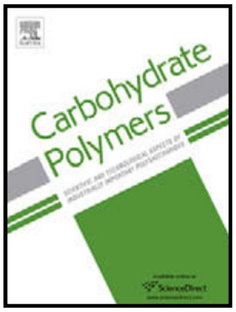

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PII: S0144-8617(17)30553-2
DOI: http://dx.doi.org/doi:10.1016/j.carbpol.2017.05.036
Reference: CARP 12322

To appear in:

Received date: 10-3-2017
Revised date: 20-4-2017
Accepted date: 11-5-2017

Please cite this article as: & Das, Sekhar., Mechanical properties of waste paper/jute fabric reinforced polyester resin matrix hybrid composites.*Carbohydrate Polymers* http://dx.doi.org/10.1016/j.carbpol.2017.05.036

Mechanical properties of waste paper/jute fabric reinforced polyester resin matrix hybrid composites

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Highlights

- Unshared waste paper/jute based composite fabrication process is summarized.
- Physicochemical characterization of reinforcing material is presented.
- Mechanical properties of composites are evaluated.

Abstract

Hybrid composites were prepared with jute fabric and un-shredded newspaper in polyester resin matrix. The experiment was designed 1:2 weights ratio jute and unshredded newspaper to have 42 (w/w)% fibre content hybrid composites and two different sequences jute/paper/jute and paper/jute/paper of waste newspaper and jute fabric arrangement. Reinforcing material is characterized by chemically, X-ray diffraction methods, Fourier transform infrared spectroscopy and tensile testing. The tensile, flexural and interlaminar shear strength and fracture surface morphology of composites were evaluated and compared. It was found that tensile and flexural properties of the hybrid composite are higher than that of pure paper-based composite but less than pure woven jute composite. The hybridization effect of woven jute fabric and layering pattern effect on mechanical properties of newspaper/woven jute fabric hybrid composites were studied. The test results of composites were analyzed by one-way ANOVA ($\alpha = 0.05$), it showed significant differences among the groups.

Keywords: Hybrid composites; Tensile properties; Flexural properties; Waste newspaper; Jute fabric

1. Introduction

In recent years, researchers have great interest to develop environment-friendly and cost-effective polymer matrix composites (Khan et al., 2010; Thakur et al., 2014). Implementation of new laws by developing countries and increasing pressure from environmental activists lead the scientists to develop new environment-friendly composite materials by using natural fibres. Natural cellulosic fibre is a cheap renewable resource abundantly available in nature (Jawaid and Abdul Khalil, 2011; Li and Sain, 2003). Cellulosic fibres have many advantages over synthetic fibres as reinforcement material with low cost, good specific modulus, light weight, lower energy requirement, lower pollutant emissions, wide availability, biodegradability, eco-friendly renewable natural resource (Saba et al., 2016; Das et al., 2015). Several other disadvantages such as high moisture absorption, incapability with hydrophobic resins, poor dimensional stability, poor wettability, ageing rapidly at moderately high temperature etc restrict its use in high-end applications. Some chemical, physical, and surface treatments may also be able to eliminate these problems which are described in the literature (Corrales et al., 2007, Dash et al., 2000). Among all cellulosic fibre, lignocellulosic fibres are widely used as reinforcement material which has been used as reinforcing materials for over 3000 years.

Jute is one of the cheap and abundantly available lignocellulosic fibre which is suitable as reinforcing material. Cellulose molecule is the basic element of jute fibre, long cellulosic fibrils embedded in hemicelluloses and lignin matrix to form ultimate jute cell. Individual jute cell is connected together by lignin so as to form a long filament (Joshi et al., 2004, Das and Bhowmick, 2015). Worldwide pulp and paper making industries produce around 406.5 million tons of paper and paperboard, in 2014 (RISI, 2015) which is used by the consumers of various countries. Waste paper is a good source of cheap cellulosic fibre in the form of compressed partially oriented network structure. Along with short length cellulosic fibre newspaper also contains a trace amount of adhesives, printing ink, fillers and loading material. Waste paper, as one of the largest solid waste materials, some part of it is used by paper mills to reprocessing it into new paper products. (Merrild et al., 2008). Proper recycling of waste paper can reduces environmental burden by decreasing the flow of waste papers to landfills. Further value addition and other suitable uses of waste papers may reduce the disposal problem (Kalpana et al., 2009; Lee et al., 2013). The most popular paper recycling process is to conversion of waste paper into new paper. Pulping process of waste paper deteriorates the strength of the fibre result inferior quality of paper than the paper made from virgin fibers (Bi and Huang, 2014).

In this regard application of some polymeric binders with nano particle to improve the mechanical and functional properties of regenerated paper fibre based composites for packaging application have been described in literature (Nassar and Youssef, 2012a; Youssef et al.2012b;Youssef et al.2013; Youssef et al. 2016).

Some of the other applications of waste paper stated in literature are bioconversion of waste paper to ethanol, production of methane and enzymatic production of glucose etc (Wayman et al., 1992, Yen and

Brune, 2007, Vynios et al., 2009). As wastepaper, is a cheap and easily available compressed form of cellulosic fibre network, it has a potential to be used as reinforcing material for production of composite. In this regard, Das et al. prepared composite using unshredded newspaper as reinforcing the material in the polyester resin matrix. They prepared 25, 33 and 48 (w/w)% fibre loading composites by hand layup technique. They reported that 48% (w/w) fibre content composite yielded 70 MPa tensile strength and 6 GPa modulus in the fibre direction (Das et al. 2015).

The incorporation of two or more reinforcing materials in a single matrix is called hybrid composites. The mechanical properties of hybrid composites are a weighted average of the individual components. In hybrid composite the reinforcement materials complement the advantages of one type of fibre over the other type. The mechanical properties of the hybrid composites depends on the properties of fibre, the aspect ratio of fibre content, orientation of fibre, length of individual fibre, fibre to matrix interface bonding, extent of intermingling of fibres, arrangement of both the fibres and also on failure strain of individual fibres. Optimum hybridization results are acquired when the fibres are highly strain compatible (Munikenche Gowda et al., 1999, Nunna et al., 2012). Some researchers used jute along with oil palm, glass, polypropylene, sisal and coir etc fibre to produce hybrid composite. Ahmed &Vijayaragan prepared hybrid laminates of woven jute and glass fabric in polyester resin matrix for evaluation of in-plane elastic properties under tension. They predicted elastic properties of hybrid composite by using rule of hybrid mixture and classical lamination theory models and concluded that the theoretical predicted results had good agreement with actual results with a deviation up to about 20% (Ahmed and Vijayaragan, 2006). Jawaid et al. studied the chemical resistance, void content and tensile properties of trilayer hybrid composites of oil palm empty fruit bunches and jute fibres for keeping oil palm as skin material and jute as the core material and vice versa in epoxy resin matrix (Jawaid et al., 2011). Gujjala and his team produced four piles and five types of hybrid laminates using woven jute and E-glass mat by hand lay-up technique in epoxy resin matrix. They investigated tensile, flexural and interlaminar shear properties of these five types of composites. They reported that the maximum tensile and flexural strength obtained composite had glass/jute/glass and jute/glass/jute/glass sequences keeping the same volume fraction percentage 17.5 and the maximum interlaminar shear strength is observed for the composite prepared with glass fiber as extreme layers (Gujjala et al., 2014). Ramesh et al. studied mechanical properties such as tensile strength, flexural strength and impact strength of sisal–jute–glass fiber reinforced polyester matrix hybrid composites. They used chopped sisal and jute fibers of 30 mm and glass fibre layers to produce five layers hybrid composite in which glass fiber layers are fixed in top middle and bottom of the specimen (Ramesh et al., 2013). Saw et al. prepared trilayer hybrid composites with two different sequences of fibre mat arrangements such as jute/coir/jute and coir/jute/coir using chopped jute and coir fibre with epoxy novolac resin matrix keeping the volume ratio of matrix to fiber is 70:30. They investigated the thickness swelling, water absorption, mechanical properties and effect of layering pattern on the composite property of these tri-layers hybrid composites (Saw et al., 2014). A group of research team, Ranganathan et al. manufactured jute-viscose hybrid composite using direct long fibre thermoplastic extrusion followed by compression moulding in the polypropylene matrix. They studied fracture toughness, fracture energy and fatigue properties of these composites. They reported that the fracture toughness and the fracture energy of the 30 wt.% jute-polypropylene composites were improved 133% and 514%, respectively. They found that addition to 10 wt% viscose fibres improved three times higher fatigue life compared with the unmodified jute composites (Ranganathan et al., 2016).

To the best of our knowledge, no research work has been reported in the literature on hybrid composites of woven jute and unshredded waste paper in the polyester resin matrix. The present work deals with the hybrid composites fabrication process and study of the mechanical properties of these composites in terms of tensile and flexural and interlaminar shear strength. The effect of hybridization of woven jute fabric and layering pattern effect on mechanical properties of newspaper/woven jute fabric hybrid composites were studied.

2. Materials and Methods

2.1. Materials

The waste newspaper grams per square meter (GSM) of 44 were obtained from local market of Mumbai, India. Jute fabric Grams per square meter (GSM) of 351 was purchased from local market of Kolkata, India. Unsaturated polyester resin for general purpose manufactured by Kanoria chembond Pvt. Ltd. was purchased from Mumbai’s local market. Cobalt octoate (accelerator) and methyl-ethyl-ketone peroxide (catalyst) manufactured by Triveni Interchem Pvt. Ltd.was also used, and these were purchased from Mumbai.

2.2. Composite Fabrication Process

Hand lay-up technique was adopted to prepare composites samples. A steel mold of 300×300 × 5 mm3 was used for fabricating the composite sample. For quick and easy removal of the composite samples, a mold release polyester sheet was put over the smooth steel plate. The unshredded newspaper sheets were marked with a marker to indicate machine and cross direction. The papers layers were laid in the alternative direction to compensate fibre orientation effect on mechanical properties of composite.

Reinforcing material, the newspaper is a compressed structure so small size holes were created in the paper by piercing to facilitate the resin flow throughout the paper.

The unsaturated polyester resin was thoroughly mixed with 2% (over the weight of resin) accelerator and 2% (over the weight of resin) catalyst. Jute fabric and newspaper layers were impregnated in mixed resin solution. The mixed resin coated samples were even out by rolling technique. Proper care was taken to avoid the formation of entrapped air in the composite samples; a smooth steel roller was used to even out the resin, removing excess resin and any entrapped air into it. For compression moulding, resin coated samples were put in a hydraulic press under a actual pressure of 1.1 kg.cm-^{2} at room temperature for 40 minute. After compression, the solid composite samples were taken out and post cured at 80°C for 4 hours. For making hybrid composite 1:2 weights ratio un-shredded newspaper and jute fabric were used. Four different types of composites such as pure paper, pure jute, jute/paper/jute and paper/jute/paper were fabricated and each composite samples having the same fibre content 42 (w/w) %. The composite manufacturing process is shown in Figure 1. The pure jute, pure paper, jute/paper/jute and paper/jute/paper arrangement composite samples were labeled as J, P, JPJ and PJP respectively.

3. Testing

3.1 Characterization of reinforcing material

3.1.1 Chemical analysis of newspaper: Alphacellulose content of the newspaper was carried out in accordance with TAPPI T 429 cm-10.

3.1.2 Determination of Moisture Content

Moisture content of the jute fabric and newspaper was determined according to ASTM D 2495-01 and TAPPI T412 test method.

3.1.3 Tensile Test

Tensile strength of the jute fabric sample in warp as well as weft direction was evaluated in an Instron testing system in according to ASTM D5035. Tensile strength of the newspaper was carried out in accordance with TAPPI T 494 om-01 standards. For this purpose two test pieces were cut from the specimen parallel to the other perpendicular to the same edge of the specimen.

3.1.4 Fourier transforms infrared spectroscopy analysis of jute fabric and newspaper:

The fourier transform infrared spectroscopy (FTIR) analysis of the jute and newspaper was carried out in a Bruker Alpha-T FTIR spectrometer over the wavelength of 500 to 4000 cm^{-1} using the KBr disc sample preparation method. The FTIR curves are presented in Figure 2.

3.1.5 **X-ray diffraction analysis**

Wide-angle X-ray diffraction (XRD) measurements of jute and newspaper samples were carried out with a X'Pert Pro XRD machine at 40 kV and 30 mA with a copper radiation of 1.54 Å and XRD radial scan ranging from 9° to 40° for jute sample and 4° to 80° for newspaper. The XRD diffraction patterns are presented in Figure 3.

The 2θ values were calculated using the following equation (1)

$$d_{hkl} = \frac{n\lambda}{2\sin\theta} \tag{1}$$

$$\frac{1}{d^2{}_{hkl}} = \frac{1}{\sin^2\beta}\left(\frac{h^2}{a^2} + \frac{k^2\sin^2\beta}{b^2} + \frac{l^2}{c^2} - \frac{2hl\cos\beta}{ac}\right) \tag{2}$$

Where θ is the angle of diffraction, n is an integer, λ is the wavelength of the X-ray, and d_{hkl} is inter atomic spacing for atoms with Miller indices *(hkl),* crystallite dimension in the direction perpendicular to the crystallographic plane hkl. The cellulose-I present in jute and paper exhibited the monoclinic form. For monoclinic crystals, $a \neq b \neq c$ and $\alpha = \gamma \neq \beta = 90°$, where *a, b, c* and α, β, γ are the lattice parameters.

The crystallinity index (*CI*) was measured from the following equation (3):

$$CI(\%) = \frac{A_c}{A_c + A_a} \times 100 \tag{3}$$

Where *CI*, A_c, and A_a are represented the crystallinity index, area under crystalline peaks, and area under amorphous region in XRD curve.

Crystallite size was calculated using following Scherrer equation (4)

$$D = \frac{K\lambda}{\beta \cos \theta} \tag{4}$$

where D, k, λ, β, and θ are respectively, crystallite size, Scherrer constant (0.94) ,wave length of X-rays (1.54 Å), full width of the peak at half maximum (FWHM), and scattering angle of the peak (Cai et al., 2015; Kamal et al., 2015).

4. Characterization of composites:

4.1Tensile and Flexural Test:

Tensile test of composites and polyester resin were performed with ASTM D3039 in an Instron testing system in order to determine the tensile properties. Three point bend tests of composites and polyester resin were performed in an Instron testing system in accordance with ASTM D790 to measure the flexural properties of the polyester resin and composite samples.

4.2 Interlaminar shear strength (ILSS)**:**

The interlaminar shear strength tests were carried out in an Instron testing system in accordance with ASTM D2344-84 to evaluate inter-laminar shear strength (ILSS). The support span/specimen thickness ratio was 5:1 and cross head speed was 2 mm/min.

Five samples from each type of composites and resin were tested and the test result data regarding their mechanical tests were expressed as mean ± standard deviation.

4.3 Scanning electron microscopy analysis

Scanning electron microscopy (SEM) of the newspaper and the tensile ruptured surfaces of composites are performed with a Philips XL 30 scanning electron microscope. Prior to testing, the samples were coated with a thin layer of conducting material (gold/palladium) by using a sputter coater, and the same were examined under the scanning electron microscope with an accelerating voltage of 10 kV.

4.4 Statistical Analysis:

Statistical analysis has been carried out using one-way analysis of variance (ANOVA) and the results are shown in Tables 3 for the difference between the samples regarding tensile strength, tensile modulus, flexural strength, flexural modulus and interlaminar shear strength, respectively.

5. Results and Discussion:

5.1 Physicochemical Characterization of newspaper and jute fabric

Table 1 shows the physicochemical properties of jute fabric and newspaper. Here newspaper of 44 GSM and plain jute fabric 351 GSM has been used for producing a hybrid composite. The jute fabric specifications were plain weave (1/1), same ends/dm and picks/dm of 66, warp tex of 255, weft tex 253 and fabric thickness of 0.70 mm respectively. It was reported in literature that jute contains 64.6% alpha cellulose (Das et al. 1954). The alpha cellulose content of newspaper observed to be 72.5%. Cellulose is the main structural constituent of plant fibre which provides mechanical properties of fibre so higher cellulose content indicates higher mechanical properties and fibre is the main load bearing component in fibre composite. Jute has been used successfully as reinforcement material for different kinds of thermosets and thermoplastics resins (Bledzki et al. 1999). The tensile breaking strength of dry jute fabric in warp and weft direction shows 670 N and 660 N respectively. Fabric strength is related to fibre strength but several others factors such as fabric count, the weave design, yarn count and yarn irregularity etc also relate to it. The tensile strength of the newspaper is measured in two different direction which are perpendicular to each other's viz machine and the cross direction. The newspaper tensile strength observed in the machine direction was 26.2 MPa whereas in the cross direction it shows the strength was around 7 MPa. It has been observed from the tensile test that most of the fibres in paper are oriented in machine direction. In the industrial papermaking process, fibres are oriented in machine direction due to hydrodynamic forces. The fibres form hydrogen-bonded network structure. Fibre orientation leads to different mechanical properties in machine direction and in cross direction (Kröling et al., 2014; Karlsson et al., 2010). The moisture content of jute fabric and newspaper was measured and the results are shown in table 1-2. It is observed that jute and paper had moisture content 12.4 and 10.2 respectively. High moisture content of reinforcing material is a major drawback for mechanical properties of the composite. Cellulosic fibres are considered to be hydrophilic in nature due to the presence of hydroxyl group in the cellulose molecules. It also reported in the literature that water molecules tends to attract to hydrophilic groups present in fibres and reacts with a hydroxyl group (-OH) of the cellulose molecules to form hydrogen bonds. The attracted water will act as a separating agent in the fibre-matrix interface which reduces mechanical anchoring and physical molecular attractive force between hydrophilic fibre and hydrophobic resin. Moreover, the absorption and desorption of cellulosic fibre can cause swelling in wet environment and shrinkage in a dry environment this phenomenon leads to debonding, void generation and micro cracking in composite (Nguong et al., 2013).

5.1.1 Fourier transformed infrared spectroscopy (FTIR)

The chemical nature of the reinforcing material was analyzed using FTIR. FTIR analysis of newspaper and jute fabric samples was carried out and the results are shown in Figure 2. The presence of broad band absorbent peak for both paper and jute is observed around 3200–3600 cm-^{1}associated with the -OH stretching of the hydroxyl group of cellulose and intra-hydrogen bond stretching of the absorbed water. The jute and news paper shows peak at 2899 cm-^{1} and 2902 cm-^{1} wave number peaks which associated with the C–H stretching vibrations of methyl and methylene groups in cellulose and hemicelluloses (Hossain et al., 2011). The jute FTIR curve shows peak at 1730 cm^{-1} corresponds to the C=O stretching of hemicellulose and lignin present in jute. The peak detected at 1639 and 1642 cm^{-1} for jute fiber and paper is attributed to the carbonyl group of the acetyl ester in hemicellulose and the carbonyl aldehyde in lignin. The peak 1510 cm^{-1} for jute and 1507 cm^{-1} for paper are observed due to C=O stretching present in lignin as Ketone and carbonyl.

5.1.2 **X-Ray Diffraction Analysis**

An X-ray diffractogram of jute and newspaper samples is shown in Figure 3 and table 2. The diffraction pattern of jute shows three main peaks at 16.55°, 22.35°, and 34.73°. These peaks are attributed to the crystalline structure of cellulose I and are assigned to $[10\overline{1}]$, [0 0 2], and [0 4 0] reflections, respectively. Similarly the diffraction pattern of newspaper shows the crystalline structure of cellulose I peaks at 15.94°, 22.55° and 34.78° and are assigned to $[10\overline{1}]$, [0 0 2], and [0 4 0] respectively (Thygesen et al., 2005). Cellulose I is thermodynamically metastable and can be transformed to either cellulose II or III. Cellulose I has two polymorphs, a monoclinic structure Iβ and a triclinic structure Iα, which coexist in various extent depending on the cellulose structure. The triclinic Iα component is a rare form, whereas Iβ is the dominant portion. The Iα polymorph is metastable and can be changed into Iβ by hydrothermal treatments in alkaline solution (Poletto et al., 2013). It is observed from table that the Iβ unit cell the cell parameters are a =7.80 Å, b = 10.32 Å, c = 7.97 Å and β = 95.41° for jute and a = 8.32 Å, b = 10.28 Å, c = 7.89 Å and β = 93.02° for paper. It is reported in the literature that the patterns for Iβ cellulose samples with preferred orientation along the c-axis. Iβ unit cell dimensions are a = 7.784 Å , b = 8.201 Å , c = 10.380 Å , and γ = 96.55° (French 2014). Further, the crystallinity index of jute and newspaper found to be 64.6 and 62.6 respectively. The crystal size of jute and newspaper samples were calculated by using

Scherrer equation, the crystal size of jute and newspaper samples are 3.18 nm and 4.93 nm respectively. It is reported in literature that microfibriller angle of jute and newspaper sample are 8° and 31.8° (Das, 2017). Crystalinity index and microfibriller angle play significant role on mechanical properties of cellulosic fibre. The tensile strength and modulus of fibres have been proved to be reliant on crystalinity index and microfibriller angle i.e the orientation of the crystalline cellulose. Fibre's mechanical properties are inversely related to microfibriller angle and increases with increase in crystallinity index. Cellulosic fibre selection for reinforcement purpose the two determining factors i.e crystalinity index and microfibriller angle of fibre plays great role on mechanical properties of composite (Mwaikambo, 2009).

-5.2. Tensile Properties of composites:

The tensile properties of a fibre reinforced composite material are predominantly influenced by tensile properties of fibre, fibre/matrix interfacial bonding and fibre loading percentage the aspect ratio of the reinforcement, the orientation of the fibres and the dispersion grade of the fibre into the matrix. (Thomason, 2002; Serrano et al., 2014). It is observed from Fig. 4 that the matrix material polyester resin had a tensile strength of 25.7 MPa and modulus of 0.97 GPa. It is also observed that pure woven jute composite had a higher tensile strength (85.30 MPa) and modulus (3.46GPa) than pure paper reinforced composite (47.45 MPa and 2.62GPa). It is showed that the pure woven jute fabric composite had a higher value of tensile strength and modulus than pure newspaper reinforced composite. The newspaper is made up short length cellulosic fibre which contents high amount of fines. The average fibre length of paper is much lower than jute fibre. The fibre length and length distribution in composite have a major role of composite mechanical properties. The tensile strength of short-fiber composites decreases rapidly as the mean fibre length, decreases. The fibres with a length lower than critical length will contribute to composite modulus but less to the composite strength. The fibre arrangement inside the composite is also an important factor for composite tensile properties (López et al., 2012; Atkinson, 1965; Fu, 1996). Two direction wise tensile strength test results confirmed that the newspaper is an anisotropic material on the other hand jute fibres are arranged in two directions i.e. warp and weft. The SEM analysis confirmed that resin does not penetrate inside the paper fibre which may weaken the physical bonding between fibre and resin. The fibre–matrix interface has an important role in determining the mechanical properties of composite materials. These reasons indirectly indicate that jute fabric may be stronger and stiffer reinforcing material than the newspaper. It is shown from Fig. 4 that hybridization of newspaper with woven jute fibre has resulted in an increase in tensile strength and modulus of the pure paper composite. The strength and modulus of the hybrid composites are greater than that of pure paper composite for both hybrids composite regardless of the different sequence of fibre arrangements such as jute/paper/jute (JPJ) and paper/jute/ paper (PJP). Jute fabric is stronger and stiffer reinforcing material which causes an increase in tensile strength and modulus of hybrid composites. It has been observed that the tensile strength and modulus of JPJ hybrid composite had 16% and 10.7% higher than PJP hybrid composite. A different sequence of fibre arrangement in hybrid composite plays a significant role on mechanical properties of the composite. It is a fact in a hybrid system that the tensile properties will be higher when the strong material is used as the skin, which the main load is bearing component (Sreekala et al., 2002). It is reported that woven fabric is better reinforcing material than nonwoven or mat in terms of tensile properties of composite (Jawaid et al., 2011).

5.3 Flexural Properties of composite:

Fig. 4 shows the flexural properties of the polyester resin, pure jute, and pure paper and hybrid composites. Flexural strength and modulus of composite material are controlled by the mechanical properties of the extreme layer of reinforcement. The concave and convex face of composite experience compressive and tensile stress simultaneously shown in Fig. 1 and most of the materials fail under tensile stress before they fail under compressive stress. The crack begins on the tension side of the beam and slowly propagates in an upward direction. Generally, the flexural modulus is very sensitive to the matrix properties and fibre matrix interfacial bonding. Average values for the flexural strength and modulus of the pure jute composites are found to be the highest and the lowest in neat polyester resin sample. Pure jute and paper composite's flexural strengths are 102 MPa and 73MPa and modulus 5.27GPa and 4.46 GPa. It is observed from the table that JPJ layering pattern composites have 18% and 15% more flexural strength and modulus than PJP composites. This increase of flexural strength and modulus of the JPJ hybrid composites may be attributed to the stronger skin of hybrid composite. The addition of jute fabric in an outer layer, the flexural strength and modulus increases, due to increased resistance to shearing. Some researchers have done the similar type of study using two or more fibres as reinforcing the material. Idicula et al. have prepared sisal/banana tri-layer composites in the polyester resin matrix and reported that sisal/banana/sisal show better flexural strength compared to banana/sisal/banana because of high strength of sisal fibre as the outer layer (Idicula et al., 2005). Jawaid et al. studied flexural properties of oil palm empty fruit bunches/jute fibre reinforced epoxy hybrid composites with a different sequence of fibre mat arrangement. They reported that stronger fibre in outer layer shows better flexural strength and modulus than stronger fibre in the core (Jawaid et al., 2010).

5.4 Interlaminar shear strength:

Short beam shear test is an effective process for explaining interfacial adhesion property of a composite. It is a 3-point short span length bend test, which generally creates failure by inter-laminar shear. A large span length in bending test increases the maximum normal stress without affecting the inter-laminar shear stress and thereby increases the tendency for longitudinal failure. Inter-laminar shear failure initiated and propagated only when the span length is short. Maximum shear stress is observed in a beam at the mid-plane. So, in short, the shear test of failure determination consists of a crack running along the mid-plane of the beam so that crack plane is parallel to the longitudinal plane. Interlaminar shear strength of the composite mainly depends on the adhesion strength between fibre and matrix, the fibre volume fraction and fibre orientation. The failure of the composite sample occurs due to bending, weak interfacial bonding, breaking of fibres, a lack of proper penetration of resin into the fibres and partial pull-out of fibres (St John et al., 1998; Romanzini et al., 2013).

Interlaminar shear strength (ILSS) properties of the composite samples are reported in the Fig. 4 It is observed that pure jute composite had higher interlaminar shear strength (12.8 MPa) than pure paper composite (7.84). Resin does not properly penetrate into paper fibre; the SEM image confirmed it which may be the cause of lower interlaminar shear strength of pure paper composite than jute fabric composite. It is also observed that JPJ layering pattern composites had 12% more interlaminar shear strength than PJP composites. This increase of interlaminar shear strength of the JPJ hybrid composites may be attributed to the stronger skin of hybrid composite.

5.5 Scanning electron microscope (SEM):

Scanning electron microscope used to study the tensile fracture zone of jute and paper composite samples. Fig. 5 presents the SEM images of newspaper (a) and rupture zones in a tensile specimen of the paper composite (b) and jute composite (c) sample after tensile test. SEM (a) depicts the newspaper's fibres are bonded with each other and pits are observed on the fibre surface. It is observed from SEM (b) that paper and resin are arranged separate layers in a paper composite. It can also be seen that the thickness of the resin layers is similar throughout the composite cross-section. Also, there may be a good bonding among the fibres in the paper. It is clearly observed that resin does not penetrate inside the fibre network in a paper. Fibre-matrix debonding, matrix crack and fibre pull out are observed in a paper composite. SEM (c) depicts the fracture of fibre with little or no pull out of jute fibre. This may be because of good physical bonding between fibre and resin. Fibre-matrix bonding plays an important role in the mechanical properties of the composite. To achieve maximum utilisation of the fibre strength in the composite very good interfacial bond is required for effective stress transfer.

5.6 Statistical Analysis:

One-way analysis of variance (ANOVA) for test results of tensile, flexural and interlaminar shear strength of the composite is carried out and the results are shown in Tables 3. The ANOVA analysis showed the variance into two components: a between-group component and a within-group component, the F-ratio is the ratio of variation between groups to variation within groups. The F-ratio, of tensile strength and modulus, are 38.504 and 61.957 respectively. The test result shows P-value of the F-test for both the results is less than 0.05. There is a statistically significant difference between the mean tensile strength and modulus from one level of the composite to another at the 95.0% confidence level. The F-ratio of flexural strength, modulus and interlaminar shear strength observed to be 42.523, 20.306 and 16.223 respectively. The test result shows P-value of the F-test for the flexural strength, modulus and interlaminar shear strength results are less than 0.05. There is a statistically significant difference between the mean flexural strength, modulus and interlaminar shear strength from one level of the composite to another.

6. Conclusion:

The main conclusions drawn from this study are as follows:

The unshreded waste newspaper is a good reinforcing material and it can successfully be used with jute fabric to produce a hybrid composite. The test results show that hybrid composites have higher tensile and flexural properties than pure paper composites. Different layering sequence exhibit a significant effect on the tensile, flexural and interlaminar shear strength properties of hybrid composites. Hybrid composites with both outer skins jute fabric show better the tensile and flexural properties than paper outer layer hybrid composites. The maximum and minimum ILSS value are observed for the pure jute and PJP composites. Fractured surface SEM image of pure paper composite shows that paper and resin are arranged separate layers in paper composite and resin does not penetrate inside the fibre network in the paper. One-way-ANOVA analysis showed that the significant differences of test results obtained from different composites.

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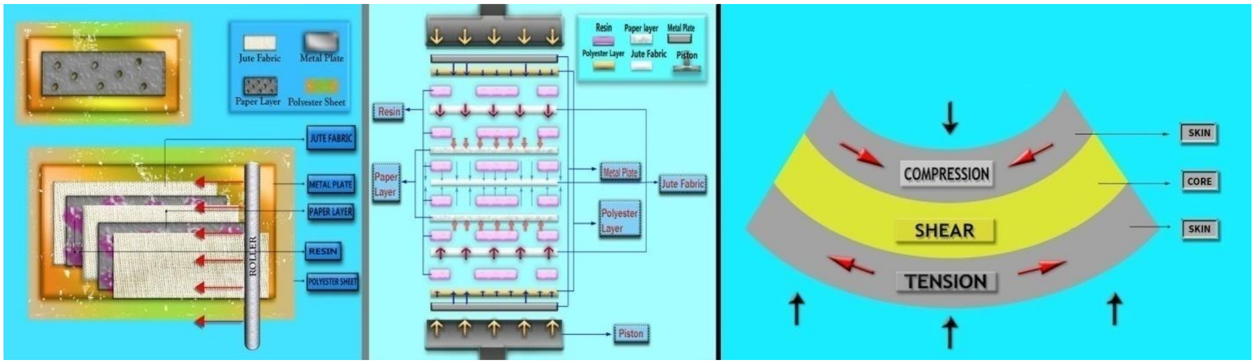

Figure 1: (Left) Jute-newspaper based hybrid composite fabrication process, (Right) The bending geometry of hybrid composite under a bending load

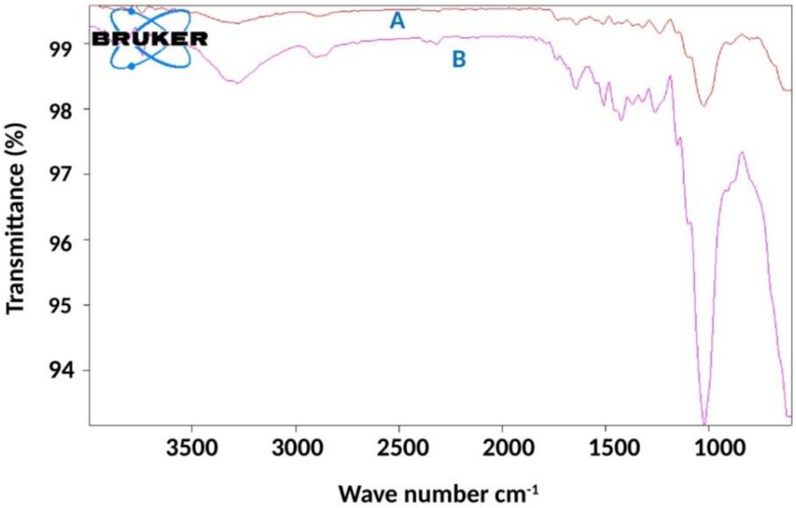

Figure 2: Fourier transform infrared spectroscopy (FTIR) analysis of jute (A) and paper (B)

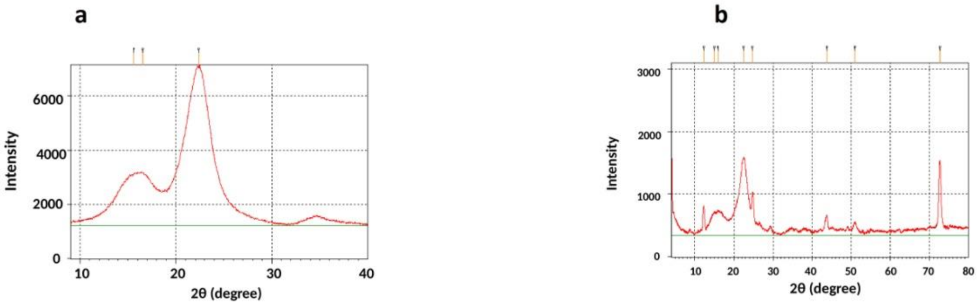

Figure 3: X-ray diffraction spectra of jute (a) and newspaper (b)

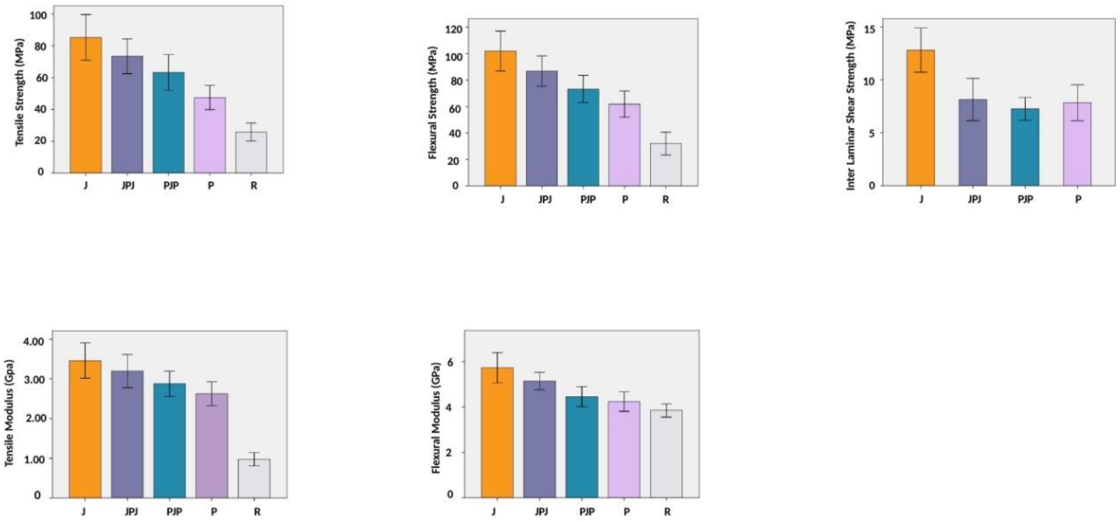

Figure 4: Comparison of tensile, flexural, interlaminar shear strength properties of pure woven jute (J), pure paper (P) and hybrid composites (JPJ, PJP) at 42% fibre content by weight.

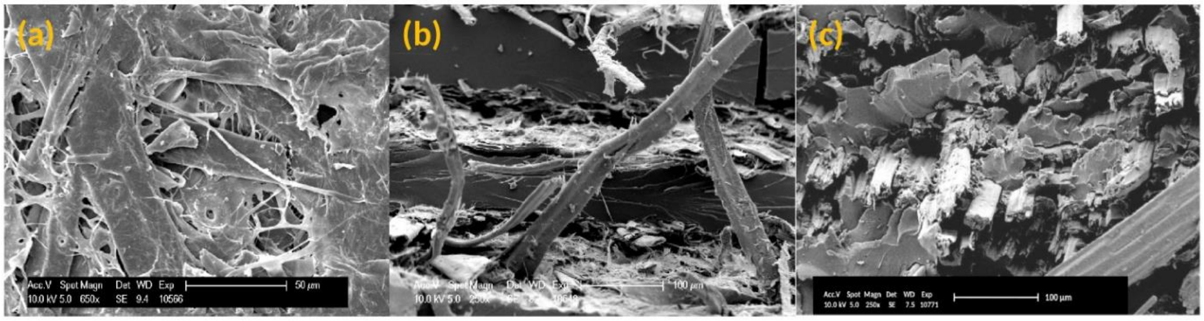

Figure 5: Scanning electron microscopy (SEM) image of newspaper (A), tensile fracture sample of paper composite sample (B) and tensile fracture sample of woven jute composite sample (C).

Table1 Physicochemical Properties of newspaper and jute fabric

Properties of Newspaper	
Alpha cellulose %	72.5
Crystallinity Index	62.6

Grams per square meter (GSM)	44
Tensile strength along fibre direction (MPa)	26.25±1.76
Tensile strength along cross direction (MPa)	7.04±1.250
Moisture Content (%)	10.2
Properties of Jute fabric	
Alpha cellulose %	64.6
Crystallinity Index	64.6
Grams per square meter (GSM)	351
Tensile strength at break along warp direction (N)	670
Tensile strength at break along weft direction (N)	660
Ends per dm	66
Picks per dm	66
Linear Density of Warp (Tex)	255
Linear Density of Weft (Tex)	253
Moisture Content (%)	12.4

Table3 Xrd analysis of jute and newspaper

Lattice parameters (Å)					**Lattice Plane**				**Crystalinit Index**	**Crystal Size (nm)**
Material	**a**	**b**	**c**	**β**	$10\bar{1}$	**101**	**002**	**040**		
Jute	7.80 Å	10.32 Å	7.97 Å	95.41°	15.20° (d=5.822 Å)	15.65° (d=5.318 Å)	22.35° (d=3.97 Å)	34.73° (d=2.58 Å)	64.6	3.18
Paper	8.32 Å	10.28 Å	7.89 Å	93.02°	15.03° (d= 5.89 Å)	15.94° (d=5.55 Å)	22.55° (d=3.94Å)	34.78° (d=2.57 Å)	62.6	4.93

Table 3 One way ANOVA test results for tensile, flexural and inter laminar shear strength properties of composites at the 95.0% confidence level.

Tensile strength					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	10787.427	4	2696.857	38.504	0.000
Within Groups	1400.834	20	70.042		
Total	12188.262	24			
Tensile modulus					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	19.049	4	4.762	61.957	0.000
Within Groups	1.537	20	0.077		
Total	20.586	24			
Flexural strength					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	14041.234	4	3510.308	42.523	0.000
Within Groups	1651.033	20	82.552		
Total	15692.267	24			
Flexural modulus					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	11.197	4	2.799	20.306	0.000
Within Groups	2.757	20	138		
Total	13.954	24			
Interlaminar shear strength					
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	98.019	3	32.673	16.223	0.000
Within Groups	32.224	16	2.014		
Total	130.244	19			