

FABRICATION OF CARBON FABRIC EPOXY COMPOSITE: A REVIEW

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Abstract: *The naturally/synthetic available materials are mostly not having as much properties as the modern life of human being requires, so that it became necessary to manufacture a material which should have more than single property in use that's why the idea of manufacturing new material which we call "composite material" by the combination of two or more than two naturally/synthetic available material would be a correct way to get optimized mechanical properties in a single material. Here using high strength carbon fabric (plain weave) reinforced epoxy composite of mould dimension 200mm×200mm×5mm were fabricated using hand-lay-up technique. This bidirectional composite were evaluated for their mechanical strength as well as tribological behaviour in adhesive wear mode. Mechanical properties (tensile strength, flexural property and hardness) are to be tested on different type of machines. Information on surface characteristic is important for possible application of surfaces. There are different methods used to measure different surface properties. The methods are-*

- Scanning Electron Microscopy (SEM)
- X-Ray Diffraction (XRD)

In this paper, tensile test, flexural test and hardness test has been done on the carbon fabric with epoxy reinforced composites. Hand-lay-up method is used for the fabrication of composites. Therefore, the bidirectional composites were tested both for mechanical as well as Tribological behaviour in adhesive wear mode. On testing, it is seen that carbon fabric reinforced epoxy composites exhibit superior mechanical properties such as stiffness and modulus.

I. INTRODUCTION

Epoxy resin is the most commonly used polymer matrix for advanced composite materials. Over the years, many attempts have been made to modify the properties of epoxy by the addition of either rubber particles or fillers so that the matrix-dominated composite properties are improved. The addition of rubber particles improves the fracture toughness of epoxy, but decreases its modulus and strength. The addition of fillers, on the other hand, improves the modulus and strength of epoxy, but decreases its fracture toughness. In recent years, micro- and nano-scaled particles have been considered as filler material for epoxy to produce high-performance composites with enhanced properties. For example, Wang et al. (2002) used SiC whiskers along the interface of composite laminates during the lay-up process to improve their interlaminar fracture toughness.

Recently, the use of microfibrillated cellulose (MFC) has attracted much attention as mechanical performance enhancer in polymers and composites due to the environmental concerns. Qui and Netravali stated that polyvinyl alcohol (PVA) with an addition of MFC increase the tensile strength and thermal stability of the composite. Okubo et al. reported that if a small amount of MFC added into the bamboo fiber reinforced composite, tangled MFC fibers prevented the growth of micro-crack along the interface between bamboo fiber and matrix. Nakagaito and Yano showed that nano-composites produced by compression molding of MFC sheets where phenol formaldehyde (PF) resin was impregnated had a high bending strength and modulus comparable to magnesium. Suryanegara et al. showed that an addition of MFC increased the tensile strength of crystallized neat polylactic acid (PLA) by 42% and the strength by 14% at an MFC content of 20%. Gabr et al. showed that the crack initiation and propagation energies increased by 80% and 44%, respectively due to an addition of 2 wt.% of MFC. They also showed that 2 wt.% MFC was the limit of inclusion into epoxy resin due to high viscosity.

MFC can be produced from a number of various cellulosic sources by several methods such as a high pressure homogenizer, micro-fluidization, micro-grinding, and cryo-crushing. Specialty engineering thermoplastics are used as matrices for advanced composites because of their additional advantages such as higher specific strength, thermal stability, resistance to fatigue and crack, recyclability, unlimited shelf life, etc. In such composites, its role is to stabilize the fibers in compression (providing lateral support), translate the fiber properties into the laminate, minimize damage due to impact by exhibiting plastic deformation, and provide out-of-plane properties to the laminate. High temperature specialty thermoplastics such as polyetheretherketone (PEEK), polyethersulphone (PES), PEI, etc. have proved superior in all these aspects. Amongst various reinforcements fabric reinforcement is the most promising for fiber reinforced composites (FRCs). Fabrics are unique in their ability to provide mechanical strength in both longitudinal as well as transverse directions.

Fabrics are easy to handle for compression molding of the composites. Besides, the unique advantage of fabrics as reinforcement lies in their ability to drape or conform to curved surfaces without wrinkling. Carbon, graphite, glass

and Aramid fabrics are the most commonly used fabrics for FRP composites especially for making tribo-components and aircraft structures that encounter harsh operating conditions such as high stresses, speeds, temperatures, etc.. Amongst these fabrics, carbon fabric (CF), not only offers maximum extent of strength and wear resistance enhancement but also boost the thermal conductivity that is crucial from a tribo-point of view. The rapid dissipation of frictional heat produced at the asperity contacts protects the matrix from degradation and fibers from delamination and helps in the retention of all performance properties. Moreover, in general, carbon fibers help in imparting additional lubricity because of layer-lattice structure of graphite. The wide use of carbon fiber as the reinforcing agent of polymers is not only attributed to its high strength and modulus but also to its excellent thermal stability. It could be rationally anticipated that the plain carbon fabric would have better mechanical and tribological properties than the carbon fiber, owing to the orderly aligned structure, good integrity, and good load-carrying capacity of the carbon fabric as compared with the carbon fiber counterpart. This could account for the increased focus on the friction and wear properties of various fabric reinforced composites and their application in the industries of bearing, aerospace, aviation, and automobile. However, carbon fibers usually have poor chemical activity and high brittleness. Therefore, it is imperative to modify carbon fibers and carbon fabrics so as to broaden the tribological application of carbon fabrics by decreasing the brittleness and increasing the anti-wear ability. This is why it is critical to seek for the effective ways to enhance the mechanical and tribological properties of carbon fabric composites so as to increase their applicability in bearing industry where the integration and multi-functionalization of the bearings made of various composites are of particular interest.

Recently, nanometer inorganic compounds such as TiO₂, ZnO, SiO₂, Al₂O₃, Si₃N₄ etc., were tried as the fillers of fabric composites and polymers to improve the tribological properties. This is related to the specific properties such as high surface activity and energy and small size effect of the nano-particulates. With a view to the feasibility to improve the tribological properties of fabric composites by the introduction of nano-particulates and in connection with our previous work on carbon fabric composites filled with various nano-particulate oxides, Al₂O₃ and Si₃N₄ nano-particulates were selected to prepare filled carbon fabric composites in the present work. This article deals with the preparation and investigation of the tribological properties of the carbon fabric composites filled with nanometer Al₂O₃ and Si₃N₄. The mechanism of the fillers in reducing wear and friction is also discussed. The present work is expected to broaden the application of carbon fabric composites in dry-sliding bearings.

II. MATERIALS AND MANUFACTURING

Fig. 1 A and B shows the pictures of as-received carbon nanofibers at different magnifications. High specific surface area and cotton-like entanglement cause the formation of

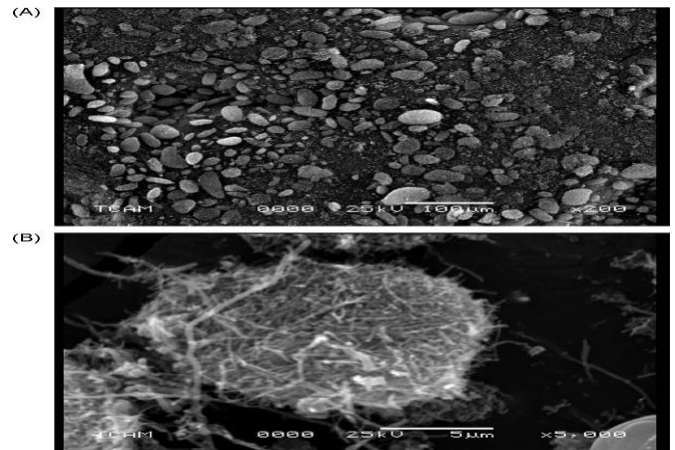


Fig. 1 – SEM pictures of as received carbon nanofiber at the magnification of 200× (A) and 5000× (B).

Agglomerates (Gojny et al., 2005b). Agglomerates of CNFs, called nanoropes, are difficult to separate and infiltrate with matrix. For polymer matrix nanocomposites, the high power dispersion methods, such as ultrasonic and high speed shearing, are the simplest and most convenient methods to improve the dispersion of nanosized fillers in a polymer matrix (Qian et al., 2000; Sandler et al., 1999). In this study, the components were mixed using a high intensity ultrasonic processor. The CNF and part A of epoxy were first mixed in a glass beaker. The mixing was carried out in pulse mode (50 s on/25 s off) using a high intensity ultrasonic irradiation (Tihorn, 20 kHz Sonics Vibra Cell, Sonics Mandmaterials, Inc., USA). The mixing time was 1.5 h. To avoid temperature rise during the sonication process, external cooling was employed by submerging the beaker in an ice-bath. Once the irradiation was complete, part B epoxy was mixed with the CNF-filled part A using a high-speed mechanical stirrer for about 10 min. The mix ratio of part A and part B. The intense mixing of part A and part B produced highly reactive volatile vapor bubbles at the initial stages of the reaction, which could detrimentally affect the properties of the final product by creating voids. To reduce the void formation, high vacuum was applied using Brand Tech Vacuum system for about 30 min. After the bubbles were removed, the mixture was used in a VARTM set up with satin weave carbon fabric to fabricate CNF-filled epoxy matrix composite panels. In parallel, neat epoxy matrix composite

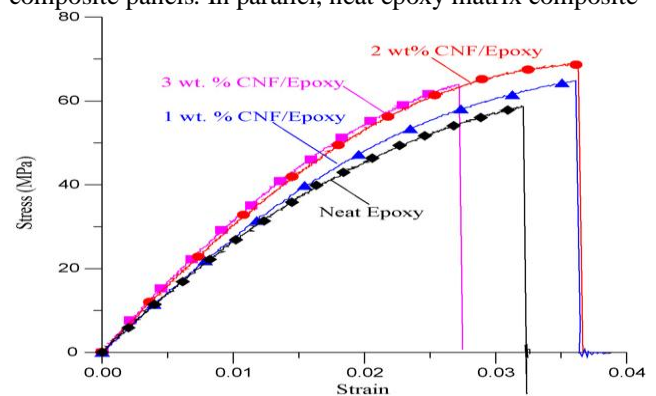


Fig. 2 – Effect of CNF content on tensile stress–strain curves of epoxy.

panels were fabricated by using the same method to compare it with the nano phased system. All panels were post-cured at 100 °C for 5h in a convection oven.

III. FABRICATION TECHNIQUES

1. Hand lay-up technique

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. The processing steps are quite simple. First of all, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats or chopped strand mats are cut as per the mold size and placed at the surface of mold after perspex sheet. Then thermosetting polymer in liquid form is mixed thoroughly in suitable proportion with a prescribed hardner (curing agent) and poured onto the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of mat is then placed on the polymer surface and a roller is moved with a mild pressure on the mat-polymer layer to remove any air trapped as well as the excess polymer present. The process is repeated for each layer of polymer and mat, till the required layers are stacked. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing either at room temperature or at some specific temperature, mold is opened and the developed composite part is taken out and further processed. The schematic of hand lay-up is shown in figure 1. The time of curing depends on type of polymer used for composite processing. For example, for epoxy based system, normal curing time at room temperatur is 24-48 hours. This method is mainly suitable for thermosetting polymer based composites. Capital and infrastructural reirement is less as compared to other methods. Production rate is less and high volume fraction of reinforcement is difficult to achieve in the processed composites. Hand lay-up method finds application in many areas like aircraft components, automotive parts, boat hulls, diase board, deck etc. Generally, the materials used to develop composites through hand lay-up method are given in table 1.

Table 1 Raw materials used in hand lay-up method

Materials used	
Matrix	Epoxy, polyester, polyvinyl ester, phenolic resin, unsaturated polyester, polyurethane resin
Reinforcement	Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax, coir, cotton, jute etc.) (all these fibers are in the form of unidirectional mat, bidirectional (woven) mat, stitched into a fabric form, mat of randomly oriented fibers)

2. Spray lay-up

The spray lay-up technique can be said to be an extension of the hand lay-up method. In this technique, a spray gun is used to spray pressurized resin and reinforcement which is in the

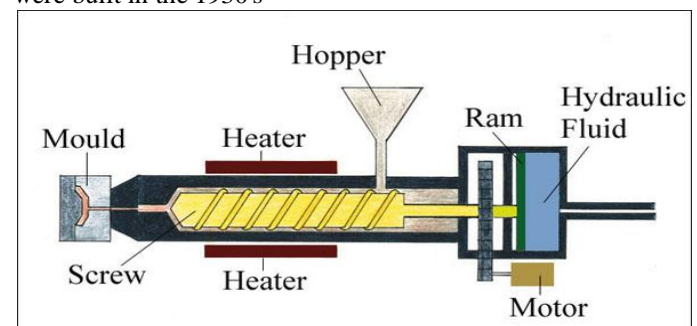
form of chopped fibers. Generally, glass roving is used as a reinforcement which passes through spray gun where it is chopped with a chopper gun. Matrix material and reinforcement may be sprayed simultaneously or separately one after one. Spray release gel is applied on to the mold surface to facilitate the easy removal of component from the mold. A roller is rolled over the sprayed material to remove air trapped into the lay-ups. After spraying fiber and resin to required thickness, curing of the product is done either at room temperature or at elevated temperature. After curing, mold is opened and the developed composite part is taken out and further processed further. The time of curing depends on type of polymer used for composite processing. The schematic of the spray lay-up process is shown in figure 2. Spray lay-up method is used for lower load carrying parts like small boats, bath tubs, fairing of trucks etc. This method provides high volume fraction of reinforcement in composites and virtually, there is no part size limitation in this technique. Generally, the materials used to develop composites through spray lay-up method are given in table 2.

Table 2 Raw materials used in spray lay-up method

Materials used	
Matrix	Epoxy, polyester, polyvinyl ester, phenolic resin, unsaturated polyester, polyurethane resin
Reinforcement	Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax, coir, cotton, jute etc.) (all these fibers are in the form of chopped short fibers, flakes, particle fillers etc.)

3. Injection Moulding

Injection Molding is the process of forcing melted plastic in to a mold cavity. Once the plastic has cooled, the part can be ejected. Injection molding is often used in mass-production and prototyping. Injection molding is a relatively new way to manufacture parts. The first injection molding machines were built in the 1930's



There are six major steps in the injection molding process:

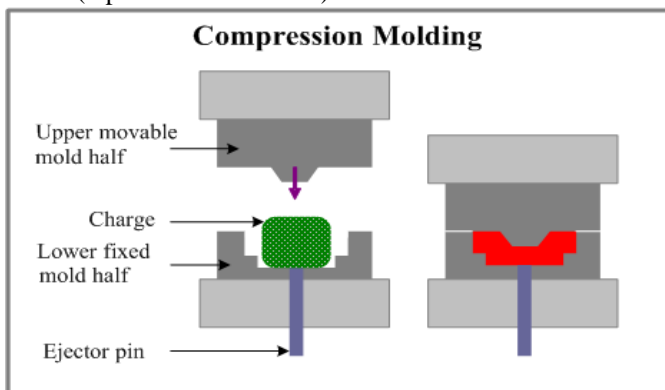
- Clamping : An injection molding machine consists of three basic parts; the mold plus the clamping and injection units. The clamping unit is what holds the mold under pressure during the injection and cooling. Basically, it holds the two halves of the injection mold together.
- Injection : During the injection phase, plastic material, usually in the form of pellets, are loaded

into a hopper on top of the injection unit. The pellets feed into the cylinder where they are heated until they reach molten form (think of how a hot glue gun works here). Within the heating cylinder there is a motorized screw that mixes the molten pellets and forces them to end of the cylinder. Once enough material has accumulated in front of the screw, the injection process begins. The molten plastic is inserted into the mold through a sprue, while the pressure and speed are controlled by the screw. Note: some injection molding machines use a ram instead of a screw.

- Dwelling : The dwelling phase consists of a pause in the injection process. The molten plastic has been injected into the mold and the pressure is applied to make sure all of the mold cavities are filled.
- Cooling : The plastic is allowed to cool to its solid form within the mold.
- Mold opening : The clamping unit is opened, which separates the two halves of the mold.
- Ejection : An ejecting rod and plate eject the finished piece from the mold. The un-used sprues and runners can be recycled for use again in future molds.

IV. COMPRESSION MOULDING

Compression molding is a well known technique to develop variety of composite products. It is a closed molding process with high pressure application. In this method, as shown in figure 1, two matched metal molds are used to fabricate composite product. In compression molder, base plate is stationary while upper plate is movable. Reinforcement and matrix are placed in the metallic mold and the whole assembly is kept in between the compression molder. Heat and pressure is applied as per the requirement of composite for a definite period of time. The material placed in between the molding plates flows due to application of pressure and heat and acquires the shape of the mold cavity with high dimensional accuracy which depends upon mold design. Curing of the composite may carried out either at room temperature or at some elevated temperature. After curing, mold is opened and composite product is removed for further processing. In principle, a compression molding machine is a kind of press which is oriented vertically with two molding halves (top and bottom halves).



Generally, hydraulic mechanism is used for pressure application in compression molding. The controlling parameters in compression molding method to develop superior and desired properties of the composite are shown in figure 2. All the three dimensions of the model (pressure, temperature and time of application) are critical and have to be optimized effectively to achieve tailored composite product as every dimension of the model is equally important to other one. If applied pressure is not sufficient, it will lead to poor interfacial adhesion of fiber and matrix. If pressure is too high, it may cause fiber breakage, expulsion of enough resin from the composite system. If temperature is too high, properties of fibers and matrix may get changed. If temperature is low than desired, fibers may not get properly wetted due to high viscosity of polymers especially for thermoplastics. If time of application of these factors (pressure and temperature) is not sufficient (high or low), it may cause any of defects associated with insufficient pressure or temperature. The other manufacturing factors such as mold wall heating, closing rate of two matched plates of the plates and de-molding time also affect the production process. Generally, the raw materials used to fabricate composites through compression molding process are given in table 1.

Table 1: Raw materials used in compression molding process

Materials used	
Matrix	Thermosetting: Epoxy, polyester, polyvinyl ester, phenolic resin, Unsaturated polyester, polyurethane resin, Urea formaldehyde. Thermoplastic: polypropylene (PP), polyethylene (PE), nylon, polycarbonate (PC), polyvinyl chloride (PVC), cellulose acetate, polyetherether ketone (PEEK), Acrylonitrile-butadiene-styrene (ABS), polystyrene (PS) biodegradable polymers such as poly lactic acid (PLA), poly vinyl alcohol (PVA), soy based plastic, starch based polymers etc.
Reinforcement	Glass fiber, carbon fiber, aramid fiber, natural plant fibers (sisal, banana, nettle, hemp, flax etc.) (all these fibers may be in the form of unidirectional mat, bidirectional (woven) mat, stitched into a fabric form, mat of randomly oriented fibers, short fibers, chopped fibers)

V. EXPERIMENTAL

Fabrication of composites
 Polyetherimide (ULTEM 1000) was supplied in the form of granules by GE plastic USA while CF of plain weave was supplied by Fibre Glast Ltd., USA. The properties of CF and PEI are listed in Tables 1 and 2 respectively. Five composites were fabricated using impregnation technique (I)

by varying the concentration of CF in PEI. Dichloromethane was used as a solvent to prepare five different solutions of PEI (5, 10, 18, 25 and 31%, w/w) to get CF as (90, 80, 72, 65 and 50 by wt% and 85, 75, 65, 55 and 40 by vol.%) in the moulded composites. PTFE coated glass fabric tape was used to seal the open strands from all four sides of carbon fabric pieces (280mm×260 mm) to avoid the fiber misalignment. These plies were then dipped individually in the containers filled with viscous solution of PEI for 12 h. The container was sealed to avoid evaporation of solvent, which was essential for wetting of fiber strands with the PEI solution. The plies were then taken out carefully to avoid the

Table : Properties of three weaves of carbon fabric measured in the laboratory

Carbon fabric	Plain
Density (kg/m ³)	1850
Area (kg/m ²)	1960
Tova	3K
Tex	20
Denier	185
Crimp (%)	0.64
Count	28
Warp (in.)	12
Weft (in.)	12
Thickness (m)	0.0034
Bending length (m)	0.072
Tensile strength (MPa)	0.3
Elongation (%)	1.25

Supplier's data.

disturbance in weave followed by drying in oven for 2 h at 100 °C in a stretched condition. PTFE coated glass fabric was placed on the top and bottom of stacked prepregs as a mould release agent. A total of 20–24 prepregs were stacked in the mould and heated at a temperature of 385–390 °C, which was attained within 2 h. These prepregs were then compression molded at the above temperature at an applied pressure of 7.35MPa. During the total compression time of 20 min, two intermittent breathings (each of 2 s) were applied to expel the possible residual solvent. The composites were allowed to cool naturally under same pressure of 7.35MPa. The thickness of the sheets was in the range 3–4 mm. It was then cut with the diamond cutter as per requirements. One special composite (IP40) was developed containing 40% CF by volume by using 60 prepregs to attain 10mm thickness. The samples (10mm×10mm×10 mm) were cut from this composite to study the influence of fabric orientations (fabric horizontal and perpendicular to sliding plane along with warp and weft fibers in different coordinations) on friction and wear performances.

VI. CONCLUSION

Thermal and mechanical tests were conducted on carbon nanofiber (CNF) filled epoxy and carbon fabric/epoxy composite. The optimal CNF content was 2.0 wt.%, which produced the highest improvement in tensile strength as compared to the neat epoxy resin. The composite fabricated with 2.0 wt.% CNF filled epoxy produced 22.3%

improvement in flexural strength and 11% improvement in tensile strength. The addition of CNF in the epoxy matrix also improved the fatigue performance of the composite. In this work, micro/nano-sized bamboo fibrils (MBFs) were fabricated from raw bamboo (1–3 years) using the alkaline treatment technique and the mechanical extraction method. The sequence followed to release MBF is the following as: (i) extraction of bamboo fibers from raw bamboo through the alkaline treatment (5% NaOH solution at 70 °C for 10 h), (ii) separation of pulp fibers (an average diameter of 18.8 μm, aspect ratio of 65) by a food mixer, (iii) the obtained MBF using micro-grinding process after passing 15 times between static grind and rotating grind stones revolving at 1500 rpm. With the addition of MBF, the fracture toughness of epoxy resin at 0.8 wt.% MBF significantly increased by 84.6% from 0.639 MPa m^{1/2} to 1.18 MPa m^{1/2}. The mode-I interlaminar fracture toughness of carbon fiber reinforced epoxy composite containing 0.8 wt.% MBF for both crack initiation and crack propagation also improved by 35.30% and 47.32%, respectively. The toughening effect could be attributed to the matrix crack encountered with obstacles (fiber bridging) which gradually deflect the crack orientation so that more energy was required, resulting in higher fracture toughness. The fatigue life of the MBF modified composites dramatically increased 12–25 times longer than that of the unmodified composites at high cycle fatigue while the tensile strength slightly increased. This could be attributed to MBF delay the onset of matrix crack, and reduce the crack growth in the CF/EP composites. The incorporation of 5% nano-Al₂O₃ and 8% nano-Si₃N₄ contributed to increase the antiwear and friction-reducing abilities of the carbon fabric composites, because they were capable of increasing the interfacial bonding strengths among the carbon fabric matrix and the resin adhesive and hence to increase the mechanical strength of the composites. The friction and wear properties of the carbon fabric composites were closely dependent on the environmental temperature and the content of the nano-particles filler. The wear rates of the composites significantly increased at elevated temperature above 180 °C, which was attributed to the degradation and decomposition of the resin adhesive thereat. The differences in the tribological properties of the unfilled and nano-Al₂O₃ or nano-Si₃N₄ filled carbon fabric composites were related to the differences in their transfer films natures formed on the counterpart steel pin surfaces.

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