An Approach towards Machining of GFRP Using Alumina Based Cutting Tools

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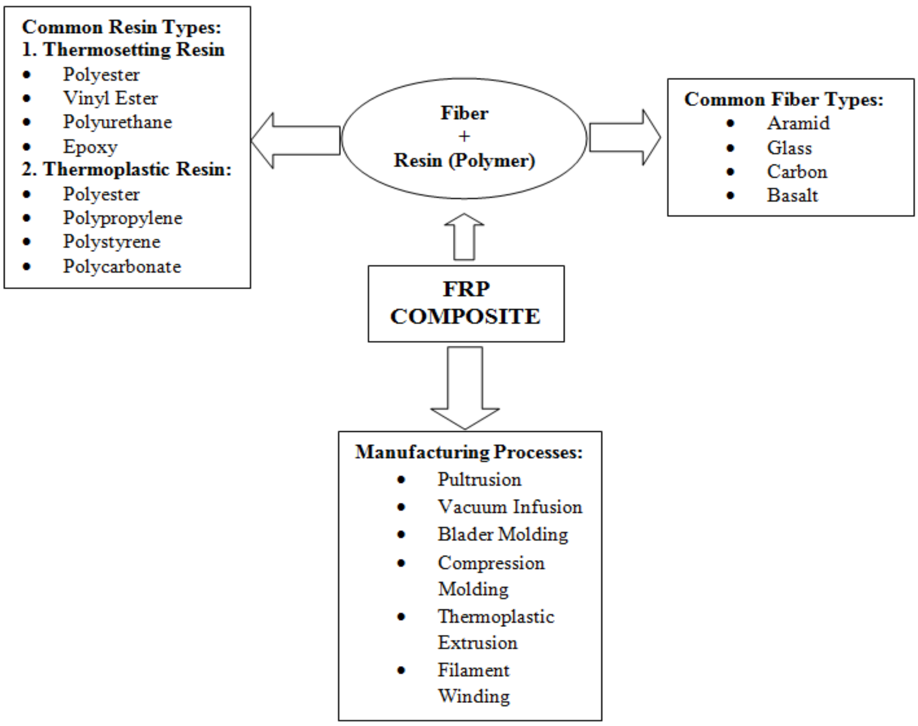
Abstract: Glass Fibre Reinforced Plastic (GFRP) Composite materials is a feasible alternative to engineering materials because of its first class properties such as higher fatigue limit, high stiffness to weight ratio, excellent design flexibility, and high strength to weight ratio [1]. Irrespective to all such properties, machining of glass fibre composite is still a major problem. To analyse the machining of GFRP, an attempt is made by using two different alumina cutting tool; namely a Ti[C, N] mixed alumina cutting tool (CC650) and a SiC whiskers alumina cutting tool (CC670). The performance of cutting tools was evaluated at different cutting speeds, at constant feed rate and depth of cut by measuring the surface roughness and flank wear. An attempt is also carried out to analyse the wear mechanism of cutting tool while machining of GFRP composite material.

Key words: Composite materials, alumina, cutting tools

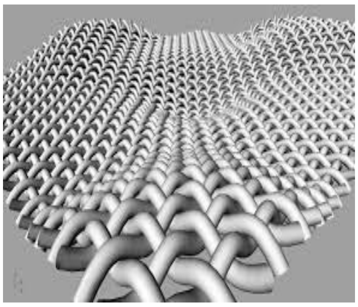
1. Introduction



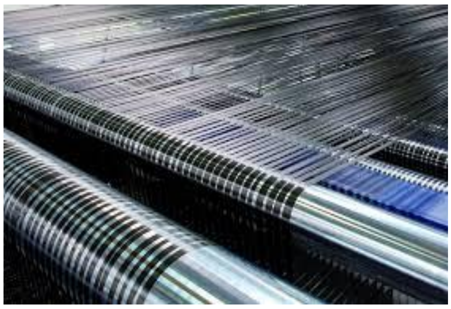
GFRP composite materials are best suited for varieties of application like automobile sector, medical sector, sports sector, and textile sector [2]. The advantage of GFRP material includes savings in weight, improvement in strength and decreased cost of material and fabrication. Glass fibre reinforced plastics are developed to meet the requirements of the industry with high strength to weight ratio. Various types of glass fibres are used as reinforcement but E-glass possess special characteristics such as good resistance to heat and moisture, good dimensional stability and electrical insulation property [3].

Different forms of Fibres:

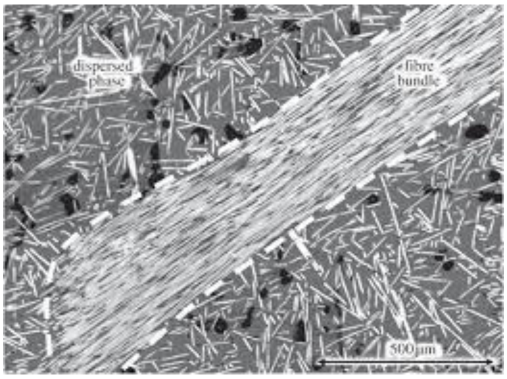
Chopped Fibre



Woven Fibre



Long Fibre



Short Fibre

Machining of glass fibre composite is a major problem, because of their high hardness and inert nature. Because of their different applications, the need for FRP machining has not been fully eliminated. For a perfect machining process, it is very important to proper selection of cutting parameters like cutting speed, geometry of cutting tool and type of tool material [4]. The mechanism of machining GFRP is quite different from metals because of non-homogenous, anisotropic nature [5]. Santhanakrishnan observed that mechanism of machining GFRP includes shearing, plastic deformation and rupture of fibre orientation [6].

The machinability of composite materials is greatly influenced by the type of fiber embedded in the composites and its orientation in composite material [7]. Bhatnagar and Sakuma (2002) studied how the fiber orientation influences both the quality of the machined surface and tool wear [8]. Sharma stated that wear performance of cutting tool decrease with 900 fibre orientation [9]. Fereirra reported that a diamond tool could be used to machine FRP tubes and obtain finish machining with low surface roughness and minimum tool wear [10]. Rahman conducted a machining study with CFRP composite using PCD and observed that polycrystalline diamond, and diamond- coated tool exhibit high wear resistance [11].

An alumina based ceramic cutting tool is a cost effective, better alternative solution for machining a hard material with good surface finish at higher cutting speed [12]. It can with stand up to 1500^0 C. Xu developed an Al_2O_3/Ti[C,N]/SiC whisker cutting tool and conducted machining studies on hard materials and found that such multiphase ceramic cutting tools have good wear resistance [13]. Aslan made an attempt to machine hard materials using CBN, Al_2O_3/Ti[C, N], and carbide cutting tool. From the investigation, it is found that Al_2O_3/Ti[C, N], CBN exhibit better performance and minimum tool wear than carbide cutting tool [14].

Table 1. Properties of E-glass Fibre Roving

Material	Density (g/cm^3)	Tensile Modulus ksi (GPa)	Tensile Strength ksi (MPa)	Tensile Strain
E glass Fibre	2.6	11,000(76)	500(3450)	4.7

Afghani reported that whiskers resist the extension of crack propagation and found that the composite tool material with higher SiC whisker content have better wear resistance during machining [15]. Abrasive wear is the predominant flank wear mechanism while machining nickel based alloy. Deng stated that cutting force play a vital role in studying the machining process and he observed that cutting force varies with fibre orientation and fibre-matrix volume fraction [16].

Table 2. Composition of E-glass Fibre

Composition	SiO_2	AlO_2	CaO	B_2O_3
Content %	52-56 %	12-16 %	16-25 %	8-13 %

It can be observed from the literature that PCD, CBN, and PcBN are widely used to machine GFRP composite. Though ceramic cutting tools are cheaper than PCD and PcBN tools, they provide equivalent performance than hard materials. Hence machining studies have been conducted on GFRP material using Ti[C,N] mixed alumina cutting tool and SiC whisker reinforced alumina cutting tool on GFRP composite with unsaturated polyester resin with E-glass fibre reinforcement.

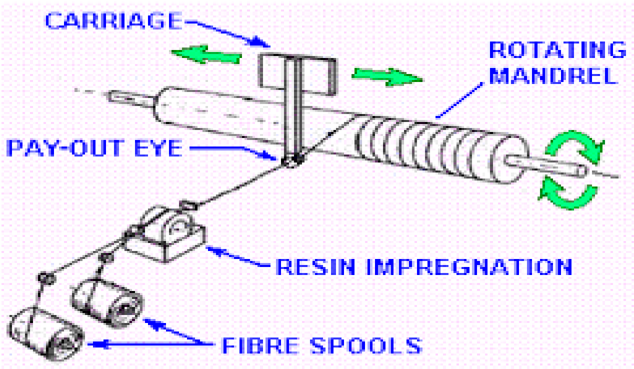


Fig. 1. Filament Winding Process

2. Experimental Procedure

2.1. Preparation of GFRP Composite Rod

The GFRP composite rod was prepared by filament winding process (shown in Fig 1.) in which E-glass fibre is passed through a polyester resin and wound to be on a steel rod having a diameter of 15mm with fibre orientation angle of 90^0. Glass fibres are strongly bonded and homogenously impregnated with polyester matrix material. E-glass fibre is selected for its excellent properties (Table 1), and its composition is presented in Table 2.

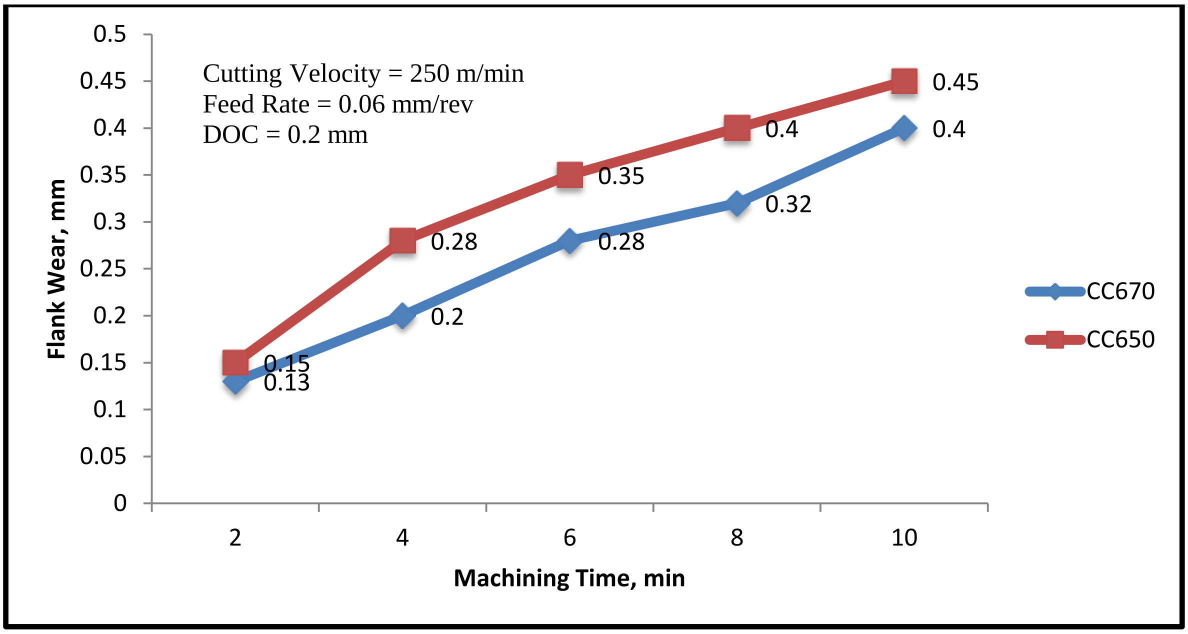


Fig. 2. Flank wear versus machining time of alumina cutting tools while machining GFRP composites.

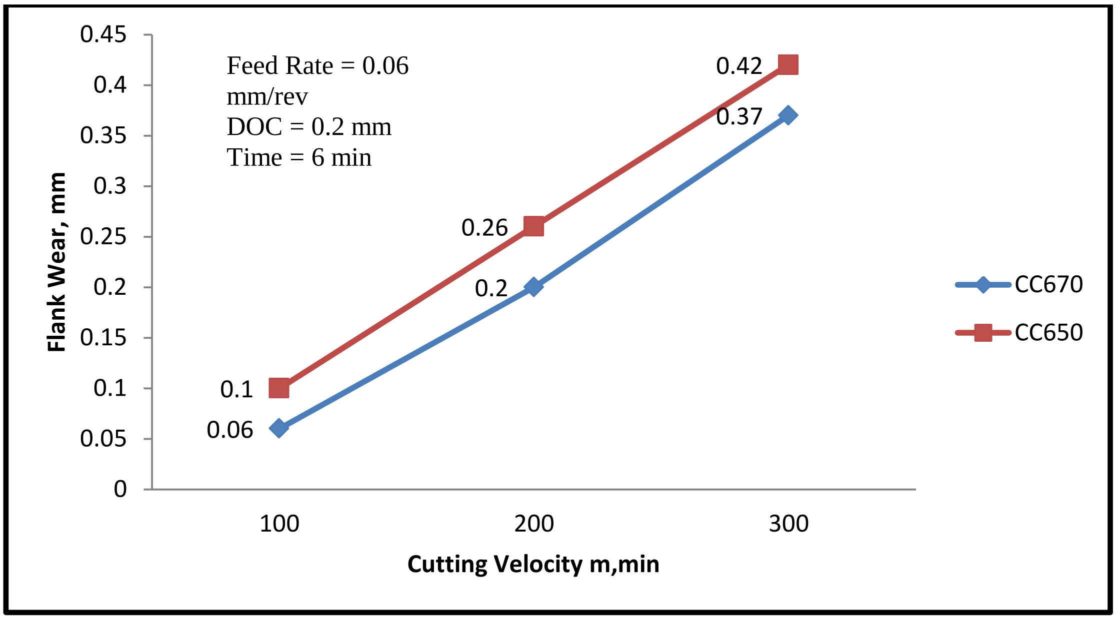


Fig. 3. Flank wear versus cutting velocity of alumina cutting tools while machining GRP composite at 6 min

2.2. Machining Study

Machining studies were carried out to machine GFRP composite material in a precision lathe cutting tool (CC670). The properties of both the alumina-based ceramic cutting tools are given in Table 3.

The machining process was performed with various cutting speed at constant feed rate and depth of cut. During the machining process flank wear, surface roughness, and the cutting force was measured. The flank wear was measured using a Metzer Toolmakers microscope, the surface roughness was measured using a TR200 surface profile meter, and the cutting force was measured using a strain gauge dynamometer.

Table 3. The Properties of the Alumina Based Ceramic Cutting Tool Material

Details of tool material	Unit	Ti[C, N] mixed alumina(CC650)	SiC alumina(CC670)
Composition		Al_2O_3 70% TiN 22.5% TiC 7.5%	Al_2O_3 80% SiC_w 20%
Density	g/cm^3	4.26	3.74
Vickers hardness	(HV10)	1800	2000
Transverse rupture strength	MPa	550	900
Young's modulus	GPa	400	390
Fracture toughness	MPa $m^{1/2}$	4.0	8.0
Thermal conductivity	W/mK	24	18
Coefficient of thermal expansion	$K^{-1}.10^{-6}$	8.6	6

3. Result and Discussion

3.1. Flank wear of the alumina cutting tool

Flank wear is the main form of wear in machining of FRP composite that affects the tool life, surface quality and production cost. Tool wear occurs due to the rubbing of the hard fibres to the cutting edge of the tool which result abrades the cutting tool and removes some of the tool material at the flank face. The wear is due to crack development, and the intersection caused by hard fibre chips acting as small indenters on the cutting face. As the cutting speed increases, the velocity of abrasion and the rate of contact of broken fibre chips also increase, leading to a higher flank wear at high speed. Fig. 2 shows the variation of flank wear with respect to machining time while machining of GFRP composite material suing the Ti[C, N] alumina cutting tool and the SiC whisker alumina cutting tool at 250 m/min. Fig. 3 shows the flank wear versus cutting velocity of the alumina cutting tools after 6 min of machining. The flank wear of alumina cutting tool increase with respect to speed & machining time. From Fig. 2, it can be noted that Ti[C, N] mixed alumina cutting tool fails after 8 min of machining at 250 m/min. Tool failure of the Ti[C, N] mixed alumina cutting tool after 6 min of machining at 300 m/min. From the above discussion, it can be noted that chip formation while machining GFPR material is an important factor in addition to fibre orientation, fibre delamination and direction of machining.

3.2. Surface Roughness

In machining process, surface integrity is the main requirement to determine the quality of finished product. The measurement of surface roughness of FRP composite is not easy than that of metals because of strong glass fibre undergoes sharp brittle fracture with deformation of matrix material, fibre micro cracking and pulverization. Surface flaws due to delamination and interlaminar crack are also observed while machining of GFRP materials.

The cutting velocity is the main factor that affects the surface roughness. Fig. 4 shows the surface roughness versus cutting velocity after machining GFRP composite with alumina cutting tool. From Fig.4, it can be concluded that the surface roughness was to be improved by increasing cutting velocity and the surface roughness of machined GFRP composite ranges from 4.5 to 6.5 µm. The advantage of machining GFRP material by using alumina based ceramic cutting tool is that they produce better surface finish other conventional cutting tools. Ceramic cutting tool eliminate a built-up edge (BUE) forming during machining.

As the cutting speed increases, the formation of a BUE is greatly reduced which result surface roughness decreases. From the above observation, it can be concluded that SiC whisker reinforced alumina cutting tool is to produce lower surface roughness with less surface damage than the Ti[C, N] mixed alumina cutting tool.

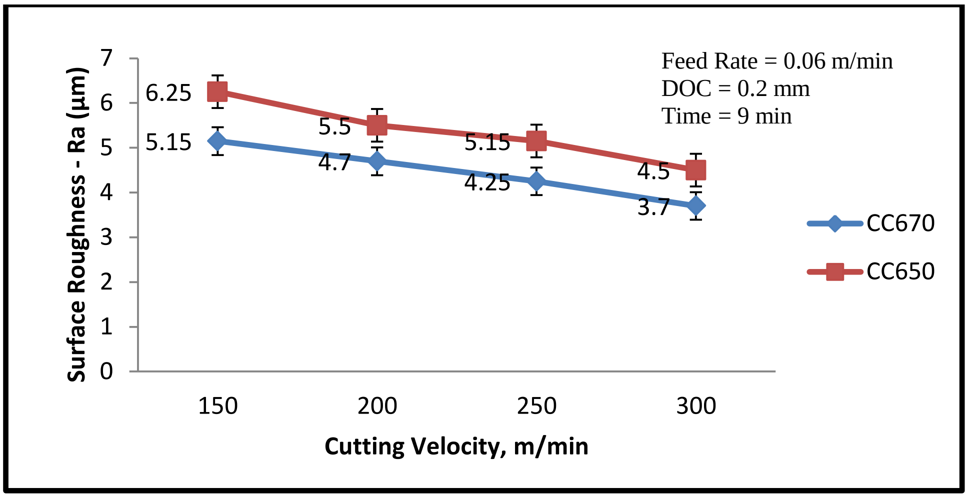


Fig. 4. Surface Roughness versus cutting velocity after machining GFRP composite material with alumina cutting tool for 9 min.

3.3. Cutting Force

The cutting force in the machining process is produced due to the relative sliding motion of cutting tool against the work piece in order to remove the material from the work piece. The cutting tool geometry, tool materials, and machining parameters are responsible for higher cutting force. Two main mechanism shows the cutting force in machining FRP composite are Shearing & Buckling. In this study, cutting tool will be perpendicular to the fibre orientation, and the shearing mechanism persists.

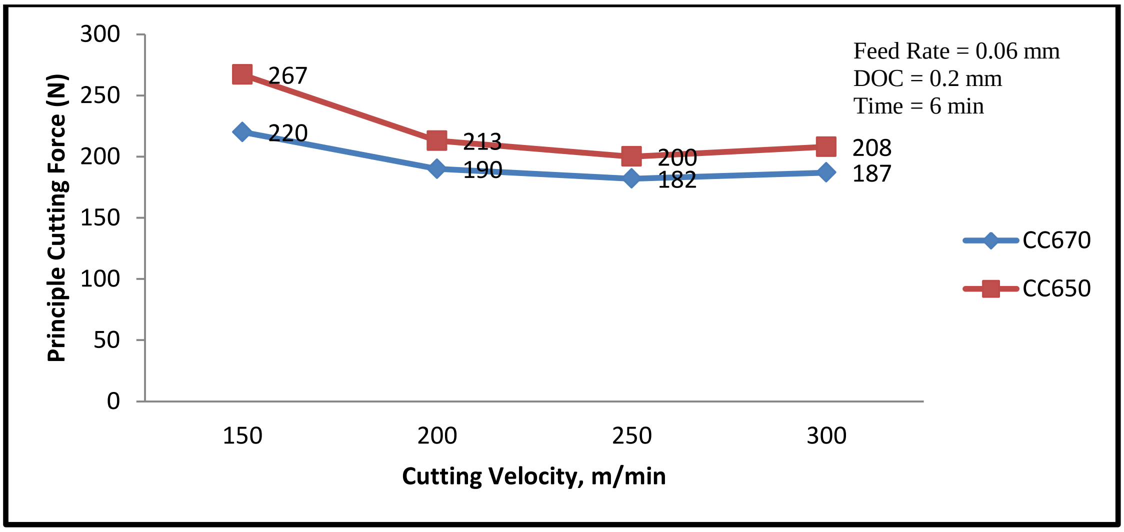


Fig. 5. Principle cutting force versus cutting velocity of alumina cutting tools while machining GFRP composite at 6 min

The cutting force was measured by lathe tool dynamometer while machining of GFRP composite using alumina cutting tool at a constant feed rate & depth of cut of 0.06 mm/rev and 0.2 mm respectively as shown in Fig. 5. The maximum cutting force occurs in the direction of cutting velocity. The cutting force does not exhibit any particular trend because of fluctuation of cutting force in machining of hard abrasive fibres & soft matrix material. Due to soft matrix material & amorphous nature of GFRP material, the principle cutting force is considerably lower than that on machining of steel.

From Fig. 5 it can be concluded that Ti[C, N] mixed alumina cutting tool produced a higher cutting force of 265 N at the cutting velocity of 150 m/min than that of the SiC whisker reinforced alumina cutting tool (220 N for the same cutting conditions). The cutting force initially decreases as the cutting speed increase but tends to increase at higher cutting speed above 250 m/min. The initial decrease in cutting force with respect to cutting speed is due to decrease in tool chip contact area, leading to higher reduction in shear strength of the work piece. As the cutting speed increases, work hardening occurs in the work piece leads to increase in tool wear and make it difficult for the cutting tool to machine the work piece.

4. Conclusion

From the above study and analysis, it can be concluded that the abrasive wear is quite smooth and less with the SiC whisker reinforced alumina cutting tool than the Ti[C, N] mixed alumina cutting tool while machining of GFRP composite material. The SiC whisker reinforced alumina cutting tool produce a better surface finish than the Ti[C, N] mixed alumina cutting tool. Overall conclusion is the performance of SiC whisker reinforced alumina cutting tool is better than the Ti[C, N] mixed alumina cutting tool on machining of GFRP composite.

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