

RESEARCH ARTICLE

Comparative studies of mechanical and interfacial properties between jute and E-Glass fiber-reinforced unsaturated polyester resin based composites

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Abstract: Jute fiber (hessian cloth)-reinforced unsaturated polyester matrix composites (50 wt% fiber) were fabricated by hand lay-up technique. Tensile strength (TS), tensile modulus (TM), bending strength (BS), bending modulus (BM), elongation at break (Eb%), and impact strength (IS) of the composites were found to be 42 MPa, 2.7 GPa, 36 MPa, 2.1 GPa, 3%, and 21 kJ/m², respectively. On the other hand, TS, TM, BS, BM, and Eb% of E-glass mat reinforced unsaturated polyester resin (UPR) composite were found to be 70 MPa, 3.8 GPa, 80 MPa, 2.5 GPa, and 5%, respectively. Then E-glass/UPR based composites (50 wt% fiber) were fabricated and the mechanical properties were compared with those of the Jute/UPR based composites. It was observed that E-glass fiber-based composites showed almost double mechanical properties as compared to jute composites. The interfacial shear strength of the jute and E-glass fiber-based systems was investigated and found to be 21 kJ/m² and 21.56 kJ/m², respectively, measured using the single-fiber fragmentation test. After flexural testing, fracture sides of both types of the composites were studied by scanning electron microscope (SEM) and the results showed that poor fiber-matrix adhesion for Jute/UPR based composites when it compared to that of the E-glass fiber composites. However, it was found that the E-glass fiber based composite has better strength as compared to jute fiber composite.

Keywords: jute fiber, E-glass fiber, unsaturated polyester resin, interfacial properties, mechanical properties, composites, scanning electron microscope (SEM)

1 Introduction

In the last century, synthetic fiber-reinforced polymer-based composites increased huge attention. Before using synthetic fiber-reinforced polymer-based composites, people all over the world use conventional structural materials such as wood, metals, and reinforced concrete. These composites are now replacing conventional structural materials^[1]. Fiber-based composite materials have several advantages such as high stiffness, good processability, ease of installation, relatively good resistance to environmental agents and fatigue, easy availability, renewability of raw materials, low cost, lightweight, etc. A “dry” carbon fiber and a “wet” resin are used when

a composite structure is manufactured^[2]. Then with the resin, the dry carbon fiber will be wetted and it put inside an oven so that the resin can solidify and “block” the carbon fibers and after that create stiffness between them. With a wide range of properties, there is a good number of matrices and fibers are being used for processing composites^[3].

Composites prescribe that a material consisting of two or more individual constituents and the reinforcing constituent is embedded in a matrix to form the composite^[4]. Composite structures are quite common in nature where fiber and matrices are combined. Synthetic fibers of reinforcing agents like carbon, aramid, glass, nylon as well as natural cellulose-based fibers such as jute, hemp, coir, sisal, ramie, kenaf, etc. are being used in composite manufacturing^[5,6]. Among all the synthetic fibers, glass fibers are now leading due to their low cost and comparatively better physico-mechanical properties, thermoset or thermos plastic properties and glass fibers are significantly stronger than the other plastic matrix^[7].

Glass fibers are the original fiber reinforcement of modern composites. They are produced when thin strands of silica-based or other formulations of glass are

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extruded into many fibers with small diameters appropriate for textile processing. The technique of heating and drawing glass into fibers has been known since ancient times. But in 1936, the first commercial production of fiber-glass was started. The most widely used glass fiber is E-glass ($54.3\text{SiO}_2-15.2\text{Al}_2\text{O}_3-17.2\text{CaO}-4.7\text{MgO}-8.0\text{BO}-0.6\text{Na}_2\text{O}$), which has good insulation properties and can maintain these properties up to 815°C ^[8]. E-glass is most popular fiber-glass for its various good properties, such as, low cost, high production rates, high strength, high stiffness, relatively low density, non-flammable, resistant to heat, good chemical resistance, relatively insensitive to moisture, able to maintain strength properties over a wide range of conditions, good electrical insulation^[9].

Nowadays, the use of E-glass as the reinforcement material in a polymer matrix composites is extremely common. E-glass fibers are often favorite as reinforcement in a polymer matrix due to their better impact resistance, good fatigue life, higher strain to failure, and good corrosion resistance in most common environments^[10]. Highest strength properties are gained when straight, continuous fibers are aligned parallel in a single direction. Laminate structures can be constructed, with continuous fibers aligned in other directions to promote strength in other directions. Such structures are used in storage tanks and the like. E-glass uses for regular fiber-glass are mats, insulation, reinforcement, sound, absorption, heat-resistant fabrics, corrosion-resistant fabrics, and high-strength fabrics. Corrugated fiber-glass panels are also widely used for an outdoor canopy or greenhouse construction^[11].

For ecological concerns, the use of natural fibers is increasing day by day. Natural fibers which are based on lignocellulose can be considered as an interesting, biodegradable and environmentally safe. For this reason, now natural fibers can be used as an alternative for the use of glass fibers as reinforcement in engineering polymeric materials. Natural fibers have low density, low cost, low abrasion multi-functionality, high toughness, good thermal properties, high availability, acceptable specific strength properties, enhanced energy recovery, and biodegradability^[12].

Various types of natural fibers are used all over the world, like flax, hemp, kenaf, jute, and sisal have a number of ecological and techno-economic advantages over E-glass fibers. So, a number of industrial sectors have motivated to use natural fibers for knowing its mechanical and physical properties together with their environmentally friendly character, especially the automotive industry, to consider these fibers as potential candidates to replace E-glass fibers in environmentally safe

products^[13]. Natural fibers are undergoing a high-tech revolution that could see them replace synthetic materials in applications such as boat hulls, bathtubs, and archery bows. The synthetics being confronted by this natural revolution are composite materials plastics reinforced with glass or carbon fibers^[14]. Instead of man-made fibers, the use of natural fibers is increasing rapidly because they are abundant, renewable, cheap, recyclable and biodegradable. They show low density and the level of environmental pollution caused is less compared to synthetic fibers. Natural fibers could use in various from cars to golf clubs. In Germany, car manufacturers aim to make every component biodegradable and recyclable. The door panels in the Mercedes have been made from plastics reinforced with flax fibers^[15]. Consequently, natural fibers have increased more attention among scientists and technologists for applications in civil, military, industrial, space-craft and biomedical sectors^[16,17]. Among all the natural fibers, jute appears to be the most useful, commercially available and inexpensive fiber. Jute fiber mostly composed of cellulose (61-71%), hemicellulose (13.6-20.4%), lignin (12-13%), ash (0.5-2%), pectin (0.2%), wax (0.5%) and moisture (12.6%)^[18-20]. Jute fibers present some disadvantages such as low thermal resistance, low thermal resistance, intrinsic polarity, poor dimensional stability, high moisture sorption, anisotropic fiber resistance, and variability^[20,28]. A number of papers have been published on jute fibers where jute was used as a reinforcing agent in thermoplastics with unsaturated polyester resin (UPR)^[21-23].

The most commonly used thermoset resins are unsaturated polyester resins (UPR) in the world. More than 2 million tons of UPR is consumed globally for the manufacture of a wide assortment of products, including sanitary-ware, pipes, tanks, gratings and high-performance components for the marine and automotive industry. UPR is produced by the chemical reaction of saturated and unsaturated di-carboxylic acids with alcohols. UPR is made up of at least two separate components; reinforced fiber and embedding matrix. UPR is used all over the world for its versatile applications, properties and among all thermosetting resins, UPR has received huge attention in various industries. UPR has been used as a polymer matrix in composites, such as fiber-reinforced plastic and polymer concrete^[24]. UPR is now widely used in a host of application where advantage may be taken of their good range of mechanical properties, low cost, good corrosion resistance, and low weight. The use of natural fiber (jute) and UPR are highly beneficial because of their strength and toughness of the resulting composites are greater than those of unreinforced plastics.

In the case of polymer-fiber systems, the quality of the interface is very important because it controls the mechanical properties of the resulting composites. The interfacial properties of fiber-reinforced composites can be measured using scanning electron microscopic (SEM)^[25]. After bending tests, using this method (SEM) fracture surface of the composites can be observed. The SEM technique has several advantages, among them the main advantage of it's the excellent resolution obtained, allowing detailed observation of the fracture process^[26,27]. However, this technique stimulates only a surface scanning, uses an expensive equipment, and requires specific preparation of the samples, which can generate artifacts and impair the analysis^[29,30].

The present investigation involves comparing the mechanical properties of the matrix (UPR) and the composites (jute fibers/UPR and E-glass fibers/UPR). The mechanical properties of jute fiber/UPR composites were compared over the E-glass fiber/UPR composites. The interfacial properties of jute and E-glass fiber-based systems were measured using the SEM. The ultimate purpose of the present research works was to compare the mechanical and interfacial properties between jute fibers/UPR and E-glass fibers/UPR based composites.

2 Experimental studies

2.1 Materials

E-glass fiber (woven roving) was purchased from Saint-Gobain Vetrotex India Limited. [Figure 1](#) shows the digital images of E-glass fiber mat (a) and roll (b). Jute fabrics (hessian cloth) was collected from the local market (Savar Dhaka). [Figure 2](#) shows the digital images of jute fabrics, [Figure 2\(a\)](#) shows the image of jute tree, [Figure 2\(b\)](#) shows the image of jute yarn and [Figure 2\(c\)](#) shows the image of hessian cloth. Unsaturated polyester resin (UPR) was purchased from Singapore High-polymer Chemical Products, SHCP which supplies high-quality UPR to over 50 countries worldwide and the curing agent is Methyl ethyl ketone peroxide (MEKP) obtained from Lam Tat Trading Company Limited, Singapore. [Figure 3](#) illustrated the structure of UPR and [Figure 4](#) indicates the digital image of jute/UPR. Table 1 indicate Physical properties of URP.

2.2 Water uptake of the jute fibers

At room temperature (25°C), for the jute fibers, water uptake tests (about 500 mg) were performed in deionized water. This process was continued up to 60 min, then the jute fibers were carried out. After that, jute samples were placed in static glass beakers containing 100

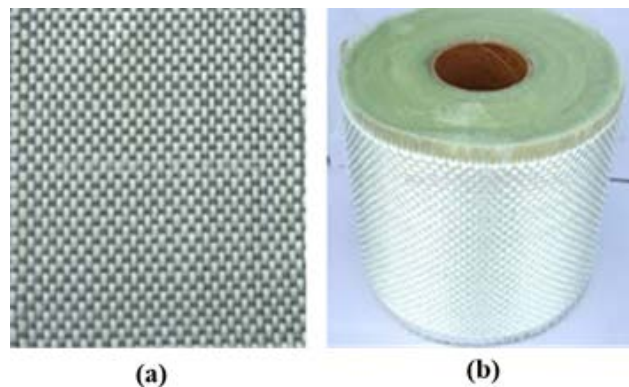


Figure 1. Digital images of E-glass fibre mat (a) and roll (b)

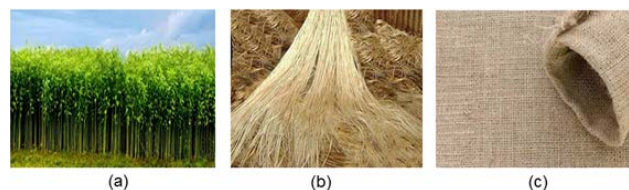


Figure 2. Digital images of Jute (a) Jute tree (b) Jute yarn (c) Hessian Cloth

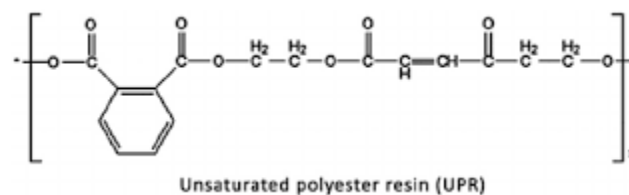


Figure 3. Structure of unsaturated polyester resin



Figure 4. Digital image of Jute//UPR composite

Table 1. Physical properties of unsaturated polyester resin

Property	Polyester Resin
Tensile Strength (MPa)	40.00
Flexural Strength (MPa)	45.00
Maximum Elongation (Eb%)	1.00
Modulus of Elasticity, E (GPa)	3.30
Density ρ (g. cm ⁻³)	1.09

ml of deionized water. Samples were taken out from the beaker at certain time intervals^[31,32]. At 105^o C samples dried for 6 hours and then re-weighed the samples. Similarly, jute fabrics reinforced unsaturated polyester resin (UPR) based composites were treated for water uptake up to 30 days. Similar procedures are repeated for E-glass fiber UPR based composite and again to continue this method.^[33–35].

2.3 Composite fabrication

Using a simple hand lay-up technique, E-glass/UPR composites were fabricated. At first, a release gel is sprayed on the mold surface to avoid the sticking of UPR to the surface. To get a good surface finish of the product, thin plastic sheets are used at the top and bottom of the mold plate. After that, reinforcement in the form of fiber mats is cut as per the mold size and placed at the surface of mold after Perspex sheet. Then UPR was mixed carefully with MEKP (methyl ethyl ketone peroxide) properly and poured onto the surface of the mat already placed in the mold. Then E-glass is poured onto the surface of the mat. The mixture is uniformly spread with the help of a brush. The second layer of E-glass fiber is then placed on the mixture surface and a roller is moved with a mild pressure on the E-glass/UPR- mat layer to remove air from the mold. After that curing this mold at room temperature. After curing opened the mold and take way the composite part from the mold. The time of curing depends on the type of UPR used for composite processing.

Jute/UPR composites were fabricated using a simple hand lay-up technique. In this method, the working surfaces were treated with releasing waxes to facilitate easy removal of samples from the mold surface. Before each operation, using commercially available UPR containing an accelerator or a promoter and a catalyst, MEKP mixed thoroughly and after that procedure, the matrix material was made. At the beginning of fabrication, 2% MEKP with a gel coat was uniformly brushed into the finished side of both parts of the mold. After 1hour when curing if the gel coat was completed, then each layer of the fiber was pre-impregnated with matrix materials and the sandwich was placed one over another. Both parts of the mold were pressed with a roller to remove any air trapped as well as the excess polymer present. After curing at room temperature, mold is opened and the developed composite part is taken out for further processed. For the different test, the released sheets of each different sample were cut into rectangular pieces of equal size (120×10×3 mm³). For each testing take at least five samples and then average the five samples for each testing.

2.4 Mechanical properties of the composites

The tensile properties such as tensile strength (TS), tensile modulus (TM) and bending properties like bending strength (BS) and bending moment (BM) were determined for both jute/UPR and E-glass/UPR composites and these properties of the composites were estimated using the Hounsfield series S testing machine (UK) with a crosshead speed of 1 mm s⁻¹ at a span distance of 25 mm. The dimensions of the test specimen were (ISO 14125): 60mm×15mm×2 mm. Composite samples were cut into the required dimension using a band saw. Impact Strength of the composites was measured using Impact tester (MT-3016, Pendulum type, Germany).

2.5 Scanning electron microscopic (SEM) analysis

Jute fibers and E-glass fibers were examined by Philips Scanning Electron Microscope (SEM) at an accelerating voltage of 10 kV. Before subjected to SEM, the non-conducting surface of the composites can be coated with gold in agar auto sputter coater (model 108A, England). The fiber matrix adhesion of the tensile fracture surface of the composites can be examined by SEM (model XL 30, Philips, Netherlands). After bending test, fracture sides of the composites were observed using SEM. In an aluminum disk plate, gold coated composites samples were kept and a computer is connected with the machine with relevant software. After that, from computer scanning electron micrographs of the sample is obtained.

3 Result and discussion

3.1 Comparative studies of the mechanical properties of the composites

The mechanical properties such as tensile, bending, and impact strength of the UPR, jute fiber/UPR, and E-glass fiber/UPR composites were evaluated and the values are summarized in Table 2. It was found that Tensile strength (TS), tensile modulus (TM), elongation at break (Eb%), bending strength (BS), bending modulus (BM), impact strength (IS) of the UPR were found to be 40 MPa, 3.2 GPa, 1%, 27 MPa, 1.98 GPa, 4.47 kJ/m², respectively. Jute-based composites made of 50% fiber significantly improved the mechanical properties (TS, TM, BS, BM, and IS) and it was found that TS, TM, Eb%, BS, BM and IS of the jute based composites were 42 MPa, 2.7 GPa, 3%, 36 MPa, 2.1 GPa, and 21 kJ/m², respectively. Jute composites gained 45% increase in TS and 29% increase in TM over that of the matrix UPR. It was also found that BS, BM, and IS also improved

by 28%, 42%, and 48% respectively than that of the matrix material UPR. It can be seen from Table 2 that UPR and jute/UPR have similar lower strength but jute-based composite was quite stronger than UPR. In the case of elongation at break (Eb%), UPR, jute/UPR, and E-glass/UPR have a value of 1%, 3%, and 5%, respectively. While UPR gets the lowest elongation at fracture of 1%. If jute/UPR compares with E-glass/UPR, it was found that jute/UPR gets the lowest elongation at fracture, which means that jute/UPR composites are more brittle. It can be concluded that UPR and jute/UPR have almost similar tensile properties, whereas E-glass/UPR have both higher tensile strength and modulus. So, it is seen from the table that E-glass/UPR perhaps has better mechanical properties than jute/UPR. From this investigation, it is clear that E-glass composites gained huge mechanical properties over the matrix material and it indicated good fiber-matrix adhesion. From Table 2, it is clear that E-glass composites possessed a significant improvement in TS, TM, Eb%, BS, BM, and IS compared to the matrix UPR. Since both UPR and the E-glass fibers are hydrophobic in nature, the fiber matrix adhesion was quite excellent. This was revealed in the mechanical properties of the E-glass-based composites. E-glass-based composites showed significantly higher TS, TM, Eb%, BS, BM, and IS over the jute composites. It was shown that the E-glass fiber/UPR based composites were found to have 106% and 216% improvement of TS and TM over the jute/UPR based composites. It was also described that BS, BM, and IS also improved by 93%, 250%, and 100% than that of the jute/UPR composites.

The reason behind why E-glass fibers reinforced composites have better tensile properties may be found from the SEM micrographs. The SEM micrographs for composite fracture were shown in Figure 5 and Figure 6. Fibers are clearly pull out in these picture and disorderly distributed in the matrix, debonding and detachment can be seen some of the reinforce fibers. In particular, large

smooth zone are clearly observed, together with isolated broken fibers. The failure mechanism basically based on the morphology achieved, fiber breaking, crack of matrix, and fiber pull-out system. These shall be the reason that why E-glass/UPR showed better tensile properties over jute/UPR.

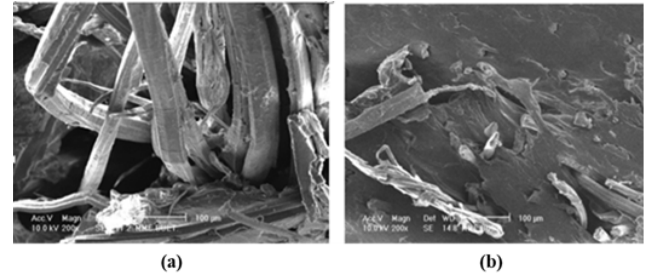


Figure 5. SEM images of the interfaces of the E-glass/UPR composites; Fibres pull-out (a) and fibre-matrix interfaces (b) of the composites

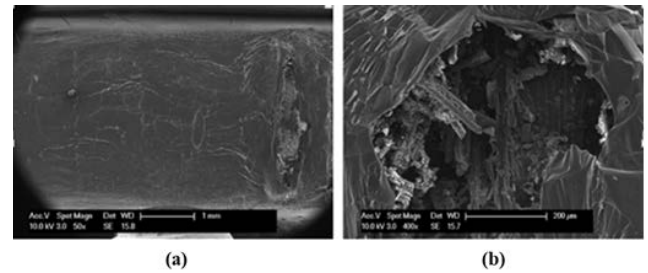


Figure 6. SEM images of rough surfaces (a) and interfaces (b) of the Jute/UPR composites

3.2 SEM images of the composites

Scanning electron microscopy (SEM) was used to study the interfacial properties of the composites based on jute/UPR and E-glass/UPR. SEM studies were more important to find out the adhesion of the fiber matrix inside the composites. Figure 5 indicates SEM images of

Table 2. Mechanical Properties (Tensile Properties, Bending properties and Impact Strength) of UPR and the UPR based Composites

Material	Mechanical Properties of UPR and the UPR based Composites					
	Tensile Properties			Bending properties		Impact
	Strength (MPa)	Modulus (GPa)	Elongation at Break (%)	Strength (MPa)	Modulus (GPa)	Strength (kJ/m ²)
UPR	40	3.2	1	27	1.98	4.47
Jute/UPR	42	2.7	3	36	2.1	21
E-glass/UPR	72	4	5	81	2.6	21.56

the interfaces of the E-glass based composites using UPR where Figure 5(a) represents fibers pull-out and Figure 5 (b) specifies fiber-matrix interfaces of the composites. The SEM image of the fracture surface describes that the fiber pull-out is quite low and fractures between E-glass fibers and UPR matrix are clearly shown in the SEM image which indicates excellent fiber-matrix adhesion between E-glass and UPR. It also conveyed very few holes in the matrix suggesting very good bonding between E-glass fiber and the UPR matrix and that why this composites mechanical properties are better than others. SEM images of rough surfaces of jute fibers Figure 6(a) and interfaces of the corresponding jute fiber/UPR composites Figure 6(b) are presented in Figure 6. It clearly indicates that the jute fiber pull-out is quite higher and the bonding between jute and UPR is not so good. The composites were prepared by hand lay-up technique so that the surface of the composites were appeared to be rough. Small gaps are evident in the matrix near the jute fibers. From the SEM images of the fracture surfaces of both jute/UPR and E-glass/UPR, it is clearly observed, a clear pictorial view is shown and this describes the interfacial properties of the composites as well as explains why jute-based composites have low mechanical and interfacial properties as compared to the E-glass-based composites. From this comparative studies of the mechanical properties and interfacial properties between jute fiber/UPR and E-glass fiber/UPR composites, it was found that the mechanical properties of the jute based composites are quite low compared to E-glass based composites. So, further investigation will have to be carried out to reduce the hydrophilic nature of jute/UPR and to try and improve the interfacial bonds between jute and UPR but retaining the inherent biodegradable properties of jute fibers. This research opens new entrances for further study to bring the mechanical properties of jute composites closer to that of the E-glass-based composites.

4 Conclusion

This paper basically shows the comparison between jute/UPR and E-glass/UPR composites. From this comparative study, it was found that the mechanical properties of E-glass UPR-based composites had almost double the values for TS, TM, Eb%, BS, BM, and IS compared to that of the Jute/UPR based composites. The result of the test showed that E-glass/UPR based composite had far better properties than that of jute fiber UPR based composite. SEM images of the fractured sides of the composites indicated the fact that jute-based composites had poorer fiber-matrix adhesion than the E-glass fiber/UPR-based composites. Although there is a big gap

compared with some synthetic fiber reinforces composite like E-glass fiber mat reinforced based composite, natural fibers mat reinforced based composite show the good tensile property as well as potential to replace E-glass UPR-based composite. E-glass fiber UPR-based composites mechanical and interfacial properties are better than jute fiber UPR based composites but the use of natural fiber composites is increasing day by day because of biodegradability in nature. Thus the uses of natural fiber may open the new path of diversified application of environment-friendly material in our modern civilization.

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