DRILLABILITY STUDY OF GLASS FIBRE REINFORCED PLASTICS

A thesis submitted to the faculty of
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MASTER OF ENGINEERING
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Certificate

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ABSTRACT

In recent years, the production of printed wiring board (PWB) has not only increased in quantity but also improved in quality. One requirement has been that the packaging density technology has allowed downsizing. For instance, from a general public point of view, television and telephones are typical cases of downsizing- that their use has changed from stationary to portable. From an industrial point of view, computing speed and memory size are increasing. Thus, high-quality micro machining is necessary for PWB. Specifically, the small diameter drilling PWD has attracted because the packaging density must be improved.

On the other hand, a great number of holes in PWB have to be drilled and drilled holes require the reliability of through-hole plating. Even if only one hole in the production has failed to be drilled, the whole production has to be abandoned.

Consequently, in order to improve the reliability of small diameter drilling in PCB, it is necessary that the relation between the tool wear and the hole quality is grasped and drilling conditions are developed in the case of present drilling machine. In addition a new drilling process which does not rely on tool life is to be researched because it is difficult to predict the tool life.

Recently, there have been few studies which have mainly dealt with the machined surface conditions of FRP and there are few studies that deal with the drilling process at a certain tool condition. However, it isn’t quite sufficient to estimate the small diameter drilling process of PWB from the results of theses studies, because it is important to relate the number of drilled holes in the case of PCB.

In the presented work, the drilled hole quality of the panel, made of GFRP, is evaluated by investigating the damage to the drilled holes. In conclusion, it is shown that, in the case of the present drilling machine, the anisotropy of the hole surface roughness can be developed by the tool tip profile.

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I would also like to thank my parents and brother for teaching me the difference between right and wrong and making me who I am today. I could not have made it this far without their love and support

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Chapter 1: Introduction

1.1 Plastics

Plastics are man-made materials that can be shaped into almost any form. They are one of the most useful materials ever created. Plastics can be rubbery or rigid, and they can be shaped into an endless variety of objects, ranging from car bumpers to squeezable bottles to soft fabrics. Plastic products, especially those used by industries, often have a useful life of many years.

Plastics consist of long chains of molecules called polymers. These chains are made of repeating patterns of smaller molecules. Each of the smaller molecules forms a "link" in the polymer' s chain. These different structures give plastics their most notable characteristic, the ability to be shaped.

Plastic parts are replacing metals in airplanes, cars, and many mechanical devices. Airplane manufacturers use plastic wing and body assemblies to reduce the weight of an aircraft, thereby reducing fuel consumption. Plastic car parts do not rust, nor do they dent as easily as metal ones. They are also easier and often less expensive to repair. Some plastic fibres are tough enough to be used for safety belts in cars or bulletproof vests. Plastics are also used to make insulating foam that blocks the flow of heat and sound.
There are two types of plastics:

- **Thermosetting plastics and**
- **Thermoplastics.**

1.1.1 Thermosetting plastics--or thermosets, can be heated and set only once. They cannot be remolded. When a thermoset is heated, it undergoes a chemical reaction called cross-linking, which binds its polymer chains together. Once it has hardened, it cannot become a liquid again. Because thermosets cannot be remolded, engineers use them in applications that require high resistance to heat.

1.1.2 Thermoplastics can be melted and re-formed. Their polymer chains do not form cross-links. Thus, the chains can move freely each time the plastics are heated.

Because their molecules can slide slowly past one another, some thermoplastics tend to lose their shape when exposed to constant pressure over a long period of time.

The polymers in plastics are made up of small molecules called monomers. Most of these molecules are composed of carbon, hydrogen, nitrogen, and oxygen atoms. Some include chlorine, fluorine, silicon, or sulphur atoms. In some polymers, these links are made up of the same kind of monomer, repeated over and over again.

1.2 Resins

Resin, Synthetic, is any one of a large group of chemical compounds that includes most of our common plastics. These resins may be made as fibres or films, or molded into a great variety of shapes, ranging from pocket combs to car bumpers. Synthetic resins are made up of many simple molecules linked together to form large, complex ones. The nature of synthetic resins is determined by the chemicals they contain and by the patterns of the new molecules.

The adhesion of the resin matrix to the fibre reinforcement or to a core material in a sandwich construction is important. Polyester resins generally have the lowest adhesive properties of the three systems described here. Vinylester resin shows improved adhesive properties over polyester but epoxy systems offer the best performance of all, and are therefore frequently found in many high-strength adhesives. This is due to their chemical composition and the presence of polar hydroxyl and ether groups. As epoxies cure with low shrinkage the various surface contacts set up between the liquid resin and the adherents are not disturbed during the cure. The adhesive properties of epoxy are especially useful in the construction of honeycomb-cored laminates where the small bonding surface area means that maximum adhesion is required. The strength of the bond between resin and fibre is not solely dependent on the adhesive properties of the resin system but is also affected by the surface coating on the reinforcement fibres.

1.3 Polyesters

Polyester is a group of widely used plastics materials. Polyesters are synthetic polymers. A polymer is a long, chainlike molecule. The "links" are repeating patterns of simple groups of atoms called monomers. Polyesters are of two types:

1.3.1 Thermoplastic Polyester (Saturated):

Thermoplastic Polyester (Saturated) is a family of polyesters in which the polyester backbones are saturated and hence unreactive. The most common commercial types are: PET (polyethylene terephthalate) produced by polycondensation of ethylene glycol [CH_2OHCH_2OH] with either dimethyl terephthalate (DMT) [$C_6H_4(COOCH_3)_2$] or terephthalic acid (TPA) [$C_6H_4(COOH)_2$]; and PBT (polybutylene terephthalate) produced by the reaction of DMT with 1,4 butanediol [$HO(CH_2)_4OH$]. Typical applications are found in packaging, automotive, electrical, and consumer markets.

1.3.2 Unsaturated Polyester

Thermosetting resins made by the condensation reaction between dysfunctional acids and glycols. The resulting polymer is then dissolved in styrene [$C_6H_5CHCH_2$] or other vinyl unsaturated monomer. The structures of the acids and glycols used and their proportions, especially the ratio of the unsaturated versus the saturated acid, and the type and amount of monomer used, are all tailored for each resin to balance economy, processing characteristics, and performance properties. One common formulation is the reaction of maleic anhydride [$(COCH)_2O$], phthalic anhydride [$C_6H_4(CO)_2O$], and propylene glycol [$CH_3CHOHCH_2OH$]. Both dicyclopentadiene [$C_{10}H_{12}$] and isophthalic acid [$C_6H_4(COOH)_2$] can be substituted for phthalic anhydride. Vinyl ester resins are linear reaction products of bisphenol A [$(CH_3)_2C(C_6H_4OH)_2$] and epichlorohydrin [CH_2OCHCH_2Cl] that are terminated with an unsaturated acid such as methacrylic acid [$CH_2C(CH_3)COOH$]. Typical applications are found in transportation, appliances, electrical, and construction markets.

1.4 Epoxy Resin

When a manufacturer combines appropriate compounds, chemical reactions cause atoms to cluster together to form monomers. Further reactions cause the monomers to **polymerize**--that is, to form long chains of molecules. Polymerization produces the **synthetic resin or epoxy resin**.

Thermosetting resins, in the uncured form, contain one or more reactive epoxide or oxirane groups. These epoxide groups serve as cross-linking points in the subsequent curing step, in which the uncured epoxy is reacted with a curing agent or hardener. Cross-linking is accomplished through the epoxide groups as well as through hydroxyl groups that may be present. Most conventional unmodified epoxy resins are produced from epichlorohydrin (chloropropylene oxide) [CH_2OCHCH_2Cl] and bisphenol A [$(CH_3)_2C(C_6H_4OH)_2$]. The other types of epoxy resins are phenoxy resins, novolac resins, and cycloaliphatic resins. Epoxy resins are used as protective coatings, bonding adhesives, in building and construction, and for electrical , and many other uses.

1.5 Resin Comparison Summary

In summary the main advantages and disadvantages of each of these types are:

Polyesters

Advantages:

- Easy to use.
- Lowest cost of resins available.

Disadvantages:

- Only moderate mechanical properties.
- High styrene emissions in open moulds.
- High cure shrinkage Limited range of working times.

Epoxies

Advantages:

- High mechanical and thermal properties.
- High water resistance.
- Long working times available.
- Temperature resistance can be up to 140°C wet / 220°C dry.
- Low cure shrinkage.

Disadvantages:

- More expensive.
- Critical mixing.
- Corrosive handling.

1.6 Glass Fibres

Materials such as glass, aramid and boron have extremely high tensile and compressive strength but in 'solid form' these properties are not readily apparent. This is due to the fact that when stressed, random surface flaws will cause each material to crack and fail well below its theoretical 'breaking point'. To overcome this problem, the material is produced in fibre form, so that, although the same number of random flaws will occur, they will be restricted to a small number of fibres with the remainder exhibiting the material's theoretical strengthTherefore a bundle of fibres will reflect more accurately the optimum performance of the material. However, fibres alone can only exhibit tensile properties along the fibre's length, in the same way as fibres in a rope.

1.7 Glass Fibre Reinforcement Plastics

It is when the resin systems are combined with reinforcing fibres such as glass that exceptional properties can be obtained. The resin matrix spreads the load applied to the composite between each of the individual fibres and also protects the fibres from damage caused by abrasion and impact. High strength and stiffness, ease of molding complex shapes, high environmental resistance all coupled with low densities, make the resultant composite superior to metals for many applications.

Since Polymer Matrix Composites combine a resin system and reinforcing fibres, the properties of the resulting composite material will combine something of the properties of the resin on its own with that of the fibres on their own.

Overall, the properties of the composite are determined by:

- The properties of the fibre.
- The properties of the resin.
- The ratio of fibre to resin in the composite (Fibre Volume Fraction).
- The geometry and orientation of the fibres in the composite.

1.8 Standard Properties of FRP's

The following can be considered as the 'standard' properties typically exhibited by an FRP composites component.

- High strength at low weight.
- Ability to tailor properties to meet wide-ranging.
- Performance specifications.
- Molding to close dimensional tolerances.
- Good impact, compression, fatigue and electrical properties.
- Ability to markedly reduce part assembly.
- Excellent environmental resistance.
- Ability to fabricate massive one-piece moldings.
- Proven in-service track record.
- Low-to-moderate tooling costs.
- Cost-effective manufacturing processes.
- Ability to build in, ex-mould, both color and texture.
- Excellent chemical and corrosion resistance.
- High ultra-violet radiation stability.
- Good-to-excellent fire hardness.
- Good structural integrity.
- Good thermal insulation.
- Ability to attenuate sound.
- Respectable abrasion resistance.
- Ready bonding to dissimilar materials.
- Medium-to-high productivity rates.

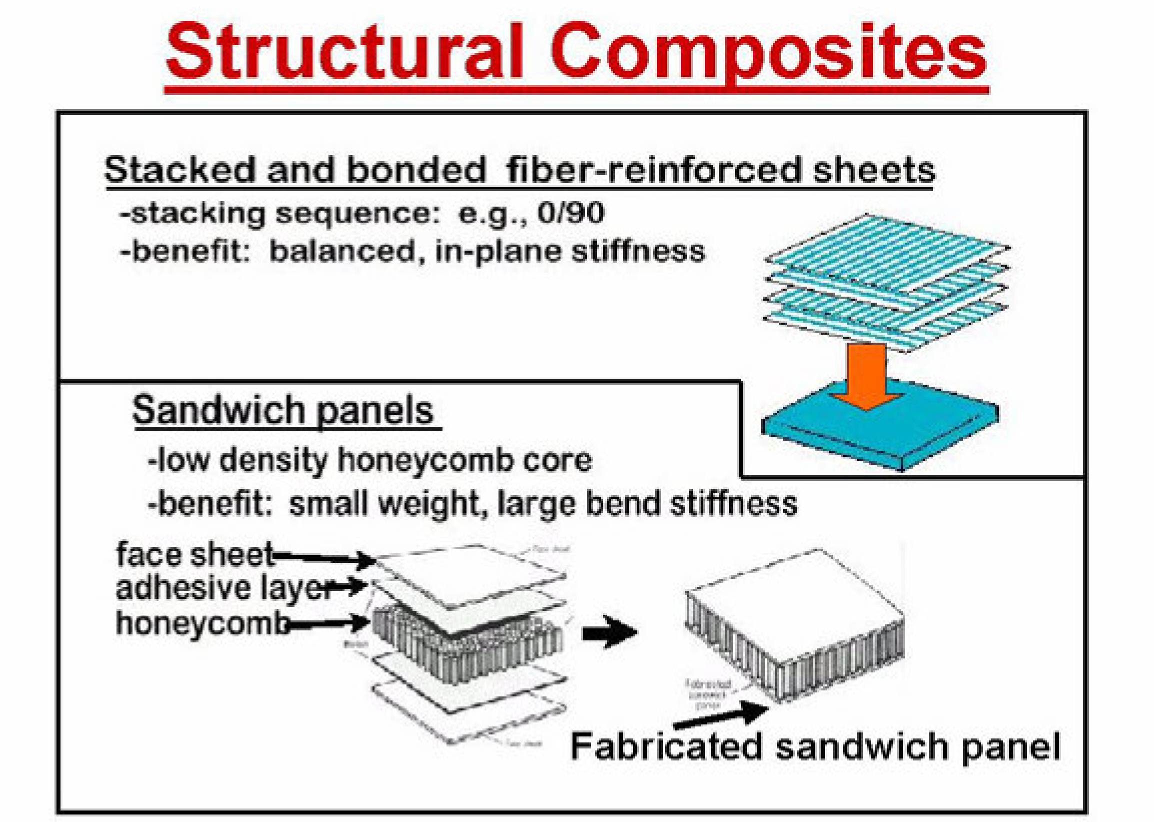
1.9 Types of GFRP reinforcing methods commonly followed

1.9.1 Laminar

It is composed of two-dimensional sheets or panels that have a preferred high strength direction such as is found in wood and continuous and aligned fibre-reinforced plastics. The layers are stacked and cemented together such that the orientation of the high-strength direction varies with each successive layer. One example of a relatively complex structure is modern ski and another example is plywood.

1.9.2 Sandwich Panels

Consist of two strong outer sheets which are called face sheets and may be made of aluminum alloys, fiber reinforced plastics, titanium alloys, steel. Face sheets carry most of the loading and stresses. Core may be a honeycomb structure, which has less density than the face sheets and resists perpendicular stresses and provides shear rigidity. Sandwich panels can be used in variety of applications which include roofs, floors, walls of buildings and in aircraft, for wings, fuselage and tail-plane skins.



Structural Composites

Stacked and bonded fiber-reinforced sheets
-stacking sequence: e.g., 0/90
-benefit: balanced, in-plane stiffness

Sandwich panels
-low density honeycomb core
-benefit: small weight, large bend stiffness

In 1972, a manufacturing engineer stated that approximately 90% of the cost of the farm equipment his firm made was involved in making and finishing holes. This seemed astounding but has since been confirmed for most moving machinery, including automobiles. Since the pleasing shapes, unique weight, cost, design flexibility, and ease of fabrication of FRP are now being used with success in automobiles, the chemist turned machinist must now develop the skills and experience to utilize modern tooling which has been designed for FRP. Slightly modified cast iron tooling is not acceptable if we want to achieve true potential of FRP. Efficient, high volume, high speed, cost effective drilling of FRP can best be accomplished with tooling engineered to perform productively with long life and to exact tolerances. Modern technology must be used to establish our unquestioned leadership in automobile manufacturing. Imagine, press fitting bearings into FRP material that has only been drilled, it is being done today.

Completely turning our backs on the machining expertise that the metal chip makers have refined and refined and refined into one of the highest art forms and most efficient energy resource skills in the world is not wise. Rather, we as engineering professionals must test the fundamental assumptions of the metal chip maker and the plastic chip maker to separate the elements into those that are transferable to plastic machining and those that are not.

1.10 High Speed Steel (HSS) Tool:

In metal cutting, the characteristics of the tool and work materials play important roles. A cutting tool should have to be harder than the work material. With increase in the work material hardness, the tool material and the cutting conditions are to be decided critically.

High Speed Steel tools are the tools made of the high-speed steel material. It is the most common tool used in present day engineering industries. It is known by the name of high speed since it can retain it' s hardnessunder high cutting speeds and temperatures of the order of 900°C.

There are three kinds of HSS tools:

(a) 18-4-1 High Speed Steel

This is the high tungsten steel containing 18% of tungsten and 4% chromium with 1% vanadium. This is the highly efficient of all high-speed steel tools.

(b) Molybdenum High Speed Steel:

It contains 6% molybdenum, 4% chromium and 2% vanadium. Such steel has high toughness and cutting strength.

(c) Cobalt High Speed Steel

It has high hot hardness and wear resistance at higher cutting speeds. It contains up to 15% of cobalt with 10-20% tungsten, 2-4% of chromium and 2-4% of vanadium. It' s advantage is that it has high machining performance, with longer tool life but it' s disadvantage is that it is costly and difficult to fabricate.

1.11 Tool wear

A tool cannot cut for an unlimited period of time. It has its definite life. If a cutting tool is to have a long life it is essential that the face of the tool be as smooth as possible. Tool life is the time a tool will operate satisfactorily until it is dulled. A blunt tool causes chatter in machining, poor surface finish, increase in cutting forces and power consumption, overheating of the tool. **The loss of sharpness of the cutting edge with usage is called tool wear**.

There are five types of tool wear:

(a) Adhesion wear: In this the tool material gets welded to the workpiece. This type of tool wear takes place under high cutting forces, high temperature and with less harder tool material.

(b) Abrasion wear: This wear is caused by the frictional force due to the moving of the chips over the face of the tool.

(c) Diffusion wear: It is a solid state diffusion phenomenon which leads to tool wear. This depends on the temperature and the contact area between the work and the tool. The rate of diffusion increases exponentially with increase in temperature.

(d) Chemical and electrolytic wear: Chemical wear is caused due to chemical reaction between the tool and the workpiece in the presence of a cutting fluid. Electrolytic wear is the result of possible galvanic corrosion between the tool and the workpiece.

(e) Oxidation wear: During cutting action the high temperatures generated at the tool work interface cause the oxidation of the tool. This results in the decrease in the strength of the tip of the tool resulting in failure.

1.12 Machining of GFRP (Drilling)

Though composites have excellent performance characteristics, but when machined they tend to develop the following flaws:

- **Surface delamination**: Separation of plies where the cutter enters and exits the material.
- **Internal delamination:** Separation that develops between the plies as a result of improper machining.
- **Fibre/Resin pull out**: Tearing away of fibre /resin from the wall of the machined edge.
- Higher tool wear due to abrasion by hard fibres.
- Lower flexural strength causes easy deformation of hole, which subsequently leads to hole shrinkage.
- Presence of powdery chip, which is a health hazard and is difficult to handle.
- Lower thermal conductivity causing local heat accumulation.

1.13 Objective of the project

This research work describes characteristics of the drilling in GFRP (plain woven cloth, glass/polyester), using a drilling machine. The investigation is carried out from the view of the relation between machined hole quality and the number of drilled holes. The surface profiles are observed by a scanning electron microscopy (SEM) along the quarter circumference of the hole. In addition, the internal damage of the drilled hole is determined by observing the shadows due to transmitted light through the one ply.

Chapter 2: Literature Review

2.1 History of composites and FRPs

For thousands of years, people used natural gums and resins with properties similar to plastics. For example, the ancient Greeks and Romans created decorative objects from amber, a fossil resin. During the middle Ages, Europeans used the natural resin lac, and its purified form, shellac, to coat objects.

By the mid-1800' s, the commercial moulding of plastics like natural substances had developed. Manufacturers molded items from lac, gutta-percha (a tree resin), and other substances obtained from animal, vegetable, and mineral sources (GUTTA-PERCHA). Products made from these natural "plastics" Included, brush handles, knobs, electrical insulation, records, and novelty items.

Despite their beauty, these natural molding materials had several disadvantages. Manufacturers often had difficulty obtaining the raw materials. Some materials proved difficult to mould, and many of the finished products turned brittle and broke easily.

Important thermosetting plastics called polyesters were introduced commercially in the 1940' s. Important thermoplastics developed during the 1940' s included polyethylene, silicones, and epoxy resins. All of these plastics found new uses during the early 1950' s. Polyethylene proved an excellent material for plates, squeezable bottles, plastic bags, and other products. Manufacturers used silicones in lubricants and electrical insulation, and surgeons used them in body implants.

Epoxy resins gained wide use as strong adhesives. Manufacturers used polyesters to make boat hulls and car bodies. The uses of plastics continued to grow during the late 1950' s and the 1960' s. This growth corresponded directly to the growth of the petrochemical industry, the major producer of the raw materials for plastics.

Engineers found new uses for plastics in medicine, nuclear and space research, industry, and architecture. Polymer chemists developed several new plastics that are especially resistant to chemicals and extreme heat.

Throughout the 1970' s and 1980' s, plastics continued to find new applications, appearing in such products as microwave cookware, personal computer housings, and compact discs. Aerospace engineers used heat-resistant polyurethane foam to cover the external fuel tanks of the United States space shuttles.

Plastics companies may be divided into three general groups: resin manufacturers (mostly chemical companies) who make and supply resins; processors who shape the resins into products; and finishers and assemblers who make products by cutting, drilling, decorating, and assembling plastic parts. Most resin manufacturers are located in regions that allow easy access to great supplies of petroleum. Most processors, finishers, and assemblers operate in areas where they can serve many industries.

It is easy now to see why composites (fibre reinforced polymers or plastics) have become the mainstay material in the marine designers' drawer of materials. However, a designer in the 1940' s would now be extremely surprised to see the proliferation of fibres, resins, sandwich core materials and manufacturing processes, which abound in the composites industry.

Since the first boat was made in glass reinforced polyester resin, now some sixty years ago, we have transgressed to high impact resistance aramid fibres (Kevlar) to high strength and stiffness carbon fibres using heat cured resin systems. Not that this progress has been without problems, because it is a material that requires little in the way of equipment, (a bucket and a brush) it has been so often used by the inexperienced, leading to poor products and unfortunately, problems. This gave the material a bad press on many occasions. But progress has been made and composites are now used widely in almost every application.

Fibre reinforced polymers are a fibre of some sort held within a resin matrix. The most common fibres are glass, aramid (Kevlar) and carbon. The most common resins are polyester, vinyl ester and epoxy. Phenolic resins are also available and incidentally, the oldest type. They have better fire resistance, but because they are more difficult to use, they are not common within the marine industry.

The fibres may be random or directional. Because of the variation in strength and stiffness of the fibres, an immediate advantage can be seen - it is possible to ' engineer' the required strength or stiffness and the direction in which these properties are required.

Glass reinforced polyester is the cheapest and the most widely used composite. The basic manufacturing process is simple – a bucket of mixed resin (resin, accelerator and catalyst), a brush to apply the resin and some fibre. The more sophisticated manufacturing methods now include resin infusion, where the resin is drawn into a closed mould under vacuum. The mould already contains the fibre, in thicknesses and direction to suit the load or stiffness requirement. Whole boat hulls are now made by this method – one-shot manufacture. At the more expensive end, and the higher property end also, we have carbon and aramid fibres.

It is this huge range of fibres, resins, manufacturing processes and supporting sandwich core materials, which give composites the real advantage over other materials.

Resin manufacturers use such reinforcements as glass fibres or carbon fibres to give plastics extra strength or rigidity. The resulting mix, called a composite or a reinforced plastic, may contain from 10 to as much as 80 percent reinforcement. Composites are lightweight and can replace metals in missiles, aircraft, and cars.

2.2 Machining of Fiber Reinforced Plastics with High Speed Steel Tools:

2.2.1 Work piece material

The Glass fiber reinforced plastic (GFRP) is characterized by high strength and rigidity at simultaneously low weight and are thus, as a light construction material in many ways superior to metal materials. In result, FRPs have substituted conventional materials during the past years in many applications in the fields of aerospace and traffic engineering, machine and plant construction, as well as leisure industries. Their machinability decreases with increasing fiber content.

In one study, Glass fiber reinforced plastics with a thermo-plastic matrix (GFRP) were used as test materials. As GFRP-materials, glass fabric reinforced epoxy resin EPR 8 (65 weight-% fibers) and glass mat reinforced polyester resin UPM 72 with 50 weight-% fibers were cut.

2.2.2 Wear

During the cutting process, wear phenomena occur on the tool that diminish its cuttability and mostly cause an increase of mechanical and thermal stresses as well as a decrease in the machining quality. The wear in machining of fibre-reinforced plastics is usually explained by the abrasive effects of the reinforcing fibers. Causes of wear such as diffusion and scaling only occur at high cutting temperatures and are therefore of only minor importance in the conventional cutting value range. Tribochemical load on the cutting material by the surrounding media, however, cannot be ruled out. Next to this actual wear, other wear-accompanying phenomena can be observed that impair the machining:

- Sediments of matrix and fiber particles on the face and flank, as well as
- Thermally and mechanically caused delaminations on the material surface.

While the first phenomenon does not define the end of the tool life, the machining process must be stopped when there are damages on the material surface, because these damages may affect the functioning of the component part. The sediments of molten matrix and/or fiber particles that are formed at the face and flank irrespective of the cutting parameters are dragged along with the chip in periodic

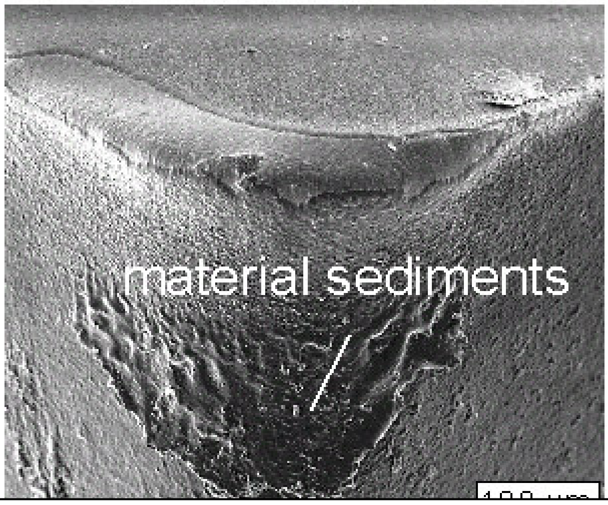


Figure 2: Material sediments at the flank after the machining of GFRP- EPR 8

intervals and develop again anew, similar to the formation of the built-up edge in aluminium machining (**Figure 2**).

In view of the poor thermal conductivity and the relatively low melting points of thermoplastics, the generated heat must be kept to a minimum, therefore avoiding build up of temperature within the product. This is in order to avoid color changes or even melting. Therefore:

- Tools must be kept sharp and smooth at all times.
- Tools must have sufficient clearance so that the cutting edge only contacts the plastic material.
- A good swarf removal from the tool must be assured.
- Coolants should be applied for operations where plenty of heat is generated (e.g. drilling).

Machining forces

Machining forces are lower for engineering plastics than for metals; therefore clamping pressures should be reduced. But as these materials are not as rigid as metals, it is essential to support the work adequately during machining in order to prevent deflecting, e.g. thin walled bushings, often require an internal plug for accurate machining of the outside diameter.

Tools

Carbon or high speed steel and hard metal tools can be used. However, tungsten carbide tipped tools or diamond bit tools are preferred for long production runs and are a must when machining glass or carbon fibre reinforced materials.

Coolants

When the use of coolants is required, cooling liquids of the soluble oil type do generally very well. They should, however, not be used when machining amorphous thermoplastics, which materials are susceptible to environmental stress-cracking. For these materials the most suitable coolants are pure water or compressed air.

Machining tolerances

The machining tolerances required for thermoplastic parts are generally considerably larger than those normally applied to metal parts. This is because of the higher coefficient of thermal expansion, eventual swelling due to moisture absorption (mainly with nylons) and possible deformations caused by internal stress-relieving during and after machining. The latter phenomenon mainly occurs on parts where machining causes asymmetric and/or heavy section changes. In these cases, a thermal treatment (stress-relieving) after pre-machining and prior to final machining of the part might prove necessary.

Safety

To avoid any risks, the general industrial safety recommendations should be followed. With respect to their hardness and moderate toughness, it is recommended that additional machining and design rules have to be observed next to what already has been said earlier some additional machining/ design rules have to be observed. This should prevent premature failure of these materials. In design and assembly, stress concentrations should be avoided.

Some tips

Always use light to moderate clamping forces. Never try to force the plastics part. Avoid sharp "internal" corners. The radius of curvature should be at least 1 mm. To avoid chipping the edges during turning, boring or milling, chamfered edges are advantageous, providing a smoother transition between the cutting tool and the plastics work.

Chapter 3: Scope of the present investigation

The intent of our present project is to determine the wear induced in the High Speed Steel (HSS) tool used while drilling a prepared specimen of Glass Fibre Reinforced Plastics and to assess the internal damage of the drilled hole and also suggest the optimum values of various parameters affecting the drilling process.

Glass Fibre Reinforcement Plastics (GFRP) are composites, which are invariably used in many applications in the fields of aerospace and traffic engineering, machine and plant construction, as well as leisure industries. The Glass fiber reinforced plastics (GFRP) is characterized by high strength and rigidity at simultaneously low weight, thus, as a light construction material in many ways superior to metal materials.

For enabling their use in the various applications GFRP should be shaped and sized into the required form by machining. Since machining of the material of the specimen directly affects the properties of the material, in this project, machining of Glass Fibre Reinforced Plastics are studied in detail with special reference to drilling.

Chapter 4: Experimental Procedure

4.1 List of the Apparatus used

- **Ceramic tiles** – Commonly called as Bathroom tiles.
- **Benzene** - Used to clean the surface of the ceramic plates and to clean the brushes and other parts that come in contact with the polymer.
- **Mould releasing agent** - Used to release the glass fibre & polymer combination from the ceramic plates.
- **Low temperature Epoxy resin (LY556)** -Used in combination with hardener to provide a binding agent for the layers of glass fibre.
- **Hardener (HY951)** - Used in combination with the epoxy to form the polymer-binding agent.
- **Glass fibre woven type.**

4.2 Detailed Explanation of each Material used

4.2.1 Ceramic Tiles:

Ceramic tiles are burned clay product. These tiles have better abrasion resistance, durability and resistance to attack to abrasive media. They exhibit high heat absorption, non-porosity and are smooth and embossed surfaces. They can be glazed further to obtain a smooth finish.

4.2.2 Benzene

Benzene is a colorless, volatile liquid with a characteristic odor. Its melting point is 5.5°C and boiling point is 80.1°C. It is immiscible with water but miscible with other organic solvents. The vapors are inflammable. It is an excellent solvent for other organic compounds.

Since it is capable of dissolving organic materials and is volatile in nature, it is used to clean the surface of the ceramic tiles as well as to wash and clean the brush and operators hands while preparing the specimens.

4.2.3 Release Agents

Whether release agents are incorporated into the resin matrix or applied externally to the mould surface, correct selection can optimize not only cycle time, but also consistency of surface finish maintaining detail, minimizing post mould operation prior to painting or bonding, even helping with fibre wet out.

To work well, a release agent must fit within the scope of the overall process and be cost effective. Application must be simple with clearly defined steps, drying times should be short and cure time if any must not delay the process. The product must not contain any ingredients that will affect the final product properties or post mould treatments. Finally release must be smooth and clean with no pre-release prior to cure.

Qualification costs are high and suppliers should ensure their products and chemical pre-cursors are available long term, anticipating changes in legislation and using safe ingredients whenever possible.

There are two types of release agents:

Internal Mould Release Agent (IMR):

A product dissolved in the resin mix, which is highly soluble in the carrier solvent i.e. styrene. During cure the product drops out of solution and migrates to the surface due to volumetric shrinkage, pressure and temperature.

The following criteria are desirable:

- Total solubility in the system.
- Minimal effect on cure.
- Minimal effect on color.
- No negative and preferably positive influence on physical properties.
- No silicone, non-stearate and no natural waxes which would adversely affect painting or bonding adhesives.
- A consistent clean release with no build-up or mould fouling caused by deposits.
- Measurable reduction in cycle time using an internal requires careful introduction. Each release agent application is not an individual event; it is

part of a long running sequence. Each molding relies as much on previous molding as it does on the IMR it deposits during its own cycle. (This is a continuous process in pultrusion). IMR' s are more commonly associated with mechanized processes, but can assist in difficult highly detailed hand lay-up moldings.

One major advantage is consistency and in high volume production, externally applied release systems rely solely on operator skill, not always meeting the requirements of the designer or formulating chemist.

External Mould Release Agent (EMR)

Externals are applied to the mould surface and as such rely on care and attention during application to ensure successful release.

The following criteria are desirable:

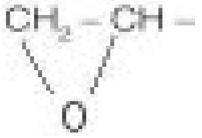
- Easy application with no complex instructions.
- No harmful solvents.
- Good wetting of all surfaces i.e. should not shrink back when applied.
- Surface tension should be correct for gel coat application.
- Quick drying.
- Easy to polish.
- Transfer to molding should be easily removed, (preferably with water).
- Predictable multiple release.

Wax release agents are used typically in low volume manufacturing where products are individual and cycle times are not critical, semi-permanents are used in high volume applications.

The semi-permanent system is ideal for all contact moldings, large or small, giving exceptional surface finish with low maintenance, but without critical application procedures. In high production processes such as RTM, the use of semi-permanent systems maximizes cycle times because of their consistent release properties.

4.2.4 Low temperature Epoxy Resin (LY556):

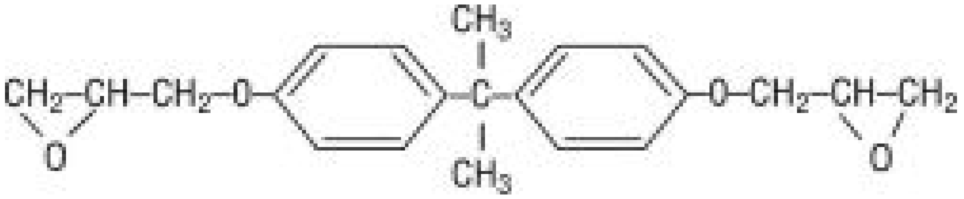
The term ' epoxy' refers to a chemical group consisting of an oxygen atom bonded to two carbon atoms that are already bonded in some way. The simplest epoxy is a three-member ring structure known by the term ' alpha-epoxy' or ' 1,2-epoxy'. The idealized chemical structure is shown in the figure below and is the most easily identified characteristic of any more complex epoxy molecule.



Idealised Chemical Structure of a Simple Epoxy (Ethylene Oxide)

Usually identifiable by their characteristic amber or brown coloring, epoxy resins have a number of useful properties. Both the liquid resin and the curing agents form low viscosity easily processed systems. Epoxy resins are easily and quickly cured at any temperature from 5°C to 150°C, depending on the choice of curing agent.

One of the most advantageous properties of epoxies is their low shrinkage during cure, which minimizes fabric ‘print-through’, and internal stresses. High electrical insulation and good chemical resistance also enhance high adhesive strength and high mechanical properties. Epoxies find uses as adhesives, caulking compounds, casting compounds, sealants, varnishes and paints, as well as laminating resins for a variety of industrial applications. Epoxy resins are formed from a long chain molecular structure similar to vinylester with reactive sites at either end. In the epoxy resin, however, epoxy groups instead of ester groups form these reactive sites. The absence of ester groups means that the epoxy resin has particularly good water resistance. The epoxy molecule also contains two ring groups at its centre which are able to absorb both mechanical and thermal stresses better than linear groups and therefore give the epoxy resin very good stiffness, toughness and heat resistant properties. The figure below shows the idealized chemical structure of a typical epoxy. Note the absence of the



ester groups within the molecular chain.

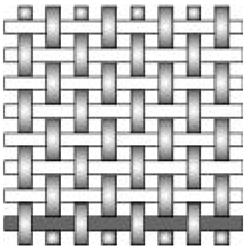
4.2.5 Hardner (HY951)

Epoxies differ from polyester resins in that a ‘hardener’ rather than a catalyst cures them. The hardener, often an amine, is used to cure the epoxy by an, ' addition reaction' , when both materials take place in the chemical reaction. The chemistry of this reaction means that there are usually two epoxy sites binding to each amine site. This forms a complex three-dimensional molecular structure. Since the amine molecules ' co-react' with the epoxy molecules in a fixed ratio, it is essential that the correct mix ratio be obtained between resin and hardener to ensure that a complete reaction takes place. If amine and epoxy are not mixed in the correct ratios, unreacted resin or hardener will remain within the matrix, which will affect the final properties after cure. To assist with the accurate mixing of the resin and hardener, manufacturers usually formulate the components to give a simple mix ratio, which is easily achieved by measuring out by weight or volume.

4.2.6 Glass Fibre

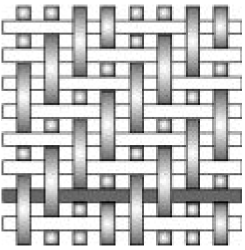
For applications where more than one fibre orientation is required, a fabric combining 0° and 90° fibre orientations is useful. The interlacing of warp (0°) fibres and weft (90°) fibres in a regular pattern or weave style produce the woven fabrics. The fabric' s integrity is maintained by the mechanical interlocking of the fibres. Drape (the ability of a fabric to conform to a complex surface), surface smoothness and stability of a fabric are controlled primarily by the weave style. The following is a description of some of the more commonly found weave styles:

Plain



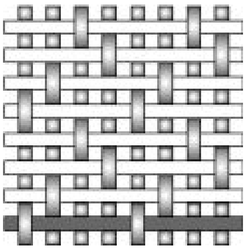
Each warp fibre passes alternately under and over each weft fibre. The fabric is symmetrical, with good stability and reasonable porosity. However, it is the most difficult of the weaves to drape, and the high level of fibre crimp imparts relatively low mechanical properties compared with the other weave styles. With large fibres (high tex) this weave style gives excessive crimp and therefore it tends not to be used for very heavy fabrics.

Twill



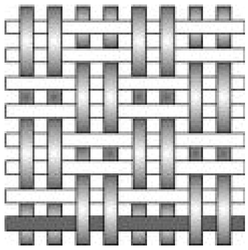
One or more warp fibres alternately weave over and under two or more weft fibres in a regular repeated manner. This produces the visual effect of a straight or broken diagonal ' rib' to th fabric. Superior wet out and drape is seen in the twill weave over the plain weave with only a small reduction in stability. With reduced crimp, the fabric also has a smoother surface and slightly higher mechanical properties.

Satin



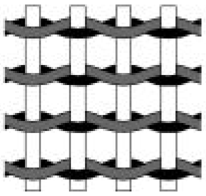
Satin weaves are fundamentally twill weaves modified to produce fewer intersections of warp and weft. The Harness number used in the designation (typically 4, 5 and 8) is the total number of fibres crossed and passed under, before the fibre repeats the pattern. A crowsfoot weave is a form of satin weave with a different stagger in the re-peat pattern. Satin weaves are very flat, have good wet out and a high degree of drape. The low crimp gives good mechanical properties. Satin weaves allow fibres to be woven in the closest proximity and can produce fabrics with a close ‘tight’ weave. However, the styles low stability and asymmetry needs to be considered. The asymmetry causes one face of the fabric to have fibre running predominantly in the warp direction while the other face has fibres running predominantly in the weft direction. Care must be taken in assembling multiple layers of these fabrics to ensure that stresses are not built into the component through this asymmetric effect.

Basket



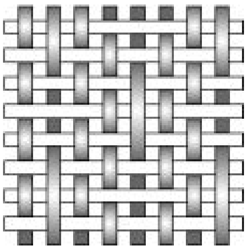
Basket weave is fundamentally the same as plain weave except that two or more warp fibres alternately interlace with two or more weft fibres. An arrangement of two warps crossing two wefts is designated 2x2 basket, but the arrangement of fibre need not be symmetrical. Therefore it is possible to have 8x2, 5x4, etc. Basket weave is flatter, and, through less crimp, stronger than a plain weave, but less stable. It must be used on heavy weight fabrics made with thick (high tex) fibres to avoid excessive crimping.

Leno



Leno weave improves the stability in ‘open’ fabrics, which have a low fibre count. It is a form of plain weave in which adjacent warp fibres are twisted around consecutive weft fibres to form a spiral pair, effectively ‘locking’ each weft in place. Fabrics in leno weave are normally used in con-junction with other weave styles because if used alone their openness could not produce an effective composite component.

Mock Leno



A version of plain weave in which occasional warp fibres, at regular intervals but usually several fibres apart, deviate from the alternate under-over interlacing and instead interlace every two or more fibres. This happens with similar frequency in the weft direction, and the overall effect is fabric with increased thickness, rougher surface, and additional porosity.

4.3 GFRP Specimen preparation procedures

- Initially, the ceramic plates are cleaned with benzene by careful application using a piece of cloth.
- Next, the plates are given a light coating of the mould-releasing agent while more amount of the agent is applied on the edges of the tiles.
- Now a 10:1 ratio of epoxy resin and hardener by weight is mixed thoroughly in a beaker with a glass rod.
- Using a brush, the epoxy-hardener mixture is gently applied on the surface of the tile. Care is taken to ensure that the layer is even and uniform.
- Now, a square piece of the chopped strand type glass fibre with the same dimensions of the tile is taken and placed on the tile.
- Next, the remaining polymer mixture is applied using a brush on the surface of the mat. It is important that the epoxy is forced against the surface of the mat to ensure that the mixture sticks and penetrates through the pores of the mat for best results.
- Now, a piece of the woven type glass fibre of the same dimension is taken and placed on the mat type and the same procedure is repeated on this layer too.

- This process is repeated until a thickness of about 4 mm is achieved, which is reasonable for drilling.
- Now the upper plate is placed on the layers and a weight is placed on this plate. The entire setup is then placed in the sun to cure for about 3 hours.
- The tiles are then carefully removed and the prepared specimen of GFRP formed is taken and marked using a marker to get as many pieces as possible so as to have adequate dimensions for drilling by cutting along the marked lines using an electric saw.
- Each of the small specimens is numbered and weighed.

4.4 Drilling Test

The procedure followed for testing the GFRP specimens prepared is as follows:

- The prepared specimens were cut down to size which could be enough to fit in a vice of the drilling machine using a electric saw.
- Then a given HSS tool is ground on a bench grinder to an angle of 55°.
- Then using a permanent marker various positions from the drill hole is marked.
- Drill diameter of 1.0 mm.
- The holes are drilled at different speeds.
- The speed is varied by changing the belt positions on the stepped cone pulley.

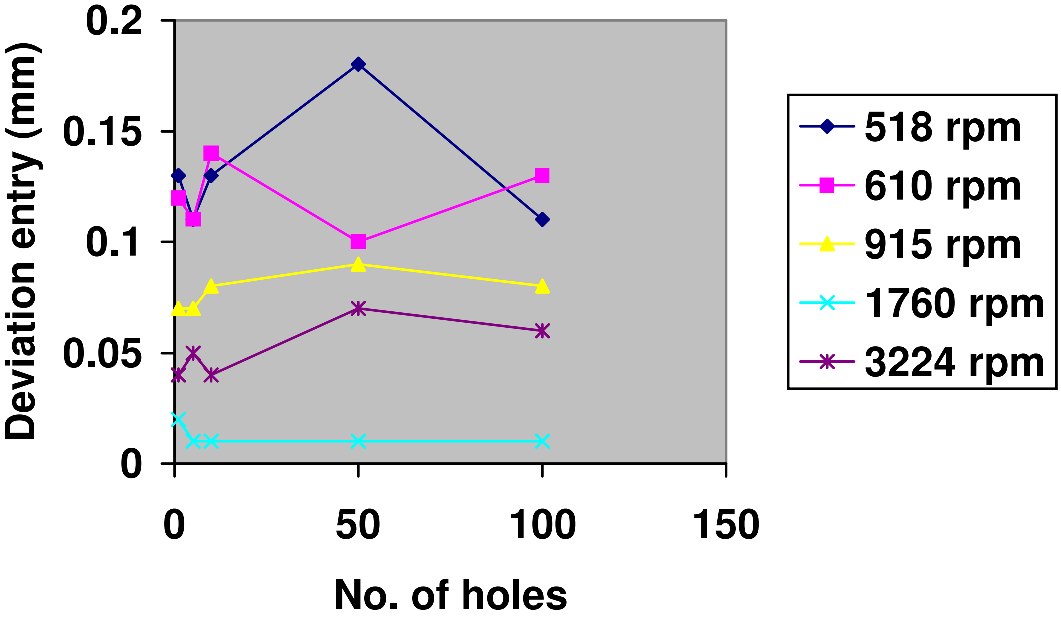
Chapter 5: Results & Discussion

After the completion of the experiments, measurements are made at the entry and exit of the drilled holes to ascertain the influence of speed on the hole diameters. The experimental data is pooled in the form of table as shown below:

Table I Influence of speed on deviation of entry and exit (518 rpm)					
		Entry		**Exit**	
No. hole	Desired dia.,mm	Actual dia., mm	Deviation mm	Actual dia., mm	Deviation mm
1	1	1.13	0.13	1.11	0.11
5	1	1.11	0.11	1.18	0.18
10	1	1.13	0.13	1.12	0.12
50	1	1.18	0.18	1.16	0.16
100	1	1.11	0.11	1.11	0.11
Table II Influence of speed on deviation of entry and exit (610 rpm)					
1	1	1.12	0.12	1.10	0.10
5	1	1.11	0.11	1.15	0.15
10	1	1.14	0.14	1.13	0.13
50	1	1.10	0.10	1.14	0.14
100	1	1.13	0.13	1.10	0.10
Table III Influence of speed on deviation of entry and exit (915 rpm)					
1	1	1.07	0.07	1.05	0.05
5	1	1.07	0.07	1.05	0.05
10	1	1.08	0.08	1.06	0.06
50	1	1.09	0.09	1.07	0.07
100	1	1.08	0.08	1.08	0.08
Table IV Influence of speed on deviation of entry and exit (1760 rpm)					
1	1	1.02	0.02	1.01	0.01
5	1	1.01	0.01	1.01	0.01
10	1	1.01	0.01	1.01	0.01
50	1	1.01	0.01	1.01	0.01
100	1	1.01	0.01	1.01	0.01
Table IV Influence of speed on deviation of entry and exit (3224 rpm)					
1	1	1.04	0.04	1.06	0.06
5	1	1.05	0.05	1.05	0.05
10	1	1.04	0.04	1.06	0.06
50	1	1.07	0.07	1.07	0.07
100	1	1.05	0.05	1.06	0.06

Table 1

The deviations in the entrance and exit dia. from the actual values are plotted as shown in the figure 5.1.



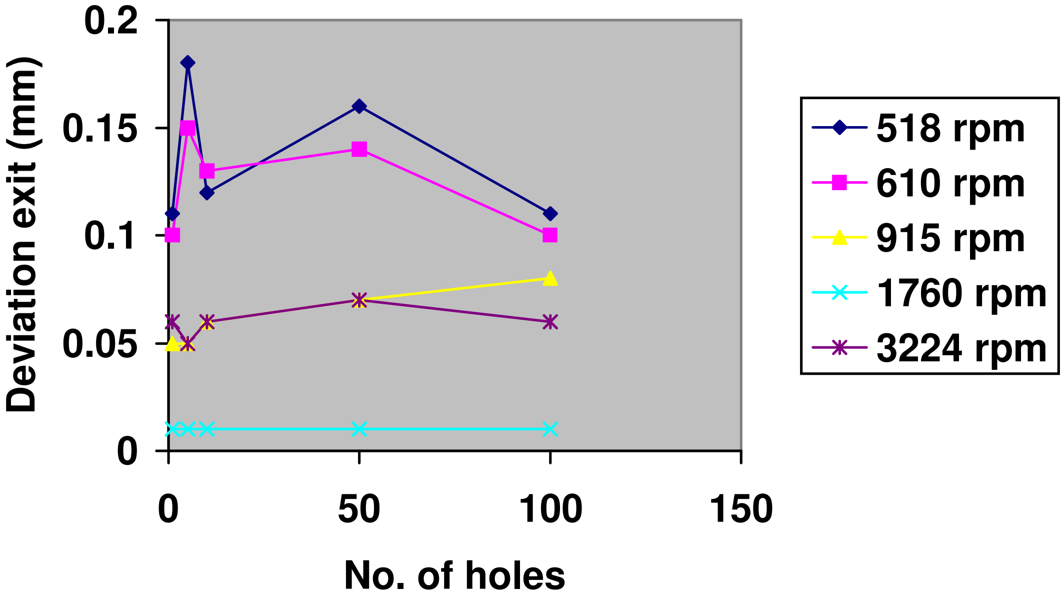


Figure 5.1 ***Results of examining deviation in hole dia. plotted against no. of holes***

Characteristics of machine drilling

In general, it is necessary to take into account the *fibre angle*[1] 0-180^0, the relative angle between the cutting direction and the fibre direction. Therefore, in the case of the plain woven cloth, the *edge position angles*[2] and the fibre angles (0/0 + 90^0). Hence, in the case of disregarding the direction of warp yarn and weft yarn, it is sufficient to assess the damage along the quarter circumference of the drilled hole, i.e. the edge position angles at 0-90^0 include the fibre angles at 0-180^0.

Table 1 shows the relation between the speed of drill bit and the hole surface roundness measured along the feed direction at the first drilling. Figure 5.2(a) shows the SEM photograph of the drilled hole at the cross section. .

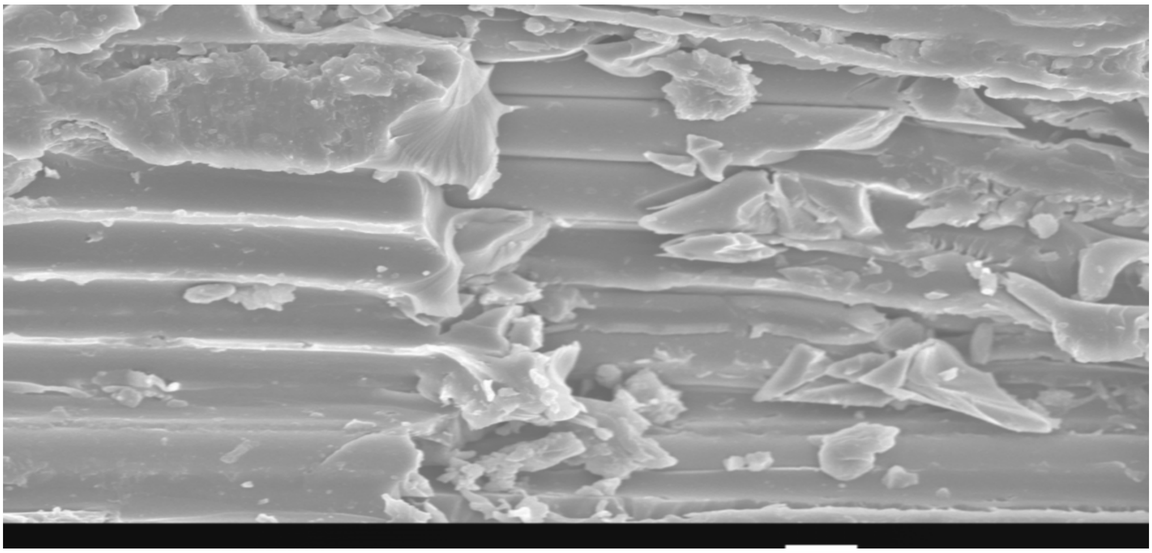


Figure 5.2(a) ***SEM photograph of the drilled hole at the cross section***

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[1] See appendix

[2] see appendix

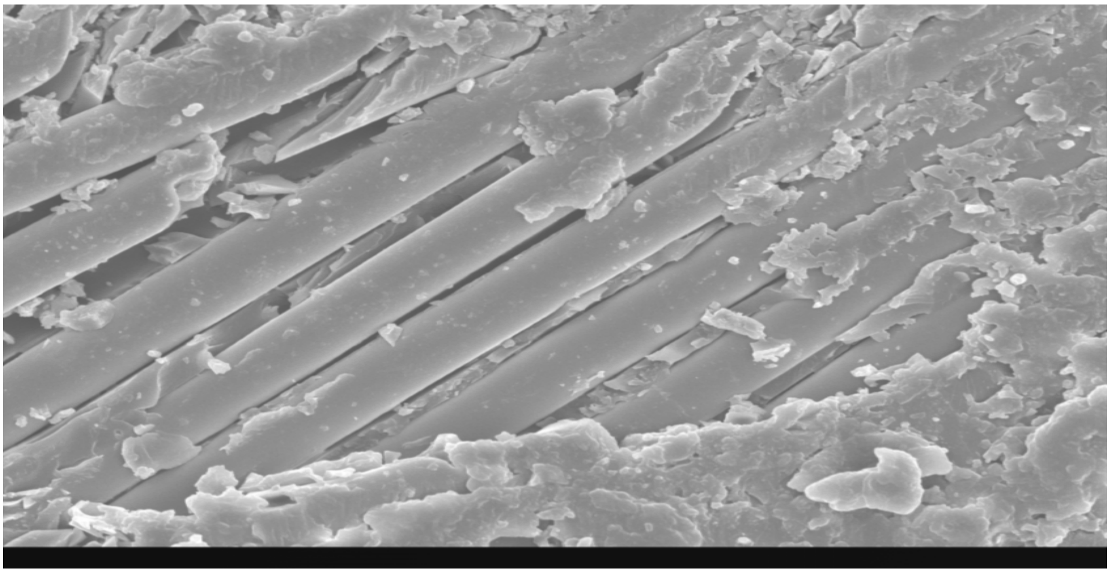

Figure 5.2(b) ***SEM photograph of the drilled hole cross section at edge position angle 60^0.***

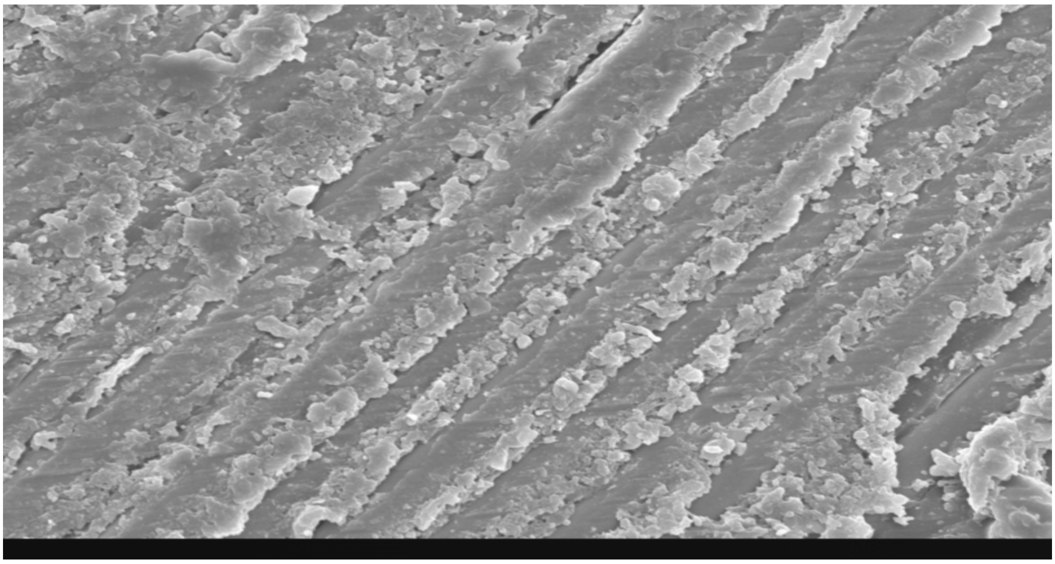

Figure 5.2(c) ***SEM photograph of the drilled hole cross section at edge position angle 0^0***

Figure 5.1(b) and Fig. 5.1(c) are high magnification photographs of the edge position angles. From Fig. 5.1(a), the surface roughness value becomes maximum at the edge position angle 30^0, compared with the other angles. At this angle, the fibre buckling is observed in Fig. 5.2(a). From Fig. 5.2(b), though there are two fibre angles (60/150^0) at the edge position angle, the buckling takes place at the fibre angle 150^0, and not at the fibre angle 60^0. So, the difference between them gives an increase of surface roughness along the feed direction in the case of a plain-woven cloth. On the other hand, buckling does not occur for either a fibre angle of 90^0 or 180^0, as shown in Fig. 5.2(c), and the surface roughness becomes small at the edge position angle 0^0. As is stated above, it is found that the surface roughness on the drilled hole is dependent on the edge position angles.

The damage of hole

Table 1 shows the relation between the number of drilled holes and the dimension of hole. Table1 indicates a decrease in the variation of hole diameter as the number of drilled holes increases. That is to say, as the number of drilled holes increases, the anisotropy damage reduces on the drilled hole surface. That is the reason the fibre buckling at fibre angle 150^0 decreases at the edge position angle 30^0 as the tool wear increases. From these results, it is found that the quality of the drilled hole surface is improved by developing the tool tip profile.

In terms of the drilled hole quality, it is essential to estimate the internal damage as well as the surface roughness. However, generally, it is complicated to deal with it because X-ray equipment, radiographic techniques and ultrasonic microscopes are required in order to detect delaminations in composite laminates. So, in this project, a simplified way is proposed that they should be determined by observing the shadows around the drilled hole due to transmitted light through one ply. This shadow is analyzed with image processing. The results of examining the maximum internal damage width are plotted against the number of drilled holes in figure 5.4. In other words, as the number of drilled holes increases, the maximum width of internal damages increases. It is considered that this phenomenon is caused by the remaining fibre on the surface of the drilled hole as the drill wear increases.

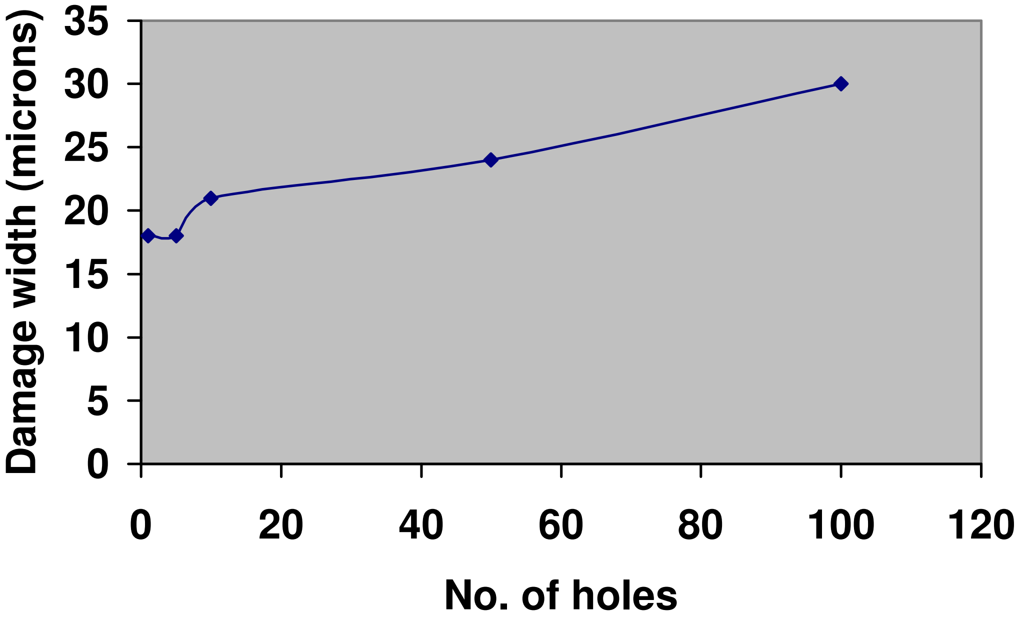

Figure 5.3 Maximum internal damage vs. no. of holes

Edge quality

Influences of speed on edge quality are shown in the figure 5.4. It shows the delamination and splintering at the hole exit are more serious with an increase in the

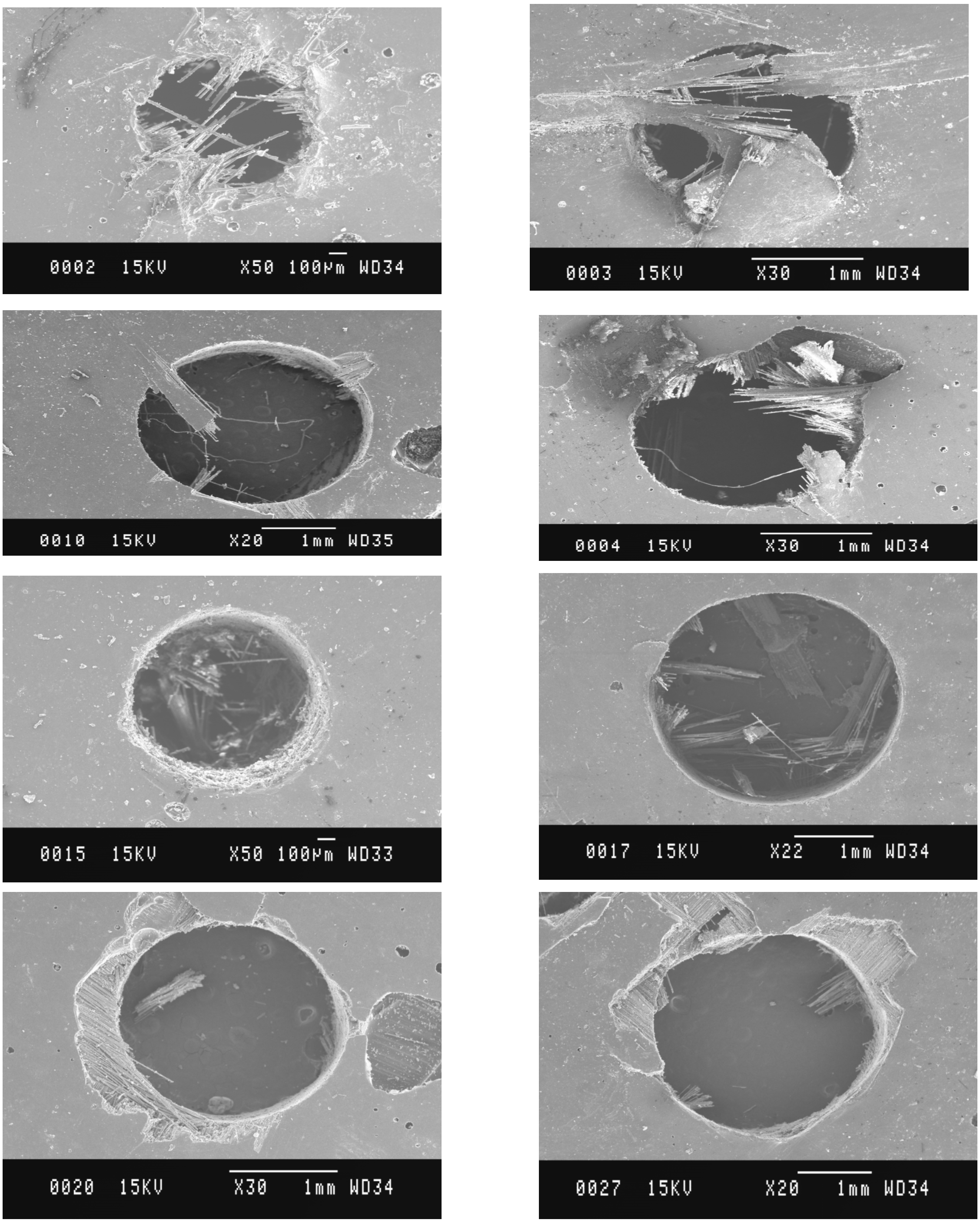

Figure 5.4 ***Influence of various speeds on edge quality (a) 518 (b) 915 (c) 1760 (d) 3224 respectively.***

static load. When machining is progressing toward the hole exit, the uncut thickness of work piece becomes insufficient to resist the push-out of material. Figure show that the best edge quality, when 1760 rpm is adopted. The speed of 1760 rpm is showing the highest edge fished. The edge quality at the hole entrance is good as shown in figure. They are free of fuzz or fiber pullout and are unaffected by machining conditions.

Tool wear

One of the major drilling variables affecting tool wear is surface speed. Surface speed is a measure of how much distance is covered by the drill' s diameter per given time while it is rotated by the spindle, and is expressed in surface mm per minute (mpm). It is used to calculate spindle speed (rpm) for a given drill diameter. The formula to calculate spindle speed using the desired surface speed is given

Rpm= (mpm x 12)/(pi x dia).
Where, dia = drill diameter in mm and pi = 3.1415.

The higher the surface speed, the higher the spindle speed and subsequently, the greater is the friction and heat that is generated during drilling. This translates into greater extents of drill wear and heat-related hole defects (i.e.: smear and plowing). An excellent example of tool wear versus surface speed is shown in the four micrographs (figure 5.5 and 5.6).

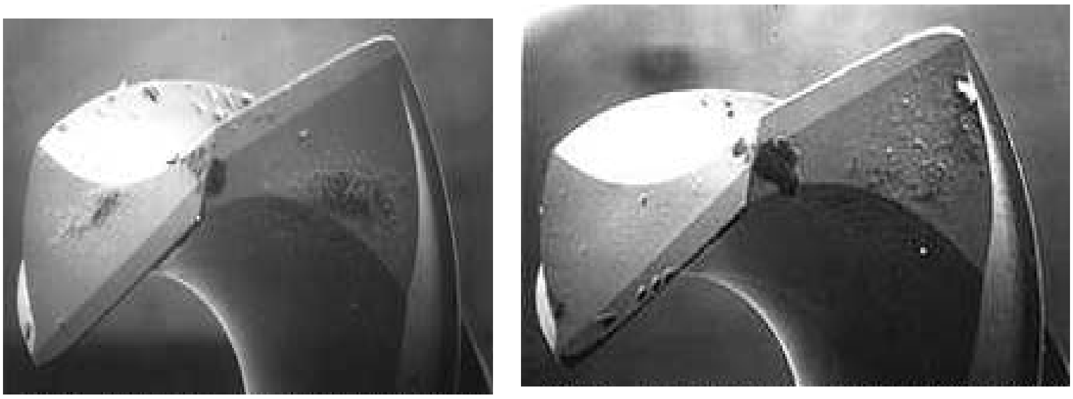

Figure 5.5 ***Influence of various speed on drill wear (a) 1760 (b) 915 rpm respectively***

Figure 5.6 ***Influence of various speeds on tool wear (a) 510 (b) 3224 rpm respectively.***

These drill bits were used on a laminate material that included a special resin additive intended to produce a lower cost. The finished construction turned out to be extremely abrasive. During one phase of the parameter optimization for drilling this product all variables were maintained equal with the exception of surface speed. Note the dramatic decrease in tool wear with a decrease in surface speed.

Chapter 6: Conclusions & Scope of future work

Fiber reinforced polymer matrix composite have been known for their high strength, low density and high toughness. FRPs tailored property by changing the fiber reinforcing manner and designing a proper matrix microstructure. FRPs are increasingly being used in engineering application because of their desirable mechanical properties and their versatility.

Specifically, the project involved investigation of the effects of machining parameters, and material properties on the chip formation, surface roughness produced in drilling of the GFRP material.

The specimens of GFRP were found to be very hard and have a good surface finish. While 'test' drilling, the material seemed to tear off in layers uniformly giving a reasonable finish.

The study shows that, even though the material behaves brittle (generating dust-like chips), surface roughness in drilling of the GFRP material is influenced by the same parameters and in similar fashion as in conventional metal machining.

Machined surfaces showed a random texture as opposed to distinct feedmarks. This explains why moulds machined out of this material require less polishing. However, the viscoelastic nature of the material plays a very important role in determining the material response to machining.

The hole surface roughness along the feed direction is due to the difference of fiber angles in the plain woven cloth. Specifically, it attains the maximum value at the edge position angle 30^0.

This anisotropy of the hole surface roughness decreases as the number of drilled hole increases. So it is possible to improve the quality of the drilled hole surface by developing the tool tip profile.

In the speed of 1760 rpm, we get the best quality of holes and also increased the life of the tool. At low speeds of around 500 rpm the deviation was quite large around the entry and exit points. At high speeds of around 3000 rpm the entry and exit points were still deviating from desired values.

Optimum speed was found to be close to 1800 rpm where entry and exit points were of least deviation. Hence, we conclude that the ***optimum speed range*** for the drilling of Polyester Glass Fiber is ***1600 ~ 1800 rpm***.

Scope of future work

The present study dealt with investigation of quality of the drilled holes using only one tool material and one machining parameter which was varied i.e. rpm. The present work can be extended to investigate the effect of using different tool materials on the quality of drilled hole in different types of FRP's and varying different machining parameters at the same time.A FEM model can also be developed to evaluate the machining characteristics of drilling GFRP's .

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Appendix

To define the position of the drilled hole wall to the glass cloth which is a reinforcement material, the angle in rotation direction of a drill positive is defined as the edge position angle ã(0-90 deg.), as shown in Figure . Also, the angle between the cutting direction of the edge of a drill and the single fiber is important in case of cutting of FRP. Therefore, the angle between moving direction of the cutting edge of a drill and the single fiber is defined as the fiber angles (ã/ ã+90 deg.) to the direction of the weft and the warp yarn, respectively.