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Original Research Article

Hydrothermal Response of Plant Fiber-Reinforced-Polyester Composites

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Abstract

This paper investigates the hydrothermal response of plant fiber-reinforced-polyester composites (PFRC). Experimental methods were used to determine the mechanical properties of PFRC (bamboo, raffia and coconut fiber composites) through the use of monasanto tensometer testing machine. All the samples were chemically modified through the use of 12.5g of sodium hydroxide. The ultimate tensile strengths and moduli of raffia, bamboo and coconut fiber -reinforced polyester composites were computed when the composites were subjected to 20, 40, 60 and 100^{o}C temperature and also soaked in water for periods of 4,8,12 and 24 hours. Numerical and micro-soft excel graphics were used to model the tensile responses of the PFRCs. From the analyses, the ultimate tensile strengths and moduli of raffia, bamboo and coconut composites for 24 hours at 100^{o}c are 4.3, 5.8, 7.7MPa and 0.1, 0.06, and 0.11GP_a respectively.

Keywords: Hydrothermal, polyester, composites, tensile.

1.0 INTRODUCTION

Non- artificial 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 250^{0}C (Sreekala *et al.*, 2002). They are fully combustible without production of either obnoxious 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. To increase the interface adhesion between plant fibers and matrices, the fibers' surfaces should be cleaned, chemically modified, and the surface roughness increased. This is because low interfacial properties between fiber and polymer matrix often reduce the potential of natural fibers as reinforcing elements. Fibrous materials, such as raffia, bamboo and coconut have found particular applications in construction and composites formations.

Natural plant fibers provide basic raw materials for industries, which use them as additives for the manufacture of different products. A 50% growth in the use of natural fibers in plastic industry is forecast for 2020-2025 (Eckert 2000). 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, PFRCsprovide 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 hygrothermal responses of plant fibers-reinforced-polyester composites, taking raffia, bamboo and coconut fibers as the reinforcements.

1.1 TENSILE PROPERTIES OF NATURAL FIBERS

Mishra *et al.*, (2001) investigated the tensile properties of untreated, chemically modified and An-grafted sisal fibers. Chemically modified fibers showed an appreciable decrease in tensile properties. This decrease was attributed to the substantial delignification and degradation of cellulose chains during chemical treatments. Also, in all cases of grafting, the tensile strengths are higher than those of untreated fibers (Bei Wang, 2000). Wang (2000) also asserted that the reinforcing ability of fibers do not just depend upon their mechanical strengths, but also on several other features, such as polarity of the fibers, surface character and presence of reactive centres. These factors control interfacial interactions. Treatment improves the young's moduli of the fibers. The crystalline regions of the fibers improve their stiffnesses. Modification positively affects the elongation properties of the fibers. Lower elongation of untreated (non- modified) fibers may be due to the three dimensionally cross-linked networks of cellulose and lignin. Treatment breaks this network structure, giving the fiber higher elongation and lower strength properties.

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

1.2.1 Hydrothermal Degradation of Composite Properties

Imposed hydrothermal condition causes substantial reductions of both strength and stiffness in graphite/epoxy composites under hydrothermal 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 hydrothermal 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.

2.0 MATERIALS AND METHODS

2.1 MATERIALS AND TOOLS

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 materials used include the natural fibres (raffia plant, bamboo plant and coconut shell), catalyst (methyl-ethyl ketone), accelerator (cobalt), polyster resin (manufactured from unsaturated orthstatic polyster), binder (polyvinyl acetate) and releasing agents (polyvinyl alcohol PVA). The catalysts help to initiate chemical reactions of converting styrene monomers from liquid to solid states while the accelerator aids the catalyst at lower temperature. The binder helps to hold the fibers together during loading. The tools used include paint brush, a pair of scissors, rubber hand gloves, rollers, and electric cutting machine.

2.2 METHODS

The procedures adopted for the research are:

2.2.1 Fiber Extraction and Treatment

Fibers were extracted from the bamboo plant, raffia plant and coconut shell. The fibers were treated to improve their mechanical properties and sodium hydroxide was used for this purpose.

2.2.2 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.

Tensile test parameters:
Cross sectional area = 21mm x5.2mm = 109.2mm^2
Gauge length = $5.65\sqrt{A_o}$ ………………….. 2.1

Where A_o is the cross sectional area
∴ Gauge length = $5.65\sqrt{109.2\ mm^2}$
= 59.04m

3.0 RESULTS AND ANALYSES

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 – stress values 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 $V_f$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 20^{0}C, 40^{0}C, 80^{0}C, and 100^{0}C. The results of the tensile tests, compressive tests, moisture absorption tests, and mechanical properties of the different fibers-reinforced-polyester composites are tabulated below.

3.1 Tensile Tests

Each sample was subjected to tension test, and the tensile strength, which is the ultimate stress reached before failure occurs was evaluated as:

Stress $= \frac{\text{Force (Load)}}{\text{Cross sectional area}}$, and srain $= \frac{\text{Extension}}{\text{Gauge length}}$ ……………… 3.1

The results of the tensile strengths of the treated and untreated composite materials were shown on Tables 3.1 to 3.7 at the various temperatures and soaking periods while the corresponding graphical illustrations were presented on Figures 3.1 to 3.24. was observed from tables 3.1 to 3.7 that the tensile strengths of the composites decrease as the temperature and soaking times increased.

Also, from tables 3.5, 3.10 and 3.15, the untreated composites have higher strength properties than the treated composites. Bamboo has more strength under hydrothermal condition than coconut and raffia.

The experimental sample results of tensile strengths for Raffia at temperatures of 20 and 40^{o}Cshown on the tables 3.1and 3.2 and the graphs were shown on Figures 3.1, 3.2, 3.3 and 3.4:

Table 3.1: Tensile Test Showing Stress-Strain Response of 300 x 21 x 5.2 mm^3 for Raffia Fiber- reinforced-Polyester Composite Samples @ 20°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	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0127	4.5790	0.0339	9.1545	0.0000	0.9138	0.0169	2.7473
0.0254	9.1580	0.0593	18.3150	0.0085	2.7473	0.0212	4.3956
0.0423	13.7360			0.0169	4.5786	0.0254	6.4103
0.0593	18.3150			0.0254	6.4103	0.0339	9.1575
0.0678	22.8938			0.0425	9.1575	0.0508	10.9890
				0.0508	11.9048	0.0593	12.8205
				0.0530	12.3626		

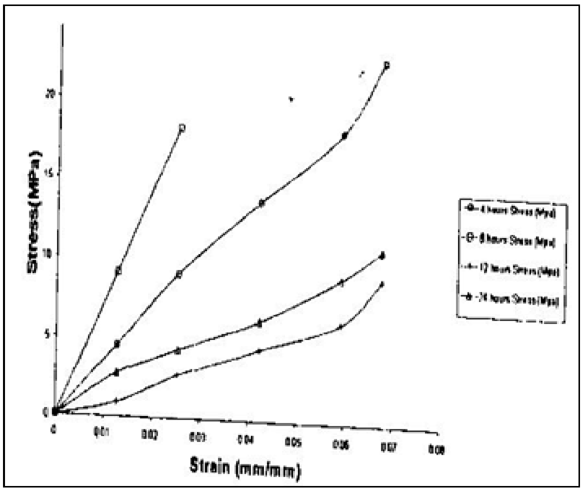

Table 3.1: Tensile Test Showing Stress-Strain Response of 300 x21 x 5.2mm^3 raffia fiber reinforced polyester Composite samples @ 20°C

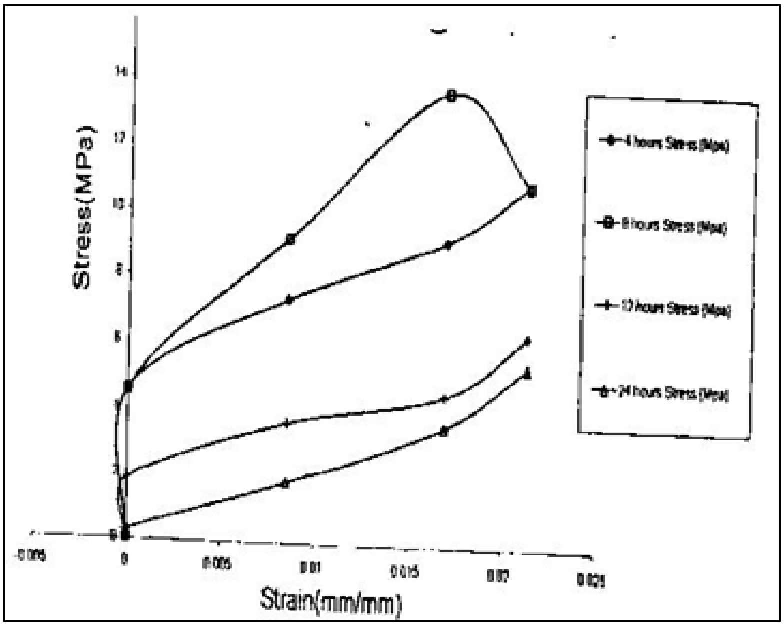

Fig 3.2: Tensile Test Showing Stress-Strain Response of 300 x21 x 5.2mm^3 Raffia Fiber-Reinforced-Polyester Composite Samples @ 40°C

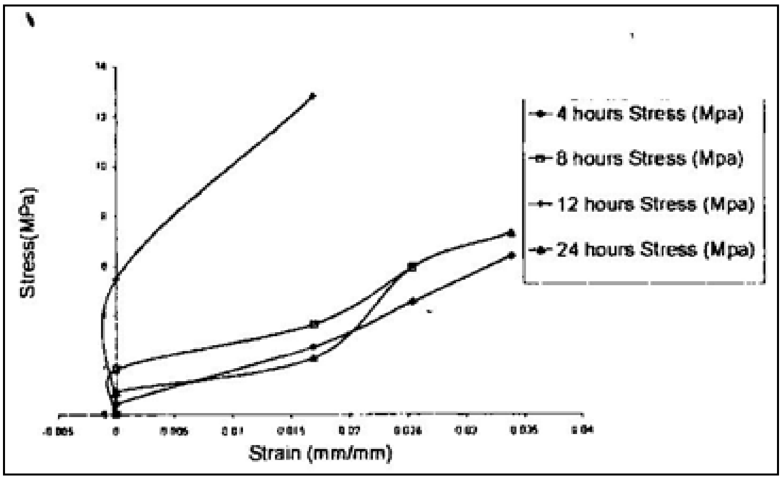

Fig 3.3: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 raffia fiber-reinforced- polyester composite samples @ 60°C

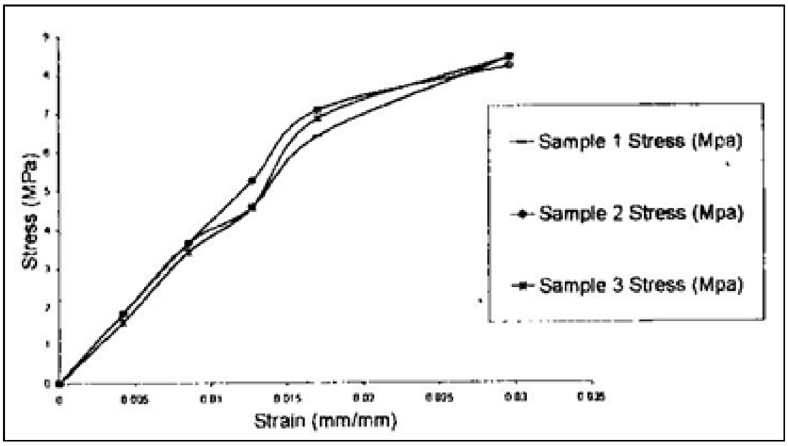

Fig 3.4: Tensile test stress-strain response of 300x21 x 5.2mm^3 raffia fiber-reinforced-polyester composite samples (untreated

Table 3.2: Tensile Test Showing Stress-Strains Response of 300x21x5.2 mm^3 for raffia fiber-reinforced- polyester composite samples @ 40°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	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	4.5790	0.0085	4.5790	0.0169	1.8315	0.0169	0.2747
0.0085	7.3260	0.0213	9.1580	0.0296	3.6630	0.0254	1.8315
0.0169	9.1580	0.0339	13.7360	0.0361	4 5 786	0.0276	3.6630
0.0213	10.9800	0.0466	10.9410	0.0446	6.4103	0.0339	5.4941
				0.0551	8.2418	0.0425	73660
				0.0593	9.1575	0.0508	9.1575
				0.0720	10.9800		

The tensile Results for Coconut Fiber at temperatures 20^o C and 40^{o}C are shown on Tables 3.3 and 3.4 while the graphs are shown on Figures 3.5 and 3.6.

Table 3.3: Tensile Test Showing Stress-Strain Response of 300 x 21 x 5.2 mm^3 for Coconut fiber-Reinforced-Polyester Composite Sample @ 20°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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0085	1.6026	0.0127	0.9158	0.0169	2.1175	0.0000	0.9200
0.0127	2.5183	0.0254	2.9762	0.0339	3.2051	0.0100	2.7500
0.0169	3.6630	0.0296	3.8919	0.0550	4.1209	0.0200	4.5800
0.0254	4.5788	0.0423	5.4945	0.0719	4.8077	0.0300	6.4100
0.0339	5.4945	0.0466	6.4103	0.0932	5.7234	0.0400	8.0600
0.0424	7.3260	0.0550	8.2418	0.1101	6.4102	0.0500	9.1600
0.0508	8.6996	0.0678	10.0733	0.1313	7.7839	0.0600	10.9900
0.0550	9.8443			0.1397	8.6996		
0.0635	10.7600			0.1609	9.3864		
				0.1778	10.3022		
				0.1948	11.2179		
				0.2033	11.9048		

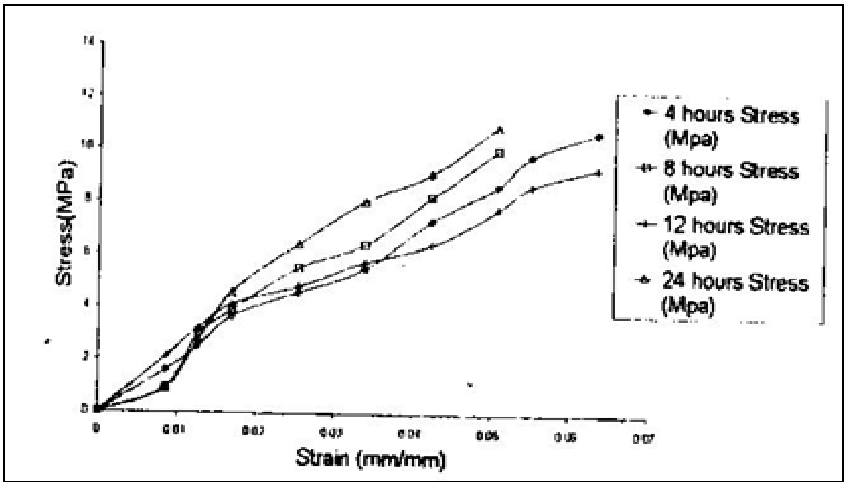

Fig 3.5: Tensile test stress-strain response of 300x21x5.2mm^3 coconut fiber-reinforced -polyester composite samples ***at*** 20^{0}C

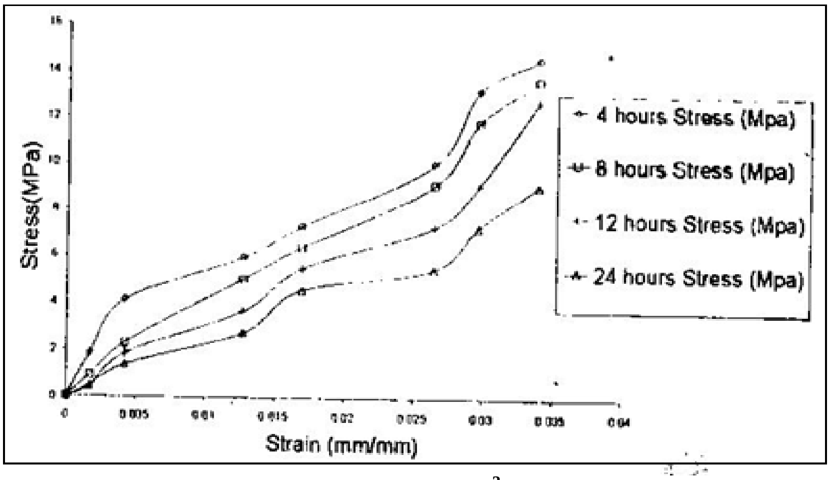

Fig 3.6: Tensile test stress-strain response of 300x21 x5 2mm^3 coconut fiber-reinforced- polyester composite samples at 40^{0}C

Table 3.4: Tensile Test Showing Stress-Strain Response of 300 x 21 x 5.2 mm^3 for Coconut Fiber-Reinforced-Polyester Composite Sample @ 40°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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0017	1.8315	0.0000	0.9158	0.0000	0.4580	0.0000	0.4578
0.0042	4.1209	0.0042	2.2894	0.0042	1.8320	0.0042	1.3736
0.0127	5.9524	0.0127	5.0366	0.0127	3.6630	0.0127	2.7473
0.0169	7.3260	0.0169	6.4103	0.0169	5.4945	0.0169	4.5787
0.0264	10.0733	0.0254	9.1575	0.0212	7.3260	0.0212	5.4945
0.0296	13.2783	0.0339	11.9048	0.0295	9.1575	0.0254	7.3260
0.0339	14.6520	0.0381	13.7363	0.0381	12.8205	0.0296	9.1575
						0.0338	10.9890
						0.0381	11.9050

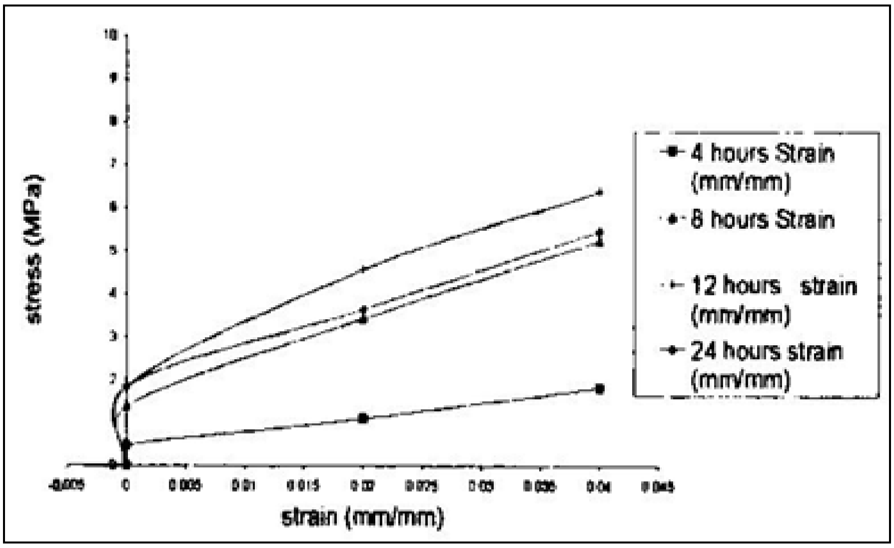

Fig 3.9: Tensile test stress-strain response of 300 x 21 x 5. 2mm^3 bamboo fiber-reinforced- polyester composite samples @ 20°C

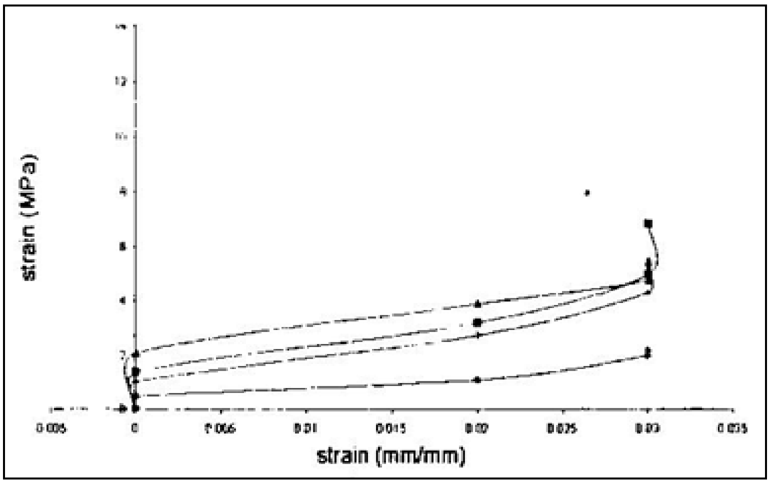

Fig 3.10: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 bamboo fiber- reinforced polyester composite samples @ 40°C

Table 3.5: Tensile test stress-strain response of300x21x5.2mm^3 for coconut fiber-reinforced-polyester composite samples (untreated)

Sam	ple 1	Sam	ple 2	Sam	ple 3
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
0.0040	1.8315	0.0040	1.8311	0.0040	1.7399
0.0085	4.0090	0.0085	4.0000	0.0085	4.2001
0.0127	5.0137	0.0127	5.1102	0.0127	5.1001
0.0170	6.4103	0.0170	6.8134	0.0170	6.6105
0.0210	6.9101	0.0210	7.0010	0.0210	6.9200
0.0296	8.4907	0.0296	8.6001	0.0296	8,4907

Table 3.6: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 for bamboo fiber- reinforced-polyester composite sample @ 20°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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000 0.0200	0.4600 1.0900	0.0085 0.0254	1.3736 3.4341	0.0042 0.0169	1.8315 4.5788	0.0085 0.0109	1.8315 3.6630
0.0400	1.8300	0.0423	5.2656	0.0254	6.4103	0.0212	5.4945
						0.0339	7.3260
						0.0423	9.1575

Table 3.7: Tensile test stress-strain response of 300x21 x5.2mm^3 for bamboo fiber-reinforced-polyester composite sample @ 40°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	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.0000	0.4600	0.0042	1.3736	0.0085	1.0026	0.0169	2.0604
0.0200	1.0900	0.0127	3.2051	0.0212	2.7473	0.0339	3.8919
0.0300	2.0100	0.0212	5.0306	0.0339	4.3498	0.0460	4.8077
0.0300	2.1900	0.0339	6.8681	0.0466	5.2656	0.0508	5.4945
		6.0508	8.6996	0.0593	6.8681	0.0509	6.4103
		0.0678	10.5311	0.0678	8.2418	0.0678	7.5260
		0.0805	11.4469	0.0762	8.6996	0.0720	8.2418
						0.0805	9.3644
						0.0889	10.0733
						0.1016	11.9047

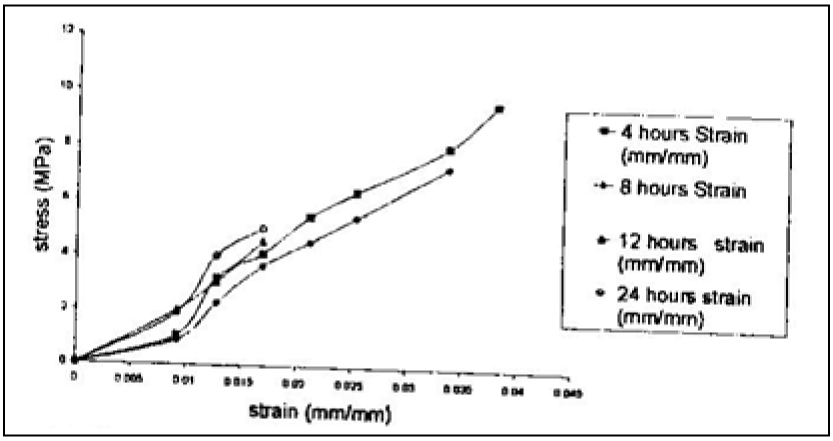

Fig 3.11: Tensile test stress-strain response of 300 x 21 x 5.2mm^3 bamboo fiber-reinforced-polyester composite samples @ 60°c

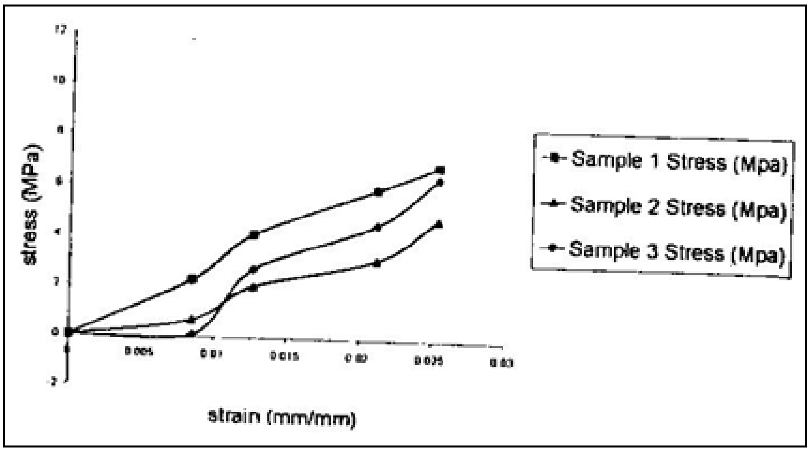

Fig 3.12: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 bamboo fiber-reinforced-polyester composite samples (untreated)

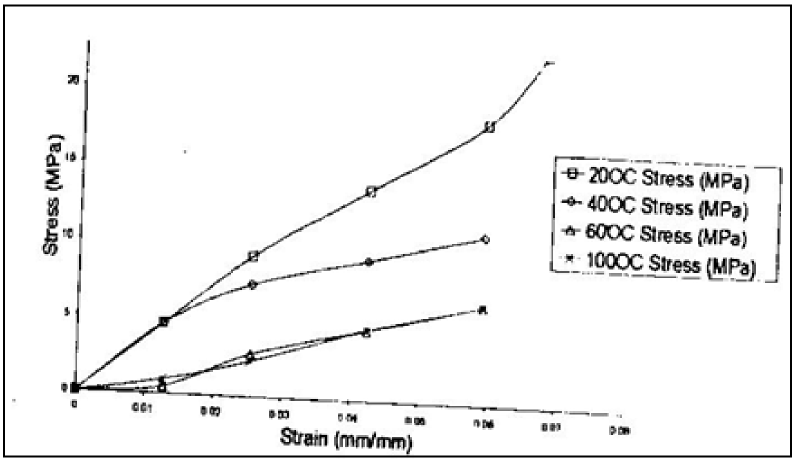

Fig 3.13: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 raffia fiber- reinforced-polyester composite samples @ 4hrs

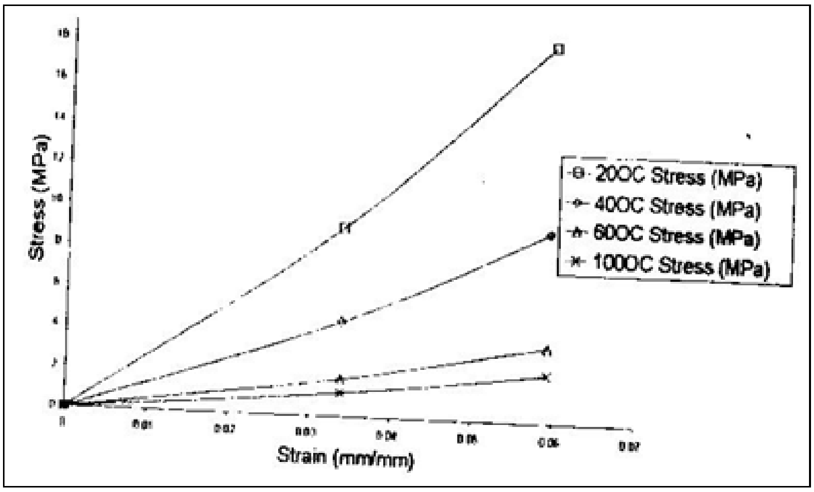

Fig 3.14: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 raffia fiber-reinforced- polyester composite samples @ 8hrs

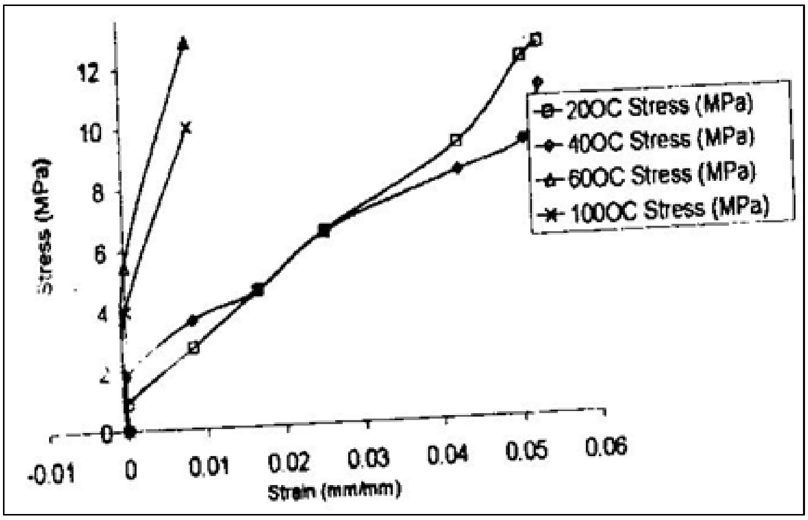

Fig 3.15: Tensile test stress-strain response of 300x21 x5.2mm^3 raffia fiber-reinforced-polyester composite samples @ 12hrs

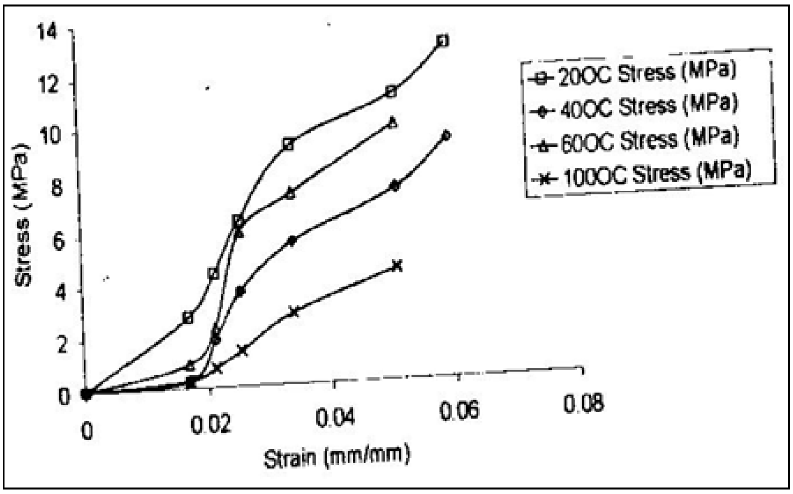

Fig 3.16: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 raffia fiber-reinforced -polyester composite samples @ 24hrs

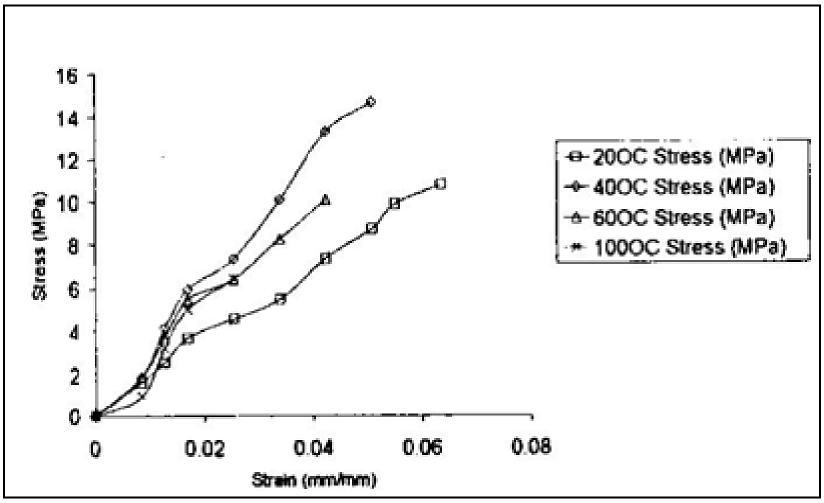

Fig 3.17: Tensile test stress-strain response of 300x21 x5.2mm^3 coconut fiber-reinforced-polyester composite samples @ 4hrs

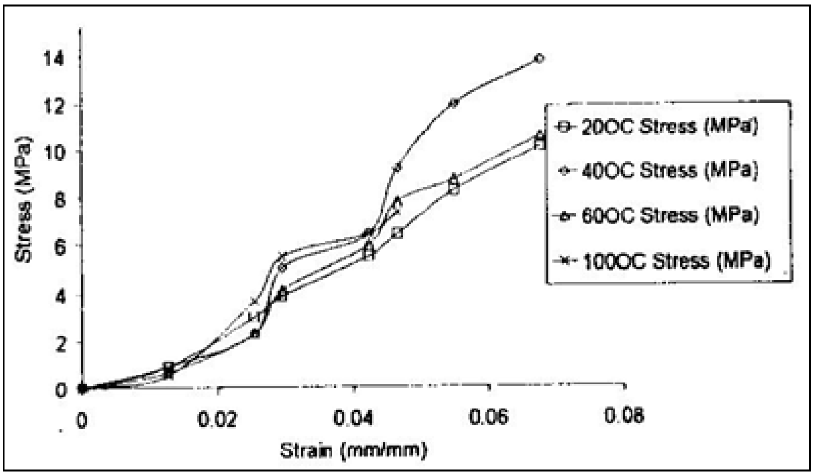

Fig 3.18: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 coconut fiber-reinforced-polyester composite samples @ 8hrs

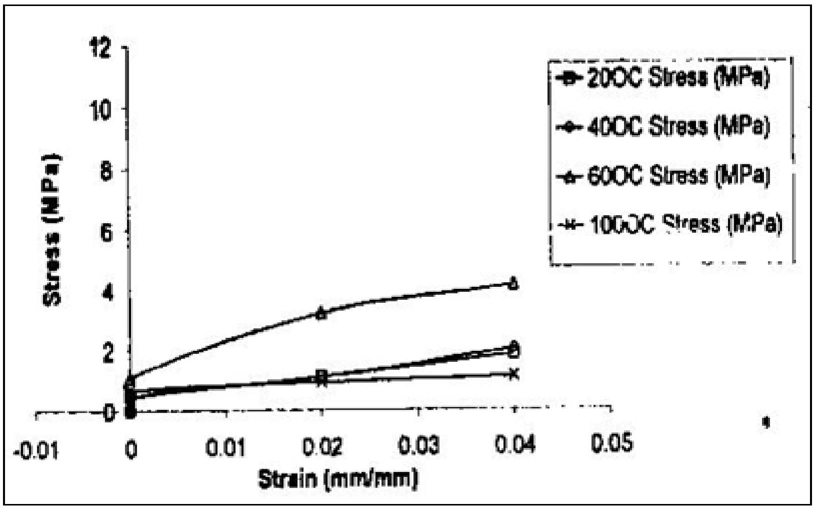

Fig 3.19: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 bamboo fiber-reinforced-polyester composite samples @ 4hrs

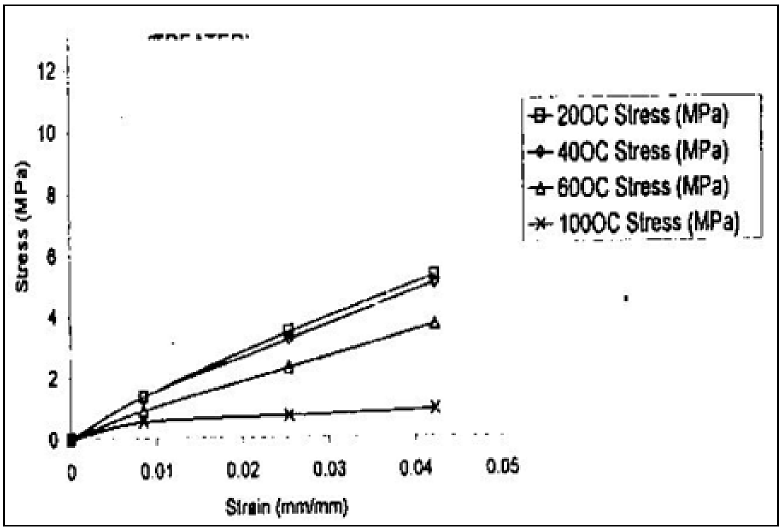

Fig 3.20: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 bamboo fiber-reinforced-polyester composite samples @ 8hrs

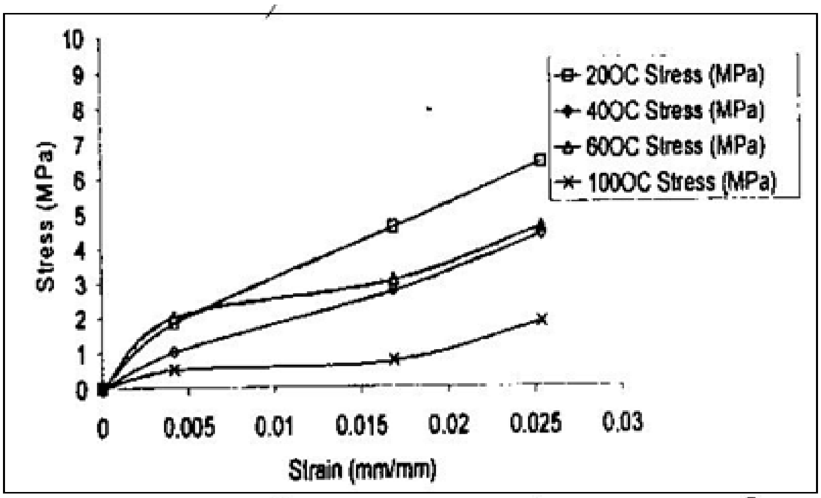

Fig 3.21: Tensile test stress-strain response of 300 x21 x 5.2 mm^3 bamboo fiber-reinforced-polyester composite samples @ 12hrs

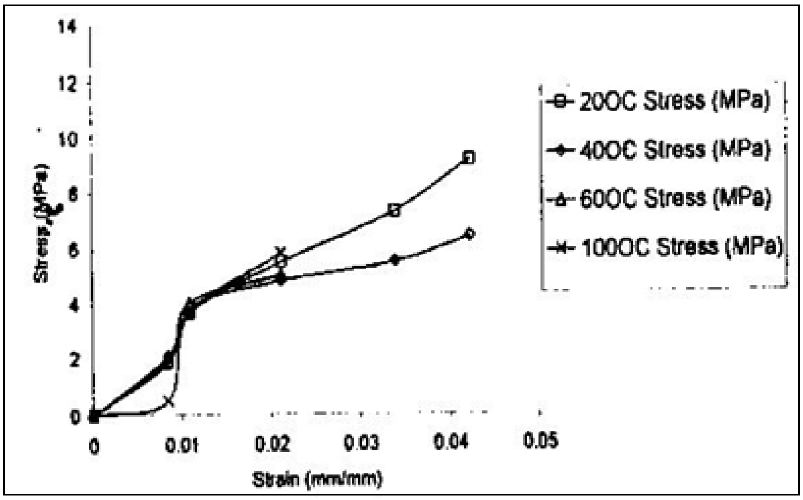

Fig 3.22: Tensile test stress-strain response of 300 x 21 x 5.2 mm^3 bamboo fiber-reinforced-polyester composite samples @ 24hrs

From the table 3.3, the tensile test for the treated fiber reinforced polyester yielded a high higher stresses for the durations of 4, 8 and 12 hours while the untreated case gave a lesser stress value. The table 3.3 showed that the at 4 hours soaked duration the tensile test result for the treated case gave a stress of 10.760MPa while at the same duration the stress value for the untreated case is 8.4907 MPa as stated in Table 3.5. This indicates that the reinforced composite material reinforced with plant fiber can withstand appreciable stress which can make it applicable for some engineering purposes especially when treated.

4.0 CONCLUSION

The following conclusions are drawn from the research results:

- Random material properties of the plant fibers made the values of the ultimate tensile strengths and elastic moduli of raffia, bamboo, and coconut fiber-reinforced composites to be non-linear.
- The tensile strengths below the composites' saturated moisture contents are decreased by the plasticization of the matrix, thereby de-bonding the interfacial property of the fiber – matrixcomposites.
- The fractured surfaces revealed de-bonded surfaces between the reinforcements and the matrices, especially for samples subjected to increased temperatures.
- 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.

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