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ON THE MACHINING OF GLASS FIBER REINFORCED COMPOSITE PIPES

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ABSTRACT

In recent years, the utilization of GFRP composite materials in many different engineering fields has undergone a tremendous increase. Accordingly, the need for accurate machining of composites has increased enormously. However, the knowledge acquired in machining of ductile metals is not suitable for composites. Most of the research work on GFRP composites has been focused on its characterization or manufacturing process with little work on machining. For the cost effective implementation of these composites, the machinability becomes a major parameter. For successful application of these composites, the surface finish and surface integrity are most important especially for surface sensitive parts subjected to fatigue or creep. This paper presents the experimental investigation on tool wear, surface roughness, on cutting tool and forces developed.

Keywords: Machining, Fiber reinforced plastic composites, Surface roughness, Tool wear.

1. INTRODUCTION

Composite materials are continuously displacing traditional engineering materials because of their high specific stiffness, high specific strength, high damping and low coefficient of thermal expansion. The Glass Fiber Reinforced Plastic (GFRP) composites are being extensively used in various fields like Chemical industries, Off Shore, Power Plants, Refinery, Oil and Gas, Pulp and Paper, Waste and Waste water, etc.

As the application fields of FRP expand the opportunity of machining such as cutting off, drilling, milling, turning, etc. has increased for its fabrication. However, the users of FRP have faced difficulties to machine it, because knowledge and experiences acquired for conventional materials cannot be applied to such a new material, of which machinability is completely different from that of conventional material.

The machining of FRP differs from metal working significantly in many respects. By their nature FRPs are inhomogeneous and atleast within one layer anistropic materials. They consist of a load carrying fiber component, which usually appears as a bundle of parallel fibers or woven rings. This fiber “skeleton”, whose geometrical orientation depends on force directions is enveloped in a matrix of thermoset or thermoplastic, which mainly provides the fixation of the fibers and the distribution of forces

For the cost effective implementation of these composites, the machinability becomes a major parameter. For successful application of these composites, the surface finish and surface integrity are most important especially for surface sensitive parts subjected to fatigue or creep. This paper presents the experimental investigation on tool wear, surface roughness, and forces developed.

2. LITERATURE REVIEW

Over the last several years, the phenomenon of machining of FRP composites has been analyzed. Konig et al. [1] investigated the machining of fiber Reinforced Plastics (FRP) using different processes like drilling, routing, milling, water jet cutting and laser cutting. The machining of FRP is different from that of metal working in many respects because, the metal behaviour is not only inhomogeneous, but also dependent on fiber and matrix properties, fiber orientation and the type of weave.

According to Eriksen [2] the first theoretical work on FRP was presented in 1971. Everstine and Rogers [3]. Sakuma [4] and Bhatnagar [5] studied how the fiber orientation influenced both the quality of the machined surfaces and Takeyama [6] studied the machinability of FRP composites using ultrasonic machining technique and Konig[7] has studied about the drilling characteristics of FRP composites. Santhanakrishnan et al.[8] studied the surface finish with respect to speed. While there has been a considerable amount of literature on the various aspects of machining of metals, only a limited amount of literature exists on machining of composites. In the present study Fiber Reinforced Plastic composites has been used for machining. The experiments were conducted as per Taguchi’s orthogonal array which is used to minimize the number of experiments. The characteristics studied include tool wear, surface roughness (R_a) and forces developed during cutting.

3. EXPERIMENT

3.1 Description of Experimental Set-up

Turning is very important operation in which single point cutting tool removes the metal from cylindrical work piece. In this experiment HERBERT all geared lathe is used. The tool material is sintered carbide (SNMG 12 04 08-5(ISO Designation) [P20] TG-Widadur coated carbides.) with the tool geometry of (-6°, -6°, 6°, 6°, 15°, 75°, 0.8mm) and are set in a standard tool holder.

The work material used in the tests for controlled machining was glass fiber reinforced plastic pipes. The inside diameter of the pipe is 40 mm and outside diameter is 60 mm. GFRP pipes are predominantly manufactured by the filament winding process and in this process the resin impregnated unidirectional rovings are wound over a rotating mandrel, which decides the inner diameter of the pipe. Fiber delivery eye travels in relation to the rotating mould to properly position the reinforcement. The rovings are wound at an angle of 30° to 90°. The typical filament winding process is shown in Fig 1. The curing was done in a microprocessor controlled curing oven. In curing, the initial gelling has been done at 80˚C for about 1 hour. Upon completion of curing, the pipe was extracted from the mandrel and cut to required length.

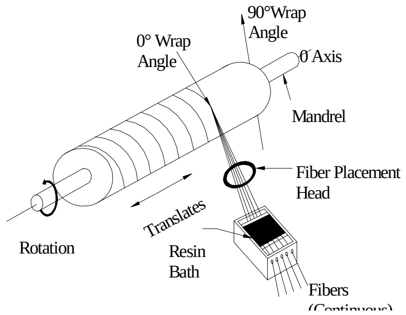

Fig 1. Typical filament winding process

The material specification and mechanical properties of fiber, resin and composite used in this work are given in Tables 1 and 2.

Table 1:Specification of fiber and resin

Fiber: E Glass- RO99 2400 P566 **Manufacturer:** Saint Gobain Vetrotex India Ltd. RO99- Multi filament roving 2400- Linear Density (Tex) P566- sizing reference for vetrotex
Resin: Epoxy **Manufacturer:** CIBA GEIGY **Product:** Araldite LY556 (Bisphenol –A epoxy resin) **Hardener:** HT 972 (Aromatic amine hardener)

Table 2: Mechanical properties of composite material

Material	**Tensile strength σ_u (Mpa)**	**Tensile modulus, E (Gpa)**	**Shear modulus, G (Gpa)**	**Mass density, ρ (Kg/m^3)**
Fiber	1724	70	30	2500
Resin	83	6	2.3	1200
Composite	930	E_1=46 E_2=13	5	1876

The experimental setup is shown in Fig 2.

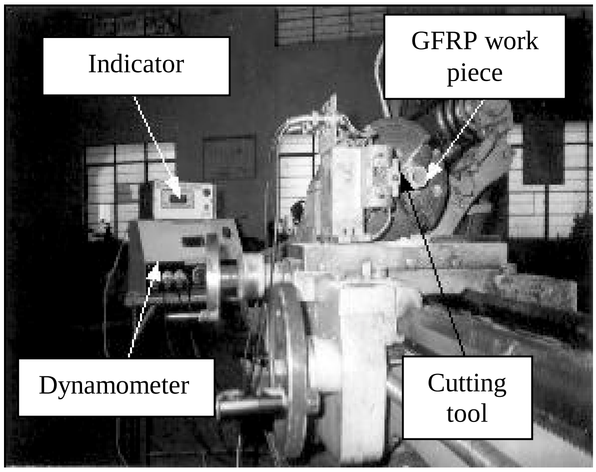

Fig 2. Experimental setup

3.2 Cutting performance measure

In this experiment tool wear, surface roughness and cutting forces were studied. The flank wear land was measured by using Radical Tool maker's microscope. The average surface roughness (R_a) which is mostly used in industries is taken for this study and was measured by using surtronic 3+ stylus type instrument. The different forces developed during cutting operations are measured using lathe tool dynamometer and the temperature on cutting tool was measured using temperature indicator as shown in figure above.

4. RESULTS AND DISCUSSION

The results showed that the roughness of the machined composite surface was highly influenced by the cutting speed, feed rate and tool radius to some extend. The relationship between the surface roughness and cutting parameters are differ from the theoretical ones applicable for metals.

This is caused by the inhomogeneous microstructure of glass fiber reinforced composites which results in surface details from deformations and fractures at micro level, e.g. fiber ends sticking out, peaks of deformed matrix material and holes from debonding between fibers and matrix.[2]. Figure 3 & 4 shows the micrographs of the work surface profile of the unmachined work piece and chip produced during the machining of GFRP composite. Figure 5 shows the effect of cutting speed on surface roughness of the work piece with various feed rate. It is clearly seen that, the surface roughness increases with the increase of feed rate. Under the consideration of speed, the curve fluctuates. This is the specific property of composites.

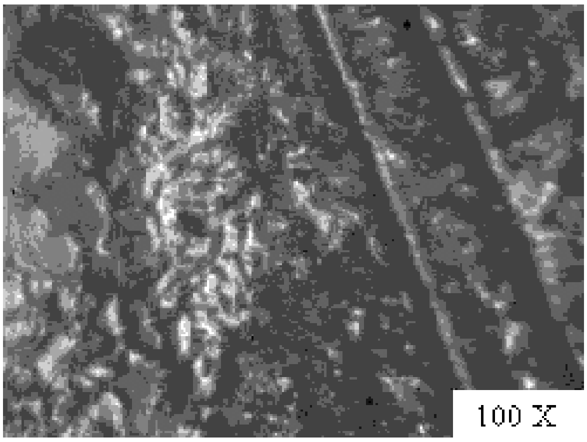

Fig 3. Microstructure of the workpiece machined

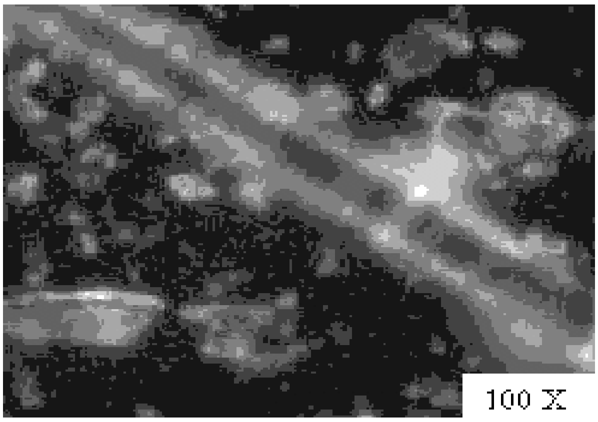

Fig 4. Microstructure of the Chip

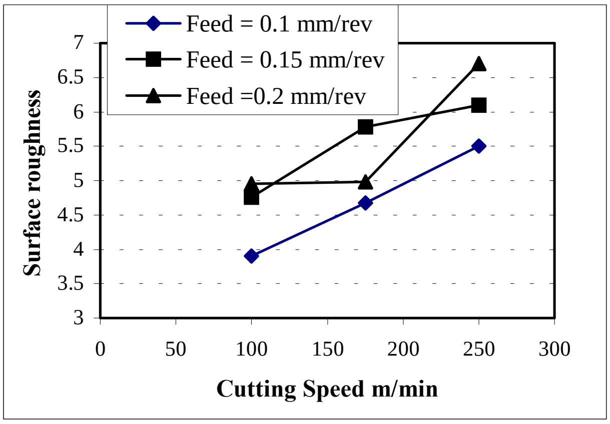

Fig 5. Effect cutting speed on surface roughness with various feed rate.

Figure 6 illustrates the roughness of machined surface with varied fiber orientation angle. Fiber orientation is the angle of fibers measured counter clock wise from the datum of the machined surface. Surface roughness of the work piece increase with increase of fiber orientation angle. The results indicates that the surface roughness is minimum in the range of 30°, and at larger fiber angles it increases steeply, this is due to the fact that at larger fiber angles, a larger compressive strain is generated within the work material [6].

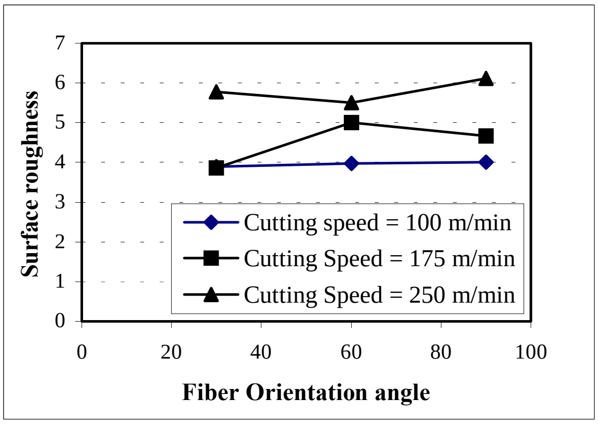

Fig 6. Relation between surface roughness and fiber angle.

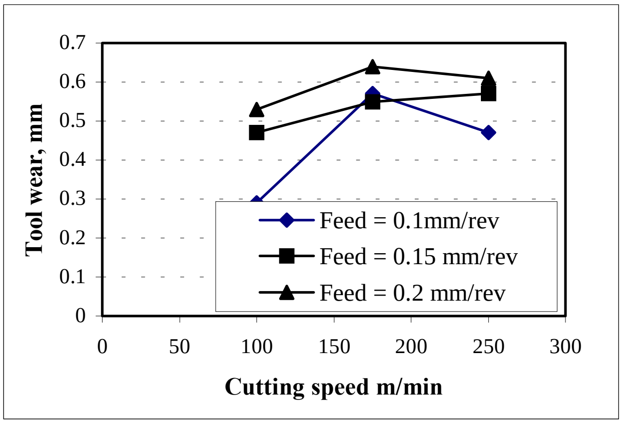

Fig 7. Relation between cutting speed and tool wear

Figure 7. illustrates the change of flank wear according to cutting speed. The tool wear is seemed to be increases with increase of cutting speed. It is known that during machining of composites, the cutting tool experienced not only fluctuating impulsive forces but also higher cutting temperature owing to poor thermal properties. During machining of composites, most of the heat of friction during machining has to be transmitted through the cutting tool. This result in thermal loading of the coated layer; the thermo mechanical phenomenon associated with frictional heating could significantlt influence the wear of coating. Usually, the higher order contact temperature will result in compressive stresses and consequent plastic flow of material [8]. Figure. 8 shows the tool wear profile observed in the machining of GFRP composites. It is clearly seen that triangle type of severe wear on the nose region.

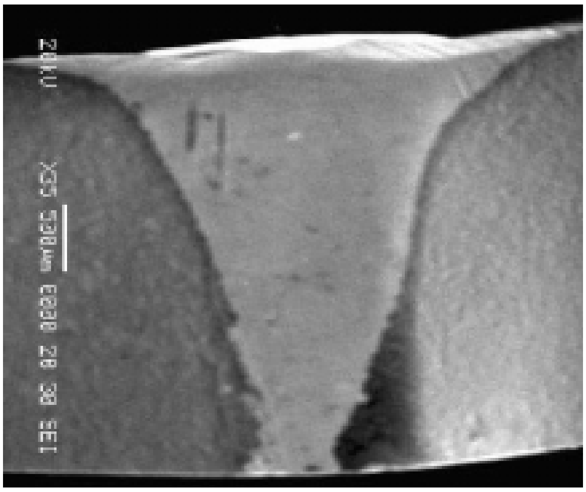

Figure 8. Microstructure of the tool with triangle wear

Figure 9 illustrates the relation between cutting speed and specific cutting pressure with varied feed rate. The results indicate that the specific cutting pressure is minimum at minimum feed rate. It is found that, at low feed rates fracture is less violent and more controllable. It is due to the fact that at low feed rate, the strain rate is low. From the experimental data, it is found that the specific cutting pressure at a feed rate 0.3 mm/rev. is higher than that at a feed rate of 0.1 mm/rev.

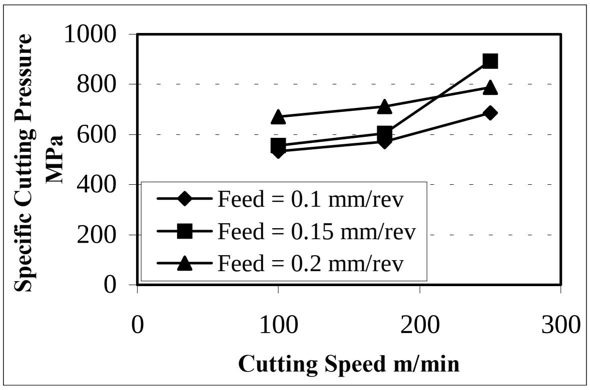

Fig 9. Relation between cutting speed and specific cutting pressure

The relation between tool radius and surface roughness is illustrated in figure10. The surface roughness is affected largely by the tool geometry but is not affected by depth of cut. This phenomenon is such that the plastics in GFRP are of good machinability, but the glass fiber itself is difficult to cut because of brittleness, this quality of the fibers influencing the machining properties of the composites. From the figure it is predicted that, an increase in the tool radius seemed to lower the surface roughness. This finding has close relationship with the results obtained by [2].

Study of the force characteristics of GFRP composite is more important due to the application field it holds. Delamination, fiber pull out, short tool life, matrix deponding, burning and formation of powder like chips are some of the important problems occur during machining. Also due to the intrinsic weakness of the matrix of the material, even a relatively low cutting force can result in high delamination and fiber pullout with matrix cracking in the work material.

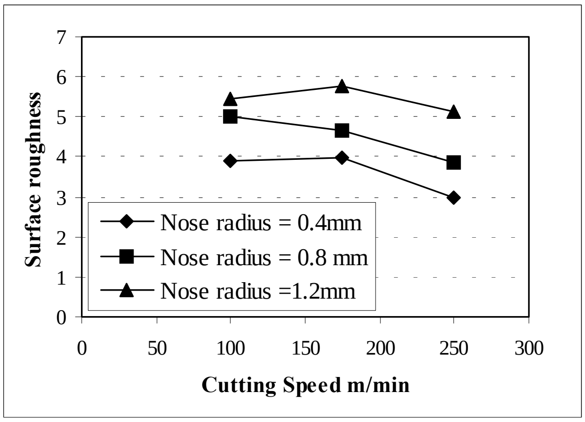

Fig 10. Relation between tool radius and surface roughness

The graphs were drawn with experimental values. Two variables at a time were considered keeping other constant. During the machining of GFRP composites, the fluctuation of cutting force is large. This is on account of the work piece being homogeneous and it is assumed that the cutting resistance fluctuates at each layer because glass fiber orientation is different on each layer[9]. The increase in fiber orientation (Fig. 11 & 12) increases cutting force, and thrust force in all cutting conditions.

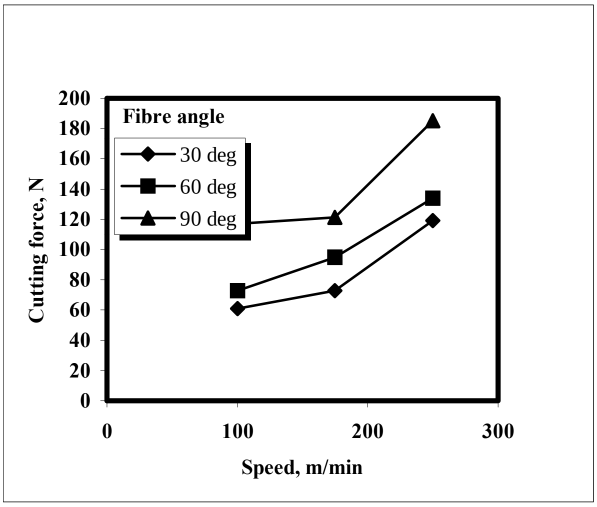

Fig 11. Relation between Cutting speed and cutting force

cutting force is greatly influenced by the fiber orientation angle, and the minimum cutting force is observed at the fiber orientation of 45°. When the orientation angle differs, the distance between the fibers may vary and accordingly, the cutting force increases. In machining GFRP, with reference to the figures, decreasing of force with an increase of cutting speed is recognized. The ratio of thrust force to main cutting force is relatively high as compared with that in cutting the metal. This finding has close relationship with the results obtained by Sakuma and Seto [4].

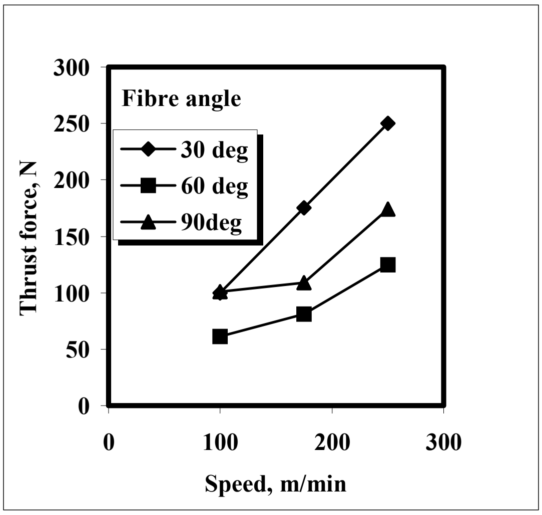

Fig 12. Relation between Cutting speed and thrust force

6. CONCLUSION

The machining characteristics of Glass Fiber Reinforced composites have been studied. The primary machining characteristics such as tool wear, surface roughness and forces were studied for turning process. The results obtained from the experiments were as follows.

- The tool wear, surface roughness and forces all increased for increasing feed rate and decreased for increasing tool radius.
- The surface roughness increased for cutting speeds upto 175 m/min and than fluctuates.
- Depth of cut shows no significant effect on the composite machining process.
- The chips produced were discontinuous and powdery form. Cutting speed and feed rate are the most significant process parameters, which affect the composite machining process.
- At higher cutting speeds, the sliding length and the kinetic energy of the abrasive particle in the composite increase. This result in higher interface temperature and tool wear increases proportionately.
- The increase in feed rate increases the thermodynamic load per unit length of the tool, which in turn is found to increase the forces and temperature. In addition, the increased area of contact increases the wear due to abrasion of glass fibers.
- The surface roughness is affected largely by the tool geometry, it will be advantageous to use high tool radius. Increase in tool radius seemed to lower the surface roughness.
- The increase in nose radius increases the contact between tool and work piece and hence it increase the tool wear.
- Nose wear, flank wear, secondary wear and mild crater are formed during the machining of GFRP.
- The results indicates that the surface roughness is minimum in the range of 30º, and at larger fiber angles it increases steeply.
- The cutting force is reduced with reduction in feed rate but the cutting force decreases with in increase in cutting speed. The trend of change in the cutting force with change in the depth of cut is similar to that for changes in the feed rate.

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