1.1 COMPOSITES A BRIEF HISTORY

Our technologically advancing society is continually challenging the limits of conventional materials and placing newer demands on materials performance. Extreme and sometimes conflicting requirements are forcing us to engineer materials not possible by conventional alloying methods. Composite materials form a material system composed of a mixture or combination of two or more macro constituents that differ in form and chemical composition and are insoluble in each other. Composite material comes under one class of engineered material developed specifically to meet such a challenge. Glass fibre reinforced resin matrix composites were first introduced in the early 1940s. Since then, the use of composites is growing steadily in various industries including aircraft, automobile, sporting goods, marine, offshore drilling platforms etc.

Some of the advantages of composites include high specific strength, high specific stiffness or modulus, good dimensional stability. Unusual combination of properties not easily obtainable with alloys, higher fracture toughness, higher oxidation and corrosion resistance, directional properties, good resistance to heat, cold and moisture, ease of fabrication and low cost. Modern composite materials, depending on the matrix materials used, can be classified as PMC, CMC and MMC.
1.1.1. Polymer Matrix Composites (PMC)
The common types of fibers used to reinforce plastic materials are glass, graphite, aramid and boron. Glass fibre reinforced plastics (GFRP) are most commonly used materials in view of their relatively high specific strength and low cost. The other materials provide higher specific strength, higher specific stiffness and light weight. They are, however, expensive and are used only for those applications where performance and not cost is the major consideration. Aramid is used instead of graphite where strength, lightness and flexibility are major considerations and less importance on stiffness and high temperature performance. The common matrix materials used are polyesters and epoxy resins. Polyester resins are lower in cost and are not as strong as the epoxy. Their use in composite includes boat hulls, structural panels, appliances, etc. Epoxy, in addition has a lower shrinkage after cure. It is used commonly in carbon and aramid fibre composites. Maximum usable temperatures of polymeric matrix composites are relatively low, as the matrix material is prone to softening or chemical decomposition (degradation) at moderate temperatures. The same conditions apply for machining these materials [1,2].

1.1.2. Ceramic Matrix Composites (CMC)
Ceramic matrix composites are being developed mainly to improve fracture toughness, in addition to their higher specific modulus and elevated temperature mechanical properties that are superior to metals. Continuous fibres, discontinuous fibres or particulate can be used as reinforcing material. The common fibre materials used are Alumina and Silicon carbide. Other CMCs include Carbon/Carbon composite in which high strength carbon fibres are embedded in a graphite matrix. The low density of Carbon in combination
with the extra ordinary strength of Carbon fibres offers potential for the
development of high specific strength material.

1.1.3 Metal Matrix Composites (MMC)
Metal matrix composites are used for applications requiring higher operating
temperature than that are possible with polymer matrix composites. Most of
these alloys are developed especially for the use in aerospace industry, but
new applications are found in the auto industry such as in automobile engine
parts, brake drums, brake shoes etc. Continuous fibres provide the highest
stiffness and strength for metal matrix composites.

The discontinuous and particulate MMCs are of low cost that, provide
higher strength, stiffness and better dimensional stability over metal alloys.
They provide increased wear resistance and contribute towards the difficulty
in machining these materials. These alloys are used for sporting equipment,
automobile engine parts, missile-guidance parts etc. even though they are
costlier today.

1.1.4 Classification of Composites based on fibre reinforcement.
Fibres are the most important class of reinforcements, as they satisfy the
desired conditions and transfer strength to the matrix constituent, influencing
and enhancing their properties as desired. The performance of the fiber
composites judged by its length, shape, orientation, composition of the fibers
and the mechanical properties of the matrix. The composites with continuous
and discontinuous fiber orientation are illustrated in Fig 1.1 and 1.2
respectively. Mono layer tapes consisting of continuous or discontinuous
fibers can be oriented unidirectionally, stacked into plies containing layers of
filaments also oriented in the same direction. Orientation of short fibers by different methods is also possible like random orientations by sprinkling on to a given plane or addition of matrix in liquid or solid state before or after the fiber deposition. Even three-dimensional orientations can be achieved in this way. Based on the fibre shape and position the composites can be classified as follows.

- **Laminar Composites**

Laminar composites can be described as materials comprising of layers of materials bonded together. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose. Sandwich and honey comb components as well as the term high pressure laminates are included. Wooden laminates, plywood and some combinations of metal foils, glasses, plastics, films and paper are laminar composite. Some ceramic and metallic composites also fall into this classification [1]

- **Flake composite**

Flakes are often used in place of fibers as they can be densely packed. Flakes are not expensive to produce and usually cost less than fibers, however they fall short of expectations in aspects like control of size, shape and show defects in the end product. Glass flakes tend to have notches or cracks around the edges, which weaken the final product. Flakes have various advantages over fibers in structural applications. Parallel flakes filled composites provide uniform mechanical properties in the same plane as the flakes. While angle plying is difficult in continuous fibres composites which
need to approach isotropic properties, it is not so in flakes. Flakes composites have higher theoretical modulus of elasticity than fiber reinforced composites.

- **Filled composites**

Filled composites results from addition of filler materials to plastic matrices to replace a portion of the matrix, enhance or change the properties of the composites. The fillers also enhance strength and reduce weight. Fillers may be the main ingredient or an additional one in a composite. The filler particles may be irregular structures or have precise geometrical shapes like polyhedrons, short fibers or spheres. Filled plastics tend to behave like two different constituents. They do not alloy and accept the bonding. The benefits offered by fillers include increased stiffness, thermal resistance, stability, strength and abrasion resistance, porosity and favourable coefficient of thermal expansion.

- **Particulate composite**

Particulate composites consist of particles dispersed in a matrix. These particles are sometimes divided into two subclasses such as skeletal and flakes. Skeletal consist of a continuous skeletal structure filled with one or more additional materials and flake consist generally of flat flakes oriented parallel to each other. Particles may have any shape, configuration or size. These particulates may be powdered, beads, rods, crystalline, amorphic or whiskered. They may be metallic, ceramic, manmade or natural materials. Concrete and wood particle board are two familiar examples of particulate composites. Metallic flakes have been added to improve electrical properties and provide some degree of radiation shielding in polymer composites. Pieces
of ceramic particles are placed in metallic matrix and used as tough, abrasion resistant cutting tools.

Figure 1.1 Composite with Continuous Reinforcements

Figure 1.2 Composites with Non continuous reinforcement

1.2 PRINCIPLES FOR USING GFRP COMPOSITES.
There are four major principles that should be recognized in using glass fibers as composite reinforcement. Mechanical properties depend on the combined effect of the amount of glass fiber reinforcement used and its arrangement in the finished composite. Chemical, electrical and thermal performance is
influenced by the resin system used as the matrix. Material selection, plus
design and production requirements, determines the proper fabrication
process to be used. The cost performance value achieved in the finished
composite is dependent upon good design and judicious selection of raw
materials and process [1,2].

1.2.1 Amount and arrangement of Glass
Strength of the finished object is directly related to the amount of glass in the
finished object. Generally speaking, strength increases directly in relation to
the amount of glass used. A component containing 80% glass and 20% resin
by weight is almost four times stronger than a part containing opposite
amounts of these two materials. Equally important, is the arrangement of
glass fibre in the finished object. When all the strands are laid parallel to each
other, maximum strength and modulus are obtained in the filament direction.
Such a parallel arrangement is used in the design of rocket motor cases, golf
and fishing rods. When half the strands are laid at right angles to the other
half, strength is highest in those two directions, although strength is less than
with parallel arrangement, it is still considerable. Bi-directional laminates find
application in boats, airplane wing tips and swimming pools. When glass
fibers are arranged in a random manner, strength is no longer concentrated in
one or two directions. Safety helmets, chairs, electrical parts, luggage and
machine housings utilize this strength. This random arrangement results in
equal but lower strength, in all directions. This condition is called isotropic.
1.2.2 Resin Mix
The major resins used in glass fibre reinforced plastics vary in resistance to corrosion and heat. Formulations of the resin mix also influences corrosion and heat resistance but has a less pronounced effect. By varying ingredients such as filler, pigment and catalyst system, each resin mix can be made to vary in performance. Resin also helps to prevent abrasion of the glass fibres by maintaining the position of the fibres and keeping them separated. Polyester resins are used in approximately 85% of all glass fibre reinforced plastics because they are economical. Other resins in use are epoxies, phenolics, silicones, melamine’s, acrylics and polyesters modified with acrylics. Some thermoplastic resins such as nylon, polystyrene, polycarbonate and fluorocarbons are reinforced with fibreglass.

1.2.3 Processes
Processes vary in ability to utilise different arrangements of glass, different amounts of glass and different resins. A given combination of raw materials required to meet performance criteria in a given application narrows the choice of processes to those, which can successfully and economically form the raw material into a completed part. Production flexibility of a process is often the single most important economic factor. If a large number of parts are to be made from one mould for example, the lowest total cost is achieved by using presses and moulds and automating materials handling. Conversely, if only a few parts are required, a process minimising investment in moulds and other equipment and would be the logical choice. Continuous forming, being used for bench slats. FRP panelling etc., can greatly improve the economics of large volume items.
1.2.4 Economy
Economical cost and performance result from good design based on judicious selection of both raw materials and process. Proper materials must be combined in a process or processes so that potential performance is realised at an economical cost of manufacturing. Design of the part must take advantage of the material’s maximum capabilities [1,2]. Wide application of UGFRP & BGFRP in engineering field and the less cost motivated to select these material for the present investigation.

1.3 FABRICATION PROCESSES OF GFRP COMPOSITES
Many processes are available to produce the desired combination of design performance and economics of glass fibre composites. Each process has its own usefulness for combining different kinds and amounts of glass and resin. The basic processes can be considered broadly in two classes: open mould and closed mould processes. The open mould processes include hand lay-up, spray-up, vacuum pressure bag, autoclave, filament winding, centrifugal casting and continuous pultrusion. Closed mould processes includes matched die moulding, injection moulding and continuous laminating [2]. The predominant fabricating processes used in the present work are briefly explained as follows.

1.3.1 Hand lay-up Process
Hand lay-up process is the oldest and simplest glass fibre reinforced plastic forming process. In fabrication the glass fibres and resin are placed in or on the mould and entrapped air is removed with squeezing rollers. Layers of glass and resin are added to build up to design thickness. If a high quality
surface is desired, a gel coat is applied on the mould prior to lay-up. The line diagram of a simple hand-lay up process is shown fig 1.3. The lay-up normally cures at room temperature but heat may be used to accelerate cure. The exposed surface is generally rough but it can be made smoother by wiping on cellophane or other suitable releasing films such as Mylar or polyvinyl alcohol. Resins used in hand lay-up are usually polyesters or epoxies.

1.3.2 Filament Winding Process

Filament winding uses continuous reinforcement to achieve efficient utilization of glass fiber strength. Roving or single strands are fed from a creel through a bath or resin and wound on a suitable designed mandrel. Pre-impregnated roving may also be used. Special winding machines lay down glass in a predetermined pattern to give maximum strength in the direction required. When the desired number or layers have been applied, the wound mandrel is cured at room temperature or in an oven. The different methods of filament winding are illustrated in fig 1.4
1.4 SIGNIFICANCE OF FRP MACHINING

1.4.1 Non Traditional Machining

In recent years the fibre reinforced composite materials are increasingly used in various fields of science and engineering application because of their unique properties. As a result there is a strong need to understand better the issues associated with the manufacturing of composite components. The existing manufacturing technique fabricating to near-net shape is incomplete.
unless the component is subjected to secondary machining operations like trimming, finish grinding, drilling holes/cavities etc. based on the requirement. Non-traditional machining (NTM) techniques were used in many of the applications as a secondary machining operation. However NTM processes also possess some limitations. As the equipment costs are very high, the process is considered to be highly expensive for small-scale production. Also they are material oriented. Any NTM process cannot be used to work on any FRP material. Aramid is the suitable material for laser machining, because of closeness in properties of fibre and resin. To use Electric discharge machining process the material should be electrically conductive. Abrasive water jet machining produces higher noise levels. In laser machining the problem like delamination, uneven kerf and thermal cracks are observed. These processes are incapable of producing blind holes/cavities. The terminology of the quality of laser cut surface is illustrated in fig 1.5. As these processes are highly expensive, they are suitable in industries where manufacturing cost is of secondary importance [3].

![Figure 1.5 Terminology for quality of laser cut surface of FRP [3]](image-url)
1.4.2 Conventional Machining
As an alternative conventional machining on FRP composite material play a vital role in meeting dimensional accuracy and good surface quality requirement. The process is cheaper compare to NTM techniques. However due to the properties of FRP materials like anisotropy, nonhomogenety and abrasiveness provides some problems like excessive tool wear, poor surface finish, delamination, fibre pullout, dimensional variation, etc. These limitations motivated for the present research, a study on the problems of conventional machining on FRP materials.

1.5 OVERVIEW OF CHAPTERS
The thesis prepared based on the above work contains nine chapters. Chapter 1 gives a brief introduction of FRP composites, fabricating techniques dynamics of machining and significance of FRP machining. The second chapter highlights the literature review, observations and scope of present work. The chapter 3 discusses the drilling performance on GFRP using HSS drill tool. The significance of delamination and tool wear was highlighted with the help of FEA model and wear profiles in chapter 4. The chapter 5 covers the experimental study on the mechanically fastened joints. Chapter 6 highlights the filament-winding fabricating technique, further it covers the study on turning operation performed on BGFRP pipe specimens. Chapter 7 covers the experimental study and FE analysis of turning operation on UGFRP pipe specimens. Chapter 8 covers the summery of all the results of the present investigation. In chapter 9 conclusions and scope for future work have been highlighted.