in carbon/epoxy for various angles between the direction of fibres and the tool cutting direction and second concerns with the numerical modelling of the orthogonal cutting in statics for the simple case of fibre orientation and the direction of the cutting speed of the tool on the chip formation as well as the rupture modes. Tsao et. al (2005) found that delamination is an important factor in drilling composites materials with the use of saw drill and a core drill. Delamination can be effectively reduced by slowing down the feed rate when approaching the exit and by using bachup plates to support and counteract the deflection of the composite laminate leading to exit side of delamination. Bagci et.al. (2006) emphasised on the surface roughness as an important factor during turning of GFRP composites using cermets tools. During the test, the depth of cut, feed rate and cutting speed were varied, but the cutting direction held in parallel to the fibre orientation.The ANN and RSM models for GFRPs turned parts surfaces are compared with each other for accuracy and computational cost. Palanikumar et. al. (2006)

discusses the application of Taguchi optimization techniques for minimizing the surface roughness in machining of glass fibre reinforced plastics on all geared lathe with a coated cermets tool inserts with two levels of factors. Jawali et. al. (2006) study a series of short glass fibre reinforced nylon-6 composites with different weight ratio of glass content and analyzed physic mechanical properties such as specific gravity, tensile properties and wear resistance. Also apply acoustic emission techniques and scanning electron microscope for study the behavior of surface morphology. Palani kumar et. al. (2007) model the surface roughness through RSM techniques in machining of GFRP composites. Four factors level central composite, rotatable design matrix is employed to carry out the experimental works and ANOVA IS used to check the validity of the model. Sreejithet.al. (2007) analyzed acoustic emission signals produced during machining of composites materials using PCBN tools and these signals results a clear picture of the status of the tool and nature of cutting of the work piece. Also apply multiple regression analysis for precise prediction of temperature and controls of machining parameters if required during machining. Davimet.al. (2007) investigate the mach inability of turning processes of glass fiber reinforced plastics (GFRP) manufactured by hand lay-up. A statistical technique, using orthogonal arrays and analysis of variance (ANOVA), has been employed to know the influence of cutting parameters on specific cutting pressure and surface roughness. Palanikumaret. al. (2007) developed a mathematical model to predict the tool wear on the machining of GFRP composites using regression analysis and analysis of variance (ANOVA) and study the interaction effect of the machining parameters such as cutting speed, feed rate, and depth of cut and work piece fibre orientation angle. This model is verified by using coefficient of determination and residual analysis. Abrao et. al. (2007) present a literature survey on machining of composites material emphasized on drilling of glass and carbon fibre reinforced plastics. Aspects such as tool material and geometry, machining parameter and their influence on the thrust force, torque, quality of the holes produced and delamination damage are investigated. Palanikumar K., (2007) made an attempt to model the surface roughness through response surface methodology (RSM) in machining GFRP composites. Four factors five level central composites, rotatable design matrix is employed to carry out the experimental investigation. Analysis of variance (ANOVA) is used to check the validity of the model. Karnik et. al. (2008) presents application of artificial neural network (ANN) model to study the machinability aspects of unreinforced polyetherketone (PEEK), reinforced polyetherketone with 30% of carbon fibres and 30% of glass fibres machining. Parameters such as tool material, work material, cutting speed and feed rate were analysed found that minimum power results from a combination of lower value of cutting speed and feed rate for all worl-tool combinations. Kuoet. al. (2008) used a grey based Taguchi method for optimizing multi-response simulation problems and adopts a grey relational analysis (GRA) to transfer multi–response problems into a single response problem. A practical case study from an integrated- cicuitpacakagingcompany illustrates that differences in performances of the proposed grey based taguchi method and other method found is not significant. Palanikumar et. al. (2008) present a study of influence of cutting parameters on surface roughness parameters such as Ra, Rt, Rq, Rp and R3z in turning of glass fibre reinforced composites. Empirical models are developed to correlate the machining parameters with surface roughness by using area graphs and three dimensional surface plots. Hsu et. al. (2008) developed a new model based on grey relational analysis and Taguchi method to optimize drilling parameters with multiple performance characteristics in drilling carbon fibre reinforced plastics (CFRP) using candlestick drill and indicate that the feed rate and the drill diameter are the most significant factos and spindle speed is insignificant in drilling CFRP laminates. Basheer et. al. (2008) presents an experimental work on the analysis of machined surface quality on Al/Sicp composites leading to an artificial neural network-based (ANN) model to predict the surface roughness and found that the predicted roughness of machined surfaces based on the ANN model was found to be in very good agreement with the unexposed experimental data set. Sait et. al. (2008) presents a new approach for machining (Turning) of GFRP pipes and found that desirability function analysis coupled with Taguchi techniques for optimizing multi response problems is very useful tool. Based on the composite desirability value, the optimum levels of parameters have been identified and significant factors is find out by ANOVA

3. Machining of UD-GFRPs

Unidirectional GFRP composites improved strength to weight ration and mechanical properties which posses' different characteristics to fibre orientations. In UD-GFRP the fibre orientation is measure along clockwise with respect to the cutting direction. If orientation is more than 90 degree then it can be considered as negative orientation. There are also several factors which affect the machining operations such as tool wear rate, feed rate, and cutting speed. The chip formation rate is highly affected by the cutting speed, cutting tool angle, Tool nose radius, type of fibre weave, and fibre-matrix materials.

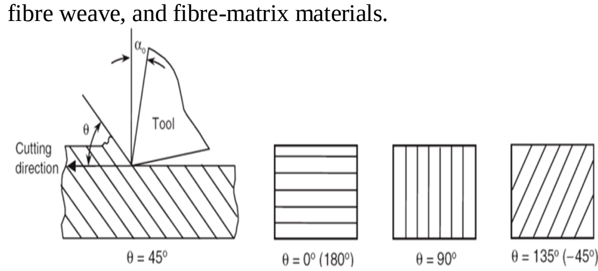

Fig: 2. Fibre orientation angle w.r.t cutting direction (Ahmad et. al 2009)

3.1 Effect of Fibre Orientation

Cutting and thrust forces are found to be primarily dependent on fibre orientation and operating conditions and tool geometry have less influence on cutting forces. The cutting force generally increases gradually with fibre orientation up to approximately 60° but a large increment when 90°. Then it decreases with further increase in fibre orientation with significant decreases occurring between 100° and 165°. Drastic increase/decrease in the principal forces is usually associated with the change in mode of chip formation. The thrust force exhibited more complex behaviour than the cutting one and it is even greater for orientations greater than 45°. An increase in the thrust force is exhibited when cutting small positive fibre orientations and then it decreases with further increase in fibre orientation. High thrust forces are attributed to the elastic recovery of the fibres, which elastic energy would be released after the fibres are severed, imparting a thrust force on the tool flank and providing a potent source for tool wear. In cutting positive fibre orientations ($0° < \theta < 90°$), the cutting force Fc and the thrust force Ft can be resolved into a shear force Fs, acting along the shear plane and a normal force Fn, to the shear plane.

$$F_s = F_c \cos\theta - F_t \sin\theta$$

$$F_n = F_c \sin\theta + F_t \cos\theta$$

The resultant force R, makes an angle λe to the fibre orientation (Fig.3). The behaviour of angle λe and normal force Fn with fibre orientation is linked to the chip formation mode.

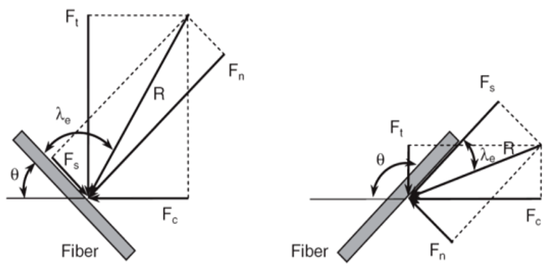

Fig: 3. Force Components Along and Perpendicular to the Plane of the Fibres (Ahmad et. al 2009)

3.2 Effect of Tool Geometry

There is generally a decrease in the cutting force and thrust force with an increase in rake angle (Fig.4), since chips slide of and slide away a little easier as the rake angle increases.

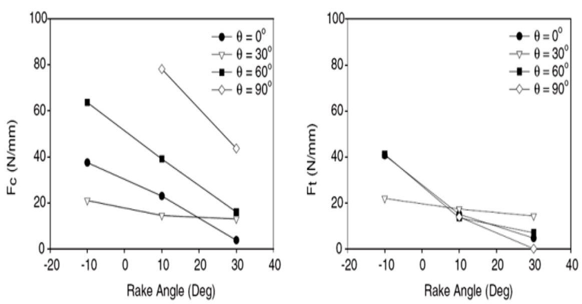

Fig: 4. Cutting Force vs. Rake Angle and Vertical Force vs. Rake Angle When Cutting CFRP. v=0.02m/min, ac=0.1mm and aw=2.28mm. (Kaneeda et. al 1991)

The effect of clearance angle on tool forces when increasing leads to slight decrease in the principal force, because of the size of the contact area between the tool and the workpiece. A decreasing angle results in a larger area, and thus in an increasing thrust force. The increase in the cutting force with depth of cut is smaller and is proportionate to the depth of cut. In CFRP the depth of cut increases beyond the critical value of 100μm, so the effect of fibre cutting denominates over the pressing action. Contrary to this behavior, when cutting GFRP, the depth of cut has only marginal effect on the cutting and the thrust forces

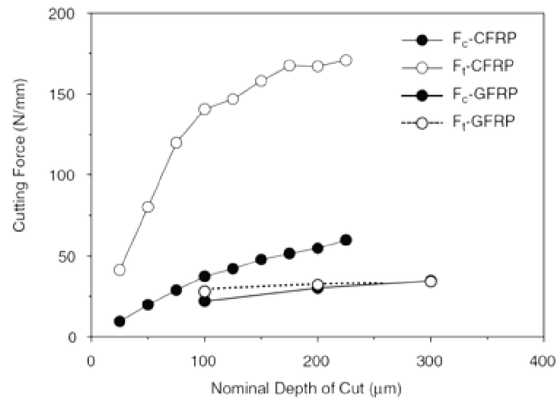

Fig: 5. Relationship between Nominal Depth of cut and cutting forces in Machining CFRP and GFRP. Fibre orientation θ = 30◦, nose radius = 50μm. (Ahmad et. al 2009)

4. Response Measurements

In machining operation such as turning the output response such as surface roughness and material removal rate (MRR) is analyzed with the help of mathematical modeling and simulation of these process responses. The machining performance has been evaluated in terms of multiple process output responses like MRR, surface roughness (Ra), tool-tip temperature and resultant cutting force (Fr). Surface roughness comes into picture due to the movement of cutting tool tip continually along the work piece at the given feed rate in turning of GFRP composites.

4.1 Ra (Arithmetic Average Height)

Roughness average Ra is the arithmetic average of the absolute values of the roughness profile ordinates. Ra is the arithmetic mean roughness value from the amounts of all profile values.

$$R_a = \frac{1}{l}\int_0^l |Z(X)|\,dx \tag{1}$$

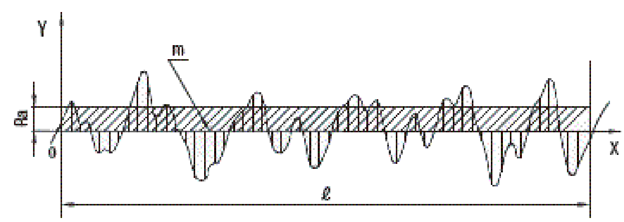

Fig: 6. Measurement of Ra

The roughness average (Ra) in the direction of the tool movement has been measured by Surf test meter. For a particular set of experiment, Ra value has been determined at three different places of the finished job, and average of these three has been taken for consideration.

4.2 Material Removal Rate

MRR can be measured as ratio of volume of material removed during operation w.r.t. machining time. Following equation may be used for determination of MRR:

$$MRR = \frac{W_i - W_f}{\rho \times t_m} \ mm^3/min \tag{2}$$

W_i initial weight of work piece

W_f final weight of work piece

ρ density of work piece

t_m Machining time

5. Conclusion

1. The machining of glass fibre reinforced polymers (GFRP) is different in many ways from machining of conventional metals and alloys. Due to in homogeneity and isotropic behavior of GFRP composites, different types of problems are faced during machining or cutting of these materials.
2. GFRP material is found suitable for transportation, power generation, offshore and marine, aircraft, spacecraft structures require high specific stiffness and strength (Glass reinforced polymers)
3. Conventional tools are not recommended for machining of composites, cutting tools such as cemented carbides, tungsten carbides, PCD, PCBN are widely used by the manufacturer.
4. This approach can be recommended for continuous quality improvement and off-line quality control of a process/product in any manufacturing/ production environment.

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