



## **Comparative Study of White Jute and Jute Felt Composites of Tetra Functional Epoxy Resin and Araldites**

**Jignesh P. Patel, Parsotam H. Parsania\***

Polymer Chemistry Division, Department of Chemistry, Saurashtra University,  
Rajkot - 360 005, Gujarat, India

\*E-mail address: [phparsania@aol.com](mailto:phparsania@aol.com) , [phparsania22@gmail.com](mailto:phparsania22@gmail.com)

Tel: +91281-2583984 and Fax: +91281-2577633

### **ABSTRACT**

White jute and jute felt fiber reinforced composites of tetra functional epoxy resin of bisphenol-C-formaldehyde (EBCF), araldites (GY508 and GY6010) and their hybrid composites were fabricated by hand layup followed by compression molding technique. White jute based composites showed somewhat better mechanical and electrical properties than those of jute felt based composites mainly due to different nature of reinforcing fibers, matrix materials and interfacial adhesion. Good mechanical and electrical properties, excellent hydrolytic stability, comparable equilibrium water absorption and equilibrium time of the composites signified their industrial importance for low load bearing, electrical, electronic and marine applications. EBCF based composites showed comparable mechanical, electrical and water absorption properties as those of araldites based composites signifying industrial utility of EBCF.

**Keywords:** Tetra functional epoxy resin; araldite; reinforcement; water absorption

## **1. INTRODUCTION**

Jute is a versatile fiber. A key feature of jute is its ability to be used either independently or blended with a range of other fibers and materials. Jute is being replaced by synthetic materials in many applications. Advantages of jute include good insulating and antistatic properties, as well as having low thermal conductivity and moderate moisture retention. Jute (*Corchorus capsularis* and *Corchorus olitorius*), is vegetable bast fiber plants next to cotton in importance. *Corchorus capsularis* is called as White Jute and *Corchorus olitorius* is called Tossa Jute. Jute and coir based composites have been developed as substitutes for plywood and medium density fiber boards. Panel and flush doors have also been developed out of these composite boards especially for low-cost housing needs. The natural fiber composites can be very cost effective material especially for building and construction industry (panels, false ceilings, partition boards etc.), packaging, automobile and railway coach interiors and storage devices [1].

Jute felt is a fabric of matted, compressed jute fibers. Jute felt is being increasingly used as an industrial good, especially for insulation and acoustic. High quality jute felt is an excellent insulating and acoustic material. Long lasting jute felt is made to serve the purpose effectively for a long time. Jute felt is made from 100% jute fiber used in various purposes. It is used for packaging purpose to protect the valuable things from scratch mark. It is very useful in construction and nursery. Other applications include promotional bags, shopping bags, wine bottle bags, ladies bags, christmas and gift bags, children bags, food bags (tea, coffee, rice), utility products, cotton bags, self inflatable bags, Hessian cloth (Burlap), geo textiles/ soil saver, jute matting, decorative fabric [1].

Natural fiber composites enjoy excellent potential as wood substitutes in building industry in view of their low cost, easy availability, saving in energy and pollution free production. Epoxy based fiber reinforced composites have become more commonly used in automobile, electronic devices, construction and aerospace industries. Recently several researchers have contributed in the field of jute-epoxy composites for their potential industrial applications [2-9]. Superior adhesive and better mechanical properties of the composites are the key factors for the best choice of load bearing complex engineering applications. There is growing demand to design and fabricate high quality reliable materials for various engineering applications. Fiber reinforced polymers have found their way into lightly loaded secondary structures in which stiffness dominate the design but there has to be a notable increase in strength as compared to the unreinforced polymer.

Growing environmental awareness and new rules and regulations [10] forced scientists to search new and improved eco-friendly bio-composites. The material scientists have explored the possibility of the development of engineering materials based on renewable natural resources such as soybean, sisal fibre, coir fiber, wood, banana, etc. [11-15]. The automotive industry benefits from lighter material and recyclable components due to improved energy efficiency [16]. Consequently there is a growing demand to utilise eco-friendly bio-based or “green composites” [17].

In comparison with the synthetic fiber composites; natural fibers are characterised with their attractive price, low density and lower abrasion. The energy consumption needed for production of synthetic fibers is much more than that needed for a similar quantity of natural fibers [18-19]. Unlike the synthetic fibers, natural fibers have a wide variation in diameter and length, which in turn affects expected mechanical behaviour of the composite. The variation

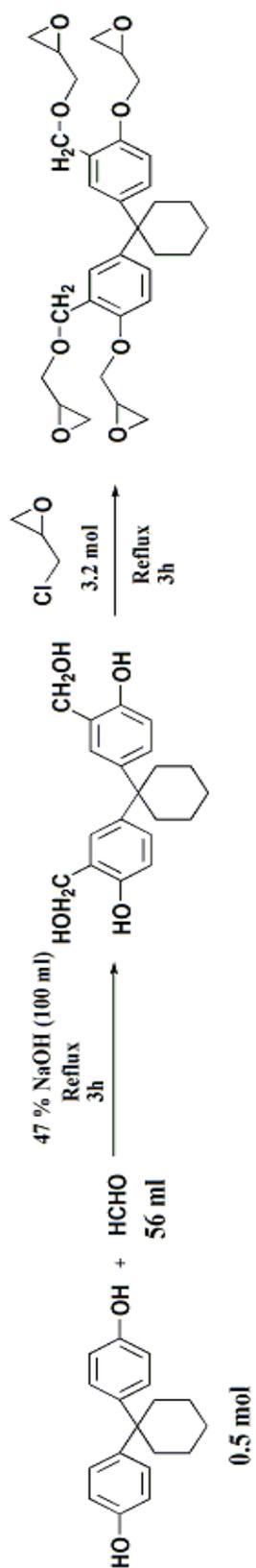
in natural fiber dimensions is contributed to fiber type, fiber maturity, harvesting time as well as processing methods adopted for the extraction of fibers, which all affect the diameter, stability of the fiber. Source, age, separating techniques, moisture content and the history of fiber also play an important role in the filament and individual fiber properties [19-21]. The implementation of natural fibers in thermoplastic and thermoset composites is attractive for different industrial sectors like automobiles and construction [22,23].

The jute fibre composites possess also some disadvantages. The main disadvantage is the poor compatibility between a hydrophobic polymer matrix and the hydrophilic fibres. This leads to the formation of weak interfaces, which result in poor mechanical properties of the composites. Other important disadvantages of the natural fibre composites are the high sensitivity of natural fibers towards water and the relatively poor thermal stability. Water absorption in the composites is an issue to be considered since the water absorbed by the fibers in the composite could lead to swelling and dimensional instability and to a loss of mechanical properties due to the degradation of the fibers and the interface between the fiber and matrix. Water absorption in fibrous composites depends on temperature, fiber loading, fiber orientation, permeability of fibers, surface protection, area of the exposed surface, diffusivity, void content, hydrophilicity of the individual components, etc.

The mechanical performance and durability of composite materials are mainly governed by type of reinforcement, the matrix, and interfacial bond strength, fiber and matrix volume fractions, void content, etc. [24]. Strength, stiffness, and stability of fibers and matrix are very important for long term service of composites. Tensile properties of materials are most widely useful for engineering design and understanding quality characteristics of polymeric materials. Flexural properties are useful for quality control and classification of materials with respect to bending strength and stiffness. Impact strength is the ability of a material to resist fracture under applied stress at high speed. Volume resistivity and electric strength data are very useful for comparing relative insulation quality of material selection, to evaluate the effects of material composition and environment and for material selection. They are useful to material scientists to design specific properties in combination.

Mechanical properties of the composites depend upon nature of matrix material and reinforcement, interfacial adhesion, degree of cure, fillers, compatibilizers, humidity, temperature, test conditions, etc. Electrical properties of the fiber reinforced composites are affected by several factors such as humidity, impurities, degree of resin cure, temperature, nature of resins and nature of fillers and additives, geometry, electrode area and electrode material, sample thickness, time of voltage application, current frequency, and extent of ageing.

In present investigation it was thought to be of interesting to study comparative mechanical, electrical and water absorption properties of white jute and jute felt fiber reinforced composites of tetra functional epoxy resin of bisphenol-C-formaldehyde (EBCF) and araldites (GY508 and GY6010). The main objective of the present work was to exploit commercial utility of EBCF and therefore comparative study was under taken with commercial resins (araldite GY508 and GY6010). Also hybrid composites were prepared to see improvement in the studied properties.



**Scheme 1.** Synthesis of tetra functional epoxy resin of bisphenol-C (EBCF).

## 2. EXPERIMENTAL

### 2. 1. Materials

Solvents and chemicals used were of laboratory grade and purified prior to their use [25]. Tetra functional epoxy resin of bisphenol-C-formaldehyde (EBCF, EEW 800) was synthesized according to our recent work (Scheme 1) [26]. Akylamine (amine value 350-390) curing agent Epikure (EPK 3251) (Hexion Specialty Chemicals Inc. Houston TX77210) and epoxy resins [araldites GY508 (EEW 370-425) and GY6010 (EEW 177-196)] (Huntsman Advanced Materials Inc., The Woodlands, TX77387-4980) were supplied by Berry Plastics Pvt. Ltd. Manjusar, Dist. Vadodara, Gujarat. Woven white jute fabric (*Corchorus capsularis*) was supplied by Reform Packaging, Ahmedabad. Jute felt was supplied by EPP Composites, Rajkot. The chemical composition, physical and mechanical properties of jute fibers [27-29] are summarized in Table I. There is, however, a major drawback is associated with the application of jute fibers for reinforcement of resin matrices. Due to presence of hydroxy and other polar groups in various constituents of jute fiber, the moisture uptake is high (approx. 12.5% at 65% relative humidity and 20 °C) by dry fiber [30].

**Table I.** Chemical composition, physical and mechanical properties of jute fibers.

Constituent	Composition, Wt %	Property	Range
Lignin	12-14	Fiber diameter	0.005-0.28 mm
$\alpha$ -Cellulose	58-63	Fiber length	150-360 cm
Hemicellulose	21-24	Density	1.3 g cm <sup>-3</sup>
Minor Constituents	2	Tensile strength	460-533 MPa
		Young modulus	2.5-13 GPa
		Elongation	1.16%

### 2. 2. Fabrication of the composites

Into a 500 mL beaker containing 300 mL 1,4-dioxane and required quantity of EBCF/GY6010 and GY508/ EBCF,GY6010 and GY508 was/were dissolved at room temperature. To this solution was added stoichiometric amount of EPK-3251 (Table II). The resultant solution was heated at 100 °C with stirring for 10 min. The solution was allowed to cool to room temperature and was applied to 20 cm x 20 cm woven white jute/ jute felt fabrics with a smooth brush. The solvent was allowed to evaporate at 100 °C for 1h and ten such plies were stacked one over the other and kept between two teflon sheets. These teflon sheets were kept between two preheated stainless steel plates and pressed under 2 bar pressure at 140 °C for 6h and at 150 °C for 2h. Hereafter jute and hybrid composites are designated as shown in Table II. The samples were machined according to standard test methods.

**Table II.** Experimental detail of white jute and jute felt composites.

Composite	Jute, g	EBCF, g	GY-6010, g	GY-508, g	EPK3251, g
WJ-EBCF	160	160	-	-	35.8
WJ-GY	141	-	70.5	70.5	31.6
WJ-EBCF-GY	190	95	47.5	47.5	42.6
JF-EBCF	279	279	-	-	62.5
JF-GY	280	-	140	140	62.7
JF-EBCF-GY	280	140	70	70	62.7

GY: 50% GY- 6010 & 50 % GY- 508 (w/w)

### 2. 3. Measurements

Tensile and flexural tests were carried out on a W & T Avery LTD Type 1010 Model No E-46234 (Birmingham, England) at a speed of 10mm/min according to ASTM D 638-01 and ASTM D 790-03, respectively. Izod impact measurements were carried out on an Izod Impact Tester, Type A1300, Model E-46204 (Birmingham, England) according to ASTM D 256-06 method. Barcol hardness tests were performed on a Barcol Hardness Tester Model 934-1 according to ASTM D-2583-95 method. Dielectric strength (IEC-60243-Pt-1-1998) measurements were carried out on a high voltage tester (Rajsan electromech Makarpura, Baroda) and volume resistivity (ASTM-D-257-2007) measurements were made on a Hewlett Packard high resistance meter in air at 25 °C after charging for 60 sec at 500 V DC applied voltage. Water absorption study was carried out at room temperature (30 ±0.1 °C) by a change in mass method according to ASTM D 570-98 method. Assuming unidirectional diffusion, water absorption in semi-infinite plate exposed on both sides to the same environment was calculated according to Eq. 1:

$$M = \frac{W_m - W_d}{W_d} \times 100 \quad \dots 1$$

where M = % water absorbed,  $W_m$  = weight of moist sample and  $W_d$  = weight of dry sample. Diffusivity in water was determined by using equilibrium water content and slope of M against  $t^{1/2}$  plot according to Eqs. 2 and 3:

$$M = \frac{4M_m}{h} \sqrt{\frac{t}{\pi}} \sqrt{D_x} \quad \dots 3$$

$$D_x = \pi \left( \frac{h}{4M_m} \right)^2 (slope)^2 \quad \dots 3$$

where  $M_m$  = equilibrium water content,  $D_x$  = diffusivity,  $t$  = time (s) and  $h$  = sample thickness (m).

### **3. RESULTS AND DISCUSSION**

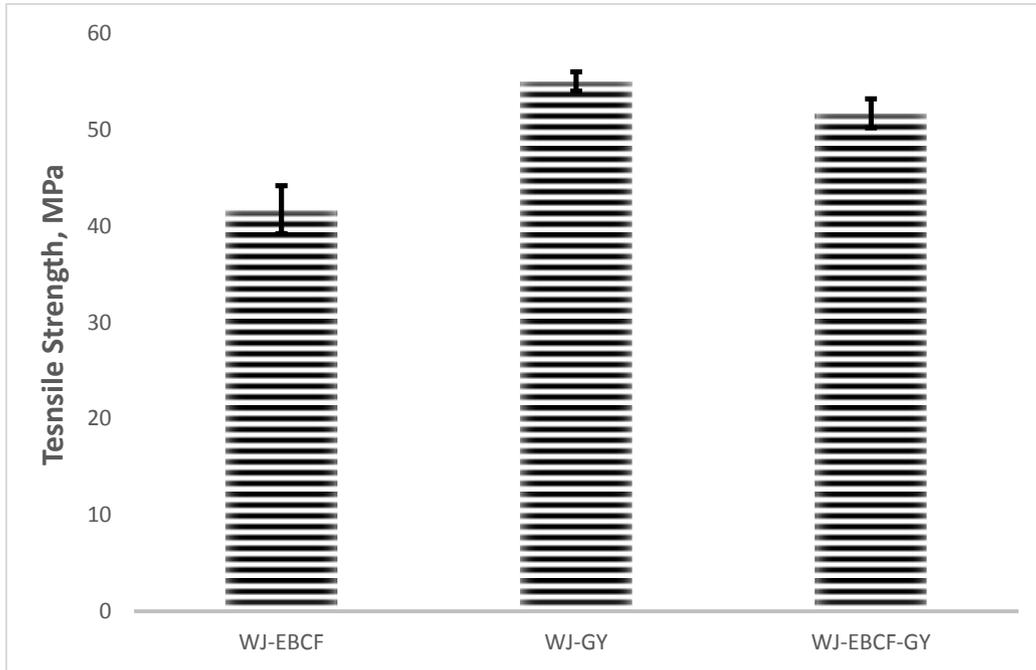
#### **3. 1. Mechanical and electrical properties**

In present work mechanical and electrical properties of the composites of EBCF are compared with that of commercial resins (araldites). For comparison purpose, the % change in properties with respect to WJ-GY and JF-GY was determined. Tensile strength, flexural strength, flexural modulus, impact strength and Barcol hardness of the white jute and jute felt fiber reinforced composites are presented in Figs. 1-5, respectively. Both white jute and jute felt composites of EBCF and araldites showed good mechanical properties. As compared to WJ-GY, WJ-EBCF showed somewhat low tensile strength (-24%), impact strength (-24.8%), flexural modulus (-10%); and comparable flexural strength (-0.8%) and slightly improved Barcol hardness (+5.7%). Similarly WJ-EBCF-GY also showed slightly low tensile strength (-6%), flexural strength (-5.3%), flexural modulus (-5%) and slightly improved impact strength (+2.4%) and Barcol hardness (+2.8%).

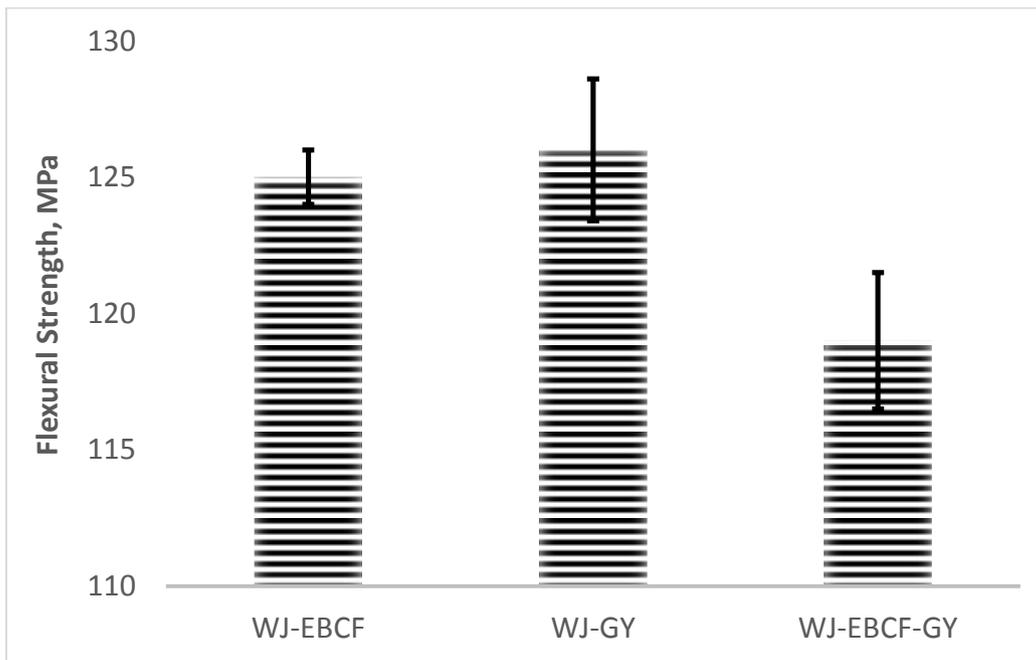
As compared to JF-GY, JF-EBCF showed somewhat low tensile strength (-34.1%), flexural strength (-6%), flexural modulus (-4.5%), impact strength (-3.6%) and slightly improved Barcol hardness (+3.4%). JF-EBCF-GY showed somewhat improved tensile strength (+6.1%), impact strength (+11.9%) and Barcol hardness (+6.7%), while flexural strength (-3.3%) is slightly decreased as compared to JF-GY. In accordance to law of additivity both hybrid composites showed change in corresponding mechanical properties. Observed variation in properties is mainly due to different nature of resins and their chemical constitution as well different nature of reinforcing fibers. For engineering application of the material scratch and wear resistance are very important. International Cast Polymer Alliance (ICPA) [31] has recommended Barcol hardness between 45 and 65 for scratch and wear resistant. A lower number indicates an under cured material, while higher number indicates too brittle material. Surface hardness depends on the resin, concentration of filler materials and other factors. Barcol hardness values of the composites are below the recommended by ICPA so they cannot be used as scratch and wear resistant engineering materials.

Observed good mechanical properties of the white jute and jute felt composites is mainly due to good interfacial adhesion and crosslink density, nature of two resins and their different chemical structure and also nature of jute fibers used in the composite preparation. The main disadvantage of hydrophilic jute fiber is its poor compatibility with hydrophobic matrix materials (EBCF and araldites), which lead to the formation of weak interfaces and hence poor mechanical properties of the composites. Other important disadvantages of the natural fibre composites are high sensitivity towards water and the relatively poor thermal stability. Electric strength and volume resistivity data of white jute and jute felt reinforced composites are presented in Figs. 6 and 7, respectively. WJ-EBCF and WJ-EBCF-GY; and JF-EBCF and J-EBCF-GY showed practically comparable electric strength and volume resistivity with little variation as compared to WJ-GY and JF-GY, respectively. Here also law of additivity is observed in case of hybrid composites.

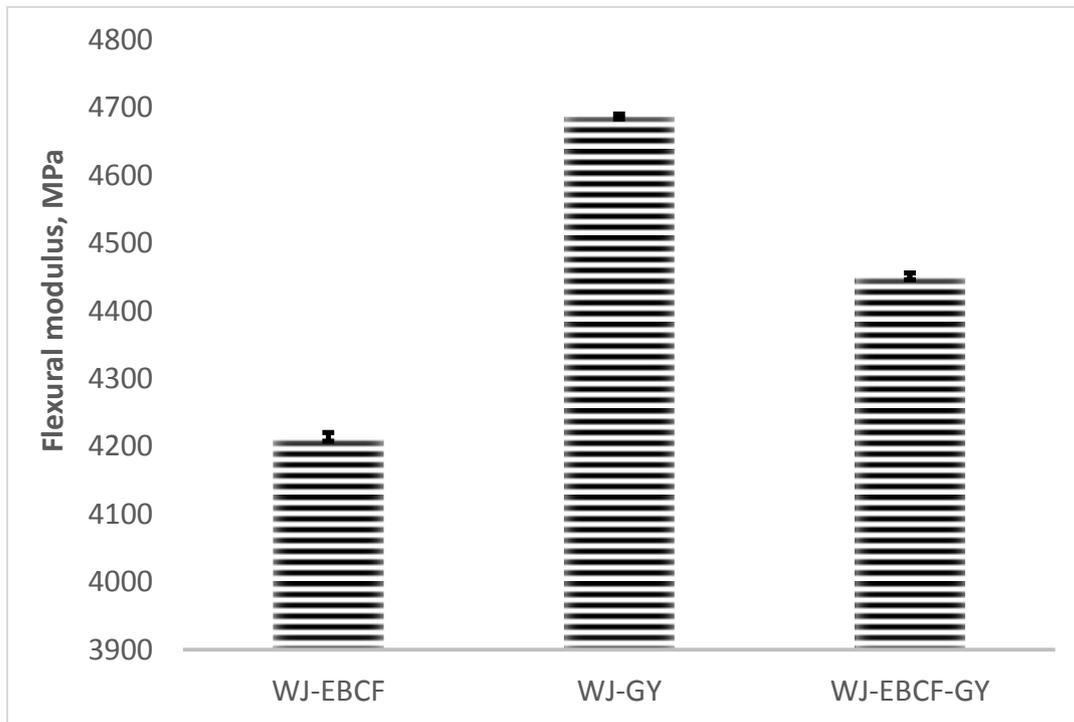
White jute based composites showed better mechanical and electrical properties than those of jute felt based composites mainly due to different chemical, physical and mechanical properties of white jute and jute felt fibers.



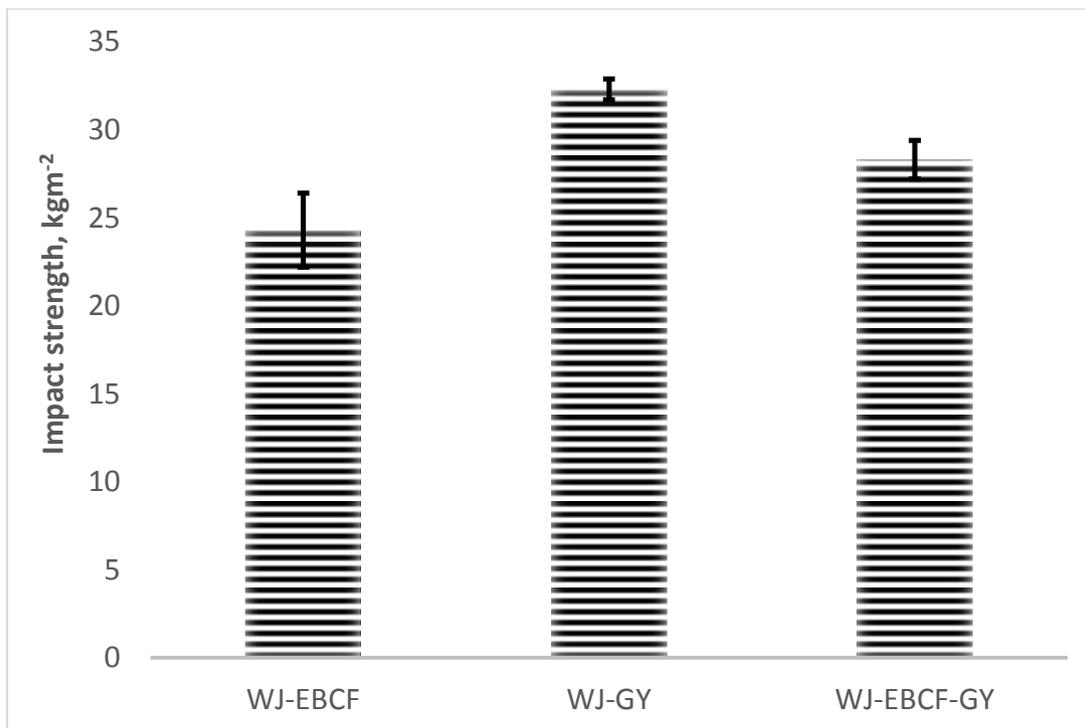
**Figure 1.** Comparative tensile strength of white jute and jute felt fiber reinforced composites.



**Figure 2.** Comparative flexural strength of white jute and jute felt fiber reinforced composites.



**Figure 3.** Comparative flexural modulus of white jute and jute felt fiber reinforced composites.



**Figure 4.** Comparative impact strength of white jute and jute felt fiber reinforced composites

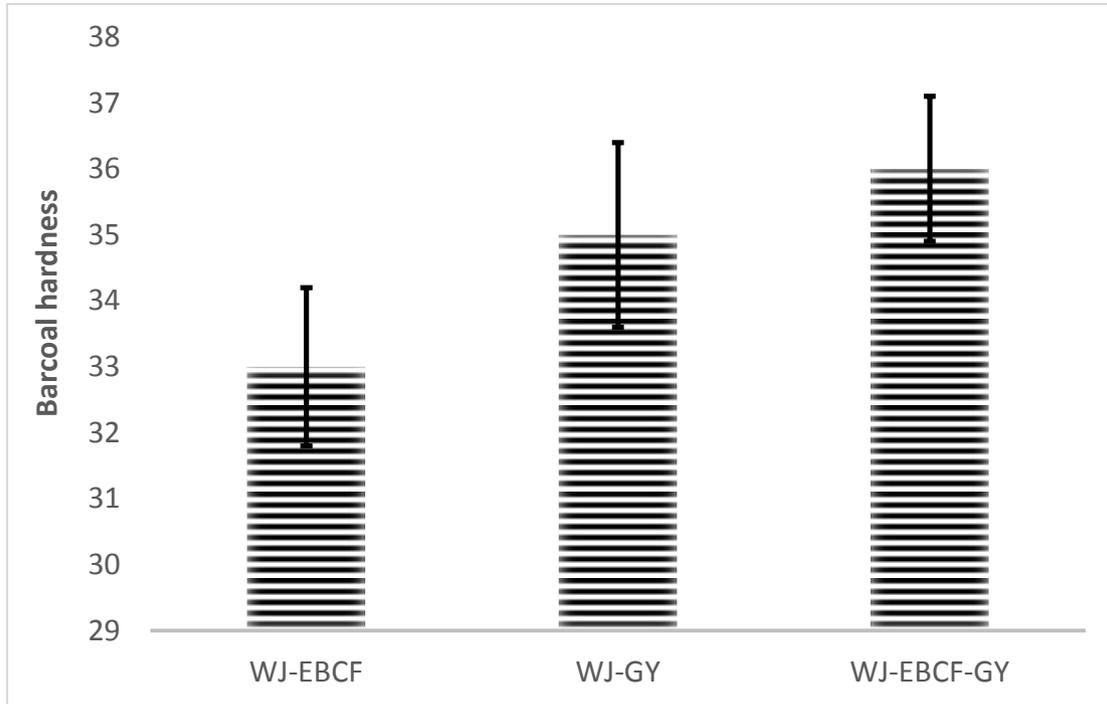


Figure 5. Comparative Barcol hardness of white jute and jute felt fiber reinforced composites

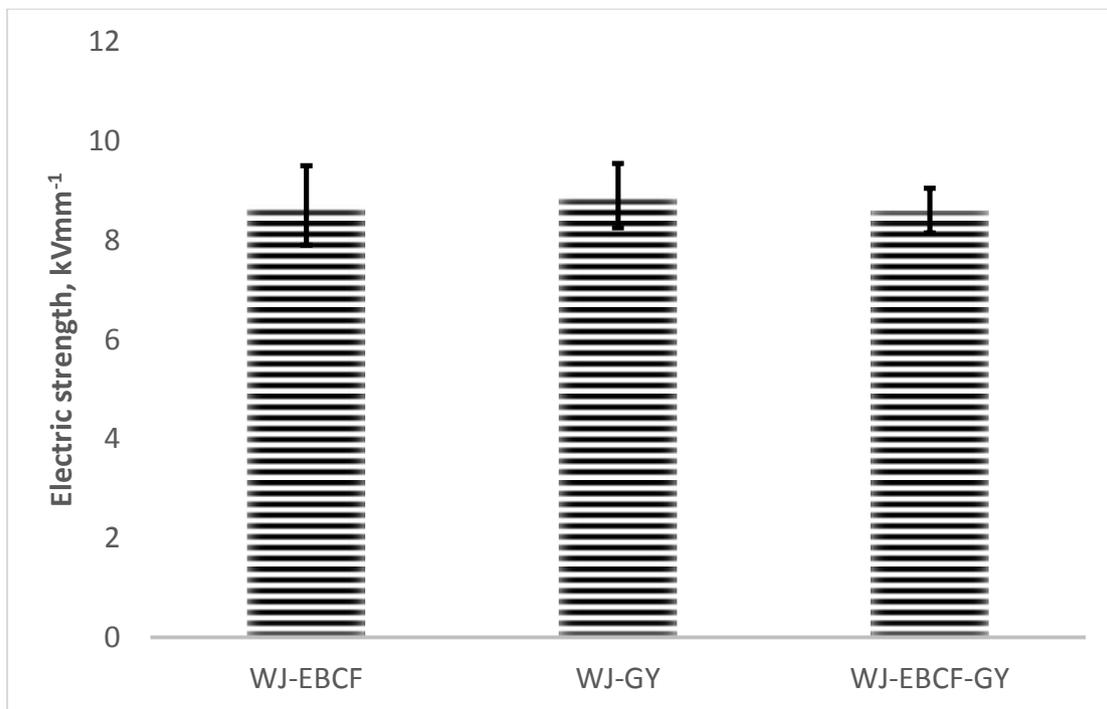
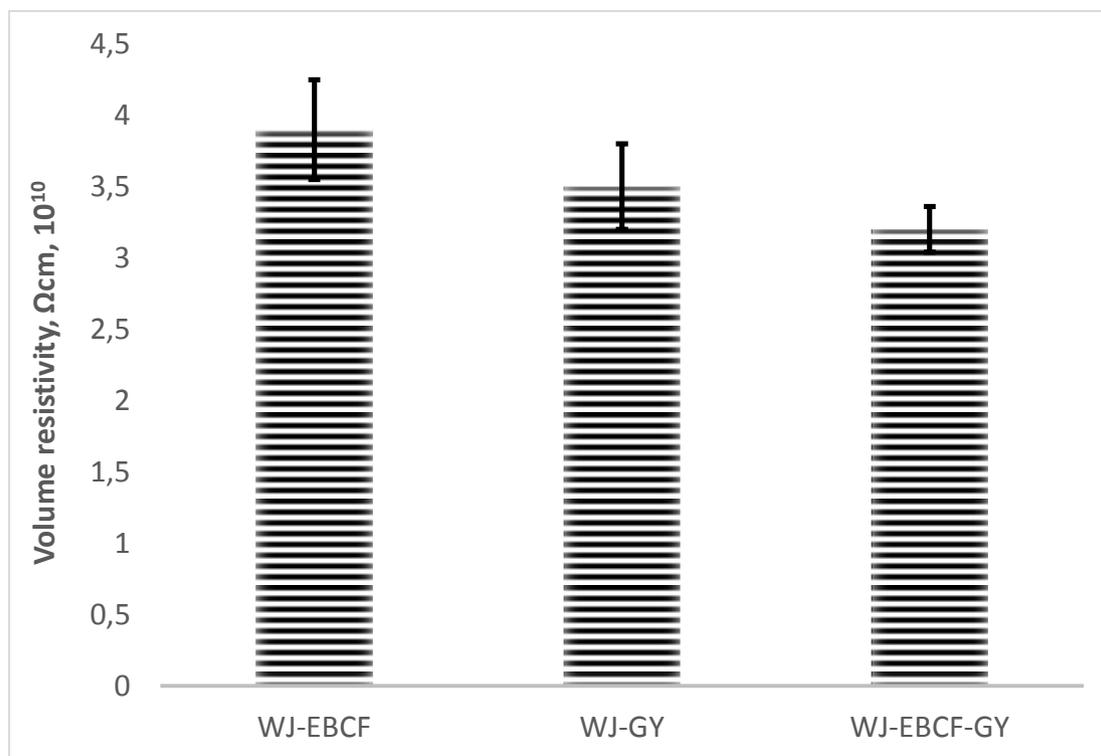


Figure 6. Comparative electric strength of white jute and jute felt fiber reinforced composites



**Figure 7.** Comparative volume resistivity of white jute and jute felt fiber reinforced composites.

Good mechanical and electrical properties of the composites signified their industrial importance for low load bearing housing, electrical and electronic applications. Fairly good mechanical and electrical properties of EBCF composites in comparison with araldite composites signified industrial utility of EBCF.

#### 4. WATER ABSORPTION

The percentage water absorbed by the composites with the passage of time at 30 °C is shown in Figs 8 and 9. The % water absorption increased with time and remained practically constant, when equilibrium was established. The % water absorption after 24h, equilibrium water content and equilibrium time for all the composites are reported in Table III. White jute and jute felt fiber reinforced composites showed practically comparable equilibrium water absorption (+14.4 to +15.8%) and equilibrium time (456h). The composites showed excellent hydrolytic stability. Observed variation in water absorption in white jute and jute felt based composites is +1 to +3% and -4 to -7%, respectively. This is mainly due to different chemical structures of the resins, cross link density and different nature of the fibers used.

Cellulose is the main component of jute fibers and the elementary unit of a cellulose macromolecule is anhydro-d-glucose, which contains three hydroxyl (--OH) groups. These hydroxyl groups form intramolecular and intermolecular hydrogen bonds and also with hydroxyl groups from moist air. The increasing water absorption is due to the higher hydrophilic nature of the jute-fiber as compared to the matrix and capillary effect.

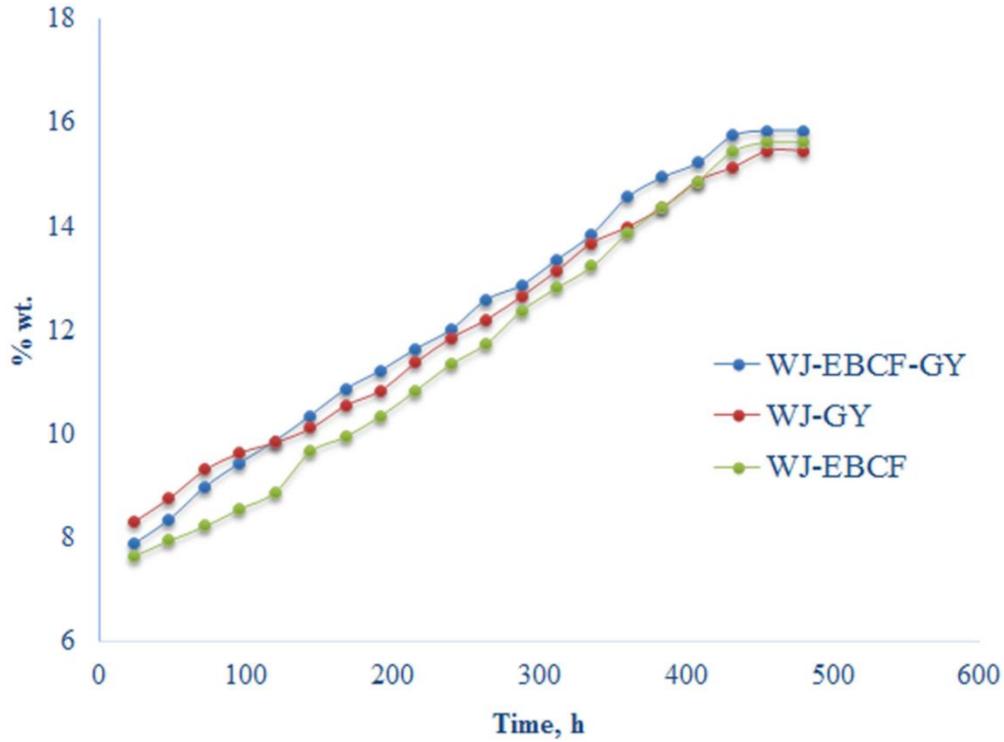


Figure 8. The plots of % water absorbed against time at 30 °C for white jute fiber reinforced composites.

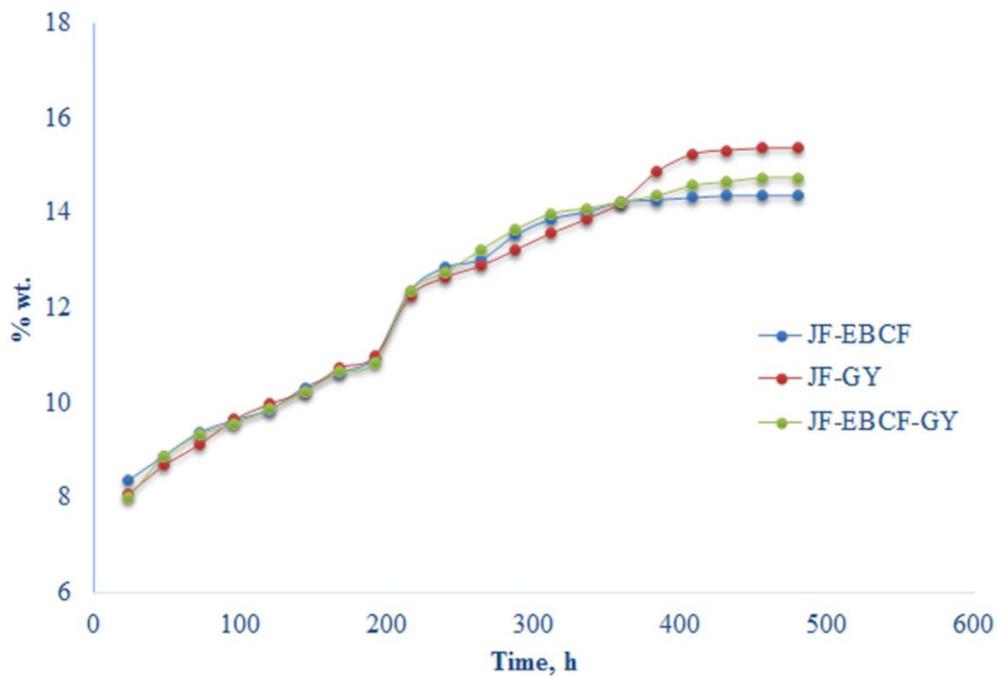


Figure 9. The plots of % water absorbed against time at 30 °C for jute felt fiber reinforced composites.

The hydroxyl groups of cellulose molecule attract water molecules through hydrogen bonding, which in turn leads to moisture build-up in the cell wall that appears as fiber swelling [32]. The swelling tendency of jute fibers in the composites with restrictions from the polymer matrix can exert an internal pressure onto the matrix. This internal pressure leads to internal stress in the matrix, and if the internal stress becomes high enough, it may cause micro-cracks in the matrix [24]. Water absorption reduces mechanical properties of the polymer matrix, which is another reason for the formation of microcracks in the matrix [32].

Water absorption in polymeric composites is shown to be Fickian as well as non-Fickian in character. Viscoelastic nature of polymers and cracks are responsible for non-Fickian diffusion. Water absorption continues till the cell walls are saturated with water. Beyond saturation point, water exists as free water in the void structure leading to delamination or void formation [33]. Absorbed water leading to weakening of interface and accelerates delamination and decreases the strength of the composites [34]. Absorbed water causes hydrolytic degradation of both matrix and interface during service [35]. Formation of voids and blistering causes high water absorption in the composites [36,37].

The diffusivity of the composites in water is reported in Table III. WJ-EBCF (+73.6%) showed high diffusivity, while WJ-EBCF-GY (-19.5%) showed low diffusivity as compared to WJ-GY. High diffusivity in WJ-EBCF may be due to formation of microcracks. Both JF-EBCF (-56.5%) and JF-EBCF-GY (-28.2%) showed considerably low diffusivity as compared to JF-GY due to different nature of the two resins and molecular architecture.

**Table III.** Water absorption data of white jute and jute felt composites.  
(The % change relative to WJ-GY/JF-GY).

Property	WJ-EBCF	WJ-GY	WJ-EBCF-GY	JF-EBCF	JF-GY	JF-EBCF-GY
Thickness, mm	6.47	6.64	5.68	5.33	7.36	6.34
% Water absorption 24h	7.9 (-5.3)	8.3	7.7 (-8)	8.4 (3.3)	8.1	8.0 (-1)
% Equilibrium water absorption	15.8 (2.6)	15.4	15.6 (1.2)	14.4 (-6.5)	15.4	14.7 (-4)
Equilibrium water absorption time, h	456	456	456	456	456	456
Diffusivity $D_x$ , $m^2 s^{-1}$ , $10^{-13}$	12.5 (73.6)	7.24	5.99 (-19.5)	5.69 (-56.5)	13.1	9.44 (-28.2)

The water absorption or moisture diffusion in polymer composites is governed by different mechanisms such as diffusion of water molecules into the gaps between resin molecular chains [24] diffusion of water molecules into the structure of fibers and making hydrogen bonding with hydroxyl group of cellulose molecules [32] migration of water molecules into gaps and flaws at the fiber/matrix interface due to capillary action [24,32] and capillary transport into microcracks in the matrix arising due to swelling of fibers [24].

## 5. CONCLUSIONS

White jute and jute felt based fiber reinforced composites of EBCF and araldites showed good mechanical and electrical properties and excellent hydrolytic stability. WJ-EBCF and JF-EBCF showed somewhat low mechanical properties in comparison to WJ-GY and JF-GY. Hybrid composites WJ-EBCF-GY and JF-EBCF-GY showed comparable studied properties as those of WJ-GY and JF-GY. White jute based composites showed somewhat better mechanical and electrical properties than those of jute felt based composites mainly due to different nature of reinforcing fibers, matrix materials and interfacial adhesion. The composites may find their applications for low load bearing housing, electrical, electronic and marine applications. On the basis of comparative study of EBCF and araldite composites, it is observed that EBCF find its potential utility for commercial applications in fiber composites.

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