Tensile Testing on Composite Materials (CFRP) with Adhesive

Syed Mobin Baba, Shaik Azgerpasha

Abstract: The world is changing day to day in many aspects, especially usage of material, earlier iron and steel are abundant in usage for construction of bridges, dams, building etc., but as the composite technology comes in to pictures there was a red signal for mostly used materials. Composite means combination of separate interconnected parts, it might be metallic or non-metallic, combined to form a metal and that will give the same strength of other high end materials. Another important aspect is combining, how a metal and non-metal will be combined irrespective of its bonding nature, even if a metal does bond how come a non-metal will be bonded to a metallic at high stress. This technology we call it as Joint Technology. In current project, we discuss about the composite materials and how they are useful for the building of the structures using the metal and non- metal variants and its strengths. And we will be knowing about the adhesive technology and its purpose and objectives. And mainly about the joining techniques we used here for the combing the materials which are of two kinds and test results of CFRP material combined with metal with adhesives and then loaded for tensile testing. The results were noted then the same material is riveted after applying adhesive and does the tensile load.

Keywords: Composite Means Combination of Separate Interconnected Parts,

I. INTRODUCTION

1.1. Introduction to Composite Materials

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

1.2. Natural Composites

Natural composites exist in both animals and plants. Wood is a composite – it is made from long cellulose fibres (a polymer) held together by a much weaker substance called lignin. Cellulose is also found in cotton, but without the lignin to bind it together it is much weaker. The two weak substances – lignin and cellulose – together form a much stronger one. The bone in your body is also a composite. It is made from a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen (which is a protein). Collagen is also found in hair and finger nails. On its own it would not be much use in the skeleton but it can combine with hydroxyapatite to give bone the properties that are needed to support the body.

1.3 Early Composites

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks. Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel), cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete.

1.4 Making Composites

Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

II. INTRODUCTION TO CFRP (CARBON FIBRE REINFORCED POLYMER)

CFRPs can be expensive to produce but are commonly used wherever high strength-to-weight ratio and rigidity are required, such as aerospace, automotive, civil engineering, sports goods and an increasing number of other consumer and technical applications

2.1. properties

CFRP’s are composite materials. In this case the composite consists of two parts a matrix and a reinforcement. In CFRP the reinforcement is carbon fibre, which provides the strength. The matrix is usually a polymer resin, such as epoxy, to bind the reinforcements together. Because CFRP consists of two distinct elements, the material properties depend on these two elements. The reinforcement will give the CFRP its strength and rigidity measured by stress and elasticmodulus respectively.Unlike isotropic materials like steel and aluminium, CFRP has directional strength properties. The properties of CFRP depend on the layouts of the carbon fibre and the proportion of the carbon fibres relative to the polymer.

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The two different equations governing the net elastic modulus of composite materials using the properties of the carbon fibres and the polymer matrix can also be applied to carbon fibre reinforced plastics.

The fracture toughness of carbon fibre reinforced plastics is governed by the following mechanisms:

1) De-bonding between the carbon fibre and polymer matrix,
2) Fibre pull-out, and
3) Delamination between the CFRP sheets.

Typical epoxy-based CFRPs exhibit virtually no plasticity, with less than 0.5% strain to failure. Although CFRPs with epoxy have high strength and elastic modulus, the brittle fracture mechanics present unique challenges to engineers in failure detection since failure occurs catastrophically. As such, recent efforts to toughen CFRPs include modifying the existing epoxy material and finding alternative polymer matrix. One such material with high promise is PEEK, which exhibits an order of magnitude greater toughness with similar elastic modulus and tensile strength. However, PEEK is much more difficult to process and more expensive.

Despite its high initial strength-to-weight ratio, a design limitation of CFRP is its lack of a definable fatigue endurance limit. This means, theoretically, that stress cycle failure cannot be ruled out. While steel and many other structural metals and alloys do have estimable fatigue endurance limits, the complex failure modes of composites mean that the fatigue failure properties of CFRP are difficult to predict and design. Thus, when using CFRP for critical cyclic-loading applications, engineers may need to design in considerable strength safety margins to provide suitable component reliability over its service life.Environmental effects such as temperature and humidity can have profound effects on the polymer-based composites, including most CFRPs. While CFRPs demonstrate excellent corrosion resistance, the effect of moisture at wide ranges of temperatures can lead to degradation of the mechanical properties of CFRPs, particularly at the matrix-fibre interface. While the carbon fibres themselves are not affected by the moisture diffusing into the material, the moisture plasticizes the polymer matrix. The epoxy matrix used for engine fan blades are designed to be impervious against jet fuel, lubrication, and rain water, and external paint on the composites parts are applied to minimize damage from ultraviolet light. The carbon fibres can cause galvanic corrosion when CRP parts are attached to aluminium.

2.3 Manufacture

The primary element of CFRP is a carbon filament; this is produced from a precursor polymer such as polyacrylonitrile (PAN), rayon, or petroleum pitch. For synthetic polymers such as PAN or rayon, the precursor is first spun into filament yarns, using chemical and mechanical processes to initially align the polymer chains in a way to enhance the final physical properties of the completed carbon fibre. Precursor compositions and mechanical processes used during spinning filament yarns may vary among manufacturers. After drawing or spinning, the polymer filament yarns are then heated to drive off non-carbon atoms (carbonization), producing the final carbon fibre. The carbon fibres filament yarns may be further treated to improve handling qualities, then wound on to bobbins. From these fibres, a unidirectional sheet is created. These sheets are layered onto each other in a quasi-isotropic layup, e.g. 0°, +60° or −60° relative to each other. From the elementary fibre, a bidirectional woven sheet can be created, i.e. a twill with a 2/2 weave. The process by which most CFRPs are made varies, depending on the piece being created, the finish (outside gloss) required, and how many of this piece are going to be produced. In addition, the choice of matrix can have a profound effect on the properties of the finished composite.Many CFRP parts are created with a single layer of carbon fabric that is backed with fiberglass. A tool called a chopper gun is used to quickly create these composite parts. Once a thin shell is created out of carbon fibre, the chopper gun cuts rolls of fiberglass into short lengths and sprays resin at the same time, so that the fiberglass and resin are mixed on the spot. The resin is either external mix, wherein the hardener and resin are sprayed separately, or internal mixed, which requires cleaning after every use. Manufacturing methods may include the following:

2.3.1 Moulding

One method of producing CFRP parts is by layering sheets of carbon fibre cloth into a mould in the shape of the final product. The alignment and weave of the cloth fibres is chosen to optimize the strength and stiffness properties of the resulting material. The mould is then filled with epoxy and is heated or air-cured. The resulting part is very corrosion-resistant, stiff, and strong for its weight. Parts used in less critical areas are manufactured by draping cloth over a mould, with epoxy either pre-impregnated into the fibres or "painted" over it. High-performance parts using single moulds are often vacuum-bagged and/or autoclave-cured, because even small air bubbles in the material will reduce strength. An alternative to the autoclave method is to use internal pressure via inflatable air bladders or EPS foam inside the non-cured laid-up carbon fibre.

2.3.2 Vacuum Bagging

For simple pieces of which relatively few copies are needed (1–2 per day), a vacuum bag can be used. A fiberglass, carbon fibre or aluminium mould is polished and waxed, and has a release agent applied before the fabric and resin are applied, and the vacuum is pulled and set aside to allow the piece to cure (harden). There are three ways to apply the resin to the fabric in a vacuum mould.The first method is manual and called a wet layup, where the two-part resin is mixed and applied before being laid in the mould and placed in the bag. The other one is done by infusion, where the dry fabric and mould are placed inside the bag while the vacuum pulls the resin through a small tube into the bag, then through a tube with holes or something similar evenly spread the resin throughout the fabric. Wire loom works perfectly for a tube that requires holes inside the bag. Both these methods of applying resin require hand work to spread the resin evenly for a glossy finish with very small pin-holes. A third method of constructing composite materials is known as a dry layup. Here, the carbon fibre material is already impregnated with resin and is applied to the mould in a similar fashion to adhesive film.

The assembly is then placed in a vacuum to cure. The dry layup method has the least amount of resin waste and can achieve lighter constructions than wet layup. Also, because larger amounts of resin are more difficult to bleed out with wet layup methods, parts generally have fewer pinholes. Pinhole elimination with minimal resin amounts generally require the use of autoclave pressures to purge the residual gases out.

2.3.3 Compression Moulding

A quicker method uses a compression mould. This is a two-piece (male and female) mould usually made of aluminium or steel that is pressed together with the fabric and resin between the two. The benefit is the speed of the entire process. Some car manufacturers, such as BMW, claimed to be able to cycle a new part every 80 seconds. However, this technique has a very high initial cost since the moulds require CNC machining of very high precision.

2.3.4 Filament Winding

For difficult or convoluted shapes, a filament winder can be used to make CFRP parts by winding filaments around a mandrel or a core.

2.4 Applications

Every day, a new application is found for carbon fibre. What started out forty years ago as a highly exotic material is now a part of our everyday lives. These thin filaments, a tenth the thickness of a human hair, are now available in a wide range of useful forms. The fibres are bundled, woven and shaped into tubes and sheets (up to ½” thick) for construction purposes, supplied as cloth for moulding, or just regular thread for filament winding.

2.4.1 Carbon Fibre In Flight

Carbon fibre has gone to the moon on spacecraft, but it is also used widely in aircraft components and structures, where its superior strength to weight ratio far exceeds that of any metal. 30% of all carbon fibre is used in the aerospace industry. From helicopters to gliders, fighter jets to microlights, carbon fibre is playing its part, increasing range and simplifying maintenance.

2.4.2 Sporting Goods

Its application in sports goods ranges from the stiffening of running shoes to ice hockey stick, tennis racquets and golf clubs. ‘Shells’ (hulls for rowing) are built from it, and many lives have been saved on motor racing circuits by its strength and damage tolerance in body structures. It is used in crash helmets too, for rock climbers, horse riders and motor cyclists – in fact in any sport where there is a danger of head injury.

2.4.3 Military

The applications in the military are very wide ranging – from planes and missiles to protective helmets, providing strengthening and weight reduction across all military equipment. It takes energy to move weight – whether it is a soldier’s personal gear or a field hospital, and weight saved means more weight moved per gallon of gas. A new military application is announced almost every day. Perhaps the latest and most exotic military application is for small flapping wings on miniaturised flying drones, used for surveillance missions. Of course, we don’t know about all military applications – some carbon fibre uses will always remain part of ‘black ops’ - in more ways than one.

2.4.4 Carbon Fibre At Home

The uses of carbon fibre in the home are as broad as your imagination, whether it is style or practical application. For those who are style-conscious, it is often tagged as ‘the new black’. If you want a shiny black bathtub built from carbon fibre, or a coffee table then you can have just that, off the shelf. iPhone cases, pens and even bow ties – the look of carbon fibre is unique and sexy.

2.4.5 Medical Applications

Carbon fibre offers several advantages over other materials in the medical field, including the fact that it is ‘radiolucent’ – transparent to X-rays and shows as black on X-ray images. It is used widely in imaging equipment structures to support limbs being X-rayed or treated with radiation. The use of carbon fibre to strengthen of damaged cruciate ligaments in the knee is being researched, but probably the known medical use is that of prosthetics – artificial limbs. South African athlete Oscar Pistorius brought carbon fibre limbs to prominence when the International Association of Athletics Federations failed to ban him from competing in the Beijing Olympics. His controversial carbon fibre right leg was said to give him an unfair advantage, and there is still considerable debate about this.

2.4.6 Automobile Industry

As costs come down, carbon fibre is being more widely adopted in automobiles. Supercar bodies are built now, but its wider use is likely to be in internal components such as instrument housings and seat frames.

2.4.7 Enivironmental Applications

As a chemical purifier, carbon is a powerful absorbent. When it comes to absorption of noxious or unpleasant chemicals, then surface area is important. For a given weight of carbon, thin filaments have far more surface area than granules. Although we see activated carbon granules used as pet litter and for water purification, the potential for wider environmental use is clear.

2.4.8 Diy

Despite its hi-tech image, easy to use kits are available enabling carbon fibre to be employed in a wide range of home and hobby projects where not only its strength, but its visual appeal is a benefit. Whether in cloth, solid sheet, tube or thread, the space age material is now widely available for everyday projects.

III. INRODUCTION FOR THE PREPARATION OF CARBON FIBRE REINFORCED PLASTIC

Polymers are particularly attractive as matrix materials because they are easily process able and their density is comparatively low when compared to other materials. They exhibit excellent mechanical properties. High-temperature resins are used as composite materials are currently used in the manufacture of high-speed aircrafts, rockets and other related space and electronics.

The reinforcements share the major load especially when a composite consists of fibre reinforcements dispersed in a weak matrix (e.g., carbon/epoxy composite), the fibres carry almost all the load. The strength and stiffness of such composites are, therefore, controlled by the strength and stiffness of constituent fibre. Carbon and graphite are superior high-temperature materials with strength and stiffness properties maintainable at temperature up to 2500^0 K.

Carbon fibre composites have been used for various aeronautical, biomedical, defence, industrial and space applications. Originally, these materials were produced for applications where hardware was exposed to extreme temperatures requiring high performance standards, such as solid rocket motors. Today carbon composites are used in commercial as well as military applications. We investigated the influence fibre orientation & thickness of laminates of different sized glass fibres on the mechanical properties of glass fibre epoxy resin composites and have conducted extensive tensile, flexure and interlaminar tests on glass/polypropylene and glass/polyester composites. And studied the effect of the fibre length on the fatigue of a short carbon/epoxy composite. They showed that fatigue life is independent of fibre length at any peak strain. The addition of long glass fibres has increased the flexural modulus of low density polyurethane structural form. Low density polyurethane composites are a new technology that provides new opportunities for the composites industry.

The compressive experimental study to identify the effects of fibre cross sectional aspect ratio on tensile & flexural properties and failure modes of glass fibre/epoxy composites by using fibres of different cross sectional Shapes was carried out investigated the influence of fibre orientation and fibre content of an epoxy resin components on mechanical prosperities the main aim of the present investigation was to study the influence of fibre orientation on mechanical properties.

IV. EXPERIMENT

4.2.1 Material

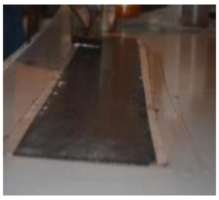


Fig.1 bi woven carbon fabric, epoxy & hardener

Fig.2 bi woven carbon lamina

Since bi woven fabrics provide greater damage tolerance and increased popularity in different applications. The present investigation carried on epoxy resin bi woven weft type carbon fibre (240 gsm) and the matrix materials are epoxy resin YD128 and hardener HY140 mixed in appropriate ratio with room temperature curing cycle of 48hours duration.

4.2.2 Instrumental

Fig.3 Computer Controlled UTM. Fig.4 Flexural Fixture Fig.5 Tensile Fixture

The composite laminates were subjected to various loads and computer controlled UTM. The specimens were clamped and tests were performed. The tests were closely monitored and conducted at room temperature. The load at which the complete fracture of the specimen occurred has been accepted as breakage load.

4.2.3 Sample Preparation

Fig.6.Sample Preparation

Composites laminated were fabricated at room temperature in shape of rectangle plates by hand layup technique proper care was taken during fabrication of laminates to ensure uniform thickness minimum voids in the material and maintain homogeneity. The laminates were fabricated by placing the Carbon fibre one over the other with a matrix in between the layers. Tools were used to distribute resin uniformly, Compact plies and to remove entrapped air.

The surfaces of the laminated were covered with 25 micron Mila film to prevent the layup form external disturbances. Laminates were cured in room temperature and constant pressure for two days. The laminated test specimens were prepared by a wire cutting machine to suit ASTM dimension and edges were grinded.

4.2.4 Test Configuration

Fig.7Test Specimen

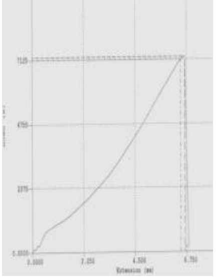
All composites work processed such that fibre fraction greater than the epoxy resin. For purpose of investigation three different specimens are prepared according the angular orientation of the fibres. Three test specimens are prepared for each type of angle oriented specimens.

Specimens selected for the experimentation being ±300, ±450, ±900. The tensile & flexural properties of the carbon fibre reinforced polymer composites were determined according ASTM test standard specifications. The average tensile and flexural properties determined from specimen test on each type of orientation.

Fig.8 Fractured Tensile Specimens

Fig.9 Fractured Flexural Specimen

4.3 Graphs For Tensile And Fluxural Test



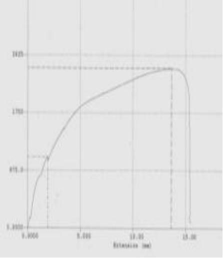
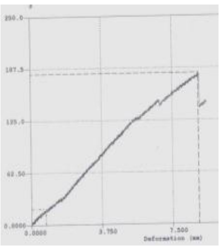


Fig.10 Load Vs Displacement Fig.11 Load Vs Displacement

Tensile Specimen (90^0) Tensile Specimen sample (30^0)



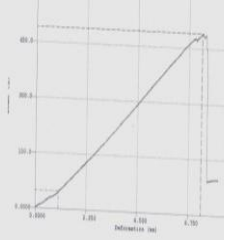
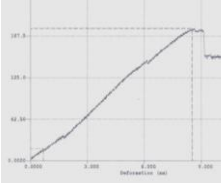


Fig.12 Load Vs Displacement Fig.13 Load Vs Displacement Tensile Specimen sample (45^0) Flexural Specimen Same (90^0)



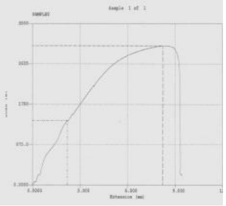


Fig.14 Load Vs Displacement Fig.15 Load Vs Displacement

Flexural Specimen sample (45^0) Fxural Specimen Same (30^0)

Table 1: Tabulated results for Tensile test of CFRP samples

Table 2: Tabulated results for Flexural test of CFRP samples

Orientation (degrees	Max. breaking load (N)	Ultimate tensile strength (N/mm^2)	Extension (mm)	Load at high yield point (N)	Young's Modulus (N/mm^2)
90	6837	341.6	5.63	3099	20364.3
30	2382	119.06	12.29	988.9	15922.3
45	3164	158.2	10.23	1028.1	4421

The experimental results clearly indicate that When composite materials are designed, the reinforcements are always oriented in the load direction.

However, if the load direction is variable and not parallel to the fibres it becomes more important to investigate the laminate mechanical behaviour. To investigate the effect of fibre orientation ±300, ±450, ±900 were selected under this study. Specimens with different fibre orientations were prepared under the same conditions as discussed earlier.

The experimental results show that the tensile and flexural strengths are affected by the fibre orientation significantly

4.4 Properties

4.4.1 Tensile Properties

The tensile strength is superior in case of 90-degree orientation.

More force is required for fracture of Carbon fibre reinforced polymer composite in case of 90-degree orientation.

More elongation will be found in 30-degree orientation. The elongation is less in case of 90-degree orientation.

Maximum load at high yield point in case of 90-degree orientation.

4.4.2 Flexural Properties

1. The flexural strength is superior in case of 90-degree fibre orientation.
2. The stiffness property is good at 90-degree orientation.
3. The load at high yield point is maximum at 90-degree orientation.

More deflection is found in 45-degree orientation. The deflection is less in case of 90-degree orientation.

V. CONCLUSION

The experimental investigations used for the analysis of tensile and flexural behaviour of carbon fibre reinforced polymer laminates leads to the following conclusions

In case of 90-degree orientation the external tensile load is equally distributed on all the fibres and transmitted along the axis of the fibres. Whereas in case of other fibre orientations, fibre axes is non-parallel to load axis, resulting in off axis pulling of fibres and increased stress concentration causing the earlier failure of laminates. Even in case of 30 degree and 45 degree orientations the displacement in case of laminates with 45-degree fibre orientation is large compared to laminates with 90 degree and 30 degree orientations, this is due to off axis loading and significant fibre pull out before fracture.

1. The tensile & flexural strengths are superior in case of 90-degree fibre orientation
2. Specimen sustain greater load at 90-degree orientation specimens than in other orientations.
3. Extension and deflection are minimum in case of 90 degree orientations and maximum in case 30degree orientations.

Deflection is maximum at 45 orientation specimens than in other orientations.

REFERENCS

1. ACI 440.4R-04(2004), “Prestressing concrete structures with FRP tendons”, Farmington Hills, Mich.
2. ACI 440.1R-06. (2006). “Guide for the design and construction of structural concrete reinforced with FRP bars.” Farmington Hills, Mich.
3. ACI-ASCE Joint Committee 445. (1998), “Recent approaches to shear design of structural concrete” Journal of structure Engineering 124(12), 1375– 1417.
4. Ahmed K. El-Sayed, Ehab El-Salakawy and Brahim Benmokrane, (2007), “Characterization of New Carbon FRP Stirrups for Concrete Members” Journal of Composites for Construction, Vol. 11, No.4.
5. Chadon Lee, P.E. Jun-Yeop Kim and Seo-Young Heo, (2010) “Experimental Observation on the Effectiveness of Fibre Sheet Strip Stirrups in Concrete Beams” Journal of Composites for Construction, Vol. 14, No. 5, October 1, 2010.
6. Shehata, E., Morphy, R., and Rizkalla, S. (1998), “Use of FRP as shear reinforcement for concrete structures” Second international concrete on composites in infrastructure, Edited by Saadatmanesh and M. R. Ehsanim, ISIS Canada, University of Manitoba, Winnipeg, Manitoba, Canada, 300–314.
7. Ehsani, M. R., Saadatmanesh, H., and Tao, S. (1995), “Bond of hooked glass fibre reinforced plastic (GFRP) reinforcing bars to concrete.” ACI Material Journal, 92 (4), 391–400. reinforcements of concrete high way bridges.” ACI Structural Journal, 94(1), 77–86.
8. Önal M. Mustafa. 2009. ―Reinforcement of Beam by Using Carbon Fibre Reinforced Polymer in Concrete Buildings‖. Scientific Research and Essay, Vol. 4, No. 10, pp. 1136-1145.

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