International Journal of Frontiers in
Engineering and Technology Research
Journal homepage: https://frontiersrj.com/journals/ijfetr/
ISSN: 2783-0497 (Online)

(Research Article)

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Investigation of water and heat response to the compression property of raffia, bamboo and coconut fiber-reinforced-polyester composites

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International Journal of Frontiers in Engineering and Technology Research, 2021, 01(01), 045–060

Publication history: Received on 03 April 2021; revised on 05 May 2021; accepted on 07 May 2021

Article DOI: https://doi.org/10.53294/ijfetr.2021.1.1.0045

Abstract

The dearth of construction materials has been the bane of the global construction industry. In a bid to curb this menace, it becomes very imperative to source for construction materials from discarded and least costly materials from raffia, bamboo and coconut fibers. This research investigates the hydrothermal response of plant fiber-reinforced-polyester composites (PFRC). Imperical methods were used to determine the mechanical properties of PFRC (bamboo, raffia and coconut fiber composites), with the usage of Monasanto Tensometer testing machine. All the samples were chemically modified with 12.5g of sodium hydroxide. Numerical and micro-soft excel graphics were used to model compressive responses of the PFRCs. From the analyses, the compressive strengths of raffia, bamboo and coconut composites are 40, 45 and 38MP_a respectively.

Keywords: Hydrothermal; Polyester composites; Compression properties; Fiber

1. Introduction

The fibers of raffia, bamboo and coconut have found particular applications in construction and in the constitution of composites. Nature has imbued the earth with plant fibers which provide basic raw materials for industries often times they used as additives for the manufacture of different products. Eckert (2000) predicted that between era 2020 – 2025 there would be fifty percent increase in the use of natural fibers in plastic industry. They, generally referred to as lignocelluloses materials are derived from woods or agricultural materials, such as bamboo, raffia, coconut, kenaf, jute, hemp, flax, etc. They are available in many different forms, and produce different properties when added to thermoplastics (Sanadi et al., 1995, Zaian et al., 1996). They may be used in the form of particles, fiber bundles or single fibers, and may act as fillers or reinforcements for plastics (Oswald, 1999).

Plant fiber-reinforced-composites (PFRCs) have gained attention in the recent times due to their high performance in mechanical properties, significant processing advantages, excellent chemical resistance, low cost, low density, availability of the natural resources and renewability of the source plants. Also, PFRCs provide positive environmental benefits and raw materials utilization. They also have better tensile strengths and stiffnesses than plastic and engineering materials. The objective of the research is to investigate the response of water and heat on the compression property of plant fibers-reinforced- polyester composites by using raffia, bamboo and coconut fibers as the reinforcements.

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1.1. Reinforcement Plant Fiber Characteristics

Natural fibers are grouped into seed, bast, leaf, grass and fruit qualities. The bast and leaf (the hard fibers) fibers are the most commonly used in composites applications (Williams and Wool, 2000). The three fibers that were used in the laboratory analyses in this research – bamboo, raffia and coconut fibers have densities of about half that of glass fibers (a synthetic fiber). These fibers can withstand processing temperatures up to 2500C (Sreekala et al., 2002). They are fully combustible without production of either noxious gases or solid residues. The strength characteristics of these fibers depend on the properties of their individual constituents, their fibrillar structures and Lamellae matrices (Joseph et al., 2000). Also, fiber quality determinant characteristics include fiber fitness, polymerization of the cellulose, cleanness or purity, and homogeneity of the sample. Plant fiber properties directly influence the physical parameters of the reinforced composites manufactured with them (John et al., 2002). The properties of these fibers are determined by their molecular fine structure, which are in turn affected by the growing conditions and processing techniques employed in the processing of the fibers.

Quality, specific strength, stiffness, and other properties of fiber depend on factors such as size, maturity and the processing methods adopted for the fiber extraction (Mohanty et al., 2001). Properties such as density, electrical resistance, ultimate tensile strength, and initial modulus are related to the internal structure and chemical composition of the fiber.

Desirable properties for fibers include high tensile strength and modulus, high durability, low bulk density, good mouldability and recyclability. Natural fibers have advantages over glass and synthetic fibers in that they are less expensive, abundantly available from renewable resources, have high specific strengths, and are of less weight.

1.2. Water and Heat Behavior of Composites

There are two principal effects of changes in the hydrothermal environment on mechanical behaviour of polymer composites. These are the matrix-dominated properties and the hygrothermal expansion or contraction of the composites.

1.2.1. Matrix-dominated Properties of Composites

These properties, such as stiffness and tensile strength are altered when the composites are subjected to transverse off-axis or shear loading. Increase in temperature causes gradual softening of the polymer matrix material up to a point. If temperature is increased beyond the so-called "glass transition region" (indicating a transition from glassy behaviour to rubbery behaviour), the polymer becomes too soft for use.

1.2.2. Water and Heat Expansion or Contraction

This changes the stress and strain distribution in the composites. Increased temperature and/or moisture content cause swelling of the polymer matrix, whereas reduced temperature and/or moisture content cause contraction.

1.3. Water and Heat Degradation of Composite Properties

Imposed hygrothermal condition causes substantial reductions of both strength and stiffness in graphite/epoxy composites under hygrothermal conditions of various combinations of temperature and absorbed moisture; with the "hot-wet" conditions (combined high temperature and high moisture content) generating the most severe degradation (Browning et al., 1994). As a result of the hygrothermal sensitivity of matrix-dominated-composite properties, composites having continuous fibers and high fiber contents absorb little moisture, and exhibit negligible changes in modulus with time of soaking.

Conversely, composites with matrix-dominated behaviour (i.e. those with chopped fibers only, and low fiber contents) are characterized with most moisture picking and greatest reduction in modulus.

2. Material and methods

2.1. Materials

The basic raw materials include fibers (coconut, raffia, palm, and bamboo fibers), polyester resin, accelerator (cobalt), catalyst (MEKP), binders, gel coat resins, release agents and formica moulds. The tools used include paint brush, a pair of scissors, rubber hand gloves, rollers, and electric cutting machine.

2.2. Methods

The methods applied are fibre extraction from raffia, bamboo and coconut and the treatment of the fibers with sodium hydroxide.

2.2.1. Preparation of the Composites for Testing

The composites were made from the processed and matted fibers. The resin was accelerated with cobalt, then catalyzed with MEKP. The composites were then cut into test specimens of the required size to suit the Monsanto universal testing machine. For the tension test, the laminates were cut into strips of average dimensions of (300x21x5.2) mm^3 and the specimens for the compressive test, of dimensions of (40 x 20 x 20) mm^3.

2.2.2. Compression Tests

Compression test was carried out with the Hounsfield (Monsanto) Tensometer – modelno. S/N8889. It is a universal tester with various interchangeable attachments for performing compression tests with their appropriate loading arms.

Compression test parameters:

$$\text{Cross sectional area} = 20\text{mm} \times 20\text{mm} = 400\text{mm}^2$$

$$\text{Gauge length} = \sqrt{cross\ sectional\ area} = 20\ mm.$$

2.2.3. Volume Fraction Measurement

Archimedes' principle was applied in the determination of the fibers' volume fraction.

$$\text{Solid volume fraction} = \frac{\text{volume of solid}}{\text{volume of fluid}}$$

$$\therefore \text{Fiber volume fraction} = \frac{\text{volume of fiber}}{\text{volume of composite}} = \frac{\mathbf{V_f}}{\mathbf{V_C}}$$

$$= \frac{V_f}{V_f + V_m} = 2.5$$

3. Results and discussion

The loads (forces) and extentions values obtained from the graphics of the Monsanto Tensometer were used to evaluate the strain and stress responses of each sample. The ultimate tensile strength (UTS) and moduli of elasticities (E) were read from the strain – stress curves.The strain – stressvalves of raffia, bamboo, and coconut fibers-reinforced-polyester composites for conditioned(modified) and unconditioned (nonmodified) samples were plotted. These processes were carried out at constant fiber-volume-fraction Vf of 0.35. The entire specimens were modified (chemically treated with NAOH). The specimens were soaked for 4hrs, 8hrs, 12hrs, and 24hrs, and heated for 200C, 400C, 800C, and 1000C. The results of the compressive tests and moisture absorption properties of the different fibers-reinforced-polyester composites are tabulated below.

3.1. Compression Test

The compressive strength of material is the ultimate stress required to cause failure under compressive loading. It is determined by

$$\text{Stress } \sigma = \frac{\text{Force (Load)}}{\text{Cross secrional area,}}, \text{ and strain} = \frac{\text{Deformation}}{\text{Guage length}}$$

The data analyzed from tables 3.16 to 3.30 show that the compressive strength of all conditioned (treated) composite samples were greater than their respective unconditioned (untreated) composites. Below are the tables and graphs of the compression test results.

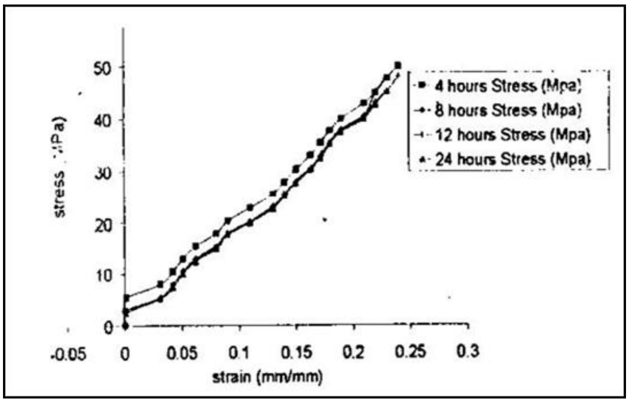

Figure 1 Compression test stress-strain response of 20x20x40mm^3 raffia fiber-reinforced-polyester composite samples at 20°C

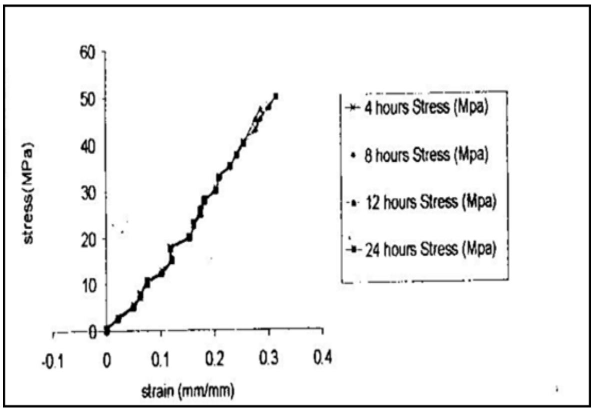

Figure 2 Compression test stress-strain response of 220 x 20 x 40 mm3 raffia fiber-reinforced-polyester composite samples at 40°C

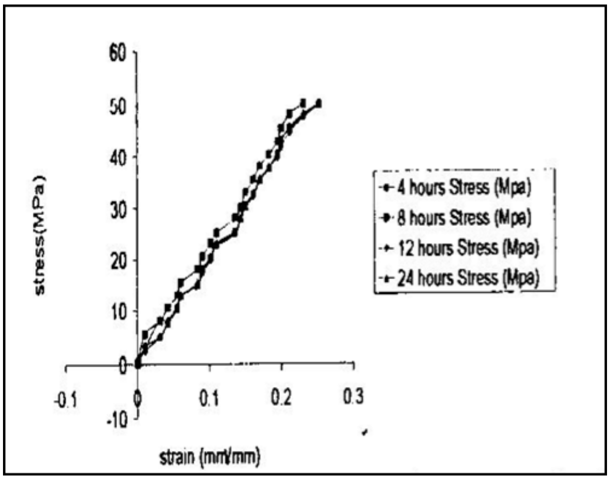

Figure 3 Compression test stress-strain response of 20 x 20 x 40 mm^3 raffia fiber-reinforced- polyester composite samples at 60°C

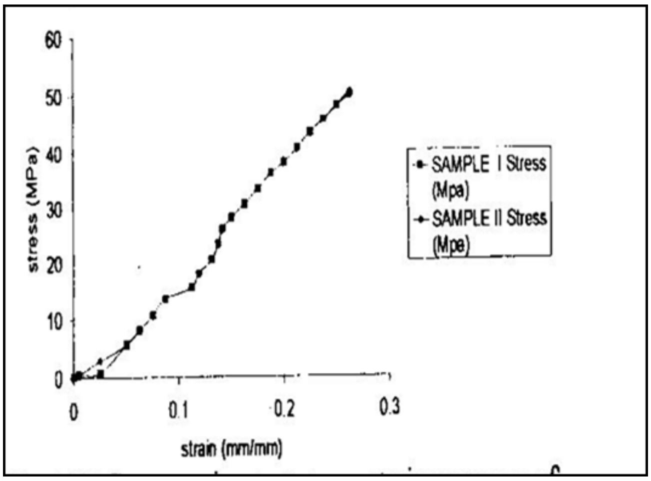

Figure 4 Compression test stress-strain response of 20 x 20 x 40 mm^3 raffia fiber-reinforced-polyester composite samples (untreated)

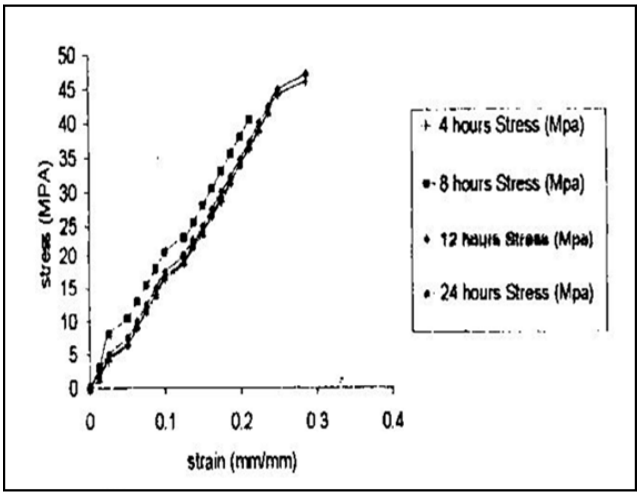

Figure 5 Compression test stress-strain response of 20 x 20 x 40 mm^3 raffia fiber- reinforced-polyester composite samples at 60°C

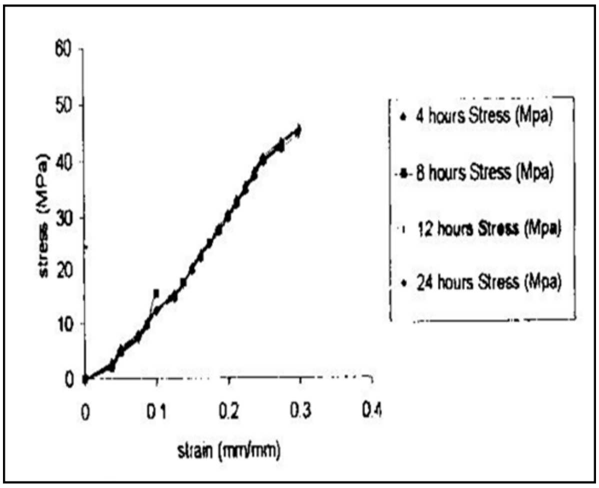

Figure 6 Compression test stress-strain response of 20 x 20 x 40 mm^3 raffia fiber-reinforced-polyester composite samples ***at***60°C

Table 1 Compression stress - strain response of 20 x 20 x 40 mm^3 for raffia fiber-reinforced-polyester composite samples at 20^0C (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	Stress (MPa)	Strain mm/mm	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0001	3.00	0.0100	0.25	0.0100	0.50	0.0000	0.25
0.0010	5.50	0.1250	3.00	0.0100	3.00	0.0100	2.50
0.0310	8.00	0.0250	5.25	0.0310	5.50	0.0621	5.25
0.0420	10.50	0.0500	8.00	0.0420	8.00	0.0930	7.50
0.0511	13.00	0.0750	10.50	0.0511	10.50	0.1131	10.00
0.0623	15.50	0.0875	13.00	0.0623	13.00	0.1302	12.50
0.0801	18.00	0.1000	15.25	0.0721	15.50	0.1601	15.00
0.0902	20.25	0.1125	18.00	0.0823	18.00	0.1723	17.75
0.1101	23.00	0.1250	20.25	0.0900	20.25	0.1801	20.00
0.1300	25.50	0.1375	23.00	0.1023	23.25	0.2102	22.75
0.1401	27.75	0.1500	25.25	0.1120	25.50	0.2301	25.25
0.1502	30.25	0.1625	27.75	0.1200	28.00	0.2400	27.50
0.1631	33.00	0.1750	30.25	0.1301	30.50	0.2601	30.25
0.1723	35.50	0.1875	32.75	0.1423	33.00	0.2801	32.50
0.1801	37.75	0.2000	35.25	0.1524	35.50	0.2902	35.25
0.1900	40.00	0.2250	37.75	0.1630	38.00	0.3101	37.50
0.2101	43.00	0.2375	40.50	0.1731	40.50	0.3300	40.00
0.2203	45.00	0.2625	45.00	0.1832	43.25	0.3601	42.75
0.2302	47.75	0.2750	47.75	0.1930	45.25	0.3902	45.25
0.2404	50.00	0.2875	50.00	0.2013	48.00		
				0.2103	50.00		

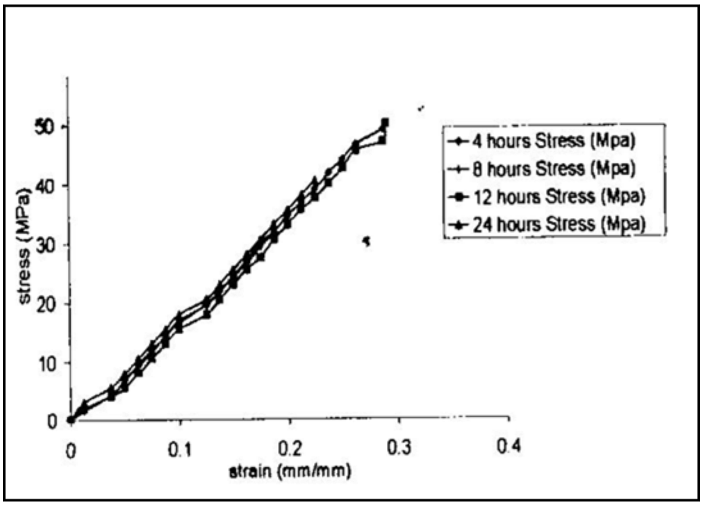

Figure 7 Compression test stress-strain response of 20 x 20 x 40 mm^3 bamboo fiber-reinforced-Polyester composite samples at 60^0C

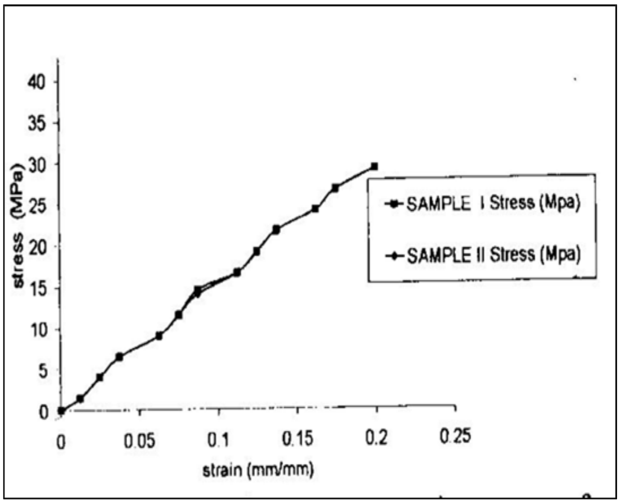

Figure 8 Compression test stress-strain response of 20 x 20 x 40 mm^3 bamboo fiber-reinforced-Polyester composite samples (untreated)

Table 2 Compression test stress-strain response of 20 x 20 x 40 mm3 for raffia fiber-reinforced-polyester composite samples at 40⁰C (treated)

4 hours		8 hours		12 hours		24 hours	
Strain	Stress	Strain	Stress	Strain	Stress	Strain	Stress
(mm/mm)	(MPa)	mm/mm	(MPa)	(mm/mm)	(MPa)	(mm/mm)	(MPa)
0,0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0000	0.50	0.0100	0.25	0.0000	0.25	0.0000	0.50
0.0213	3.00	0.0120	2.75	0.0701	2.50	0.0013	2.50
0.0500	5.75	0.0201	5.25	0.1102	5.00	0.0500	5.25
0 0625	8.00	0.0423	7.50	0.1504	7.25.	0.0625	7.75
0.0750	10.50	0.0637	10.00	0.1723	10.00	0.0750	10.75
0.1023	13.00	0.0721	12.50	0.1563	12.50	0.1108	12.20
0.1208	15.50	0.0900	15.25	0.2130	15.00	0.1186	15.25
0.1186	18.00	0.1101	17.50	0.2234	17.50	0.1438	17.75
0.1538	20.50	0.1103	20.00	0.2605	20.00	0.1625	20.25
0.1625	23.00	0.1321	22.50	0.2703	22.50	0.1750	23.25
0.1750	25.50	0.1438	25.25	0.2953	25.00	0.1938	26.00
0.1823	28.00	0.1521	27.75	0.3050	27.75	0.2125	28.25
0.2038	30.50	0.1652	30.00	0.3123	30.00	0.2250	30.00
0.2100	33.00	0.1832	32.75	0.3350	32.75	0.2375	32.75
0.2301	35.50	0.1963	35.00	0.3528	35.25	0.2563	35.25
0.2425	38.00	0.2001	37.75	0.3629	37.50	0.2625	37.50
0.2550	40.50	0.2132	40.00	0.2721	40.00	0.2750	40.25
0.2775	43.25	0.2340	42.75	0.4035	45.25		
0.2863	45.50	0.2430	45.00	0.4100	47.25		
0.3025	48.00	0.2601	47.50	0.4326	47.75		
0 3150	50.00	0.2703	50.00	0.4705	50.00		

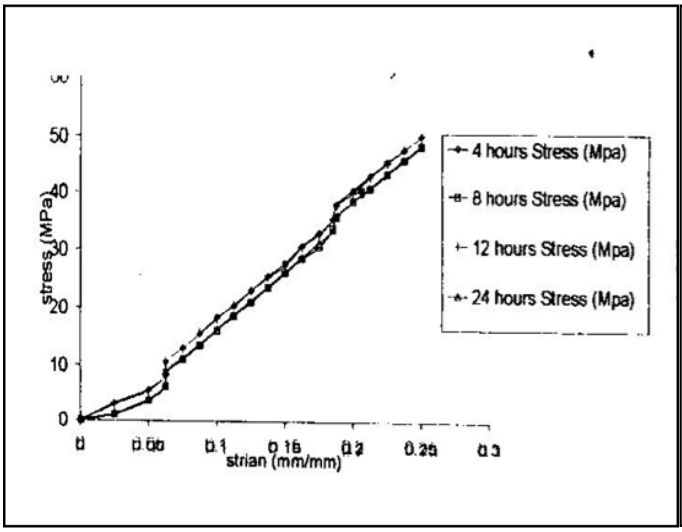

Figure 9 Compression test stress-strain response of 20 x 20 x 40 mm^3 coconut fiber-reinforced-polyester Composite samples at 20⁰C

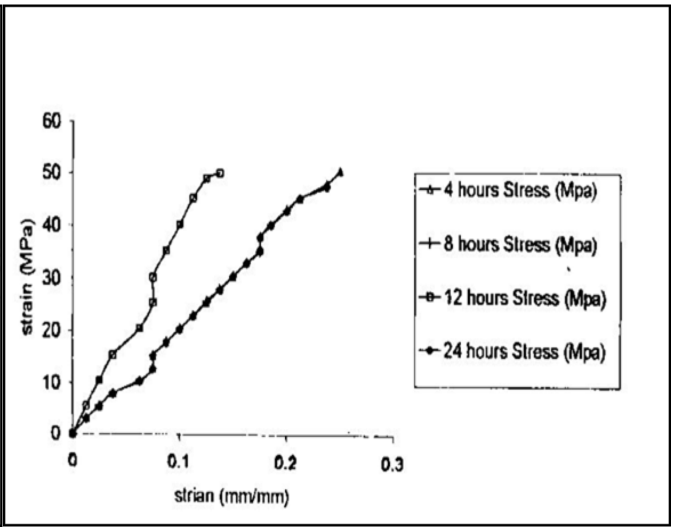

Figure 10 Compression test stress-strain response of 20 x 20 x 40 mm^3 coconut fiber-reinforced-polyester Composite samples at 40⁰C

Table 2 Compression test stress-strain response of 20 x 20 x 40 mm3 for raffia fiber-reinforced-Polyester composite samples at 60⁰C (treated)

4 hours		8 hours		12 hours		24 hours	
Strain	**Stress**	**Strain**	**Stress**	**Strain**	**Stress**	**strain**	**Stress**
(mm/mm) —' *t*	(MPa)	mm/mm	(MPa)	(mm/mm)	(MPa)	(mm/mm)	(MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0000	0.25	0.0100	0.50	0.0125	0.25	0.0400	0.25
0.0100	3.25	0.1000	5.50	0.0313	2.50	0.0500	2.75
0.0310	5.00	0.1125	8.00	0.0438	5.00	0.1368	8.25
0.0423	8.00	0.1250	10.50	0.0563	7.50	0.1550	7.75
0 0552	10.50	0.1375	13.00 -	0.0688	10.25	0.1975	10.50
o 0601	12.75	0.1625	15.50	0.0750	12.75	0.2000	13.00
0.0832	15.25	0.17.50	18.00	0.0875	15.00	0.2225	15.00
0.0900	17.75	0.1875	20.50	0.1000	17.25	0.2450	18.00
0.1015	20.25	0.2000	23.00	0.1125	20.00	0.2514	20.25
0.1100	22.75	0.2125	25.00	0.1250	22.50	0.2675	23.00
0.1356	25.25	0.2250	28.00	0.1314	24.75	0.2900	25.25
0.1432	27.75	0.2500	30.00	0.1375	27.75	0.3025	28.00
0.1501	30.50	0.2565	33.00	0.1500	30.25	0.3150	30.25
0.1610	32.75	0.2625	35.50	0.1625	32.25	0.3313	32.75
0.1702	35.25	0.2860	38.00	0.1750	35.28	0.3475	35.50
0.1830	37.75	0.3000	40.25	0.1813	37.75	0.3536	37.75
0.1952	40.50	0.3125	42.75	0.1875	39.75	0.3600	40.50
0.2001	42.50	0.3250	45.25	0.1936	41.75	0.3825	43.00
0.2120	45.50	0.3500	48.00	0.2000	44.50	0.3950	45.25
0.2312	47.50	0.3625	50.00	0.2125	47.50	0.4113	48.00
0.2530	50.00			0.2250	50.00	0.4475	50.00

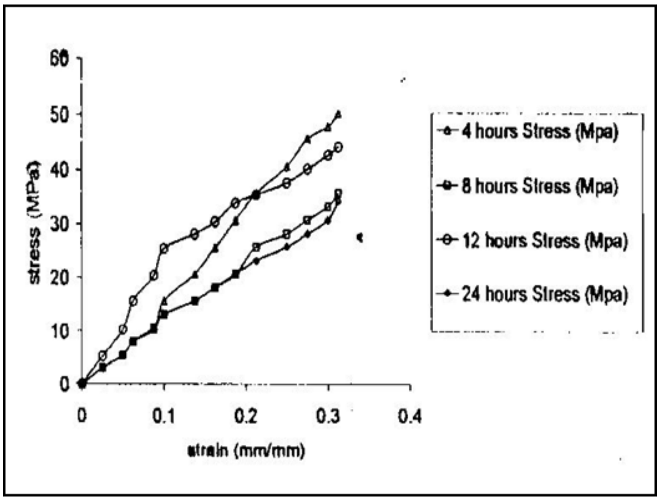

Figure 11 Compression test stress – strain response

Of 20 x 20 x 40 mm³ coconut fiber-reinforced-polyester Composite samples at 60 ⁰C

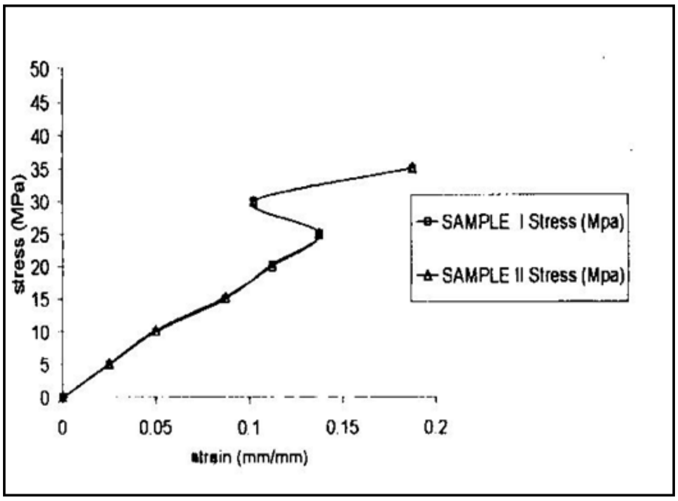

Figure 12 Compression test stress – strain response

Of 20 x 20 x 40 mm³ coconut fiber-reinforced-polyester Composite samples at 100⁰C (untreated)

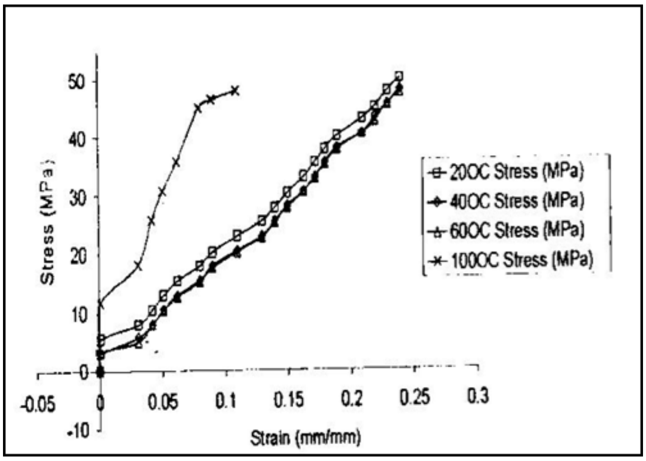

Figure 13 Compression test stress-strain response of 20 x 20 x 40 mm³ raffia fiber-reinforced-polyester composite samples at 4hrs

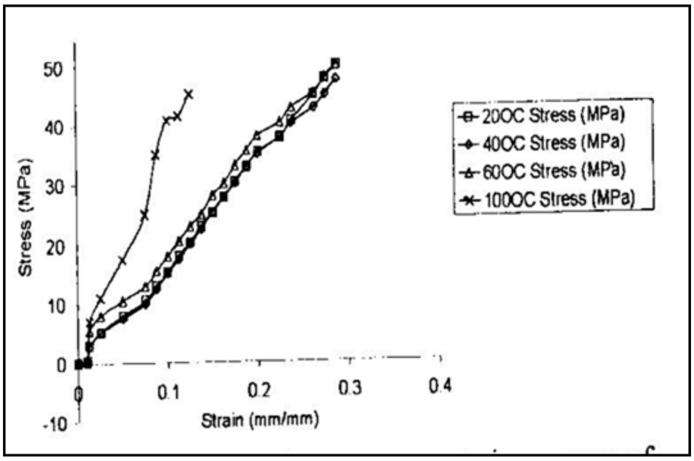

Figure 14 Compression test stress-strain response of 20 x 20 x 40 mm³ raffia fiber-reinforced-polyester composite samples at 8rs

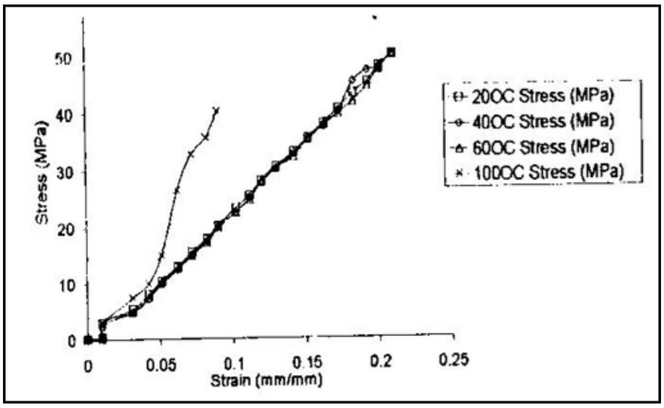

Figure 15 Compression test stress-strain response of 20 x 20 x 40 mm³ raffia fiber-reinforced-polyester composite samples at 12hrs

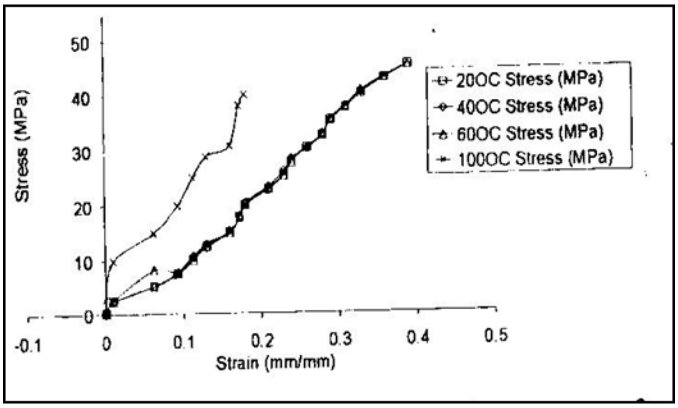

Figure 16 Compression test stress-strain response Of 20 x 20 x 40 mm³ raffia fiber-reinforced-Polyester composite samples at 24hrs

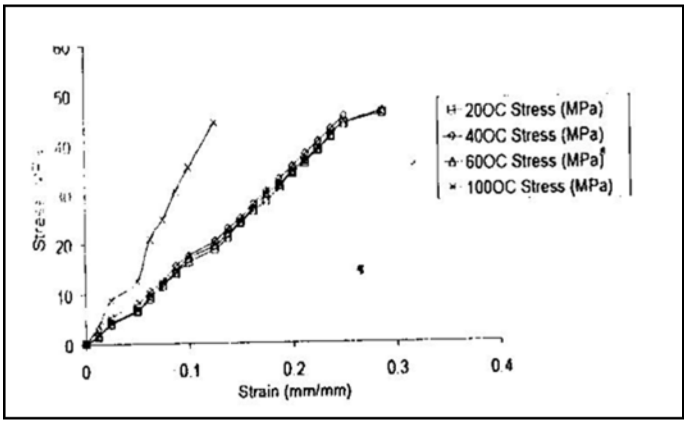

Figure 17 Compression test stress-strain response Of 20 x 20 x 40 mm³ bamboo fiber-reinforced-polyester composite samples at 4hrs

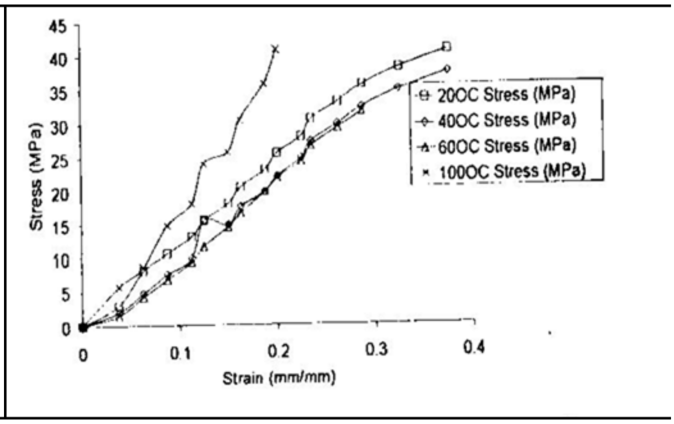

Figure 18 Compression test stress-strain response Of 20 x 20 x 40 mm³ bamboo fiber-reinforced-polyester composite samples at8hrs

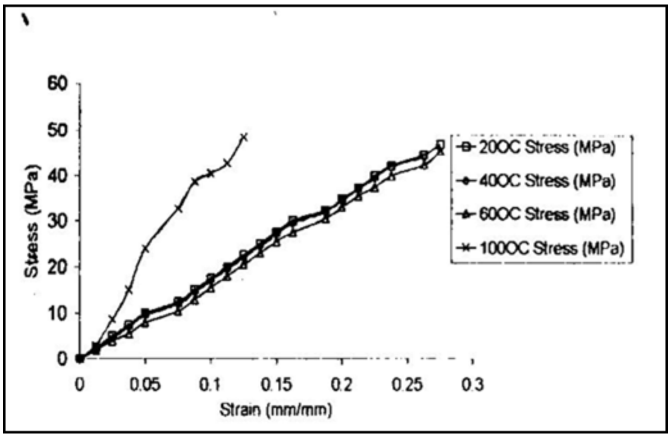

Figure 19 Compressiontest stress-strain response Of 20 x 20 x 40 mm^3 bamboo fiber-reinforced-polyester composite samples at 12hrs

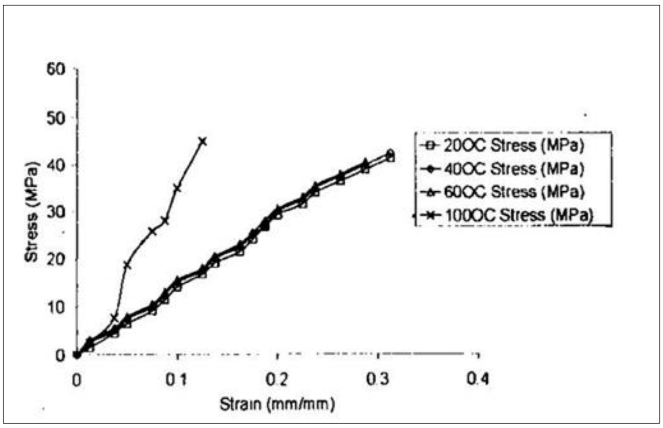

Figure 20 Compression test stress-strain response Of 20 x 20 x 40 mm^3 bamboo fiber-reinforced-polyester composite samples at 24hrs

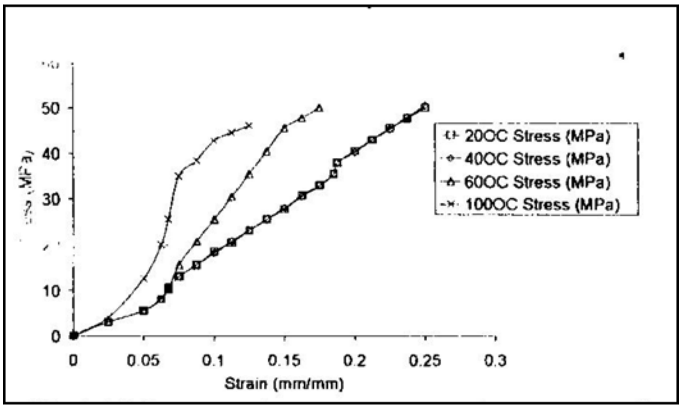

Figure 21 Compression test stress-strain response Of 20 x 20 x 40 mm^3coconut fiber-reinforced- polyester composite samples at 4hrs

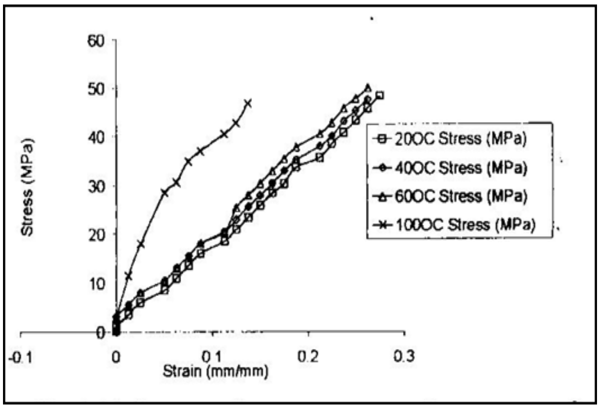

Figure 22 Compression test stress-strain response Of 20 x 20 x 40 mm^3coconut fiber-reinforced-polyester composite samples at 8hrs

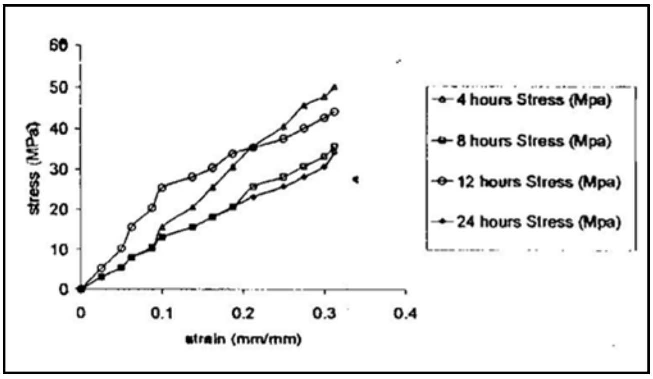

Figure 23 Compression test stress-strain response Of 20 x 20 x 40 mm^3coconutfiber-reinforced -polyester composite samples at 12hrs

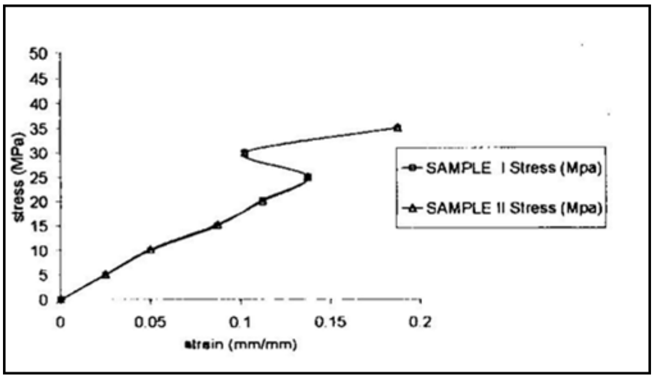

Figure 24 Compression test stress-strain response Of 20 x 20 x 40 mm^3coconutfiber-reinforced-polyester composite samples at 24hrs

Table 3 Compression test stress – strain response of 20 x 20 x 40 mm^3 for raffia fiber-reinforced-Polyester composite samples at 100^{0}C (treated)

4hrs		8hrs		12hrs		24hrs	
Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)
0.0000	0.0000	0.0000	0.00C0	0.0000	0.0000	0.0000	0.0000
0.0310	4.0000	0.0100	0.4000	0.0125	0.5000	0.0875	2.7500
0.0601	11.7500	0.1125	7.0000	0.0438	3.0000	0.1550	10.0000
0.1015	18.2500	0.1375	11.0000	0.0688	7.5000	0.2000	15.0000
0.1432	25.7500	0.1875	17.5000	0.0875	10.0000	0.2450	20.0000
0.1610	30.7500	0.2250	25.0000	0.1125	15.0000	0.2675	25.0000
0.1830	35.7500	0.2860	35.0000	0.2312	26.5000	0.3025	28.7500
0.2001	45.0000	0.3125	40.7500	0.2860	32.7500	0.3475	30.7500
0.2120	46.5000	0.3125	41.5000	0.3250	35.7000	0.3825	38.0000
0.2530	48.0000	0.3625	45.2500	0.3845	40.2500	0.4134	40.0000

Table 4 Compression test stress – strain response of 20 x 20 x 40 mm^3 for raffia fiber-reinforced-Polyester composite samples (untreated)

SAMPLE I		SAMPLE II	
Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0050	0.00
0.0050	0.50	0.0315	0.50
0.0250	0.75	0.0375	2.75
0.0500	5.50	0.0565	5.50
0.0625	8.00	0.0625	8.00
0.0750	10.50	0.0875	10.50
0.0875	13.50	0.0940	13.50
0.1125	15.50	0.1125	15.50
0.1190	18.00	0.1190	18.00
0.1315	20.50	0.1315	20.50
0.1375	23.25	0.1375	23.25
0.1415	26.00	0.1415	26.00
0.1500	28.00	0.1500	28.00
0.1625	30.50	0.1625	30.50
0.1750	33.25	0.1750	33.25
0.1875	36.00	0.1875	36.00
0.2000	38.00	0.2000	38.00
0.2125	40.50	0.2125	40.50
0.2250	43.25	0.2250	43.25
0.2375	45.50	0.2375	45.50
0.2500	48.00	0.2500	48.00
0.2625	50.00	0.2615	50.50

Table 5 Compression test stress – strain response of 20 x 20 x 40 mm^3 forbamboo fiber-reinforced- Polyester composite samples at 200C (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	Stress (MPa)	Strain mm/mm	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0125	1.50	0.0375	3.00	0.0125	2.50	0.0125	1.50
0.0250	4.00	0.0625	8.00	0.0250	5.00	0.0375	4.50
0.0500	6.50	0.0875	10.50	0.0375	7.50	0.0500	6.50
0.0625	9.00	0.1125	13.00	0.0500	10.00	0.0750	9.25
0.0750	11.50	0.1250	15.50	0.0750	12.50	0.0875	11.50
0.0875	14.00	0.1500	18.00	0.0875	15.00	0.1000	14.00
0.1000	16.25	0.1625	20.50	0.1000	17.50	0.1250	16.75
0.1250	18.75	0.1875	23.00	0.1125	20.00	0.1375	19.00
0.1375	21.25	0.2000	25.50	0.1250	22.55	0.1625	21.50
0.1500	24.00	0.2250	28.00	0.1375	25.00	0.1750	24.00
0.1625	26.50	0.2350	30.50	0.1500	27.50	0.1875	26.75
0.1750	28.50	0.2625	23.00	0.1625	30.00	0.2000	29.25
0.1875	31.25	0.2875	23.50	0.1875	32.25	0.2250	31.50
0.2000	34.00	0.3250	38.00	0.2000	34.75	0.2375	34.00
0.2125	36.25	0.3750	40.50	0.2125	37.25	0.2625	36.50
0.2250	38.75			0.2250	40.00	0.2875	39.00
0.2375	41.50			0.2375	42.25	0.3125	41.50
0.2500	44.00			0.2625	44.75		
0.2875	46.00			0.2750	47.00		

Table 6 Compression test stress –strain response of 20 x 20 x 40 mm3 for bamboo fiber-reinforced- polyester composite samples at 40 0C (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	Stress (MPa)	Strain mm/mm	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0375	3.00	0.0750	2.00	0.0125	2.00	0.0250	2.50
0.0500	5.50	0.0875	4.75	0.0375	4.50	0.0500	5.00
0.0750	8.00	0.1125	7.50	0.0625	7.00	0.0625	7.50
0.0875	10.50	0.1375	9.75	0.750	9.50	0.0875	10.00
0.1000	12.50	0.1400	15.50	0.0875	12.00	0.1000	12.50
0.1250	15.50	0.1500	14.75	0.1000	14.50	0.1250	15.00
0.1375	17.50	0. 1625	17.50	0.1125	17.00	0.1500	17.50
0.1500	20.50	0.1750	19.75	0.1375	19.50	0.1625	20.00
0.1625	23.00	0.2000	22.00	0.1500	22.00	0.1875	22.50
0.1750	25.00	0.2125	24.75	0.1625	24.50	0.2000	25.00
0.1875	28.00	0.2250	27.25	0.1750	27.00	0.2125	27.00
0.2000	30.50	0.2500	29.75	0.2000	29.50	0.2250	30.00
0.2125	33.00	0.2625	32.25	0.2125	32.00	0.2500	32.50
0.2250	35.50	0.2750	34.75	0.2250	34.50	0.2625	35.00
0.2375	38.00	0.3000	37.25	0.2375	37.00	0.2750	37.50
0.2500	40.50	0.3125	39.75	0.2500	39.50	0.3000	40.00
0.2750	43.00	0.3625	42.00	0.2750	42.00	0.3250	42.50
0.3000	45.50			0.3000	44.25	0.3500	45.00
						0.3750	47.25
						0.4000	49.00

Table 7 Compression test stress –strain response of 20 x 20 x 40 mm^3 for bamboo fiber-reinforced- polyester composite samplesat 60^{o}c (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	Stress (MPa)	Strain mm/mm	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0125	1.75	0.0250	1.50	0.0125	2.00	0.0375	3.00
0.0375	4.25	0.0625	4.25	0.0500	4.00	0.0625	5.50
0.0500	6.75	0.0750	6.75	0.1000	5.50	0.0875	8.00
0.0625	9.50	0.1000	9.25	0.1250	8.00	0.1000	10.50
0.0750	12.00	0.1125	11.50	0.1500	10.50	0.1125	13.00
0.0875	14.25	0.1250	14.50	0.1625	13.00	0.1375	15.50
0.1000	17.00	0.1375	16.50	0.1750	15.50	0.1500	18.00
0.1250	19.50	0.1625	19.75	0.2000	18.00	0.1625	20.50
0.1375	22.00	0.1750	21.75	0.2125	20.50	0.1875	23.00
0.1500	24.25	0.2000	24.25	0.2250	23.00	0.2000	25.50
0.1625	27.00	0.2125	26.50	0.2375	25.50	0.2125	28.00
0.1750	30.00	0.2250	29.25	0.2500	27.50	0.2375	30.50
0.1875	31.75	0.2500	31.50	0.2625	30.50	0.2625	33.00
0.2000	34.50			0.2750	33.00	0.2750	35.50
0.2125	36.75			0.2875	35.50	0.3250	38.00
0.2250	39.00			0.3000	37.50	0.3450	40.50
0.2375	41.75			0.3125	40.00		
0.2500	44.00			0.3250	42.50		
0.2625	46.50			0.3500	45.50		
0.2875	49.00			0.3265	47.00		
0.2900	50.00			0.3750	50.00		

Table 8 Compression test stress –strain response of 20 x 20 x 40 mm^3 for bamboo fiber-reinforced- polyester composite samplesat 100^{o}c (treated)

4hrs		**8hrs**		**12hrs**		**24hrs**	
Strain (mm/mm) 0.0000	**Stress (MPa) 0.0000**	**Strain (mm/mm) 0.0000**	**Stress (MPa) 0.0000**	**Strain (mm/m) 0.0000**	**Stress (MPa) 0.0000**	**Strain (mm/mm) 0.0000**	**Stress (MPa) 0.0000**
0.(53 75	3.7500	0.0750	5.7500	0.0125	3.0000	0.0125	2.5000
0.0625	8.7500	0.1000	8.5000	0.1250	8.7500	0.1375	7.7500
0.0875	12.5000	0.1375	14.7500	0.1625	15.0000	0.2350	18.7500
0.1375	21.0000	0.1625	18.0000	0.2125	24.0000	0.2875	25.7500
0.1750	25.0000	0.2000	24.0000	0.2500	32.7500	0.3125	28.0000
0.2125	30.7500	0.2125	25.7500	0.2875	38.7500	0.3625	35.0000
0.2375	35.5000	0.2375	30.5000	0.3125	40.5000	0.4025	45.0000
0.2875	44.4700	0.3000	35.7500	0.3500	42.7500		
		0.3125	40.7500	0.3625	48.5000		

Table 9 Compression test stress –strain response of 20 x 20 x 40 mm3 for bamboo fiber-reinforced- polyester composite samplesat 100oc (treated)

SAMPLE I		SAMPLE II	
Strain (mm/mm)	**Stress (MPa)**	**Strain (mm/mm)**	**Stress (MPa)**
0.0000	0.00	**0.0000**	0.00
0.0125	1.50	0.0125	1.50
0.0250	4.00	0.0250	4.00
0.0375	6.50	0.0500	6.50
0.0625	9.00	0.0750	9.00
0.0750	11.50	0.0875	11.50
0.0875	14.50	0.1000	14.00
0.1125	16.50	0.1125	16.50
0.1250	19.00	0.1375	19.00
0.1375	21.50	0.1500	21.50
0.1625	24.00	0.1675	24.00
0.1750	26.50	0.1750	26.50
0.2000	29.00	0.2000	29.00
		0.2125	31.50
		0.2250	33.75
		0.2500	36.25
		0.2875	38.75

Table 10 Compression test stress –strain response of 20x20x40mm3 for coconut fiber-reinforced- polyester composite samplesat 20oc (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	Stress (MPa)	Strain mm/mm	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0250	3.00	0.0000	1.00	0.0125	2.75	0.0250	1.25
0.0500	5.50	0.0125	3.50	0.0250	5.25	0.0375	3.75
0.0625	8.00	0.0250	6.00	0.0500	8.00	0.0500	6.25
0.0625	10.50	0.0500	8.50	0.0625	10.50	0.0750	8.75
0.0750	13.00	0.0625	11.00	0.0750	13.00	0.0875	11.25
0.8750	15.50	0.0750	13.50	0.0875	15.50	0.1000	13.75
0.1000	18.25	0.0875	16.00	0.1000	18.00	0.1125	16.25
0.1125	20.25	0.1125	18.50	0.1125	20.50	0.1250	18.75
0.1250	23.00	0.1250	21.00	0.1250	23.00	0.1375	21.25
0.1375	25.50	0.1375	23.50	0.1375	25.25	0.1500	23.75
0.1500	27.75	0.1500	26.00	0.1500	27.25	0.1625	26.25
0.1625	30.75	0.1625	28.50	0.1625	30.50	0.1750	28.75
0.1750	33.00	0.1750	30.50	0.1625	32.75	0.2000	31.25
0.1850	35.50	0.1875	33.75	0.1750	35.50	0.2125	33.50
0.1875	38.00	0.2125	35.75	0.2000	37.75	0.2250	36.00
0.2000	40.50	0.2250	38.50	0.2125	40.00	0.2375	38.50
0.2125	43.00	0.2375	40.75	0.2125	42.75	0.2625	41.00
0.2250	45.50	0.2500	43.25	0.2250	45.25	0.2750	43.50
0.2375	47.75	0.2625	45.75	0.2375	47.75	0.2875	46.00
0.2500	50.00	0.2750	48.25	0.2500	50.00	0.3125	48.50
		0.3000	50.00			0.3250	50.00

Table 11 Compression test stress – strain response of 20 x 20 x 40 mm^3 for coconut fiber-reinforced-polyester composite samplesat 40^{o}C (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	Stress (MPa)	Strain mm/mm	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0125	3.00	0.0125	3.00	0.0375	5.50	0.0126	3.00
0.0250	5.50	0.0250	5.50	0.0625	10.50	0.0250	5.50
0.0375	8.00	0.0375	8.00	0.1000	15.50	0.0500	8.00
0.0625	10.50	0.0625	10.50	0.1375	20.50	0.0625	10.50
0.0750	13.00	0.0750	13.00	0.1750	25.50	0.0750	13.00
0.0750	15.50	0.1000	15.50	0.2000	30.25	0.0875	15.50
0.0875	18.00	0.1125	18.00	0.2500	35.25	0.1125	18.00
0.1000	20.50	0.1250	20.50	0.2875	40.25	0.1250	20.50
0.1125	23.00	0.1375	23.00	0.3250	45.25	0.1375	23.00
0.1250	25.50	0.1500	25.75	0.3875	49.00	0.1500	25.50
0.1375	28.00	0.1625	28.00	0.4175	50.00	0.1625	28.00
0.1500	30.50	0.1750	30.50			0.1875	30.50
0.1625	33.00	0.1875	33.00			0.2000	33.00
0.1750	35.50	0.2000	35.25			0.2125	35.50
0.1750	38.00	0.2000	38.00			0.2250	38.00
0.1850	40.25	0.2125	40.00			0.2500	40.25
0.2000	43.00	0.2250	43.00			0.2625	42.75
0.2125	45.25	0.2375	45.25			0.2875	45.25
0.2375	48.00	0.2500	47.50			0.3250	47.25
0.2500	50.50						

Table 12 Compression test stress – strain response of 20 x 20 x 40 mm^{3}for coconut fiber-reinforced- polyester composite sample at 60^{o}c (treated)

4 hours		8 hours		12 hours		24 hours	
Strain (mm/mm)	**Stress (MPa)**	**Strain mm/mm**	**Stress (MPa)**	**strain (mm/mm)**	**Stress (MPa)**	**strain (mm/mm)**	**Stress (MPa)**
0.0000	0.00	0.0000	0.00	0.0000	0.00	0.0000	0.00
0.0250	3.00	0.0250	3.00	0.0375	5.25	0.0125	3.00
0.0500	5.50	0.0375	5.50	0.0625	10.25	0.0250	5.50
0.0625	8.00	0.0625	8.00	0.1000	15.50	0.0500	8.00
0.0875	10.25	0.0750	10.50	0.1375	20.25	0.0625	10.50
0 1000	15.50	0.0875	13.00 '	0.1875	25.25	0.0750	13.00
o 1375	20.50	0.1000	15.50	0.2250	28.00	0.0875	15.50
0.1625	25.50	0.1125	18.00	0.2375	30.25	0.1000	18.00
=0.1875	30.50	0.1125	20.50	0.2500	33.75	0.1125	20.50
0.2125	35.50	0.1375	25.50	0.2750	35.25	0.1250	23.00
0.2500	40.50	0.1500	28.00	0.2875	37.50	0.1375	25.50
0.2750	45.50	0.1625	30.50	0.3125	40.00	0.1500	28.00
0.3000	47.75	0.1625	33.00	0.3500	42.50	0.1625	30.50
0.3125	50.00	0.1750	35.50	0.4000	44.00	0.1750	33.99
		0.1875	37 75			0.1875	35.50
		0.2000	40.50			0.2000	38.00
		0.2125	42.75			0.2125	40.50
		0.2250	45.75			0.2250	43.00
		0.2375	47.75			0.2500	45.00
		0.2500	50.00			0.2500	49.00

Table 13 Compression test stress – strain response of 20 x 20 x 40 mm3for coconut fiber-reinforced-polyester composite samplesat 1000C (treated)

4hrs		8hrs		12hrs		24hrs	
Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0310	4.0000	0.0100	2.5000	0.1900	0.2500	0.1368	6.7500
0.0601	12.5000	0.0700	11.5000	0.0313	2.7500	0.1875	10.7500
0.0900	19.7500	0.1250	18.0000	0.0875	7.7500	0.1900	15.0000
0.1100	25.5000	0.1650	28.5000	0.1250	15.0000	0.2500	20.0000
0.1501	35.0000	0.1875	30.7500	0.1875	25.7500	0.2750	25.0000
0.1830	38.5000	0.2250	35.0000	0,2250	30,0000	0.3000	27.5000
0.2001	42.7500	0.2565	37.0000	0.2475	33.0000	0.3200	30.7500
0.2530	44.5000	0.2860	40.5000	0.3016	37.7500	0.3560	33.0000
0.3080	46.0000	0.3000	42.7500	0.3580	40.0000	0.3840	38.0000
		0.3500	46.7500				

Table 14 Compression test stress – strain response of 20 x 20 x 40 mm3 for coconut fiber-reinforced-polyester composite samples (untreated)

Sample 1		Sample 11	
Strain (mm/mm)	Stress (MPa)	Strain (mm/mm)	Stress (MPa)
0.0000	0.00	0.0000	0.00
0.0250	5.00	0.0250	5.10
0,0500	10.00	0.0625	10.25
0.0875	15.00	0.0875	15.25
0.1125	20.25	0.1125	20.00
0.1375	25.00	0.1375	25.00
0 1025	30.00	0.1625	30.00
0.1875	35.00	0.1875	35.00
		0.2250	40.00
		0.2625	42.00
		0.2875	45.00

With the tables and figures, it can be deciphered that bamboo- fiber- formed composite is the best in compression among the raffia and coconut-formed composites. Moisture in both normal and elevated temperature conditions has detrimental effect on the mechanical properties of raffia, bamboo, and coconut fiber-reinforced- polyester composites. The extent of damage is more severe in cases of high temperature and moisture.

4. Conclusion

- The fractured surfaces revealed de-bonded surfaces between the reinforcements and the matrices, especially for samples subjected to increased temperatures.
- The maximum yield stresses of compression test results are far greater than the tension test results because the plant fibers were chopped strand fibers, which have high resistance to compression loads than to the tensile loads.
- Plant fiber-reinforced-polyester composites (PFRPCs) specimens developed with the modified fibers and polyesters are human and environmentally friendly.

The hand lay-up method used in this project, though labour intensive, is economically effective. We foresee that in the near future, plant fiber-reinforced composites will be better engineering materials substitutes for synthetic fiber-reinforced composites.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest.

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