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Research Article

Effect of Alkalization on Fabrication and Mechanical Properties of Jute Fiber Reinforced Jute-Polyester Resin Hybrid Epoxy Composite

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Abstract This work aims to improve the mechanical properties of jute fabric reinforced composites. Jute fabric were treated with 5% alkali (NaOH) solution for different time durations (3 hrs. 5 hrs. 7 hrs.) at room temperature. Treated jute fabrics were used as reinforcing material to produce jute/unsaturated polyester resin epoxy composites. Recycled (R-UPR) and virgin (V-UPR) polyester resin were used at different combinations (100%V-UPR, 100%R-UPR, 50%V-UPR and 50% R-UPR) as epoxy. The effect of alkali treatment and mixing proportion of recycled and virgin polyester resin on tensile strength, tensile modulus, flexural strength and flexural modulus of the composites were studied and characterized as referred as in corresponding ASTM standards. Results indicates an improvement on tensile strength and flexural strength in alkali treated composites compared to untreated composites may due to better adhesion of polyester resin with alkali treated fiber matrix present in jute fabric. Higher tensile and flexural strength on the composite produced by using recycled polyester resin compared to the composite produced by using virgin polyester resin also been perceived in the consequences.

Keywords: Alkali treatment; Epoxy composites; Mechanical properties; Jute fabric; Polyester resin

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1. Introduction

When two or more materials with different properties are combined together, we call them as composites. We combine two materials to produce composites, so that the composites possess superior properties compared to individual constituents. Most of the composites can be characterized by the following three constituent elements namely reinforcement, matrix and interface material.[1, 2] In the last two to three decades in the development of composites, textile materials were used extensively as reinforcement material.[3-6] Use of textile material as reinforcement in composites has number of unique advantages. These composites have found number of applications in automobile, ballistic protection, aerospace industry, and light weight tools etc. [7, 8] The textile material used in such reinforcement applications are mostly aramids, high performance polyethylene fibre etc. These materials are derived from of petroleum and they are not biodegradable or recyclable one. The main reason for using these fibres is basically low fibre density high tensile strength. There are number of natural fibres which can match these synthetic fibres for their strength.[1, 9, 10] Most of the natural fibres are very strong and they are relatively cheap. Among the natural fibres jute fibre has high tensile strength than other natural fiber like flax, sisal, coir fibers which can be used as reinforcement in composites.[11-13] Unsaturated polyester resin is synthesis from recycled PET in the form of flakes was obtained by crushing PET beverage bottles.[14] Waste polyethylene terephthalate (PET) flakes were de-polymerized by using ethylene glycol (EG), in the presence of zinc acetate as catalyst to get the glycolzed product as, bis(hydroxyethyl) terephthalate (BHET).[15, 16] All glycolysis products were reacted with maleic anhydride and mixed with styrene monomer to get unsaturated polyester (UP) resins with cross linked.[17, 18] An advantage of recycled polyester resin is reduce plastic waste, improve the environmental performance, good adhesion properties with jute reinforcement, reduce the cost of the raw material, minimize usage of petroleum product, low density and Minimum water absorption. In this work, an attempt made to produce low weight modified alkali treated Jute reinforced composite using 100% virgin unsaturated polyester resin (V-UPR), 100% recycled unsaturated polyester resin (R-UPR) and combined 50%V-UPR/50%R-UPR. The mechanical properties of the above composites were compared with the composites prepared by using untreated jute fabric

2. Experimental

2.1 Materials

The jute woven fabric (260 GSM, 11 EPI, 10 PPI, warp and weft count of 8 Ne and fabric width 44 inches) was procured from Chetty & Co. Ltd. (India). Sodium Hydroxie (NaOH, 97%,mw-40 gm/M), recycled (density 1.12g /cc, Viscosity 220-300 CPS, Acid value 13-14, Gel time 5-6 ℃/min) and virgin unsaturated polyester (PET) resin (density 1.14g /cc, Viscosity 260-320 CPS, Acid value 20-21, Gel time 6-7 ℃/min), Methyl ethyl ketone peroxide ($C_8H_{18}O_6$) and Cobalt octate ($(C_8H_{15}O_2)_2Co$) were procured from Aiswarya Polymers (India) with analytical grade, and used as received without further purification. Water used in all experiments was purified using a Milli-Q Plus 185 water purification system (Millipore, Bedford, MA) with resistivity higher than 18 MX cm. Methyl ethyl ketone peroxide was used as catalyst for polymerizing the unsaturated polyester resin. And Cobalt octate was used as accelerator for polymerization of unsaturated polyester resin. The composites were produced using alkali treated jute fabric and unsaturated polyester resins with different experimental combinations. The fiber volume fraction of the composites is maintained constantly for all the samples as 20% by using 4 plies prepreg. Proportion of resin, catalyst and accelerator for matrix preparation was maintained in weight proportion as 10:0.117:0.048 respectively for all the composites preparation.

2.2 Alkali treatment of Jute fabric

The required jute fabrics were soaked in a 5% NaOH solution at 30 ℃ maintaining a liquor ratio of 20: 1. The initial weight of fabric piece (W1) was noted. The fabrics were treated separately in alkali solution for 3 hrs. 5hrs. and 7 hrs. duration. It is understood that 0 hr. treatment refers to fabric not subjected to alkaline treatment. After the alkali treatment, the fabrics were washed thoroughly to remove all NaOH components from the fibre surface. And then dried at room temperature for 48 h followed by oven drying at 100 ℃ for 2h. The final weight of the fabric (W2) was measured. Weight loss due to alkali treatment was calculated in % by following formula given here; Weight loss in % = [(W1 – W2) /W1] x 100. [19]

2.3 Preparation of jute/unsaturated polyester resin epoxy composites

Composites were produced by hand lay-up technique for prepreg preparation and a tailor made mold was used to produce the composite of size (25 x 25 x 0.4) cm. The prepared prepreg was placed on the bottom mold along with resin filled in it. Then, top mold was placed over it and fastened and compressed. Then it is allowed in the compressed state for gelation. The composites is taken out of mold and allowed for curing for about 48 hrs. at room temperature.

2.4 Characterization

The composite produced were then evaluated for the tensile and flexural strength. Tensile strength test of composite sample is carried out as referred as in ASTM D3039-76 test standard. Three-point bend tests were performed in Instron 3369 (Instron, USA) machine in accordance with ASTM D790 to measure the flexural strength of the composites. A typical application of the flexure test is to gain strength and ductility information on a brittle material.

3. Results and Discussion

This chapter discusses the results of alkali treated jute fabric and mechanical properties of jute fabric reinforced composite produced with 100% virgin unsaturated polyester resin (100%V-UPR),100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR.

3.1 Effect of alkali treatment on weight loss of jute fabric

Jute fabrics have been treated with 5% NaOH solution at room temperature for different process. In this process, hemicellulose and lignin were removed from the fabric; hence the fabric loses its weight. The different levels of removal of hemicellulose and lignin at different process durations, plays an important role in the mechanical properties of composites. The weight loss of the fabrics after different duration of treatment were determined as % weight loss and calculated. Figure 1 illustrates the Weight loss % of jute fabric after alkali treatment. It has been found that, the difference between weight loss at 3 hours and 5 hours treatment periods is 1% only. But at 7 hours treatment period the weight loss is nearly double compared to the 5 hours treatment period.

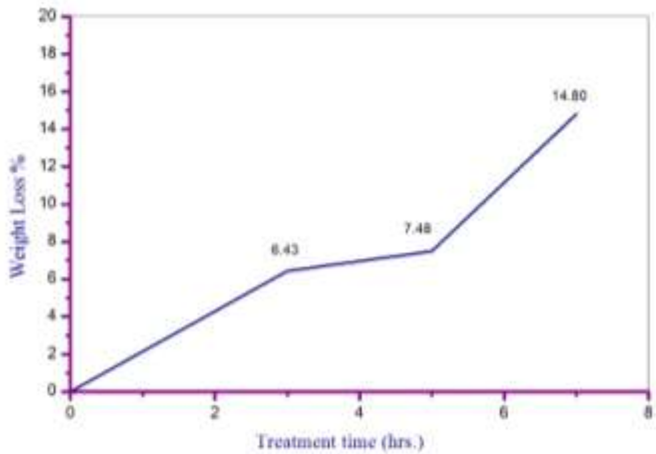


Figure 1 Weight loss % of jute fabric on different alkali treatment time.

Table 1 Effect of alkali treatment on tensile properties of jute/unsaturated polyester epoxy composites

Sl. No	Treat-ment Time (hrs.)	Sample weight in grams	Maximum Load (N)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum load (MPa)	Tensile strain at Maximum load %	Modulus (automatic young's) (GPa)
100%V-UPR	0	10.24	1518.257	0.877	59.774	1.538	5.719
	3	11.28	1396.961	0.971	54.998	1.704	5.694
	5	10.68	1670.063	0.838	65.751	1.471	6.448
	7	10.42	1508.778	0.892	59.401	1.564	5.842
100%R-UPR	0	9.85	1756.048	1.120	69.136	1.965	5.261
	3	10.51	2244.164	1.372	88.353	2.406	5.544
	5	9.74	1904.564	1.337	74.983	2.345	4.852
	7	10.29	1886.240	1.322	74.261	2.319	5.255
50% V-UPR 50% R-UPR	0	9.93	1513.234	1.090	59.576	1.912	5.028
	3	10.71	2082.187	1.223	81.976	2.146	5.817
	5	9.88	1687.989	1.030	66.456	1.807	5.527
	7	9.60	1950.843	1.727	76.805	3.029	4.384

3.2 Improvement of tensile properties of jute/unsaturated polyester epoxy composites

Tensile properties of composites produced using alkali treated jute fabric for 3 hrs. 5 hrs. 7 hrs. and 100% virgin unsaturated polyester resin (100%V-UPR),100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR has been shown in **Table 1**. The tensile strength of a composite material is mainly depends on the strength and modulus of fibers, the strength of matrix, chemical stability of the matrix and the effectiveness of the bonding strength between matrix and fibers in transferring stress across the interface.

All alkali treated fabric composites compared with control sample (0h). Composite consist of 5 hrs treated jute reinforcement shows the higher tensile strength and modulus Composite with 3 hrs treated fabrics shows the decreased in the modulus and tensile strength. This is because of the loss of the structural integrity in the amorphous cellulose and contribution to withstand the applied load. Besides the crystalline cellulose also not contribute to withstand the applied load and removal of some amount of amorphous cellulose was improves the wettability and hence more area available for bonding which also increase the performance of the composite. But composite with 5 hrs treated fabrics, the contribution of crystalline cellulose is more but the continuity of the crystalline cellulose structure may support by the amorphous cellulose. And also the improved wettability and more surface area for bonding increases the performance of the composites. In case of 7 hrs treated fabric reinforced composite the amorphous cellulose system were collapsed fully and the fabric stiffness level was improved to maximum. But, the structural integrity of crystalline cellulose is not adequate to distribute the applied load. Hence, the composites could not attain any improvement in mechanical properties. The comparative tensile strength and modulus of composites having 4 plies along with 0 hr, 3 hrs, 5 hrs and 7 hrs treated and untreated jute fabric reinforced composite prepared by 100% virgin unsaturated polyester resin (100%V-UPR), 100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR are shown in **Figure 2 and Figure 3.**

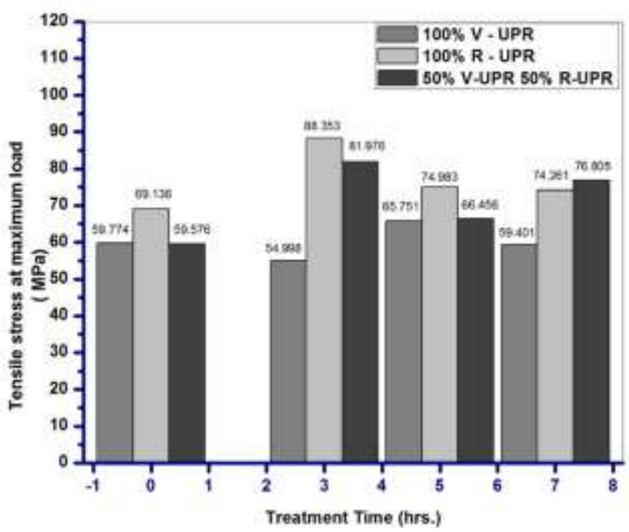


Figure 2 The comparative tensile strength analysis of composite prepared by 100% virgin unsaturated polyester resin (100%V-UPR), 100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR

It is obvious that the strength and modulus of the composite increased consistently with the increased time of alkali treated jute fabrics, the treated jute - 100% recycled unsaturated polyester resin (100%

R-UPR) composite generally exhibits higher tensile values compared to the untreated. The tensile modulus of composites also increases with the increased alkali treatment period of jute fabrics and showed better tensile properties than composite consists of untreated fabrics due to enhancement in bonding between fibre and matrix. Similar improvement or increase in the tensile properties of alkali treated natural fibres reinforced composites were reported by Rout et al (1999)[20], Ray et al (2001)[11]. The experimental results obtained in this work have confirmed this. So, tensile strength and modulus were increased with increasing time of alkali treatment. Therefore, the treatment condition of 5% NaOH and 3hours treatment time duration is assumed to be the optimal for composite preparation. The value of tensile modulus of 5hrs fabric treated composite 4.852 GPa was less than 7hrs fabric treated composite. Generally a void in the composites causes the reduced modulus reported by Soma Dalbehera et al.[21] It has clearly observed that the NaOH treatment improves the tensile strength and Energy to Break Point. An improvement in the tensile strength of the composites consists of untreated fabric and fabric treated with 5% NaOH for 3 hrs has increased from 59.576 MPa to 81.976 MPa for composite produced by combined 50% Virgin unsaturated polyester resin and 50% recycled unsaturated polyester resin.

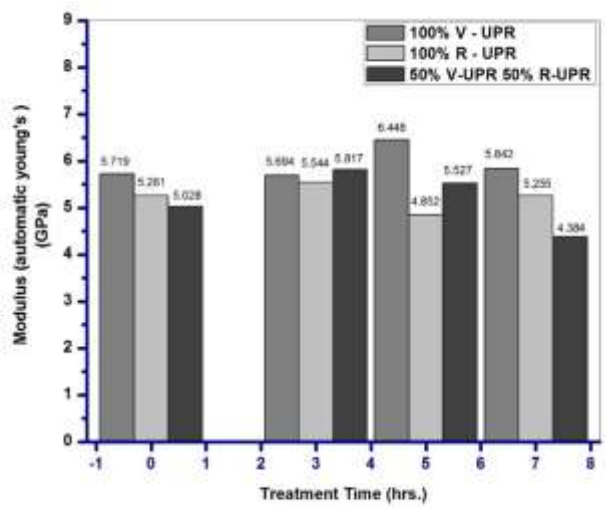


Figure 3 The comparative modulus analysis of composite prepared by 100% virgin unsaturated polyester resin (100%V-UPR), 100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR

This can be understood that the removal of the hemicellulose and a part of the lignin by alkali treatment can increase the interfacial adhesion between the matrix and NaOH treated fabric. However, at higher alkali treatment time (5 hrs, 7 hrs), the tensile strength of the composites was observed to level off. It is possible that the fibres became rigid at fabric and somewhat brittle afterwards owing to the development of crystallinity causing high strength and low extensibility. On application of stress, these fabric suffered breakage due to increased brittleness and could not take part in effective stress transfer at the interface, thus lowering the strength of the composites were reported by Rout et al [20] and E.Sinha et al [22]. Therefore, the treatment condition of 5%NaOH, 3 hrs is assumed to be the optimal for the treatment. The tensile strength of 5 hrs fabric treated composite was less than 7 hrs fabric treated composite because of may be due to presence of void were reported by Soma Dalbehera et al [21].

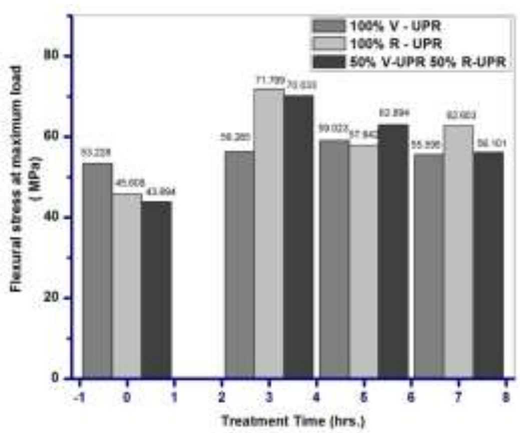
3.3 Improvement of flexural properties jute/unsaturated polyester epoxy composites

The flexural properties of composites having 4plies of 0hr, 3hrs, 5hrs and 7hrs treated and untreated jute fabric reinforced composite prepared by 100% virgin unsaturated polyester resin (100%V-UPR), 100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR are shown in **Table 2.** The flexural properties highly inclined on the fibre volume % reported in the D. Ray et al [11]. So, in general wettability of the matrix will improve the flexural properties. Heavy fibre pull-out and breakage was observed in untreated fabric composite. These were found to be decreased in case of alkali treated fibre composites, imperative of a better bonding at the interface between the fibre and the matrix. The mechanical properties of composite reinforced with 3 hrs and 5 hrs alkali-treated fabric were found to be superior in comparison to the untreated fabric reinforced composite and 5hours treated fabric reinforced composite having increase in the flexural strength illustrated in the **Table 2**. This proves that the wettability and adhesion of matrix improved gradually in the composites made up of alkali treated jute reinforcement. The maximum improvement in strength was observed for composite prepared with 5 h alkali treated fabric although 7 h treated fabric had superior fabric characteristics. Alkali treatment makes the fabric rigid and somewhat brittle afterwards owing to the development of crystallinity causing high strength and low extensibility. On the application of stress, these fabric suffered breakage due to increased brittleness and could not take part in effective stress transfer at the interface, thus lowering the strength of the composite.

Table 2 Effect of alkali treatment on flexural properties of jute/unsaturated polyester epoxy composites

Sl. No	Treatment Time (hrs)	Sample weight in gram	Maximum Load (N)	Flexural extension at Maximum Load (mm)	Flexural stress at Maximum load (MPa)	Flexural strain at Maximum load %	Modulus (automatic young's) (GPa)
100% V-UPR	0	8.064	115.327	3.79564	53.228	2.224	3.371
	3	8.718	121.951	4.65404	56.285	2.727	2.958
	5	7.970	127.882	3.72226	59.023	2.181	3.882
	7	7.316	120.456	5.60468	55.595	3.284	2.861
100% R-UPR	0	7.532	98.818	3.79334	45.608	2.223	2.920
	3	8.142	155.564	4.66416	71.799	2.733	3.790
	5	7.40	125.324	6.08600	57.842	3.566	2.831
	7	7.634	135.641	5.70183	62.603	3.341	3.194
50% V-UPR 50% R-UPR	0	7.054	95.104	5.88506	43.894	3.448	2.323
	3	8.248	151.737	5.57118	70.033	3.264	3.479
	5	7.484	136.270	5.14565	62.894	3.015	3.312
	7	7.354	121.553	6.20166	56.101	3.634	2.717

Analyzing the flexural properties of composites having 4 plies of 0hr, 3hrs, 5hrs and 7hrs treated and untreated jute fabric reinforced composite prepared by V- UPR has been shown in **Figure 4 and Figure 5,** it has been found that, flexural strength and flexural modulus are increased in various alkali treated jute fabrics laminates such as 3hrs, 5hrs and 7hrs were compared to untreated jute fabrics laminates. So the values of flexural strength of treated jute fabrics laminates are 71.799Mpa, 57.842 MPa and 62.603 MPa. The value of flexural modulus of alkali treated jute fabrics laminates is found to be higher, compared to the untreated jute fabrics laminates. The flexural behavior of composites having 4plies of 0hr, 3hrs, 5hrs and 7hrs treated and untreated jute fabric reinforced composite prepared by combined 50% Virgin-unsaturated polyester resin (V-UPR) and 50% Recycled-unsaturated polyester resin (R-UPR) found similar with the trend of tensile strength. It is evident that alkali treated jute fabric laminates consistently improved the flexural strength compared to the untreated jute fabric laminates. The flexural strength and modulus were consistently better for 3hrs, 5hrs and 7hrs alkali treated jute fabric laminates compared to untreated jute fabric laminates. Maximum flexural strength and modulus values were consistently obtained from 3hrs alkali treated jute fabrics laminates composite in comparison to the 5hrs and 7hrs alkali treated jute fabrics laminates.



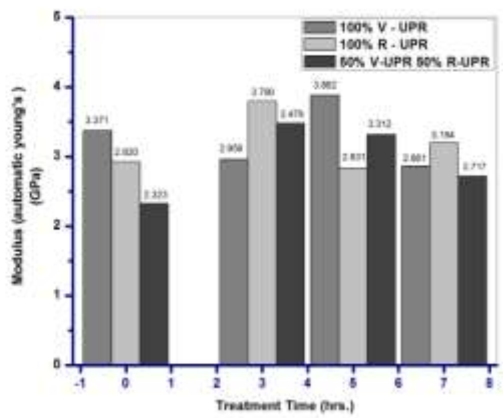


Figure 4 (left) The comparative flexural strength analysis of composite prepared by 100% virgin unsaturated polyester resin (100%V-UPR), 100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR

Figure 5(right) The comparative modulus analysis of composite prepared by 100% virgin unsaturated polyester resin (100%V-UPR), 100% recycled unsaturated polyester resin (100%R-UPR) and combined both 50%V-UPR and 50% R-UPR

The condition above indicates that 3hrs alkali treated jute fabrics reinforced composite with combined 50%V-UPR and 50% R-UPR composite is stiffer and stronger than 5hrs and 7hrs alkali treated jute fabrics laminates composite with combined 50%V-UPR and 50% R-UPR. Because increased time of treatment which helps the jute fibres to achieve higher stiffness. But due to lack of structural integrity between the stiffer fibres, the expected performance was reduced. Average values for the ultimate flexural strength and flexural modulus for the composites are 70.033 MPa and 3.479 GPa respectively, and the corresponding values for the untreated jute fabrics laminates are 43.894 MPa and 2.323GPa.

4. Conclusion

The effect of alkali treatment of jute fabric on the mechanical properties of jute/unsaturated polyester resin composites was studied. Treatment of jute fabrics by 5% NaOH at room temperature for varying times showed an overall improvement in properties of jute fabric reinforced composites. The treated fabric composite showed better tensile properties than untreated composite due to enhancement in bonding between fabric and matrix. The improved properties of the fabric with alkali treatment were also as the result of dissolution of hemicellulose and development of crystallinity and fibrillation, thus created superior bonding with unsaturated polyester resin. The untreated jute fabric generally exhibited a higher tensile strength values compared to the alkali treated specimens. The alkali treatment produced an important drop or decreased in tensile strength of the jute fabrics as a consequence of the severe alkaline treatment that was applied to jute fabrics prior to composite fabrication. The composites produced presented a brittle behaviour with higher tensile and flexural properties. The fibres were finer after treatment of fabrics, having less hemicellulose content, increased crystallinity, reduced amount of defects resulting in superior bonding with the unsaturated polyester resin. The mechanical properties were maximum when reinforced around 3–5 h treated jute fabric. The results showed that the mechanical properties are varied indicating the possibility of two different failure modes before 2h and after 5h treatment. Improper bonding between fibres and matrix so fibre pull out was predominant up to 2h and after 5h the fracture occurred with minimum fibre pull out due to the superior bonding and improved tenacity and low extensibility of the fibres. A treatment time between 3-5 h was therefore optimal to get maximum strength of the unsaturated polyester resin reinforced with jute fabrics treated with 5% NaOH solution at 30 ℃.

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