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Effects of Chemical Treatment on Impact Property of Coir Fibre Reinforced Polyester (CFRP) Composites

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Abstract

The present paper investigates the effects of fiber content and alkali treatment on impact property of coir fibers reinforced polyester resin composites which are partially biodegradable. The coir fibers were collected from the foliage of locally available coconut fruit through the process of water retting and mechanical extraction. The usual problem in natural fiber reinforced composites is seen in its poor adhesion between fiber and matrix, hence, in this study, specific physical and chemical treatments were administered for surface modification of the fibers. Both untreated and treated fibers were used for coir fibers reinforced polyester resin composites formations; and the impact properties were determined at three different control factors of the fiber contents. Applying Taguchi robust design technique for the greater-the-better, the highest signal-to-noise ratio (S/N ratio) for the quality characteristics being investigated was obtained employing Minitab 16 software. The treated coir fibres reinforced polyester matrix composites were better in impact having the expected optimum impact strength of 6.2J/mm^2 at the optimum setting of control factors, while that of the untreated composites have an expected optimum impact strength of 5.5J/mm^2 at the optimum setting of control factors. The reinforcement combinations of control factors and chemical treatment of coir fiber contribute greatly to the impact property.

Keywords

Coir Fiber, Impact Property, Alkali Treatment, Composite, Retting

1. Introduction

The use of natural fibers is gaining popularity in many sectors especially in the automotive industries [1]. Natural fibers have many distinctive advantages over other fillers with its limitless application areas. The reinforcing constituent is embedded in a matrix to form the composite. Composite structures are quite common in nature where fiber and matrices are combined.

Coir fiber is widely used along with rubber, thermoset and thermoplastics resins to make polymer composites. Research on alkali treatment where coir fibers were treated with NAOH (conc. 2, 4, 6, 8 and 10%) for 10 days and fiber lengths of 10, 20 and 30mm presented their effect on impact behavior of coir fiber reinforced epoxy composites [2]. Alkali treated coir fiber reinforced epoxy composite had better impact strength (27kJ/m^2) along with increased fiber length. Coir fiber (30mm) showed better impact strength compared to other lengths. Untreated coir fiber resulted in low impact strength due to poor interfacial bonding. However, adhesion was improved by surface modification of coir fiber. No significant difference in impact strength of composite was noticed for 6% and 8% alkali concentrations. When alkali concentration was increased to 10%, decreased in fiber strength was observed. Among alkali treated coir fiber reinforced epoxy composites, 6% alkali treated composite showed better impact strength compared to untreated coir fiber reinforced epoxy composites.

In another study, the green husk coir fibers were treated with different levels of soaking time and concentration of alkali solution their effect on mechanical properties of coir–polyester composites. As a result of alkali treatment, the surface modifications were done on the fiber surface as shown using scanning electron micrographs. The effect of soaking time and concentration of NaOH solution were studied based on evaluated values of mechanical properties to find out optimum fiber treatment parameters. The work showed that Alkali treatment of coir fiber in 5% aqueous solution for 72hrs results in a 31% increase in tensile strength, 2% aqueous solution for 96hrs results in a 22% increase in flexural strength and 8% aqueous solution for 24hrs results in a 30% increase in impact strength. The mechanical properties are greatly improved by the fiber treatment process and treatment parameters namely soaking time and concentration of NaOH solution which played a major role to increase the tensile, flexural and impact properties of green husk coir fiber reinforced composites [3].

2. Material and Methods

In this study, coir fibers are used as the reinforcement; aqueous sodium hydroxide (NaOH), potassium permanganate ($KMnO_4$) solid and acetone liquid are used for fiber chemical treatment; and polyester resin as the matrix.

Figure 1. Dried Coir Fibers.

2.1. Coir Fiber Extraction and Chemical Treatment

Retting process which is a curing process during which the husks are kept in an environment that encourages the action of partial decomposition of the husk's pulp, allowing it to be separated into coir fibers and a residue called coir pith were used to source coir fibers used for this work from coconut husk. Coconut husks were soaked in few buckets of water (freshwater retting) with some biodegradable materials that will increase decomposing organisms thereby reducing the retting period to four (4) months. After the retting process, loosed fibers were separated and washed by washing off the residue in water. The clean fibers were spread loosely in the air to dry. Figure 1 represents the well dried coir fibers.

Figure 2. Treated Coir Fibers.

In this study, alkaline treatment was conducted on coir fibers by immersing them in 5% aqueous (NaOH) solution for 72hours at room temperature for proper depolymerisation of cellulose, removal of lignin and better strength of coir. Afterwards the treated fibers were carefully spread on mat and then finally air-dried. Afterward, the alkaline treated coir fibers were dipped in permanganate solution at concentrations of 50% in acetone for 10 min for neutralization of the alkaline treated fibers; and hence, the hydrophilic tendency of the coir fibers, and the water absorption of CFRP composite are expected to decrease. Figure 2 represents the treated coir fibers.

2.2. Fiber Volume Fraction Through Archimedes Principle

Calculations of volume fraction of coir fibers are achieved following the derivations from rule of mixtures based on the procedures [4] and implementation of Archimedes principals [5].

2.3. Sample Formation

Simple hand lay-up process was followed for forming these CFRP composites. Composite formation using permanganate treated coir and untreated coir fibers were carried out in a square mold of volume $300mm$x$300mm$x$7mm$ in a matching group of 5, 10 and 15% volume fractions and 10, 20, 30 ${}^{mm}/_{mm}$ aspect ratio based on design matrix [6], [7]. Initially, the mold was polished; and Poly vinyl acetate (PVA) mold release agent was applied on its surface before the fabrication. Afterwards, the binding mixture resin system consisting of unsaturated orthophthalic polyester, methyl ethyl ketone peroxide (MEKP) catalyst and cobalt naphthanate accelerator was prepared and used for the composites formation. The resin mixture was then poured on to the well dispersed coir fiber placed in the mold. The

CFRPs were pressed with a roller to avoid any air trap. When the coir fibers were completely wet by the resin, the mold was closed with a polished and Poly vinyl acetate (PVA) release agent surface-coated cover after the fabrication then pressed and cured at room temperature. At the time of curing, a compressive pressure of 0.05MPa was applied and maintained on the mold and the composite specimens were cured for 24 hours. Replicate samples of CFRP composites were formed as shown in Figure 3.

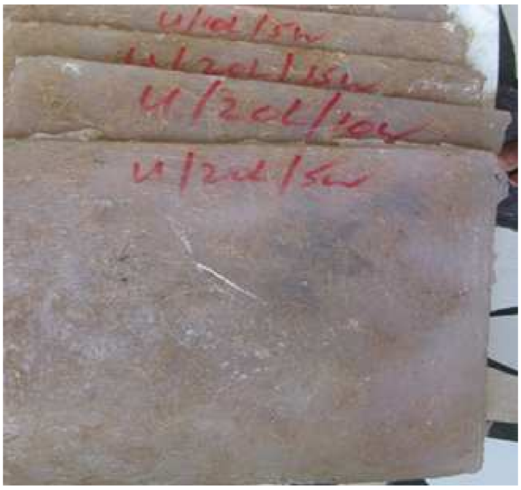

Figure 3a. *Untreated CFRP composites.*

Figure 3b. *Treated CFRP Composites.*

Table 1. *Experimental outlay and variable sets for mechanical properties.*

Control factors	Level 1	Level 2	Level 3	Units
A: Aspect Ratio (l_f/d_f)	10	20	30	$^{mm}/_{mm}$
B: Volume Fraction	5	10	15	%
C: Fiber Orientations	0/90	30/60	45/45	degree

2.4. Design of Experiment (Doe) – Taguchi Experiment

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources [6], [8]. The general steps involved in the Taguchi Method were followed as well detailed in article [8].

The most important stage in the design of experiment lies in the selection of the control factors.

Table 2. *Applicable Taguchi Standard Orthogonal array L9 (3^3).*

Experiment Number	Parameter 1: A	Parameter 2: B	Parameter 3: C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

The signal-to-noise ratio measures the sensitivity of the quality investigated to those uncontrollable factors (error) in the experiment. The higher value of S/N ratio is always desirable, because greater S/N ratio will result in smaller product variance around the target value. In order to perform S/N ratio analysis, mean square deviation (MSD) for "the-larger-the-better" quality characteristic and S/N ratio were calculated from the following equations 1 and 2 [7], [8].

$$MSD = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \tag{1}$$

$$S/N = -10Log_{10}(MSD) \tag{2}$$

Where, y_i is a particular mechanical property for *i*th replicate experiment.

3. Results and Discussion

Impact strength testing was carried out using impact testing machine as per ASTM D256-06 standard. The specimens were cut from the fabricated composites for Izod impact test.

3.1. Evaluation of Mean

The experimental results of impact response according to their fiber parameters and levels for both treated CFRP is shown in Tables 3; and untreated CFRP composites is given in Tables 5. Since the L_9 experimental design orthogonal is possibly used to separate out the effect of each factor. This is done by looking at the control matrix, Table 3 for treated CFRP and Table 5 for untreated CFRP based on the methods of [9]. The computations of the average SN ratio and mean responses for each factor at each of the three test levels for treated CFRP for untreated CFRP were implemented in Minitab 16 software and the results are presented in Tables 4 & 6 respectively. Figures 4(a & b) and 5(a & b) are the excel graphics for SN ratio and Impact strength of CFRP composites based on Larger is better quality characteristics.

Table 3. *Experimental design matrix for Impact test of Treated CFRP composites (ASTM-D256).*

Expt. No.	A: Aspect ratio[lf/df] (mm)	B: Volume fraction (%)	C: Fibre orientation (degree)	Mean Impact Response-Treated (J/mm^2)	MSD	SNratio
1	10	5	0/90	1.6	0.39063	4.0824
2	10	10	30/60	1.8	0.30864	5.1055
3	10	15	45/45	1.4	0.51020	2.9226
4	20	5	30/60	3.6	0.07716	11.1261
5	20	10	45/45	8.0	0.01563	18.0618
6	20	15	0/90	1.6	0.39063	4.0824
7	30	5	45/45	1.2	0.69444	1.5836
8	30	10	0/90	2.0	0.25000	6.0206
9	30	15	30/60	4.0	0.06250	12.0412

Table 4. *Summary Response Table for SN ratio and Mean Impact strength of Treated CFRP composites based on Larger is better quality characteristics.*

Response	Signal –to- Noise Ratios			Means		
Level	A: Aspect Ratio (l_f/d_f)	B: Volume Fraction (%)	C: Fibre Orientations (degree)	A: Aspect Ratio (l_f/d_f)	B: Volume Fraction (%)	C: Fibre Orientations (degree)
1	4.037	5.597	4.728	1.600	2.133	1.733
2	11.090	9.729	9.424	4.400	3.933	3.133
3	6.548	6.349	7.523	2.400	2.333	3.533
Delta	7.053	4.132	4.696	2.800	1.800	1.800
Rank	1	3	2	1	2	3

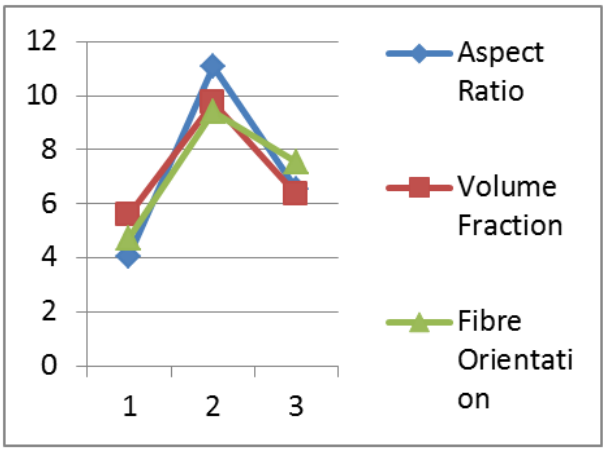

Figure 4a. *Main effect plots for signal-noise ratio-CFRP (Impact).*

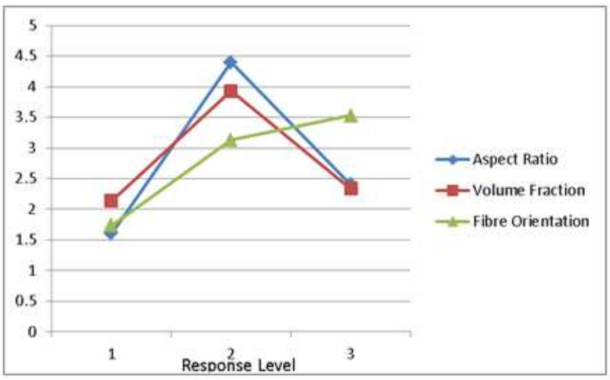

Figure 4b. *Main effect plots for means-Treated Treated CFRP (Impact).*

Treated CFRP response tables for SN ratios shows that the aspect ratio has the highest contribution in influencing the composite impact strength, followed by fiber orientation; and the fiber orientation has the highest contribution in influencing the composite impact strength, followed by volume fraction for Means as depicted in Table 5 and Figures 4a-4b.

Untreated CFRP response tables for SN ratios shows that, the aspect ratio has the highest contribution in influencing the composite impact strength, followed by fiber orientation; and the aspect ratio has the highest contribution in influencing the composite impact strength, followed by volume fraction for means as depicted in Table 6 and Figures 5a-5b.

Table 5. *Evaluated quality characteristics, signal to noise ratios and orthogonal array setting for evaluation of impact responses of Untreated CFRP.*

Expt. No.	A	B	C	Mean Impact Response-Untreated (J/mm^2)	S/Nratio
1	1	1	1	2.4	7.6042
2	1	2	2	1.2	1.5836
3	1	3	3	2.2	6.8485
4	2	1	2	1.4	2.9226
5	2	2	3	1.8	5.1055
6	2	3	1	3.8	11.5957
7	3	1	3	4.2	12.4650
8	3	2	1	4.0	12.0412
9	3	3	2	4.4	12.8691

Table 6. *Summary Response Table for SN ratio and Mean for Impact strength of Untreated CFRP composites based on Larger is better quality characteristics.*

Response	Signal –to- Noise Ratios			Means		
Level	A: Aspect Ratio(l_f/d_f)	B: Volume Fraction (%)	C: Fibre Orientations (degree)	A: Aspect Ratio(l_f/d_f)	B: Volume Fraction (%)	C: Fibre Orientations (degree)
1	5.345	7.664	10.414	1.933	2.667	3.400
2	6.541	6.243	5.792	2.333	2.333	2.333
3	12.458	10.438	8.140	4.200	3.467	2.733
Delta	7.113	4.194	4.622	2.267	1.133	1.067
Rank	1	3	2	1	2	3

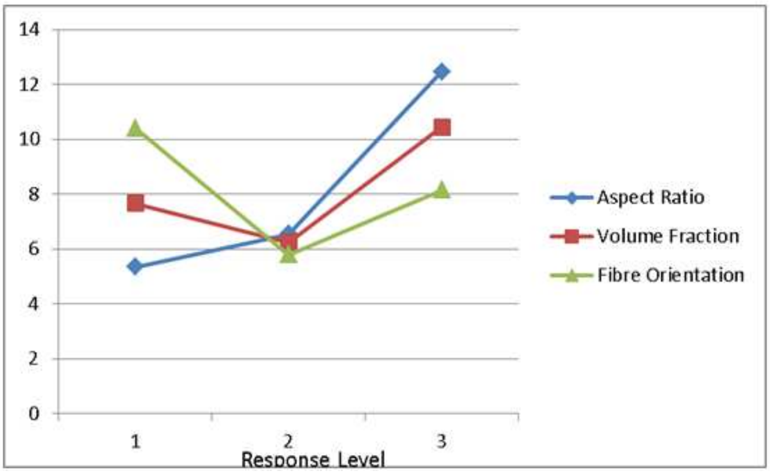

Figure 5a. *Main effect plots for signal-noise ratio-Untreated CFRP (impact).*

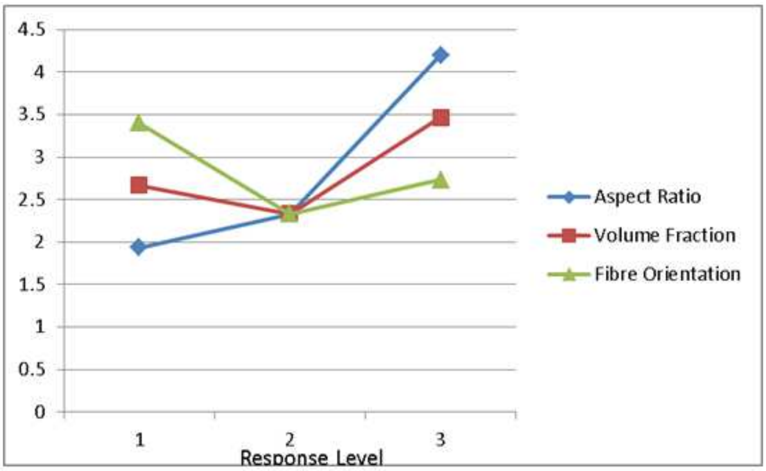

Figure 5b. *Main effect plots for means-Untreated CFRP (Impact).*

3.2. Estimation of Expected Responses Based on Optimum Settings

The expected response is estimated using the optimum control factor setting from the main effects plots; by employing the response table for signal to noise ratio and the response table for mean [10], the expected response model is as in equation (3):

$$ER = AVR + \left(A_{opt} - AVR\right) + \left(B_{opt} - AVR\right) + \left(C_{opt} - AVR\right) + \text{---} + \left(n_{opt}^{th} - AVR\right) \quad (3)$$

Where, ER= expected response, AVR = average response, A_{opt} = mean value of response at optimum setting of factor A, B_{opt} = mean value of response at optimum setting of factor B, C_{opt} = mean value of response at optimum setting of factor C.

- For the treated CFRP from Figures 4a &b and Table 4

$$ER_{Treated\ (Impact)} = 2.8 + (4.4 - 2.8) + (3.9 - 2.8) + (3.5 - 2.8) = 6.2J/mm^2$$

- For the untreated CFRP from Figures 5a &b and Table 6

$$ER_{Untreated\ (Impact)} = 2.8 + (4.2 - 2.8) + (3.5 - 2.8) + (3.4 - 2.8) = 5.5J/mm^2$$

The Impact Average Response of Treated CFRP and Untreated CFRP are the same. Also as a result of plots of Figures 4-5 one can conclude that the optimal settings of control parameters are as presented in Table 7 for both treated and untreated CFRP.

Table 7. *Optimum setting of control factors and expected optimum impact strength of composites.*

Composite/property	Control factor	Optimum level	Optimum setting	Expected optimum strength
Treated CFRP /Impact	A	2	20	$6.2J/mm^2$
	B	2	10	
	C	3	45/45	
Untreated CFRP /Impact	A	3	30	$5.5J/mm^2$
	B	3	15	
	C	1	0/90	

Optimum settings of both Treated and Untreated CFRPs are totally different from each other in all the control factors. But then, the Expected Optimum Impact strength of Treated CFRP is bigger than that of Untreated CFRP, though small difference. It implies that the rough surface and hydrophobic natures of the treated coir fiber offer better advantage over the untreated coir fiber under the same considered Control factors in reinforced Polyester resin composites. The higher Expected Optimum Impact strength of Treated CFRP occurred in the absence of Maleated coupling agents which are widely used for strengthening composites containing fillers or fiber reinforcements [9], [11].

4. Conclusion

The treated CFRP composite has the optimum impact strength of 6.2 J/mm^2 when the control factors (aspect ratio of fibers, volume fraction of fibers and fibers orientation) are set 20, 10% and 45/45 degree respectively, while untreated CFRP composite has the impact strength of 5.5 J/mm^2 when the control factors are set 30, 15% and 0/90 degree respectively.

The impact result indicates that fibers aspect ratio and fibers orientation have the highest effect on the impact strength of the composites. The effect of fibers volume fraction is significantly less for both treated and untreated coir, and it cannot be ignored.

Generally chemical treatment has assisted in improving the impact strength, which is energy absorbed in fracturing a test piece at high velocity, of treated CFRP than that of untreated CFRP. The treated CFRP exhibits better impact property than the untreated CFRP due to some reasons which include: better hydrophobic nature, rough surface characteristics and pits disclosure of the chemically treated Coir which thereby enhanced the composite formation and could also serve adequately within the wide scale of applications and products in the automotive industry.

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