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Properties of Jute Fibre Reinforced Polymer Composites – A Review

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ABSTRACT

Jute fibres is of great interest to be used as reinforcement in thermoset or thermoplastic composites, in order to provide positive environmental benefits in-terms of degradability, abundance, low density, nominal cost and recyclable. During fabricating the composites, researchers facing complications such as high water absorbing (WA) character, poor incompatibility of fibre with resins, quality variations in fibres, low thermal stability, etc. Therefore, chemical treatments are considered and it will be the most effective way to enhance the interfacial bonding with matrix, improve mechanical strength and less WA as well. Many research works were carried out on the influence of chemical treatment on the properties of jute fibre and their composites. The investigated treatment methods and the impact of chemical treatment on the properties of jute fibre reinforced polymer composites are comprehensively presented in this review.

1. Introduction

Plant fibres have a long history of economic significance in human civilisation and are now produced globally on a wide scale. This fibres used in the production of composites has been significantly growing in terms of their fundamental research as well as in industrial applications. Compared to metals and alloys, this fibres are relatively cheap, light-weight, noncorrosive, abundant in nature, renewable, lower energy consumption during manufacturing and most of the fibres are obtained from agricultural waste (banana, coir, rice husk, grass fibres). Plant fibres have several benefits over synthetic, and have broader application in packaging, automobile, building, sports, home appliances and construction (Olgun et al. 2016). Based on their source, plant fibres were classified into: bast or stem fibres are obtained from the stalk of various dicotyledonous plants such as banana, jute, flax, ramie, kenaf, hemp etc; leaf fibres also referred to as hard fibres, extracted from the leaves of monocotyledonous plants like sisal, pineapple leaf etc; seed fibres derived from the seeds of plants includes cotton, kapok, oil palm, coir, etc (Mwaikambo, 2006). Several researchers determined the mechanical

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properties, water absorption, porosity and thermal analysis of the concrete casted using the plant fibres (Wafa, 2019; Arsene et al. 2013; Amiandamhen, 2020).

Among these plant fibres, Jute (Corchorus Capsularis), is a common vegetable fibre exhibit better mechanical properties and used in various industries for the production of new consumer goods (Sudhir et al. 2011). An annual plant that can grows up to 2cm to 3.5cm belongs to the Tiliceae family (Faruk et al. 2012) falls under the category of kenaf, hemp, flax and Ramie. Jute fibre (JF) production is second to cotton and can easily grow in humid and warm atmosphere. Fibres are off-white to brown, extracted from the bast of the plant and have potential candidate to replace glass or man-made fibres. A complex agricultural fibre have a major load bearing capacity to develop high performance biodegradable polymer composites (Pinku et al. 2014). Jute based polymer composites have found wide application in engineering fields like electrical, electronic, bio-medical, automotive (car interiors, door panels), handicrafts, packaging, construction, cottage (sacks, coarse cloth) industries.

2. Constituents of Jute fibre

Jute fibres consists of several cells that are constructed from helical, crystalline cellulose fibrils, which are bound to the entire layer by amorphous lignin and hemicellulose, with helical angles of 20–30°. The major constituents of JF are cellulose (60-72%), hemicellulose (12-24%), lignin (11-24%) and have minor traces of pectin (0.2%), ash (0.5 to 2%), wax (0.5%) and fats (Sunil et al. 2019, Park et al. 2010, Ramakrishna et al. 2010). Cellulose is the prime source for imparting the stiffness to the jute fibres. Other components also increases fibre stiffness by transferring load to cellulose chains. Hence, the mechanical strength of fibres highly dependent on the orientation of microfibrillar angle (MFA). The cellulose content affects MFA that means decrease in cellulose, increasing value in MFA (Komuriah et al. 2014). Sur and Amin (2010) determined the value of MFA of jute fibre is 7^o-9^o. Moisture regain of Jute fibre is 12.6%, but with conditions of high humidity it can absorb up to 23% of the water and had non-static, low thermal conducting properties (Mwaikambo 2009). Also, the percentage of ingredients governing the fibre's mechanical and thermal characteristics, as well as composite's mechanical and adhesion (with matrix) properties. The chemical proportions of any plant fibres are well depend upon the plant's geographical conditions, growing period extraction methods adopted, harvesting time, size and maturity of the plant etc. This versatile agro-based fibre exhibited numerous advantages over synthetic fibres, such as excellent acoustic insulation (Mohammad et al. 2019), low carbon footprint, eco-friendly, cost effectiveness, high specific modulus, light-weight, low energy requirements during processing (Suhad, 2019), low density, sustainable, low extensibility etc. Due to the hydrophilic nature of JF, it has some disadvantages which includes hydrophilicity, poor durability, fade on exposure to sunlight, crease resistance, poor compatibility and it is vulnerable to microbial attack in humid climates. Hence, material scientists, researchers and engineers have challenge to mitigate the drawbacks such as water absorption, susceptibility to microbial attack etc.

3. Surface modification of jute fibre

Jute fibres are able to reinforce different polymeric matrices because of their good strength and stiffness. However, its high hydrophilicity contributes in humidity consumption and low hydrophobic matrices compatibility. The hydrophilic nature are responsible for the large hydroxyl groups on the plant cell walls. These hydroxyl groups have been modified to improve durability and matrix compatibility. Most frequently used method to keep the fibres more compatible with the polymeric matrices are surface modifications. Various chemical treatments utilized to remove the impurities (wax, ash, lignin) of JF and their effects were studied by many researchers (Dogan et al. 2016; Karaduman et al. 2012; Arulmurugan and Venkateshwaran 2020; Kutlay et al. 2012; Kumarjyothi et al. 2020). Most commonly used method is alkaline or mercerisation (Katogi et al. 2016; Nguyen et al. 2009; Xue et al. 2019), in some studies succinic, silane, malei anhydride grafting, H_2O_2, $KmNO_4$ (Tran et al. 2012; Haydaruzzaman et al. 2010; Muzammel et al. 2020). The physical treatments such as UV, γ-radiation, electron beam radiation, plasma, corona, and biological treatments like enzyme, laccase, PLA coating, etc were used (Gautam et al. 2008; Yoldas 2009; Liu et al. 2016; Dong et al. 2014; Xiaoyan et al. 2015). Many of the research works revealed that the effect of surface modification improved the mechanical properties of polymer composites compared to untreated fibres and composites. This review work focuses on properties of Jute Fibre (with or without treatments) Reinforced Polymer Composites involving various thermoplastics, thermosets, jute based hybrid, green composites and the effect of different form of Jute (Fibre mat/yarn/twill/fabrics) reinforced composites.

4. Physical properties of Jute fibres

Umit et al. (2016) determined the physical properties of jute fibre with the effects of alkali (AJ), alkali+silane (ASJ), alkali+fluorocarbon (AFJ) and alkali+argon plasma (APJ) treatments. From the Table 1, it was examined that the particle size and CI were higher for ASJ due to the crystallite packing order of JF. The carbon/oxygen ratio (143.9%) was greater for AFJ fibres indicating more hydrophobic surface character. In another interesting works, surface modification was applied to the fibre to remove lignin and new covalent bonds was formed between the cellulosic chains with the influence of stearic acid, potassium permanganate, sodium chlorite, isocyanate groups, and triazine derivatives (Li et al. 2007). From the elemental analysis data, Tuffaha et al. (2020) found that oxygen content was increased of about 9.58% for untreated JF, whereas carbon as 6.13% higher for epoxy treated JF. This is due to the presence of epoxy groups on the surface of the fibre. Sekhar et al. (2019) investigated the lengthwise JF properties variation in three sections (root, middle and tip). They found that crystal size (3.35nm), fibre fineness(2.74tex), fibre diameter (61μm) and TS (534MPa) were higher for root JF compared to the middle and tip JF (Figure 1). This is attributed that root portions were coarser than other fibres. In the same study, the similar result pattern were reflected in root JF/PE composites.

Table 1.
Physical Properties of Jute fibre (Umit et al. 2016)

Fibre	**Particle Size(μm)**	**Density (g/cm^3)**	**Crysallinity index, CI (%)**	**Moisture(%)**
Untreated Jute	70.73	1.33	73.0	7
AJ	93.6	1.01	83.8	18
ASJ	99.67	1.01	85.9	4.5
AFJ	69.68	N/A	83.2	4.5
APJ	74.96	1.07	82.2	6

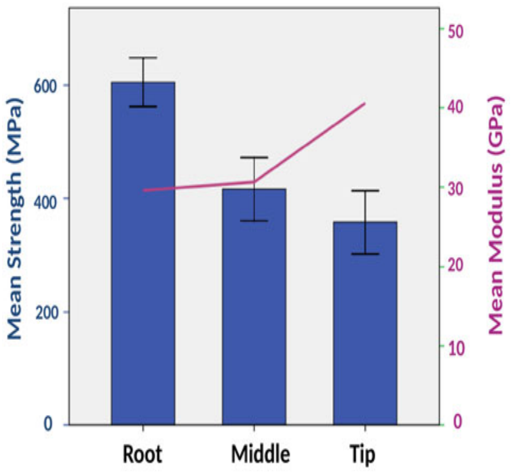

Figure 1. Tensile properties of three portions of jute fibre (Sekar et al. 2019)

5. Jute fibre reinforced thermoplastic composites

A lot of research work has been done on the jute fibre reinforced thermoplastic composites (Table 2). Among the various thermoplastic, polyester resin is extensively used because of its ability to recycle, durability in tough conditions and low cost. The influence of surface modification with respect to different concentration, treatment time and temperatures on the properties of JF with various thermoplastic composites are as follows.

Table 2.
Mechanical Properties of jute based thermoplastic and thermoset composites

Fibre content	Chemical treatment	Matrix used	Fabrication process	Mechanical Properties	Reference
			Thermoplastic composites		
28% to 45%	$KMnO_4$	PP	Hot press molding	TS-69.8, TM-1.28 FS-80.2, FM-4.75 IS-24.4J/m^2	Jahangir et al., (2012)
20%wt	oligomeric siloxane(OS)	HDPE	Hot press molding	TS-29.1, TM-1.47 FS-46.8, FM-1.67 ILSS-15.6MPa	Yoldas et al., (2012)
Hybrid (PPLSF:jute as 100:0, 75:25, 50:50, 25:75, 0:100)	5%NaOH	PE	Compression moulding	TS-83.3 TM-5.07, FS-176 FM-19.26 IS-36.3kJ/m^2	Shanmugam and Thiruchitrambalam (2013)
10wt%	3%MAPP (maleic anhydride grafted polypropylene)	PP	Injection molding	TS-25.11 TM-1.86	Mirza et al., (2014)
			Thermoset Composites		
20%wt	6% NaOH	Epoxy	Manual Layering process	TS-33.46, TM-1.86 FS-96.50, FM-4.70	Xue et al. (2019)
30%wt	5% to 10% NaOH	Epoxy	Hand lay-up	TS-5019 FS-90.89, IS-88.5	Britto et al., (2019)
10 to 40%wt	Benzoyl chloride	Epoxy	Hand lay-up	TS-90.33 TM-4.008 FS-74.05 IS-1.902J ILSS-69.61	Swain et al., (2018)

Fibre content	Chemical treatment	Matrix used	Fabrication process	Mechanical Properties	Reference
30wt%	Benzoylation treated with PLA coating	Epoxy	Static Compression	TS-33.45 TM-5.34 FS-110.35 FM-8.89 IS-6.21	Arun and Gupta, (2020)
10 to 40%wt	NaOH	Epoxy	Hand lay-up method	TS-55, TM-550 FS-5.45, IS-6.21J FM-120.92 Hardness-67	Kumaran et al. (2019)
40wt%	Alkali+Silane	Epoxy	Vacuum bag moulding	FS-128.5 FM-70.1 IFSS-9.3	Anna et al. (2018)

TS and FS–tensile and flexural strength in MPa, TM and FM-tensile and flexural modulus in GPa, ILSS and IFSS-interlaminar and interfacial shear strength in MPa, IS-impact strength

Dong et al. (2016) analysed the effect of lacasse and lacasse octadecylamine (OA) treated jute fibre/PP composites. The experimental results revealed that the tensile properties, contact angle, static and dynamic properties were higher for OA grafted jute/PP composites than the lac treated and untreated JF/PP composites.

Different treatments were subjected to jute fibre, oxygen plasma treatment using low frequency (LF) and radio frequency (RF) at different plasma powers of 30W, 60W and 90W for 15minutes. Composites were prepared with the treated JF reinforced HDPE using hand lay-up process (Sever et al. 2011). The tested results denoted that, the plasma treated composites in LF reached the maximum mechanical properties with power of 60W. Further increase in power (90W), a declining tendency was noticed. In RF plasma system, the mechanical strength were improved, when the power raised upto 90W.

Novel treatment such as poly (lactic acid, PLA)-coated, alkali treated and alkali-treated coated with PLA were done on the jute fibre, which was used as a reinforcement with polyester composites (Gupta 2018). Alkali-treated JF composites with PLA coating provided the highest mechanical performance, thermal stability and water resistance properties. Chemical treatments have usually been performed to enhance the mechanical properties of the composites, but in certain cases, impact strength has been found to decrease, after treatment, which suggests a negative effect of chemical treatment. However, the alkali treated fibre with PLA, has exhibited the highest impact strength and lower water absorption. PLA, a bio-degradable polymer, can be used as an effective treatment for enhancing the overall performance of the natural fibre matrix composites.

Harichandra et al. (2019) studied the mechanical properties of JF/PP composites by taking into account the influence of fibre (30wt%) modification with alkali, $KMnO_4$ (0.03wt% 2min), silane (5wt% for 4h). From the SEM analysis, surface micropores, surface roughness and porous were seen for the untreated and treated fibres. The $KMnO_4$ treated jute/PP has exhibited greater TS and elongation at break than all the treated and untreated jute/PP composites. Similarly, the silane treated jute/PP showed greater FS (20%), TM (22%) and WA properties. According to impact strength value, it was lower for all chemically treated jute/PP composites. The authors suggested that both silane and $KMnO_4$ treatment provide a satisfactory requirements for the industrial applications of the composites.

The impact of hydrophobic treatments [fluorocarbons (OLEOPHOBOL CP-R), hydrocarbons (PHOBOLRSH), and fluorocarbons (OLEOPHOBOL 7713)] on jute fibres reinforced unsaturated polyester resin composites were prepared by Azam et al. (2015). This modification results, an increase in tensile and flexural properties of hybrid FC treated jute/PE specimens at

40g/L was noted compared to other composites. The order of moisture regain was follows the order of: hybrid FC treated (2.71%)<FC treated (3.05%)<hydrocarbon (3.10%) < untreated (12%) fibre/PE composites.

Researchers also investigated the improvement in tensile and flexural properties of JF compounded with PE composites after the chemical treatment of jute fibre with NaOH and H_2O_2 (Hossen et al. 2018). Also the lower thermal conductivity (0.4395W/mK) and higher thermal resistance (1.172K/w) were found for treated composites. Untreated composites absorbed more water rapidly i.e., within 2hrs it absorb (0.302%) and for 24hrs it was 0.858%. The treated specimens absorb less amount, i.e., 0.097% for 2h and 0.417% for 24h. From the SEM analysis, a few air gaps, fibre solidarity and the better adhesion between the fibre-matrix was noted for the untreated and treated composites respectively.

Composites derived from JF reinforced PE matrix (1:3) by hand lay-up and compression moulding process (Ammayappan et al. 2016a). The different treatments, solvent lac, alkali and alkali+lac with different conc. of 2%, 3%, 4%w/v were applied to the jute fibres. It was found that the highest flexural property was achieved for 1% alkali treated jute fibre/PE composites. 2% lac treated and 1% NaOH treated composites improved the ILSS, than the other treated and untreated jute PE composites.

An experimental study was performed by Alamgir et al. (2010) and studied the properties of JF/PP composites. The fibre were modified with o-hydroxy benzenediazonium salt (O-HBDS) in alkaline medium and different matrix fibre ratio (80:20, 75:25, 70:30, 65:35) were used for the composite preparation. The mechanical behaviour were higher for O-HBDS treated JF/PP than raw, alkali treated jute and plain PP composites. Conversely, the FS and IS of O-HBDS treated JF/PP had lower value with the increase of fibre loadings.

Jute fibre reinforced PE composites were prepared using compression moulding technique and studied its properties (Sridharan and Muthukrishnan 2013) with the effect of surface modification of fibre by alkali(5% for 90min). The delamination factor $f_d = \frac{d_{max}}{d}$ was calculated and it was maximum at higher feed rate(both entry and exit). Reduction in delamination occurred for alkali treated specimens. Digital image processing technique showed the optimum speed and feed rate for untreated composites was 9.42/min and 0.03mm/rev.

Using hand lay-up process, the unsaturated polyester (UP) based jute fibre composites were manufactured and studied its mechanical, thermal and swelling behaviour (Jaideep et al. 2016). The effect of different fibre loadings (5%, 10%, 15%, 20wt%), treatment with alkali, aluminium oxide (Al_2O_3) and zirconium oxide (ZrO_2) were subjected to raw fibres. The higher microhardness value of 18.52 was observed for ZrO_2 treated composites with an increase of fibre content (Figure 2). Similarly, the thermal stability (37˚C), limiting oxygen index (LOI as 44), degradation temperature (352˚C) and were higher for UP/JF/ZrO_2 treated composites. WA behavior showed the greater hydrophobicity of UP/JF/ZrO_2 treated composites at different environmental conditions (normal, boiling, alkali, acidic and stimulate).

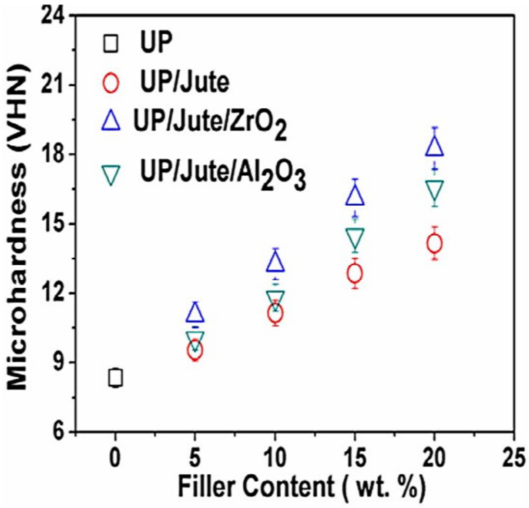

Figure 2. Microhardness of different UP based composites with varying filler contents (Jaideep et al. 2016)

Wang et al. (2020) investigated that sodium lignosulfonate (SL) were deposited on the surface of jute fibre, which gave an improvement in TS, TM, FS and FM of jute fibre –SL-PP composites by 16.79%, 8.25%, 19.71% and 16.87% respectively. The authors concluded that SL possesses a potential candidate to be used as a compatibilizer, because of the improved properties of composites.

Different surface modifications were done on the fibre to increase the tensile properties of JF based PP composites. The influence of fibre loading (5%, 10%, 15%, 20%, 25% wt), fibre length (3mm) and alkali treatment of fibre (at 5%, 10%, 15% conc.) followed by H_2O_2 were used for the preparation of composites. From the experimental findings, it was observed that an increase in tensile properties with increase in fibre loading up to 20wt% as well as with increase in 10%NaOH. Further increase in fibre loading, a reduction in tensile properties was noted. A considerable decrease in density, change in weight and diameter of fibre after the treatment was noticed for the composites (Leela et al. 2014).

Ammayappan et al. (2016b) investigated the influence of alkali (1%) treatment on physical and mechanical properties of JF/PE composites by hand lay-up and compression moulding method. Three different effects, material to liquor ratio (1:5, 1:10, 1:15), temperature (30, 40, 50) and time (30, 60 and 90min) were used for the treatment of fibres. Alkali treated jute fibre composites has the highest density of 1.148gpcc, at the fibre volume fraction of 0.282, at the same time the void volume fraction (0.148) and thickness (2.64mm) was higher for untreated one. The optimized alkali treated jute/PE composites with 2.35mm thickness and 28.2% fibre volume indicated a higher TS, TM, FS, FM and ILSS at 23.4%, 32.8%, 59.3% and 207.3% respectively.

6. Jute fibre reinforced thermoset composites

Of the various thermosets (epoxy, vinyl ester, polyurethanes, silicone, urea formaldehyde, phenolic), epoxy is the most commonly used matrix and family of high performance resins, due to its sustainability, durability, good mechanical (Table 2) and thermal properties. From the Table 2, it was inferred that both thermoplastic and thermoset composite's mechanical properties were higher, compared to untreated composites.

The treatments like alkali (5%w/w, 2h) and silane (Dow corning Z-6175 and APTES 1% w/v 5min) were given to jute fibres and this treated JF were used to prepare the epoxy laminates by hand lay-up and vacuum infusion process (Pinto et al. 2014). The results showed that silane treatment (Z-6175) has imparted layer interfacial adhesion and moisture resistance in JF/epoxy composite. In this work, experimentally proved that the vacuum infusion process is the optimized method to prepare composite with zero voids and good fibre volume fraction as compared to hand lay-up (void content 15%). The tensile strength and modulus increased by 34% and 40% respectively for unidirectional fabric architecture than plain weave. The obtained results were compared with glass fibre/epoxy laminates, and it showed that jute/epoxy composites are comparable in stiffness to mass ratio.

Reshmi et al. (2018) prepared the short JF/epoxy composites with the effect of bleaching (H_2O_2) and silane treatment (3-Amino Propyl Triethoxy Silane APTES). The findings clearly pointed out that at high temperature, the wetting characteristics and mechanical properties had better effects for silane treated JF composites than the H_2O_2 treated and untreated composites. Moreover, the physical appearance of the JF were improved by the H_2O_2 treated fibres.

The other researchers, Anna et al. (2018) performed different treatments on JF involved alkali, silane, alkali+silane treatment. The treated fibres were used for the preparation of composites reinforced with epoxy using vacuum bag molding technique. They found that the alkali+silane treatment increased the mechanical properties such as FS (128.5MPa), FM (70.1GPa) and IFSS (9.3MPa), where the percentage of increment were 47.6%, 90.6% and 15.4% respectively. Moreover, the order of the T_g values has the following pattern: alkali+silane (110.21˚C) > silane (100.51˚C) > alkali and untreated (90.24˚C). The WA rate was lower for treated composite than the untreated one. A considerable reduction in mechanical properties was noted with the influence of moisture absorption.

The influence of alkali treatment (5%, 10%, 15% 20%) and 15 plies of jute fabric were used for the preparation of JF/epoxy composites. It was found that, for 15%NaOH treated JF/epoxy, the Izod (14.053), charpy impact strength (15.423) flexural strength (162MPa) and TS (156MPa) of the JF/epoxy were higher whereas the elongation at break is higher for neat epoxy. WA rate decreased with increasing alkali concentration (%) of fibre. From their findings, it was analysed that 15%NaOH treatment is the optimum parameters for achieving better properties of the composites (Parth M. 2019).

Surface modification with enzyme, CO_2 pulsed infrared (IR) laser and ozone treatments were subjected to the JF, used as a reinforcement to epoxy composites (Jiri and Abdul 2015). The obtained results revealed that the infrared laser treated epoxy composites had the better mechanical and dynamic-mechanical performance compared to the other treated and untreated composites. An indication of changes in surface morphology was noticed for all treated fibre composites whereas in an untreated fibre composite, the multicellular nature with the smooth surface was observed in SEM.

Ma et al. (2018) investigated the effects of alkali (5% for 30 min), silane (γ-amino propyl triethoxy silane) treatment on JF/epoxy composites. The results reported that a significant reduction in moisture gain was observed for the alkali and silane treated composites. Under aging conditions, a small decrease in TS was noted for silane and alkali treated, than the untreated composites.

Hand lay-up process was used by (Hemalatha et al. 2022) to fabricate the jute fibre epoxy composite where the marine waste such as clam shell was used as a filler material, they reported that the inclusion of clam shell into the composites enhanced the tensile, flexural, interlaminar strength, dynamic mechanical strength and hardness value. But the impact strength inferred the adverse effect.

7. Jute fibre reinforced green composites

Composites formed form biodegradable resins reinforced with plant fibres are referred to as green composites, which has better mechanical properties, ecologically friendly, low cost, productivity and ease at their end of life cycle. Biodegradable resins used for reinforcing jute fibre composites are soybean oil (Semih et al. 2020, Peter et al. 2017), CNSL (Prabakaran et al. 2016, Nithesh et al. 2019, Barreto et al. 2010), tamarind seed gum (Arunavathi et al. 2017).

Bhanu et al. (2012) reported on the fabrication and characterization of the mechanical and wear performance of JF/polylactide (PLA) unidirectional composites using hot pressing techniques. The influence of different treatments (NaOH 5% for 1h, permanganate 0.125% for 1 min, peroxide 6% for 3min, and 2 silane agents i.e., a) 3-aminopropyl trimethoxy silane (S1) and b) trimethoxy methyl silane (S2)) were given. The experimental results revealed that the TS, FS, FM, TM, follows the order of: silane 2 > silane 1 > peroxide > alkali > untreated, whereas for Izod impact strength the reversing order is noted.

Fully biodegradable composite based on JF/biopol were developed via compression molding technique and studied its characteristics. The effect of detergent washing (5%, 1h), dewaxing (5% ethanol 1h), alkali (5%, 2h) and acetic acid (2%, 1h) treatment were given to the fibres. It was reported that alkali treated JF showed increment in mechanical properties by 13% and 17% respectively when compared to untreated fibre. The theoretical (1.30gm/cm^2) and experimental density (1.230gm/cm^2) was higher for 3% nanoclay treated jute fibre composite. The void content of 10.8% was higher for untreated jute fibre composites. Storage modulus of 1605MPa and flexural properties was higher in treated jute biopol composites compared to untreated fibre (1467MPa) composites. Percentage of moisture absorption of untreated jute/biopol was higher for after 7 days (3.98%), after 14 days (5.81%), 20 days (6.14%), 30 days (6.18%), 60 days (6.27%) respectively (Hossain et al. 2011).

Jute fibre (5%, 10%, 15%, 20%, 25%) reinforced PLA composites were prepared using injection molding process (Gunti and Atluri, 2014). Different formulations with various conc. of NaOH (5%, 10%, 15% for 6h) and H_2O_2 were given to modify the surface of fibres. From the result, a reduction in fibre diameter by 13.7% and weight of fibre by 21% after the alkali treatment was noted. Further decrement was observed for the fibre bleaching with H_2O_2. Compared to untreated JF composites, considerable increase in TS and lower density value for the treated composites was noticed.

Green composites were prepared with JF as reinforcement in vinyl ester matrix (Exequial and Gaston, 2015). Jute fibre was successfully treated with alkali and coated with polyhydroxybutyrate (PHB. The results showed that flexural modulus of dry composites was found to be same and 10% increase was observed for PHB coated alkali treated fibre composites. Flexural strain for samples immersed in water (1400h) at room temperature increased by 66%, compared to dry samples, i.e., alkali treated by 66%, alkali/PHB coated by 57% and untreated composites by 27%. Impact properties was increased for the PHB treatment and proposed that the PHB coating over alkali treated showed to be the best treatment for reducing the degradation of flexural modulus followed by the alkali treatment.

Pruttipong et al. (2014) studied the effect of fibre loading (0%, 10%, 20%, 40wt%) and surface modification (H_2SO_4 at 0.1%) on jute fibre/green rubber (NR) composites. From the result, the mechanical properties like TS, TM and elongation at break were improved for jute treated deproteinized NR compared to high ammonia NR composites.

Based on the research of Tran et al., (2012) up to 50% of fibre weight, an increase in mechanical strength and modulus for untreated JF/PBS composites, after that a reduction in mechanical strength was noticed with further addition of fibre content. Similarly, the effect of soaking time (1 to 6h) of alkali treated jute/PBS revealed that up to 3h, the mechanical properties raises and then reduced. This was attributed to that, after alkali treatment, fibre was rigid and brittle owing the development of crystallinity. Chemically treated jute/PBS composites have the lowest WA compared to untreated jute/PBS composites. The authors proposed that in this study, 50wt% jute fibre enhanced PBS biodegradable composites have the strongest mechanical properties.

Jute fibre reinforced PLA based composites were prepared by compression molding and studied the mechanical properties with the effect of silane treatment (Takemura et al., 2012). At environment temperature 60˚C, the tensile creep strain of silane treated JF/PLA was approximately 80% lower than that of untreated JF/PLA composites. Also, the flexural creep strain of silane treated was lower than untreated one, at environment temperature 40˚C and 60˚C.

8. Jute based hybrid composites

The incorporation of two or more fibres (natural or man-made) enhanced with the same matrix referred as hybrid composites. The hybridization of jute fibres with other fibres such as curua, bamboo, areca sheath, basalt, glass fibres were used to reinforce epoxy composites are discussed as follows.

Pramendra et al., (2018) reported the fabrication and mechanical properties of hybrid glass/jute reinforced epoxy composite with the different wt% of matrix and different layers of fibres. The maximum FS (100.78MPa) was achieved by the composites with glass (1-layer) and JF (3-layers) epoxy whereas glass (3-layer) and JF (1-layer) composite has maximum impact strength of 72.24 J/m. The later composite could be used to replace the existing industrial safety helmet material.

Jothibasu et al. (2018) developed a new hybrid laminates made of areca sheath/JF/glass fibre /epoxy with various stacking sequence of fibres (5 layers). The effect of alkali treated fibres epoxy laminates (glass-jute-areca-jute-glass) exhibited the highest ultimate tensile strength (46.99MPa), UCS (44.5MPa), ultimate shear strength (32.58MPa) and UFS (5.4MPa). The energy absorption(5.9J) property was higher for glass-jute-jute-jute-glass/epoxy composites. The authors suggested that the fabricated laminates could be used as light-weight applications.

Novel composites derived from hybrid fibres (JF/basalt(B) fibre/Aluminium (Al) sheets reinforced epoxy were manufactured and studied its characteristics (Nabiollah et al. 2019). For the sample preparation, the effect of alkali (5wt% for 2h) treatment and the different stacking sequence of fibre metal laminates were used. Increase in TS (213MPa), TM (39.5GPa) and ILSS (16.67MPa) were noticed for Jute fibre sandwiched basalt. The lowest mechanical properties and highest energy absorption were achieved by basalt sandwiched jute epoxy composites.

Aguiar et al. (2016) studied the effect of alkali (5% NaOH, 1h) and H_2SO_4 (10%) treatment on the JF/curaua hybrid fibres reinforced polycaprolactone (PCL) composites. Jute fibre treated with H_2SO_4 has the highest crystallinity index (CI) of 62.9% than other treated fibers. DMA inferred that at 5wt% of fibers, an increase in modulus and T_g of the composites was noted. The inclusion of treated jute and curaua fibres in the PCL matrix act as a nucleating agent, thus increasing the CI of the composites and presence of nanofibrillated cellulose were evidenced by XRD and SEM.

The effect of alkali (5%, 4hrs) treated jute/epoxy/tea leaf fibre reinforced hybrid glass fibre composites were prepared by compression molding process. Prabhu et al. (2019) reported that the maximum mechanical properties were obtained for glass: jute: tea leaf (10:20:10) hybrid fibre composites than the untreated fibre and various combination of hybrid fibre (Jute/glass/tea leaf) composites.

Dynamic-mechanical and thermal stability of hybrid fibres (oil palm empty fruit bunch EFB and jute fibres) epoxy composites were prepared (Jawaid et al. 2015) by hand lay-up process. In order to remove the surface impurities present in the fibres, 2-hydroxy ethyl acrylate (2-HEA for 5min) treatment were given. The storage modulus was higher for jute/EFB/jute - 2HEA treated hybrid composites and the loss modulus was higher for EFB/jute/EFB, untreated jute/EFB/jute hybrid composites. Char residue yield for jute/EFB/jute and EFB/jute/EFB were 12.9% and 12% respectively.

Fui et al. (2017) studied the influence of Nanoclay and Tin (IV) Oxide Nanopowder on the Properties of Hexamethylene Diisocyanate (HDI) Treated Jute/Bamboo/ Polyethylene Hybrid Composites. From the findings, a significant increment in mechanical properties for all treated hybrid composites and a small reduction in crystallinity index was noted, by 12.9% and 11.5% for HDI treated hybrid/nanoclay/PE composites respectively. The percentage of WA was follows the order as: HDI treated hybrid/SiO2/PE (1.06%) < HDI treated hybrid/PE composite (2.27%)< HDI treated hybrid nanoclay/PE (3.26%) < untreated hybrid/PE (28.9%). Thus, all treated composites showed >25 times reduction in WA with reference to untreated hybrid composites.

9. Effect of different form of Jute (Fibre mat/yarn/twill/fabrics) reinforced composites

Plant fibres have been widely used as a reinforcement in the polymeric composites in various forms includes fibres, yarns and fabrics. To prepare complex-shaped and sandwich fabrics, flat knitting techniques were used in cotton fibre reinforcement. But in the case of jute, a fibre form is mostly used. Some research works, only used in the form of mat, yarn, twill, fabrics of JF reinforced composites.

Vacuum bag mould method was utilized for the fabrication of JF/vinyl ester composites (Sathishkumar et al. 2017). The effect of stacking sequence (4- layers of fibre mat) and unidirectional oriented JF based composite showed the better mechanical properties and reduced the void fractions. From XRD analysis, it was noted that the treated fibre composites had the natural phenomenon angle 2 is 21.9860 and for untreated it is 24.9690.

The influence of jute fabric structures (plain, twill, single jersey, rib) on the mechanical, morphological and WA performance of jute/PP composites were studied (Sharfun et al. 2015). It was reported that composite with twill structure/PP exhibited the highest value of TS (47.55MPa), TM (4.35GPa), FS (54MPa), FM (4.76GPa), IS (28.29kJ/m^2) and lower WA were achieved, than the other jute fabric structures. The better mechanical interlocking of fibre matrix for twill and rib fabric composite, while for plain and single jersey composite, a large gaps in fibre matrix was noticed (SEM analysis).

Jianxiu et al. (2020) fabricated jute twine/PP prepeg tapes and studied the effect of alkali, lacasse treatments and impregnation. From the result, a considerable increment in dynamic-mechanical and tensile properties were observed. The prepeg prepared with lacasse treated Jute twine/PP gave the better tensile strength of 2.88MPa. Various surface modifications were applied to jute yarns and the results were summarized by Gao et al. (2018). From their findings, the higher TS (152.7MPa) and TM (9.1GPa) were noticed for untreated jute yarn compared to alkali and silane treated yarns. Similarly, untreated jute yarns yielded highest mechanical behaviour than the yarns immersed in normal water and exposed to the temperature (at 105^{o}C) was experimentally proved by Ben et al. (2020).

According to their research (Vimal et al. 2015) the sterilized bidirectional jute fibre mats were modified chemically and then reinforced with epoxy resins by using hand layout process. The results reported that maximum weight gain (37.92%) was obtained for succinic anhydride treated JF/epoxy than the phthalic anhydride treated mats. In the same way, the mechanical properties were higher for phthalic anhydride fibre mats with increasing fibre volume fractions (from 30 to 70wt%).

Arifuzzaman et al. (2016) designed poly-L-lactic acid (PLLA) based composites containing benzoylation treated jute fabrics. They found that the treated JF/PLLA had the highest TS (87MPa), TM (1.42GPa), FS (121MPa), FM (5.3GPa), IS (18.1kJ/m^2) respectively than the untreated JF/PLLA composites.

Sunil et al. (2019) tried to improve the characteristics of jute yarn with two chemical modifications like alkali and fumed silica coating. From their studies, it was found that good mechanical and thermal properties were achieved by alkali+fumed silica coating jute yarns than the untreated and uncoated yarns.

10. Comparative study of JF reinforced thermoset and thermoplastic composites

Ajith et al. (2014) manufactured the jute reinforce epoxy and jute/polyester composites with the effect of fibre length (5-6mm), alkali treatment (5% and 10% NaOH), and fibre resin weight ratio as 18:82. According to their findings, 5% alkali treated fibre improved the mechanical properties (Figure 3) of jute epoxy composites than the JF/Polyester composites. Moreover low water absorption rate was observed because of the better interfacial bonding between the fibre and the matrix.

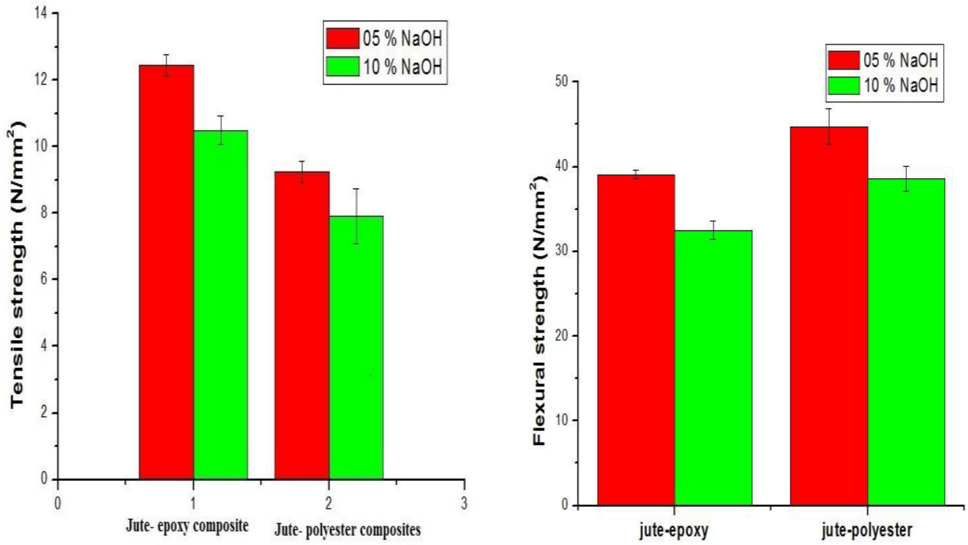

Figure 3. Mechanical properties of a) jute epoxy b) Jute polyester composites (Ajith et al. 2014)

Onur et al. (2015) developed and compared two different type of composites: JF/PP and JF/PE composites, and studied their characteristics with untreated, alkali (30min), impregnated jute fibres. The results indicated the higher tensile properties and lower WA was achieved for alkali treated JF with maleic anhydride as a compatibility. The TS of pristine jute fibre reinforced PP and PE based composite increased strength by 90% and 40% respectively.

11. Conclusions

On the basis of this review, the following conclusions were drawn:

- Many researchers were prepared and investigated the jute fibre reinforced polymer composite (JFRPC) using various thermoplastic (polyester, polypropylene, polystyrene), thermosets (epoxy, vinyl ester, silicone), biodegradable matrix (PLA, PHB, biopol), hybrid composites (JF with glass fibre, curua, bamboo, tea leaf fibre).

- The Effect of different form of jute as fabric, yarns, twill reinforced composites were also reported.
- Various types of surface modifications (chemical, physical. biological) are used by various researchers, in order to improve the properties of JFRPC and established better results of surface treatments as an improvement in mechanical properties.
- From this, it was noticed that, compared to untreated fibre, the chemically modified fibre provide better interfacial bonding between the matrix and fibres. The treated fibre roughens the surface of the fibre and promote good mechanical properties for fibres as well as to the composites.
- Compared to synthetic fibres, the natural jute fibres has more advantages includes less toxic, 100% biodegradable, less energy consumption, carbon dioxide neutrality (Wambua et al., 2003). Based on these results, natural fibre has increased the interest in the preparation, for the replacement of traditional non-degradable plastics, of environmentally friendly materials.

Conflict of Interest

The authors declare that there is no conflict of interest.

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