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# Study And Analysis Of GFRP Machining Using Alumina Based Cutting Tools

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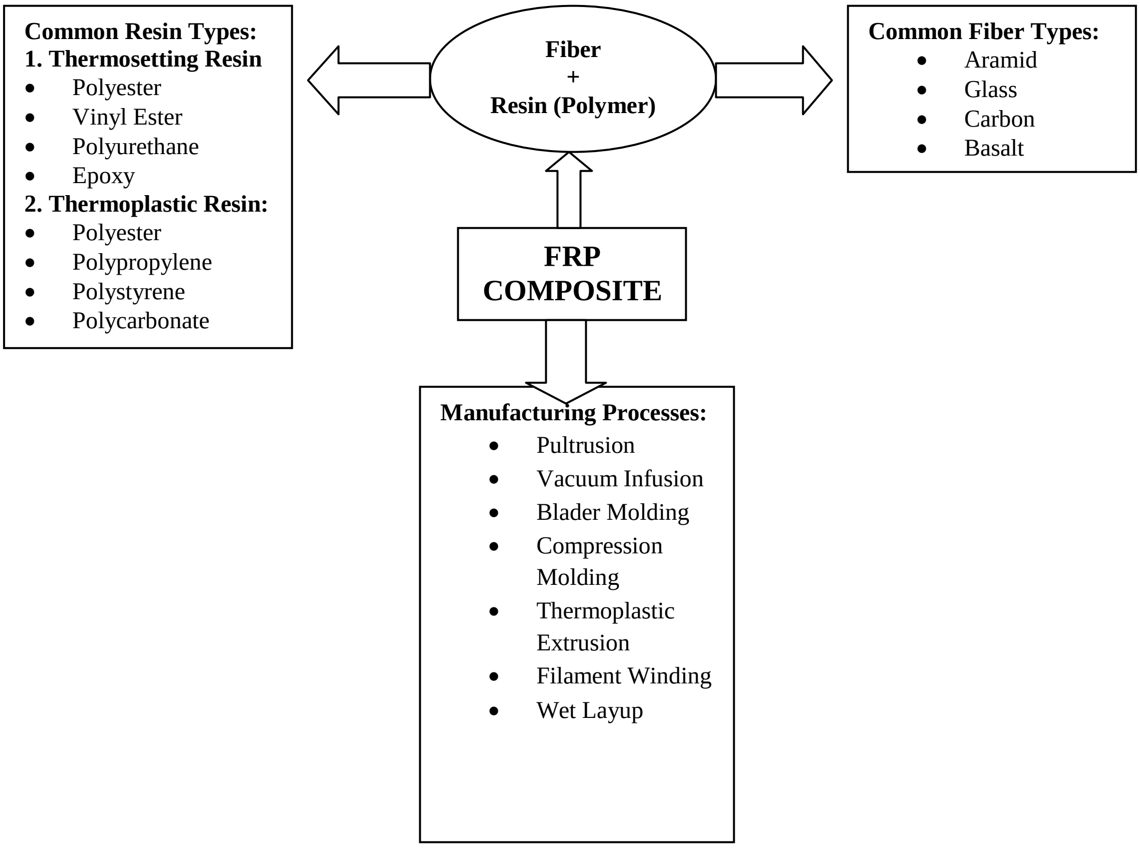
## ABSTRACT

*Glass Fibre Reinforced Plastic (GFRP) Composite materials is a feasible alternative to conventional 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.*

*Keywords- GFRP, Alumina Cutting Tools, Surface Roughness, Flank Wear*

## 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].




Everstine and Rogers have proposed an analytical theory of machining FRPs. In a classical study, they developed a theory of plane deformation of incompressible composites reinforced by strong parallel fibers [4]. Sakuma et al and Bhatnagar et al studied how the fiber orientation influence both the quality of the machined surfaces and tool wear. The machinability of composite materials is influenced by the type of fiber embedded in the composites, and more particularly by the mechanical properties [5]. On the other hand, Rehman et al demonstrated that the selection of cutting parameters and the cutting tool are dependent on the type of fiber used in the composites and which is very important in the machining process [6].

Davim and Mata studied the influence of cutting parameters on surface roughness in turning glass-fiber reinforced plastics using statistical analysis [7]. Ramulu et al. carried out a study on machining of polymer composites and concluded that higher cutting speeds give better surface finish [8]. Tekeyama and Lijma studied the surface roughness on machining of GFRP composites, according to them, higher cutting speed produce more damage on the machined surface. This is attributed to higher cutting temperature, which results in local softening of work material. They also studied the machinability of FRP composites using the ultra-sonic machining technique [9]. According to Koing measurement of surface roughness in FRP is less dependable compared to that in metals, because protruding fiber tips may lead to incorrect results. Additional errors may result from the hooking of the fibers to the stylus [10].

Palanikumar studied the effect of cutting parameters on surface roughness on machining of GFRP composites by polycrystalline diamond (PCD) tool by developing a second order model for predicting the surface roughness [11]. Palanikumar et al. have developed a procedure to asses and optimize the chosen factors to attain minimum surface roughness by incorporating response table and response graph, normal probability plot, interaction graphs, and analysis of variance (ANOVA) technique [12]. Adamkhan et al. have carried out machining studies on GFRP composites using two alumina cutting tools. The machining process was performed at different cutting speeds at constant feed rate and depth of cut. The performance of the alumina cutting toll was evaluated by measuring the flank wear and surface roughness of the machined GFRP composite material [13]. 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 [14]. 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

**TABLE 1 Properties of E-glass fibre roving**

| Material | Density (g/cm3) | Tensile Modulus (GPa) | Tensile Strength (MPa) | Tensile Strain |
|---|---|---|---|---|
| E glass Fibre | 2.6 | 11,000(76) | 500(3450) | 4.7 |

Hard materials and found that such multiphase ceramic cutting tools have good wear resistance [15]. 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 [16].

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 [17]. 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 [18].

**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.

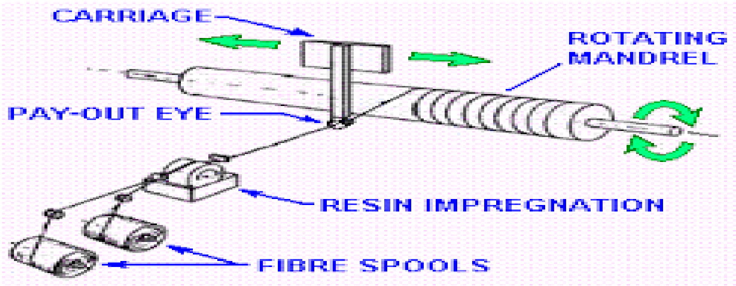



**Fig 1: Filament Winding Process**

## 2. EXPERIMENTAL PROCEDURE

### 2.1Preparation 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.

### 2.2 Machining Study

Machining studies were carried out to turned GFRP composite rod in a BHARAT all-geared lathe of model NAGMATI-175 with a maximum speed of 1200 rpm and power of 2.25KW. The ISO specification of the toll holder used for the turning operation is a WIDAX tool holder PC LNR 2020 K12 and the tools used are Ti[C, N] mixed alumina cutting tool (CC650) and a SiC whisker reinforced alumina cutting tool (CC670). The properties of both the alumina-based ceramic cutting tools are given in Table 3.

**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%<br>TiN 22.<br>TiC 7.5% | $Al_2O_3$ 80%<br>$SiC_w$ 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 |

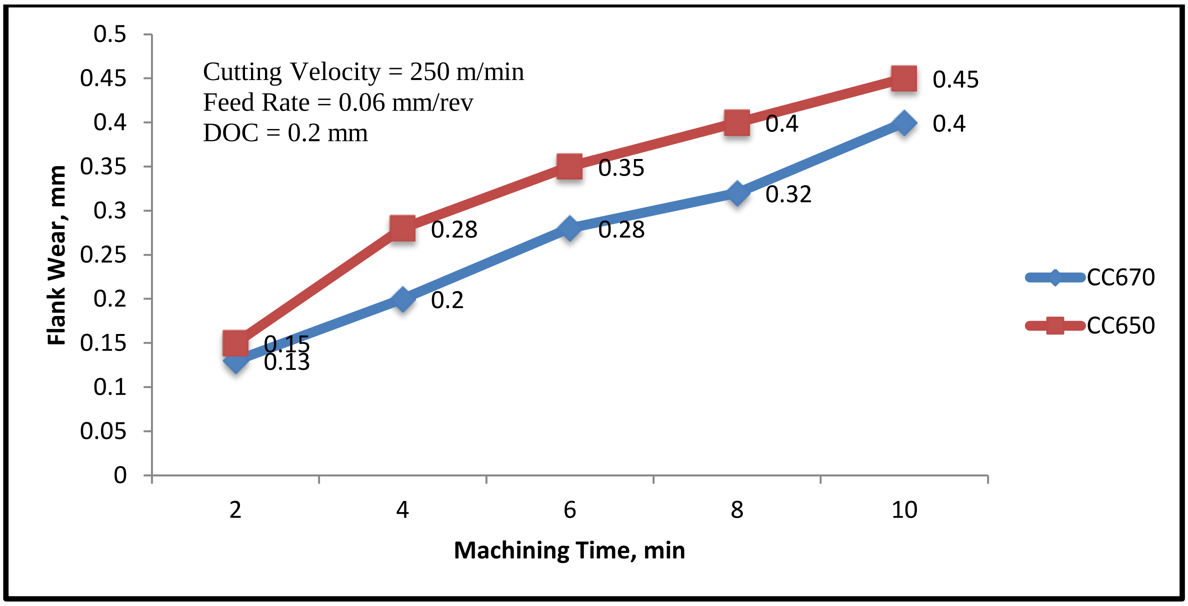
The machining process was performed with various cutting speed at constant feed rate and depth of cut. During the machining process flank wear, surface roughness, and the cutting force was measured. The flank wear was measured using a Metzer Toolmakers microscope, the surface roughness was measured using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

## 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 using 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 increases 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.




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

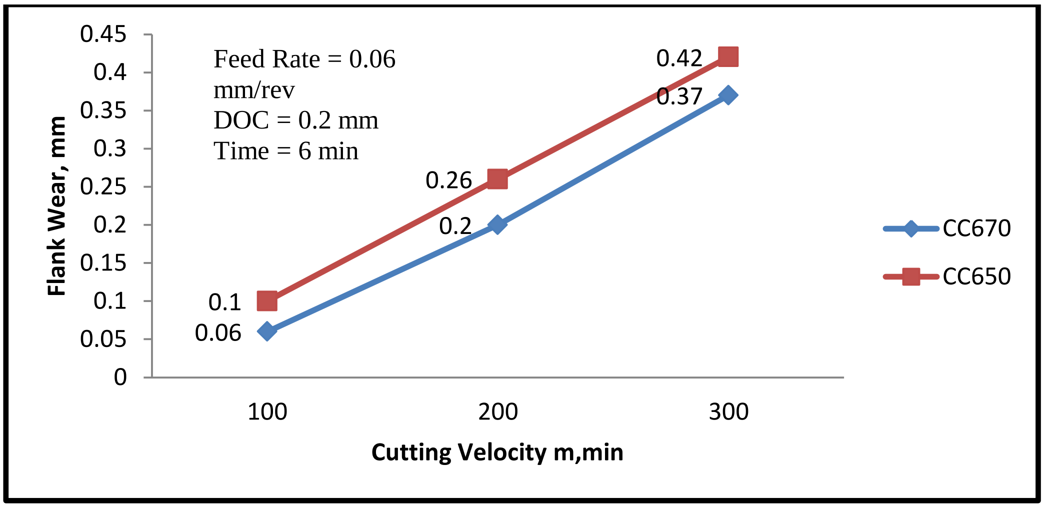



**Fig 3: Flank wear versus cutting velocity of alumina cutting tools while machining GRP composite At 6 min**

## 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.

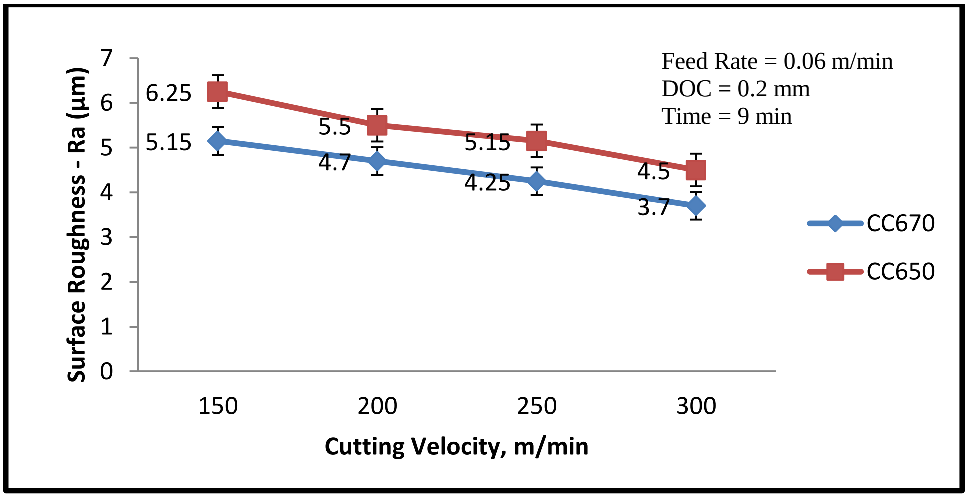



**Fig 4: Surface Roughness versus cutting velocity after machining GFRP composite material with alumina cutting tool for 9 min.**

### 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.

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.

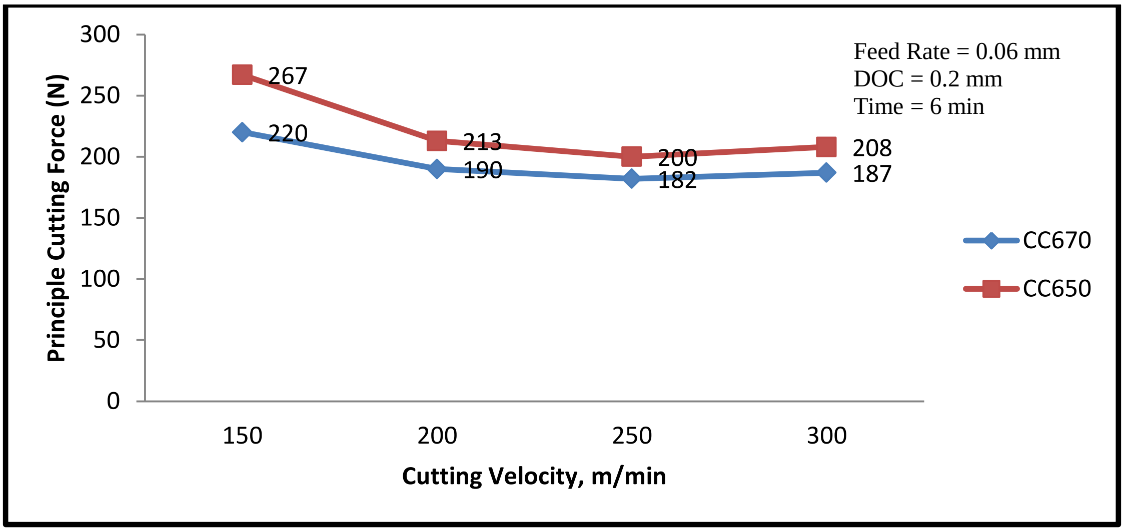



**Fig.5: Principle cutting force versus cutting velocity of alumina cutting tools while machining GFRP composite at 6 min**

## 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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