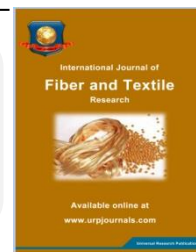




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Review Article

Potential of Jute Fibre Reinforced Polymer Composites: A Review

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Abstract

Scientists and researchers have challenge to reduce the immense use of synthetic fibre and its composite's cost. Natural fibres may be suitable replacement of synthetic fibre as a reinforcement of polymer composites for healthy environment. Natural fibres have many advantages such as low cost, low density, renewability etc. The potential, huge production and lower cost properties of jute fibre motivated us for this work. This review paper is focused on mechanical characterization of jute fibre reinforced polymer composites (JFRPC). The mechanical properties such as tensile, flexural and impact properties of JFRPC are studied in this work. The effect of various factors such as fibre loading, fibre size, fibre orientation and chemical treatment on the mechanical properties of JFRPC is also explained.

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Keywords: Jute fibre, polymer composite, mechanical properties, chemical treatment.

1. Introduction

Fibre reinforced polymer composite (FRPC) is consist of polymers (thermosets or thermoplasts) as a matrix and fibres (natural or synthetic) of high strength as reinforcement. FRPC is main class of polymer composite. A typical classification of composite is given in Figure 1. In FRPC, fibre is load carrying member along their longitudinal direction while matrix transfers the stress between reinforcing fibres. Glass, carbon and other synthetic fibres as reinforcement have already set their impression in the field of polymer composites. These fibres are very expensive and not good for environment. Natural fibres are the recent field of attention for scientists and technologists due its excellent properties. Natural fibres have properties such as lightweight, low cost, environmental friendly, high flexibility, renewability, biodegradability, high specific strength, good thermal properties, high toughness, reduced tool wear, non-irritation to skin and easy processing [1-8]. Recently, the use of natural fibres like jute, banana, hemp, flax, sisal, bamboo etc. as a reinforcement in the polymer composite material has increased and is being better replacement of conventional fibres. The natural fibre reinforced polymer composites are being used in various fields like transportation (automobile parts, aerospace etc.), defence sector, building and construction industries etc. [9-15]. As compared to synthetic fibre, natural fibres have some drawbacks such as poor adhesion between matrix and

fibre, highly moisture absorption and highly polar nature due to the presence of hydroxyl group (-OH). These drawbacks can be removed by chemical treatments of fibre [16].

Jute is the cheapest vegetal bast fibre and found in abundance in Bangladesh and India. The traditional use of jute fibre is to make hessian clothes, ropes, shopping bags and floor mats, etc. [17]. Jute fibres have many advantages such as low cost, eco-friendly and moderate mechanical properties which makes them better alternative of synthetic fibre in many applications [18]. It was observed that during the lifespan of 120 days, jute plants absorbs 15 tons of carbon dioxide (CO₂) from the atmosphere and give 11 tons of oxygen (O₂). This potential of jute shows that jute is the best eco-friendly natural fibre. The fertility of soil is also increased by the decomposed roots and leaves of jute plants which reduce the cost of fertilizers [19].

This review work focuses on mechanical properties of JFRPC. Effect of chemical treatments on mechanical properties of JFRPC is also studied and found the positive results of chemical treatments in terms of improved mechanical properties as compared to untreated composite.

2. Materials

In fabrication of jute fibre reinforced polymer composites different types of polymers as a matrix are used. Polymers may be either thermosets namely epoxy, polyester, vinyl ester etc. or thermoplasts namely polypropylene, poly lactic acid, high and low density polyethylene etc.

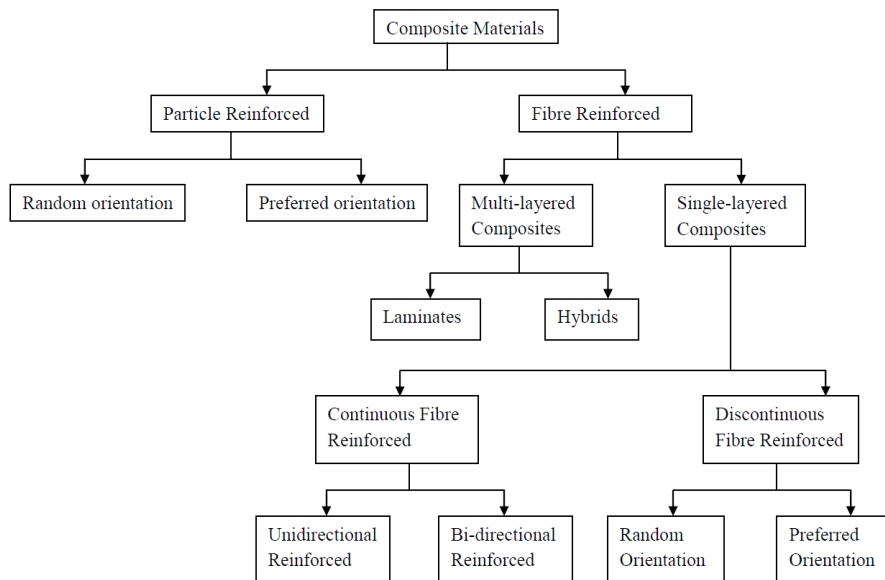


Figure 1 Classification of composite materials

2.1 Matrix

Matrix plays an important role in preparation of the composite. It offers many functions such as keeps the fibres in proper position, offers resistance against an adverse environmental condition (chemicals and moisture), transfer of stress to fibres and protecting fibre's surface from mechanical degradation such as abrasion [20]. In current era polymer as matrix has replaced many traditional materials in various fields due to its light weight, high specific strength, easily processing, productivity and economic in cost [21]. Polymer is made of long-chain molecules having one or more repeating units of atoms joined by covalent bonds. A polymer material is also known as plastic, consists of a large number of polymer molecules having similar chemical structure. Polymers are classified into two major groups as thermoplastics and thermosets. Individual molecules are not chemically joined together in thermoplastic polymer. They are bonded by weak secondary bonds such as Vander Waals bonds and hydrogen bonds. A thermoplastic polymer can be softened and reshaped by the application of heat. In a thermosets polymer, the molecules are chemically joined together by cross-links, having a rigid and 3-D network structure. The thermosets polymer cannot be melted by the application of heat [20].

2.1.1 Mechanical properties of thermoplastic and thermosetting polymers.

Mechanical properties of polymers are given in Table 1. Among the entire mentioned thermoplastic, the maximum tensile strength is shown by LDPE followed by polylactide and PVC while maximum impact strength is shown by polypropylene. PVC shows the maximum density among thermoplastic polymer followed by polylactide and HDPE. Among the entire mentioned thermosets polymer, epoxy shows the highest tensile strength followed polyesters and vinylsters while maximum tensile modulus is shown by phenolic. The maximum flexural strength is shown by epoxy followed by vinylsters and phenolic while maximum flexural modulus is shown epoxy resin.

2.2 Reinforcement

In FRPC, reinforcements are fibres with various size and orientations. Fibres are thread like structure has circular cross-section and diameter less than 0.0025 mm (depending on material). Among all the natural fibre, fibres having aspect ratio (l/d) > 1000 are favourable as reinforcement for polymer materials due to their low density and high mechanical properties [42]. Fibres are stronger and stiffer than that of matrix. It may be due to presence of flaws in bulk material while in fibre possibility of internal flaws is very less [22]. In FRPC, either natural fibre or synthetic fibre can be used as reinforcement. The main elements of natural fibre are cellulose, hemicelluloses, lignin, and pectin. Hydrophilic nature of natural fibre is due to presence of cellulose. The function of hemicellulose is to support matrix agents of cellulose. Hemicellulose is hydrophilic in nature, soluble in alkali and easily hydrolysed in acids. Nature of lignin is amorphous and hydrophobic. Pectin is like waxes which provide plant flexibility [23]. Jute fabrics are hydrophilic in nature and their moisture content is up to 12.6%. The mechanical properties of composite made of hydrophilic fibre with hydrophobic or non-polar polymer matrix are poor compared to pure polymer [24].

2.2.1 Jute fibre

Jute is a bast fibre whose scientific name is *Corchorus capsularis* of Tiliaceae family. Plant of jute takes nearly 3 months to grow to a height of 12-15 feet. Jute plant is cut and kept immersed in the water for Retting process during season. The inner stem and outer gets separated and the outer plant gets individualized to form fibres [19]. Jute fibre is known as golden fibre of Bangladesh, jute is an important fibre of Eastern Indian and Bangladesh. According to facts collected from Food and Agriculture Organization of the United Nations (FAOSTAT)-2012, the total production of jute (tones) in the world is 3461964. India and Bangladesh are top jute producing countries in the world [31]. The chemical composition, physical and mechanical properties of jute fibre are given in Table 2.

3. Chemical Treatment

Instead of many advantages of jute composite it suffers from certain disadvantages. The main disadvantages are as follows [19, 21].

- ❖ The jute fibres are polar and hydrophilic in nature due to presence of hydroxyl and other oxygen containing groups.
- ❖ Hydrophilic nature of jute fibre is due to presence of cellulose. Jute fibre has moisture content in the range of 5-13 %.
- ❖ The dimensions of jute fibre changes with change in moisture content. It might be explained by the fact that the cell wall polymers contain -OH and other oxygen containing group which attract moisture through

hydrogen bonding.

- ❖ Thermal degradation of fibre is two stage process, degradation of hemicellulose (220-280°C) and degradation associated with lignin (280-300°C). At higher processing temperature (above 250°C) jute fibre is unsafe to degradation.
- ❖ The reinforcement of cellulosic fibre and thermoplastic causes poor dispersion of fibre due to inter fibre hydrogen bonding responsible for holding fibre together.
Jute fibre (hydrophilic/polar) + Polymer (hydrophobic /non-polar) = poor interfacial adhesion between fibre and matrix.

Table 1 Mechanical and physical properties of polymers

Polymers	Density (g/cm ³)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Impact Strength	Ref.
Epoxies	-	55-130	2.7-4.1	110-150	3-4	-	[25]
Phenolic	-	50-60	4-7	80-135	2-4	-	[25]
Polyesters	-	34-105	2.1-3.5	70-110	2-4	-	[25]
Vinylesters	-	73-81	3-3.5	130-140	3	-	[25]
Poly lactide	1.24	56.3	3.6	-	-	-	[26]
Polyester	1.2	61	4	-	-	-	[27]
Polyvinyl chloride (PVC)	1.35	48	3.300	-	-	0.32 J/cm	[28,30]
Polystyrene	-	46	2.9	-	-	0.17 J/cm	[28]
Polypropylene (PP)	0.899 - 0.920	26 - 41.4	0.95 - 1.776	55.2	0.83-1.73	21.4 -267 J/m	[29]
Low density polyethylene(LDPE)	0.910 - 0.925	4-78.6	0.055 -0.38	-	-	>854 J/m	[29]
High density polyethylene (HDPE)	0.941-1	14.5- 38	0.413- 1.490	-	0.41-1.07	26.7 J/m	[29]

Table 2 Chemical and mechanical properties of jute fibre

Properties	Jute fibre	Reference
Cellulose (%)	64.4	[32]
Hemi-cellulose (%)	12	[32]
Lignin (%)	11.8	[32]
Pectin (%)	0.2	[59]
Waxes (%)	0.5	[59]
Moisture content (%)	1.1	[32]
Density (g/cm ³)	1.46	[32]
Fibre length (mm)	0.8-6	[32]
Diameter of fibre (µm)	5-25	[32]
Tensile strength (MPa)	393-773	[34]
Young's modulus (GPa)	13-26.5	[34]
Elongation at break (%)	1.16-1.5	[34]
Micro-fibrillar angle (°)	8.0	[34]
Price (EUR/kg)	0.3	[60]

The poor interfacial adhesion between matrix and fibre is existed in natural fibre reinforced polymer composites. On the contrary the strong interfacial adhesion between matrix and fibre in composites is required for proper transferring the load from matrix to fibre. Surface modifications of fibre are needed to improve surface characteristic such as adhesion between fibres and matrix, wetting of fibres, porosity etc. [19]. Different chemical treatment of fibre includes alkaline treatment (NaOH), silane treatment (SiH₄), acetylation, permanganate, acrylation, maleated coupling agents and others are used to improves the interfacial adhesion between polymer matrix and fibres. It also modifies the surface of fibre to reduce the moisture absorption tendency of composite and hence increases the mechanical properties [33]. The different chemical

treatment methods and their mechanism are listed in Table 3.

4. Methods of composite fabrication

The fabrication methods of composites depend upon matrix materials, productivity, shape and size of product etc. The frequently used fabrication method by different researchers is given in following section [58].

4.1 Hand Lay-up method

The processing steps in this method are quite simple. Initially, a releasing agent is sprayed on the surface of mould to avoid the sticking of polymer to the surface. Thin plastic sheet is placed at the top and bottom of the mould plate for good surface finish of the product. Reinforcement is placed at the surface of mould in the form of woven mats or chopped strand mats are cut as per the mould size. The

Table 3 Different chemical treatment methods of fibre [33, 34]

Process	Agent/Chemical compound used in treatment	Mechanism/ action
Alkaline treatment or mercerization	NaOH	<ul style="list-style-type: none"> It increases surface roughness by disturbing hydrogen bonding in the network structure. Certain amount of lignin, wax and oils covering external cell wall of fibre removed by alkaline treatment. It also reduces the fibre diameter causes increase in aspect ratio (l/d).
Acetylation treatment (Known as esterification method which causes Plasticization of natural fibres)	Acetyl functional group (CH ₃ CO) compound	<ul style="list-style-type: none"> The reaction between acetyl group hydrophilic hydroxyl groups (OH) of fibre which pare moisture presented and hence decreases the hydrophilic nature of the fibre. Dimensional stability of composites is increases.
Silane treatment	SiH ₄	<ul style="list-style-type: none"> Silane is used as coupling agents. Cellulose hydroxyl groups in the fibre-matrix interface may be reduced by silane coupling agent.
Benzoylation treatment	Benzoyl chloride	<ul style="list-style-type: none"> Benzoyl (C₆H₅C=O) in benzoyl chloride decreases hydrophilic nature of treated fibre causes improvement in interfacial adhesion, thermal stability of the fibre.
Permanganate treatment	MnO ₄ ⁻ group	<ul style="list-style-type: none"> Graft copolymerization is initiated by highly reactive (Mn³⁺) generated in the treatment of fibre by potassium permanganate (KMnO₄) in acetone solution.
Peroxide Treatment	Benzoyl peroxide (BP, ((C ₆ H ₅ CO) ₂ O ₂) and dicumyl peroxide (DCP, (C ₆ H ₅ C(CH ₃) ₂ O) ₂)	<ul style="list-style-type: none"> Free radical form by decomposition organic peroxides reacts with hydrogen group of matrix and cellulose of fibre. It improves interface properties between fibre-matrix and also reduces moisture absorption tendency by the fibre and hence improves thermal stability.
Maleated coupling agents	PP grafted with maleic anhydride (PP-g-MA) and Acrylic acid (PP-g-AA)	<ul style="list-style-type: none"> This improves the wettability and interfacial adhesion of the fibre.

matrix is prepared by mixing thermosets polymer with suitable proportion of hardener. Then matrix is poured onto the surface of reinforcement already placed in the mould. The matrix is uniformly spread with the help of brush. The second layer of reinforcement is then placed on the polymer surface and a roller is moved with a pressure to remove air and excess amount of polymer.

Hand lay-up method have a lot of advantages such as low setup cost, less lead time, not requirement of skilled labour and fabrication of complex feature. This method has some limitations such as not suitable for large volume production, requires long cure time (material hardens at

room temperature), quality control is difficult, surface finish is not good, wastage of materials and variations in quality of product. The process is suitable for the fabrication of wind-turbine blades, boats and architectural mouldings.

4.2 Filament Winding

Filament winding is most common method to produce composite parts which are axi-symmetric. Composite parts such as pipes, tubes, tanks, cylinders, domes, spheres can be fabricated using filament winding technique.

In this process, fibre strands are unwind and passed continuously to the resin tank. In resin tank, fibre strand are

impregnated completely with the resin. Now, these resin impregnated strands are passed onto a rotating mandrel. These strands are wound around the mandrel in a controlled manner and in a specific fibre orientation. Materials are used in this method as matrix are epoxy, polyester, polyvinyl ester, phenolic resin and reinforcement are as glass, carbon, aramid. This method is not suitable for woven mat or stitched into a fabric form of fibres. Filament winding process has a lot of advantages such as high degree of uniformity in fibre distribution, labor involvement is minimal as it is an automated process, fibre orientation in a specific direction is possible, lower cost of product as compared to other method and size of the component is not restricted. This method has some disadvantages such as capital investment is relatively high, very precise control over the mechanism is required for uniform distribution and

orientation of fibre. It is not possible to produce the reverse curvature.

4.3 Compression Moulding

Compression moulding is a hydraulically operated press to fabricate the polymer composite. It has two plates, lower plate as a stationary plate and upper plate as movable plates. The mixture of reinforcement and matrix are placed between preheated these plates. The required pressure to fabricate the composite depends upon its size. This method is suitable for all kinds of polymer and all kinds of fibres. It is widely used for long production of doors and cab panels for commercial vehicles.

4.4 Injection Moulding

Injection moulding process is used to produce the parts by injecting material into a mould. Injection moulding can be used for different materials such as metals, glasses,

Table 4 Mechanical properties of jute fibre reinforced thermosets polymer composites

Reinforcement	Matrix	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Impact Strength	Ref.
Bidirectional jute fibre mat	Epoxy	110	4.450	55.80	3.02	4.875 J	[15]
Jute	Epoxy	69.66	6.19	94.08	5.91	-	[16]
Woven jute	Epoxy	15.53	0.2554	79.20	1.355	0.28 J	[37]
Woven jute	Epoxy	12.79	0.1985	81.81	1.381	0.35 J	[37]
Jute laminate (Longitudinal 0-0)	Epoxy	112.69	14.59	-	-	-	[18]
Jute laminate (Transverse 0-90)	Epoxy	39.1	8.97	-	-	-	[18]
Jute	Epoxy	16.62	0.664	57.22	8.956	13.44 kJ/m ²	[38]
Jute	Epoxy	26.53	6.32	66.67	5.78	80 J/m ²	[39]
Jute	Polyester	60	7	92.5	5.1	29 kJ/m ²	[35]
Jute	Polyester	48.52	4.23	63.01	3.62	-	[16]
Jute	Polyester	77.1	5.07	176	19.26	24.71 kJ/m ²	[40]
Long jute (Longitudinal)	Polyester	162	5.58	-	-	1295 J/m	[25]
Long jute (Transverse)	Polyester	0.43	0.98	-	-	148 J/m	[25]
Jute mat	Polyester	23.0	4.0	-	-	-	[41]
Jute	Vinylester	-	-	199.1	11.890	22.10 kJ/m ²	[36]
Jute mat	Vinylester	42.0	1.61	56.2	3.78	-	[25]

thermoplastic and thermosets polymers. To produce the parts, material is fed into a heated barrel, mixed and then forced into a mould cavity. Materials are allowed to cool and hardened to produce the product. It is widely used for manufacturing a variety of parts, from the smallest components to entire body panels of cars.

5. Mechanical properties of jute fibre reinforced polymer composite

Mechanical properties of jute fibre reinforced polymer composites are studied with different weight and volume fraction of fibres. The composites are fabricated by different manufacturing techniques with different fibre orientations. Mechanical properties of jute fibre reinforced thermosets/thermoplastic composites are given as follows.

5.1 Mechanical properties of jute fibre reinforced thermosets polymer composite

Many researchers have used jute fibre as reinforcement with thermosets polymer matrix and reported that the jute fibre based thermosets polymer composites have sufficient mechanical strength. Mechanical properties of jute fibre

reinforced thermosets polymer composite are given in Table 4. Mishra et al. [15] investigated physical and mechanical properties of epoxy based composite using bidirectional jute fibre. The composite was fabricated by hand lay-up method with different fibre loading (0, 12, 24, 36 and 48 wt. %). The maximum value of tensile strength, tensile modulus, flexural strength, flexural modulus and impact energy was recorded 110 MPa, 4.45 GPa, 55.80 MPa, 3.02 GPa, and 4.875 J respectively for composite having 48 wt. % fibre loading. The increase in mechanical properties with the increase in jute fibre loading into epoxy composite might be explained by the proper transmission of stress from epoxy matrix to jute fibres. Hossain et al. [18] investigated tensile properties of jute fibre reinforced epoxy laminated composite and also reported the effect of fibre orientation on its tensile properties. The composite was prepared by vacuum assisted resin infiltration technique by keeping constant 25 vol. % of fibres. The stacking sequences of jute fibre were (0/0/0/0), (0/+45°/-45°/0) and (0/90°/90°/0). It was observed that for lamina composite with stacking sequences 0/0/0/0 and 0/+45°/-45°/0 showed

higher values of tensile strength in longitudinal direction as compare to transverse direction. Tensile strength were very close to each other in both directions for 0/90°/90°/0 lamina composites. Gowda et al. [35] investigated the mechanical properties of polyester based composites using jute fabric as reinforcement. The composites were prepared by hand lay-up method by keeping constant 45 vol. % of fibres. Tensile, flexural and impact properties of composites were studied. It was observed that the longitudinal tensile properties of composites are found improved by five times as compared to polyester resin and two times as compared to transverse tensile properties of composites. The flexural properties of composite were found improved by approximately two times as compared to polyester resin while large enhancement in impact properties of polyester resin is observed due to reinforcement of jute fabric. Ray et

al. [36] investigated the mechanical properties of jute fibre reinforced vinylester resin composites. The composites were prepared by pultrusion method with different vol. % (8, 15, 23, 30 and 35) of fibres. They concluded that the mechanical properties of composite are found improved with increasing the jute fibre content. The optimum mechanical properties are recorded for composite with 35 vol. % fibre content.

5.2 Mechanical properties of Jute reinforced thermoplastic and biodegradable polymer composite

Biocomposites material may be explained by the composite of biodegradable polymer matrix reinforced with natural fibres [36]. Mechanical properties of jute fibre reinforced thermoplastic and biodegradable polymer composites are given in Table 5. Rashed et al. [43] examined the effect of fibre length on tensile strength of jute / polypropylene

Table 5 Mechanical properties of jute fibre reinforced thermoplastic and biodegradable polymer composites

Reinforcement	Matrix	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Impact strength	Ref.
Jute	LDPE	17.5	1.1	20.7	0.6	-	[47]
Jute	HDPE	27.24	-	34.83	-	51.28 J/m	[44]
Jute	Polycarbonate (PC)	63.5	-	87	4.1	-	[45]
Jute fibre	Polypropylene (PP)	23.56 - 29.49	0.79 - 2.4	42.63- 48.31	1.28-3.1	22.34- 39.87 J/m.	[17]
Jute fabric	PP	52	1.03	63	3.27	19.1 kJ/m ²	[48]
Jute	PP	28.4	-	35.1	-	65 J/m	[54]
Short jute	PP	32	0.85	38	1.685	18 kJ/m ²	[58]
Non-woven jute fabric	poly(L-lactic acid) (PLLA)	55	0.867	67	2.83	12.98 kJ/m ²	[49]
Untreated Woven jute fabric(X-direction)	PLLA	81	1.12	82	4.3	16.4 kJ/m ²	[49]
Untreated Woven jute fabric (Y-direction)	PLLA	71	0.78	81	3.62	14.3 kJ/m ²	[49]
Jute strand	Starch	22.2	2.47	36.4	-	10.5 kJ/m ²	[46]
Non-woven jute	Soy	37.1	1.040	38.4	1.120	-	[50]
Woven jute	Soy	35.6	0.972	33.5	1.026	-	[50]
Jute	Biopol	81.42	1.92	-	-	-	[51]
Jute	Maleated castor oil (MACO)	-	-	14	1.7	-	[52]
Jute	Unsaturated polyester resin	-	-	34	1.8	-	[52]
Jute	Soyprotein	64	6.1	24.1	4.074	-	[53]

composite. The composites were prepared by hot compression process with different wt. % (5%, 10% and 15%) of jute fibre and different fibre length (1, 2 and 4 mm). It was observed that tensile strength of composite increases with increase in fibre size and weight percentage

of fibres but after a certain fibre size and weight percentage of fibres, the tensile strength is found decreases. The maximum value of tensile strength was obtained for composite with 2 mm fibre length and 10 wt. % of jute fibre content. The decrease in tensile strength after 10 wt.

Table 6 Mechanical Properties of chemically treated jute fibre reinforced polymer composites

Composites	Treatment	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Impact strength	Ref.
Jute/ Epoxy	Alkali	65.35	6.28	89.63	5.94	-	[16]
Jute/ Epoxy	Alkali & oligomeric siloxane	67.06	5.74	83.99	5.34	-	[16]
Woven jute/ Epoxy	Alkali	19.86	0.300	93.32	1.401	0.25 J	[37]
Woven jute/ Epoxy	Alkali	19.58	0.24	134.5	1.71	0.49 J	[37]
Jute/ Epoxy	Alkali	12.46	1.06	39.08	3.08	2.63 J	[55]
Jute/ Epoxy	Alkali	10.5	-	32.5	-	2 J	[55]
Jute/ Polyester	Alkali	9.24	0.811	44.71	1.91	3.25 J	[55]
Jute/ Polyester	Alkali	7.92	-	38.6	-	2.75 J	[55]
Jute/ Polyester	Alkali	45.55	5.57	64.25	3.99	-	[16]
Jute/ Polyester	Alkali & oligomeric siloxane	62.49	6.75	85.32	4.75	-	[16]
Jute/ Polyester	Alkali	-	-	238.9	14.69	21.92 kJ/m ²	[36]
Jute mat/ Vinyl ester	Alkali	47.3	1.72	92.6	5.51	-	[25]
Jute mat/ Vinyl ester	Permanganate	56.1	1.84	86.3	5.34	-	[25]
Jute mat/ Vinyl ester	Silane	63.5	1.97	99.7	5.97	-	[25]
Jute/ LDPE	Alkali	21.6	1.5	23.2	0.7	-	[47]
Jute/ LDPE	Alkali & Oligomeric siloxane					-	[47]
Jute/ HDPE	Maleic Anhydride grafted Polyethylene (MAPE)	40.14	-	47.97	-	65.69 J/m	[44]
Jute/ PC	2-hydroxy ethyl methacrylate	70.6	-	93.3	5.5	-	[45]
Jute/ Irradiated PP	Irradiated	63	-	73	-	2.93 kJ/m ²	[24]
Woven jute fabric (X-axis)	Benzoylated	87	1.42	121	5.3	18.1 kJ/m ²	[49]
Woven jute fabric (Y-axis)	Benzoylated	79.2	0.91	111	4.72	16.6 kJ/m ²	[49]
Jute/ PP	Silane	33.7	-	43.8	-	62.8 J/m	[54]
Jute/ PP	Alkali	38.1	-	55.2	-	57.4 J/m	[54]
Jute/ PP	Alkali	42.2	-	59.0	-	54.1 J/m	[54]
Jute fabric/ PP	K ₂ Cr ₂ O ₇	68	1.25	77	4.49	23.5 kJ/m ²	[48]
Jute Strand/ Starch	Alkali	26.3	2.49	41.2	-	11.9 kJ/m ²	[46]
Jute Strand/ Starch	Ph-NCO	11.5	1.93	20.3	-	8.4 kJ/m ²	[46]
Jute/ Biopol	Alkali	92.54	2.25	-	-	-	[51]
Jute/ Biopol	Alkali	80	2.28	-	-	-	[51]

% of fibres loading may be due to more addition of fibres into matrix causes poor adhesion between fibres and matrix. Mohanty et al. [44] investigated the mechanical

properties of jute fibre reinforced high density polyethylene (HDPE) composites. It was obtained that the tensile, flexural and impact strength of composite were found

maximum at 30 wt. % fibre loading. Khan et al. [45] also observed similar type of investigation on jute fibre reinforced polycarbonate composite. The composite was prepared by compression moulding method with different jute fibre content (13%, 23%, 26%, 32%, 35%, and 42%). The maximum value of tensile strength and flexural strength were found for composite with 32 % of jute fibre content. Villisca et al. [46] investigated mechanical properties of jute strands reinforced biodegradable starch polymer composites. The composites were prepared by injection moulding with different wt. % (10, 20 and 30) of jute fibre. They observed that tensile and flexural strength of composites increased with increased fibre wt. % while impact strength is not found to increase by the reinforcement of jute fibre into starch matrix.

5.3 Effect of chemical treatments on mechanical properties of jute fibre reinforced polymer composites

Khan et al. [48] investigated the effect of potassium dichromate ($K_2Cr_2O_7$) on the mechanical properties of polypropylene based composites using jute fabric as a reinforcement. Jute fabric-polypropylene composite was fabricated by heat-press moulding technique with different volume fraction of jute fibre content. The results suggested that mechanical properties was found maximum for jute/polypropylene composite having 45 vol. % of fibre content. The maximum mechanical properties of untreated composite were found to further increase due $K_2Cr_2O_7$ treatment of jute fibres. Seki et al. [16] studied the effect of oligomeric siloxane treatment on mechanical properties of jute fibre reinforced epoxy composite and jute fibre reinforced polyester composites. The composites were fabricated by compression moulding technique taking jute fibre as reinforcement and unsaturated polyester and epoxy resins as a matrix. The results showed the positive effect of oligomeric siloxane treatment on both alkali treated jute composites with increase in tensile and flexural properties. Sever et al. [47] investigated similar type of observation that the effect of oligomeric siloxane treatment on the mechanical properties of jute fabric reinforced low-density polyethylene (LDPE) composites. The results indicated positive effect of oligomeric siloxane treatment on mechanical properties of jute fabric/LDPE composite. The tensile and flexural strength of oligomeric siloxane treated jute fabric/LDPE composite were found improved by 58% and 39% respectively as compared to untreated jute fabric/LDPE composites. Owen et al. [37] investigated the mechanical properties of epoxy based composites using jute fabric and effect of alkali treatment on it also. The woven jute/epoxy composites were fabricated by Hand-lay-up technique. The positive effect of alkali treatment is observed on mechanical properties of jute epoxy composite. It was found that both tensile and flexural properties enhanced by alkali treatment while impact properties is not found enhanced by treatment. Khan et al. [49] observed the effect of treatment of benzylation on mechanical properties of woven jute fabric (WJF) reinforced poly (L-lactic acid) (PLLA) composites. The composites were fabricated by hot press moulding method. The positive effect of benzylation on the mechanical properties of composites was recorded. The chemically

treated WJF/PLLA composite shows better strength and modulus than untreated WJF/PLLA composite. Khan et al. [45] observed the effect of 2-hydroxy ethylmethacrylate (HEMA) on mechanical properties of jute (hessian cloth)-polycarbonate composites which was fabricated by compression moulding. The enhancement in mechanical properties of HEMA treated fabrics composite as compared to untreated jute composite was recorded. X. Y. Liu et al. [54] studied the effect sodium hydroxide (NaOH) and Maleic anhydride-grafted polypropylene (MPP) emulsion on the performance of jute/polypropylene (PP) composite fabricated by film stacking method. It was observed the positive effect of treatment on the performance of composite. Treatment of jute fibre led to improve the fibre-matrix adhesion in the composite. Mechanical properties of chemically treated jute fibre reinforced polymer composites are given in Table 6.

6. Applications of jute fibre reinforced polymer composite

Jute fibre and its polymer based composites have a lot of applications. Jute fibre are being used in manufacturing of sacks, hessian cloth, carpet and twines ropes, carpet backing, packaging material (bags) and cords whereas jute fibre reinforced polymer composite are being used in sports (helmets, chest guards, leg guards), decorative materials (wall decoration), sanitary items (slab, ring tec), chairs and tables, roof tiles and kitchen sinks, primary structural application (indoor elements in housing), temporary outdoor application (low cost housing for defence) and transportation (automobile door/ceiling panel and panel separating the engine and passenger compartment). Jute fibre reinforced polymer composites are also used in as covering of industrial buildings, roofing of residential house and commercial buildings.

6. Conclusions

Following conclusions can be drawn from present study:

- Jute fibre may be better replacement of synthetic fibres due to properties such as low cost, high specific strength, easy availability, availability in abundance and eco-friendly nature.
- Different researchers have used different types of manufacturing methods to prepare the jute fibre reinforced polymer composite using various weight fraction, size and orientation of jute fibres.
- Mechanical properties of jute fibre reinforced polymer composite is found to increase up to a certain limit then decreased due to poor adhesion between fibres and matrix.
- Different types of chemical treatments are used by different researchers to enhance the mechanical properties of jute fibre reinforced polymer composite and found positive results of chemical treatments as increase in mechanical properties.

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