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Empirical Assessment of the Effects of Water and Heat on the Mechanical Properties of Plant Fiber-Reinforced-Polyester Composites.

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ABSTRACT: The optimal use of materials considered as wastes was the major driving force towards the conception of the research work. The research focused on the effects of water and heat on the mechanical properties 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 application of the 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 the tensile and compressive responses of the PFRCs. From the results of this research, it was deduced that the 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.

Keywords: water, heat, composite, polyester, mechanical properties,

I. INTRODUCTION

Raffia, bamboo and coconut have found particular applications in construction and composites formations. They contain fibrous contents which can be applied in the reinforcement of other materials to form composite materials in the form of plant fiber-reinforce-polyesters.

Natural plant fibers provide basic raw materials for industries, which use them as additives for the manufacturing of different products. The projected growth of fifty percent rise has been predicted for the use of natural fibers in the plastic industry for the period of 2020-2025 (Eckert 2000). These fibers generally referred to as lignocelluloses materials and are derived from woods or agricultural materials, such as bamboo, raffia, coconut, kenaf, jute, hemp, flax, etc. They exist in many different forms, and give rise to 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 including their significant processing advantages, excellent chemical resistance, low-cost, low density, the readily-availability of the natural resources and the renewability-capacity of the source plants. In addition, 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 assess empirically the effects of water and heat on the mechanical property of plant fibers-reinforced-polyester composites with raffia, bamboo and coconut fibers as the reinforcements.

1.1 Characteristics of Plant Fibers

Basically, natural fibers are clssified 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 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.

The 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. The engineering desirable properties for fibers include high tensile strength and modulus, high durability, low bulk density, excellent mouldability and recyclability. Fibers of natural origin 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.

Table 1.1 Comparative properties of natural fibers and conventional man-made fibers (Mohanty et al., 2000).

Fiber	Density (g/cm^3)	Diameter (Um)	Tensile strength (MPA)	Young's modulus (GPA)	Elongation at break (%)
Jute	1.3-1.45	70-200	393-773	13-26.5	7-8
Flax	1.5	-	345-1100	13-26.5	2.7-3.2
limp	-	-	690	-	1.6
Bamboo	1.3-1.4	60-200	110-700	5-15	1.2
Raffia	1.15-1.5	50-200	100-650	5-15	1.3
Ramie	1.5		400-938	61.4-128	1.2-3.8
Sisal	1.45	50-200	468-640	9.4-22	3-7
Palf	-	20-80	413-1627	**34.5-82.51**	1.6
Cotton	1.5-1.6	-	287-800	5.5-12.6	7.8
Coconut	1.15	100-450	131-175	4-6	15-40

E-glass	2.5	-	2000-350	70	2.5
S-glass	2.5	-	4570	86	2.8
Aramid	1.4	-	**3000-3150**	63-67	3.3-3.7
Carbon	1.7	-	4000	230-240	1.4-1.8

To increase the interface adhesion between plant fibers and matrices, the fibers' surfacesshould 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.

1.2 Mechanical Characteristics of Composite Materials

The mechanical characteristics of composite materials are largely predicated on its structure. The characteristics typically depending on the shape of the inhomogenities, the volume fraction occupied by inhomogenities and the interfaces between components. The strenght of composites depends on such factor as the brittleness or the ductility of the inclusions and matrix. For instance, failure mechanisms in fibre filled composites involves fracture of the fibers, shear failure along the fibers, fracture of the matrix in tension normal to the fibers or failure of the fiber matrix interface. If the material characteristics depend on the composite material's orientation, the property is said to be anisotropic. Anisotropic composites provide greater strength and stiffness than the isotropic materials. But the material properties in one direction are gained at the expense of the properties in other directions. It is more sensible to use anisotropic materials if the direction that they will be stressed is known in advance.

Isotropic materials are materials that have properties that are independent of orientation. Stiff platelet inclusions are the most effective in creating a stiff composite, followed by fibers and then by spherical particles.

1.3 Role of Water and Heat on 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 hydrothermal expansion or contraction of the composites.

1.3.1 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.

1.3.2 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, whereasreduced temperature and/or moisture content cause contraction.

1.4 Water and Heat 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.

II. MATERIALS 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 formicamoulds. The fibers used were extracted from the stem of bamboo plant, raffia plant and coconut husk.

Catalysts were used and they are chemical compounds used to initiate the chemical reactions of the unsaturated polyester in styrene monomers from liquid to solid states. The catalyst used is methyl-ethyl ketone peroxide (MEKP). Accelerator was used to promote the catalyst at lower temperature. The accelerator used is cobalt.

The resin used is unsaturated orthostatic polyester. It consists of linear modulus, which is not connected. A binder was used during loading of the fiber to hold the fiber together, thereby facilitating effective handling. Polyvinyl acetate was used as the binder. Polyvinyl Alcohol (PVA) was used as the releasing agent to form Gel coat resin: This is a protective initial layer of a fiber-reinforced-laminate. 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 fiber extraction from coconut, fiber extraction from bamboo and fiber extraction from raffia palm. Fiber Treatment was carried out for the modification of the fibers' surface using suitable coupling agents so as to improve the mechanical properties of the fibers. For this purpose, sodium hydroxide (Naoh) was employed.

The fiber loads were formed with regard to chopped strands mat approach. Figure 2.1 exhibits the three samples of the fiber loads formed.

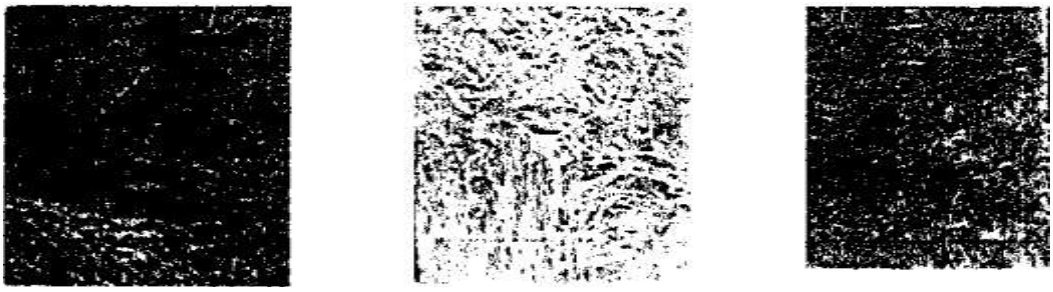

Raffia mat Bamboo mat Coconut mat

Figure 2.1: "Three samples of formed fiber loads."

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.

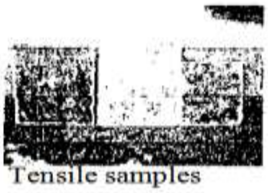
For the tension test, the laminates were cut into strips of average dimensions of (300x21x5.2) mm^3 and the specimens for the compressive test, of dimensions of (40 x 20 x 20) mm^3.

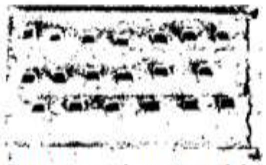

Gel coat resin for tensile test

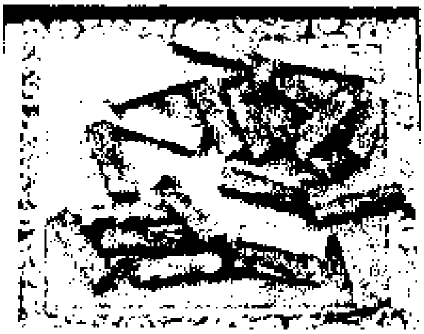

Fiber impregnation


Mould coupling


De-moulding


Tensile samples


Compression mould



Compression samples

Figure 2.2: Diagram of the moulds and laminates formation.

2.2.2 Mechanical Tests

Mechanical test was carried out with the Hounsfield (Monsanto) Tensometer – modelno. S/N8889. It is a universal tester with various interchangeable attachments for performing various tests, such as bending, tensile, compression, shear and hardness tests, with their appropriate loading arms.

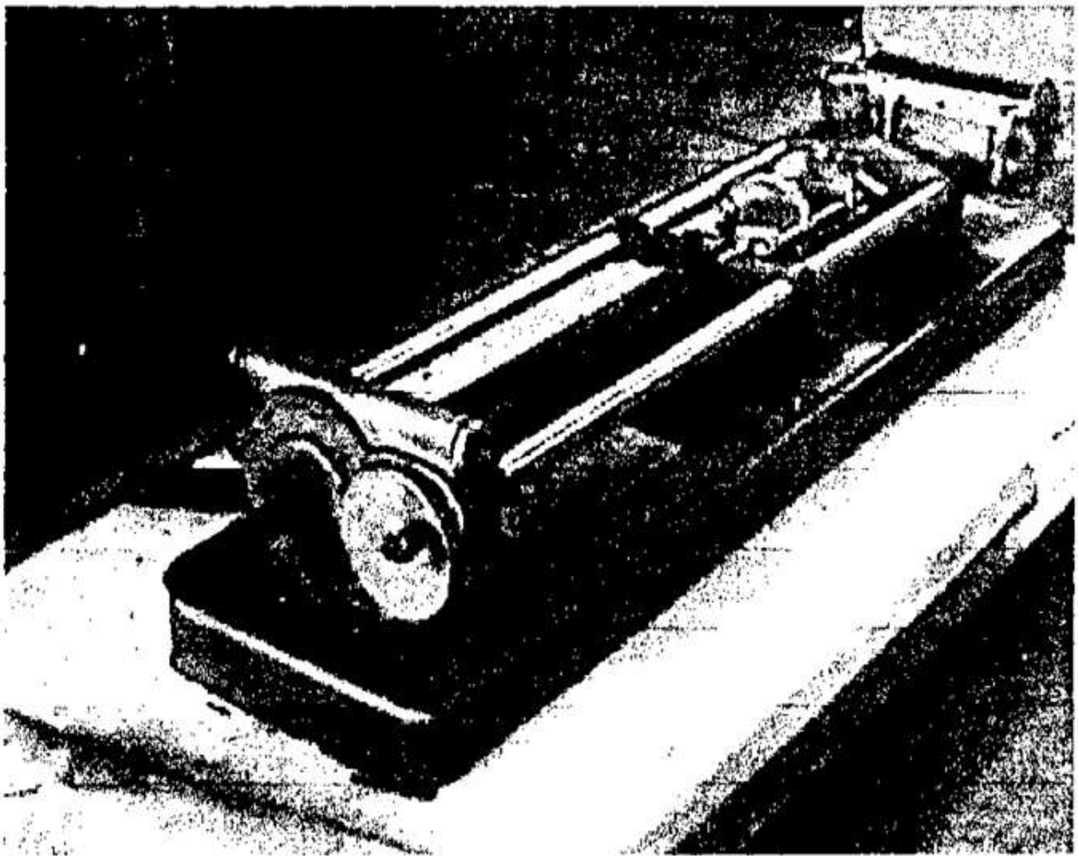


Figure 2.3 Hounsfield (Monsanto) Tensometer (model No. S/N 8889).

2.6 Volume Fraction Measurement

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

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

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

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

∴

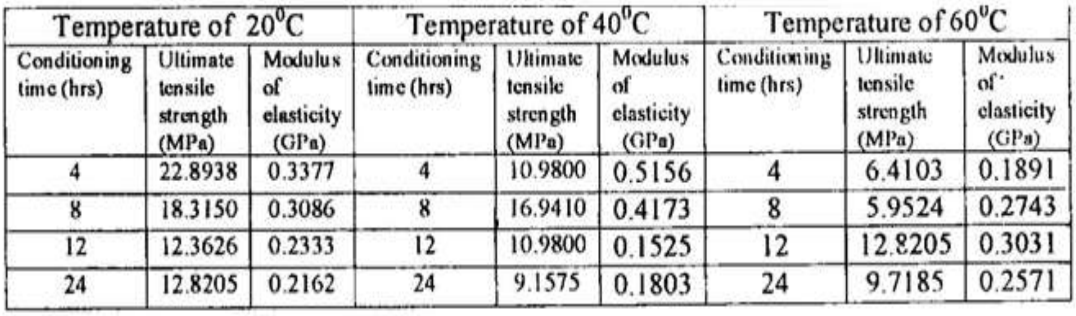
III. RESULTS ANALYSES AND DISCUSSION

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. 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 20^0C, 40^0C, 80^0C, and 100^0C.

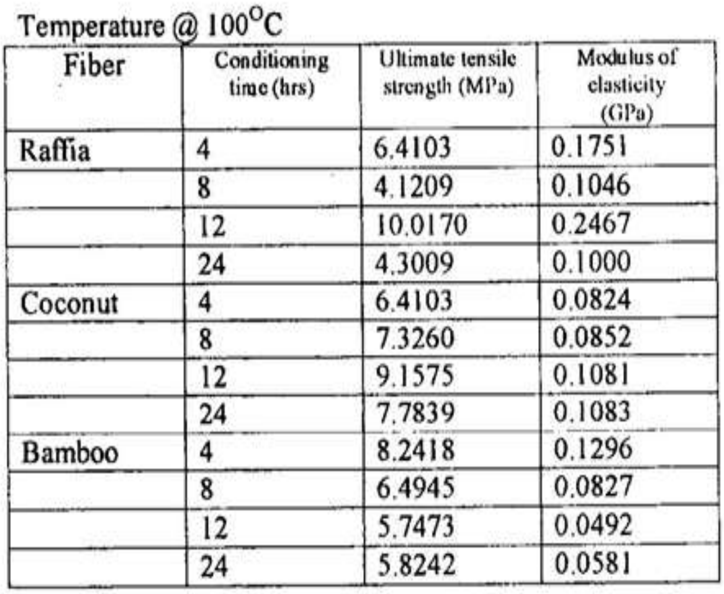
3.1 Mechanical Properties of Plant-Fiber-Reinforced Composites

Ultimate tensile strength is the maximum stress required for fracture of a material to occur. The modulus of elasticity is the ratio of the maximum stress over the maximum strain. From tables 3.1 to 3.33, the ultimate tensile strengths and the moduli of the composites decreased as the temperature and soaking times increased. Below are the tables and graphs of the mechanical properties of the plant fibers.

Table 3.1 Mechanical properties of raffia fiber-reinforced-polyester composites (treated);$V_f = 0.35$



Temperature of 20^0C			Temperature of 40^0C			Temperature of 60^0C		
Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)
4	22.8938	0.3377	4	10.9800	0.5156	4	6.4103	0.1891
8	18.3150	0.3086	8	16.9410	0.4173	8	5.9524	0.2743
12	12.3626	0.2333	12	10.9800	0.1525	12	12.8205	0.3031
24	12.8205	0.2162	24	9.1575	0.1803	24	9.7185	0.2571



Temperature @ 100^0C

Fiber	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)
Raffia	4	6.4103	0.1751
	8	4.1209	0.1046
	12	10.0170	0.2467
	24	4.3009	0.1000
Coconut	4	6.4103	0.0824
	8	7.3260	0.0852
	12	9.1575	0.1081
	24	7.7839	0.1083
Bamboo	4	8.2418	0.1296
	8	6.4945	0.0827
	12	5.7473	0.0492
	24	5.8242	0.0581

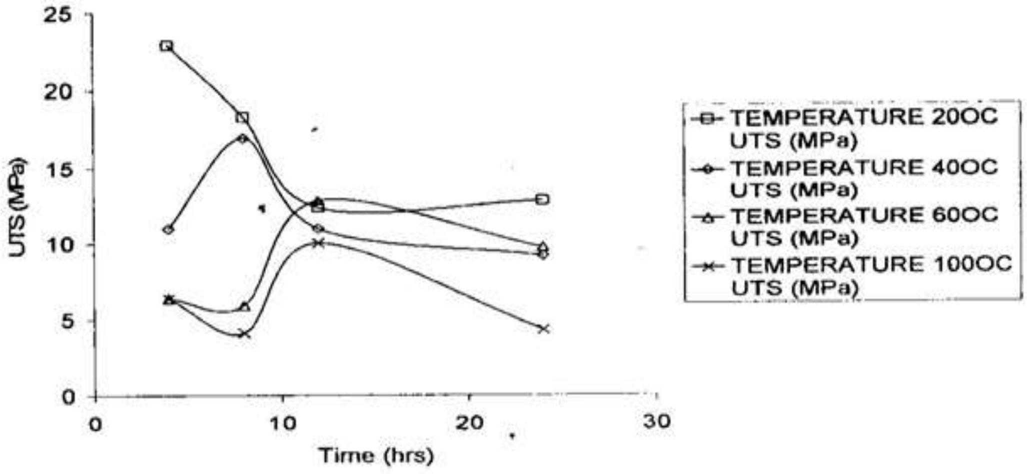


Fig 3.1 ultimate tensile strength vs time graphs of raffia fiber-reinforced-polyester composites (treated), V_f= 0.35.

Table 3.2 Mechanical properties of bamboo fiber-reinforced-polyester composites (treated), V_f = 0.35.

Temperature of 20^0C			Temperature of 40^0C			Temperature of 60^0C		
Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)
4	1.8300	0.0458	4	2.1900	0.0730	4	9.6154	0.2524
8	5.2656	0.1245	8	11.4469	0.1422	8	7.3300	0.1560
12	6.4103	0.2524	12	8.6996	0.1142	12	4.5800	0.0573
24	9.1575	0.2165	24	11.9047	0.1172	24	5.0400	0.0187

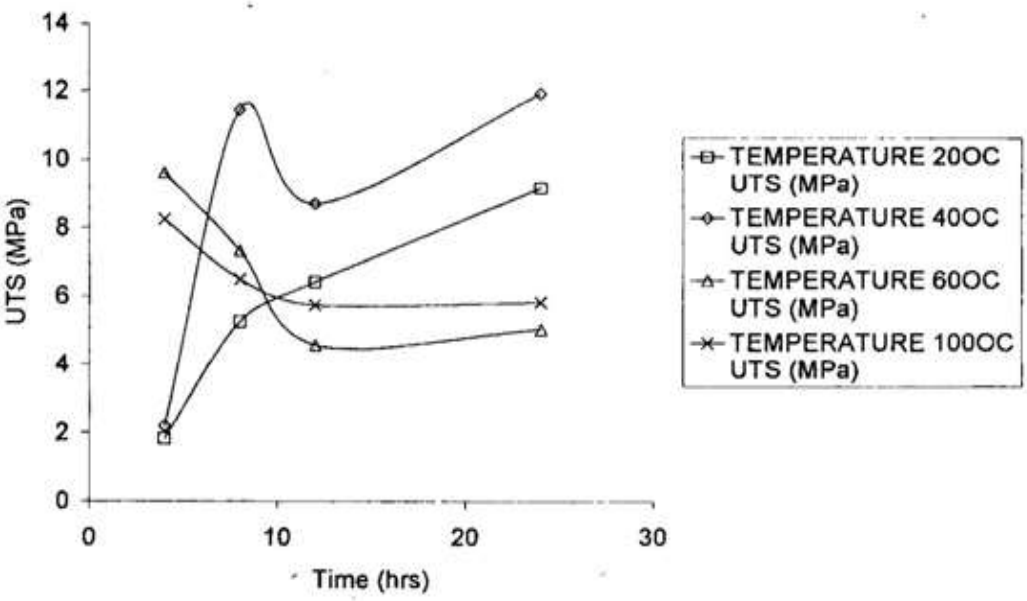
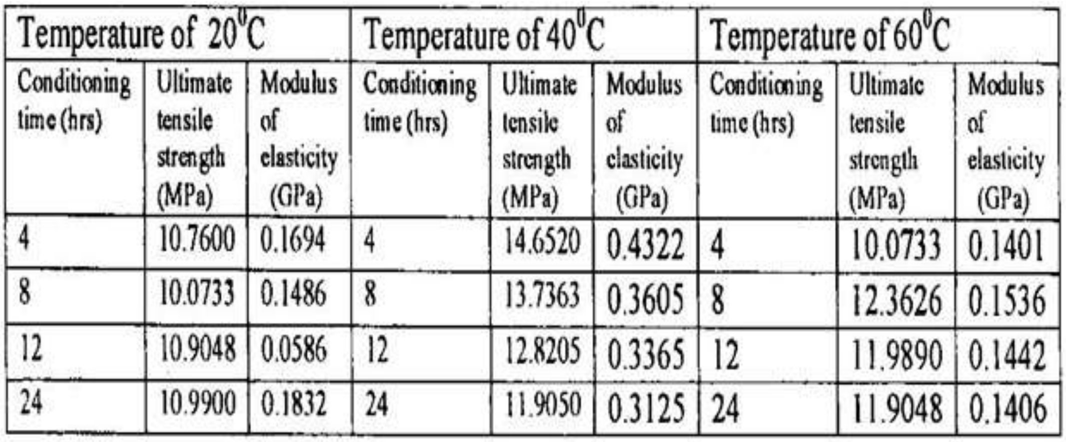


Fig 3.2 Ultimate tensile strengthvs time graphs of bamboo fiber-reinforced-polyester composites (treates), V_f= 0.35.

Table 3.3 Mechanical properties of coconut fiber-reinforced-polyester composites (treated), $V_f = 0.35$.



Temperature of 20^0C			Temperature of 40^0C			Temperature of 60^0C		
Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)	Conditioning time (hrs)	Ultimate tensile strength (MPa)	Modulus of elasticity (GPa)
4	10.7600	0.1694	4	14.6520	0.4322	4	10.0733	0.1401
8	10.0733	0.1486	8	13.7363	0.3605	8	12.3626	0.1536
12	10.9048	0.0586	12	12.8205	0.3365	12	11.9890	0.1442
24	10.9900	0.1832	24	11.9050	0.3125	24	11.9048	0.1406

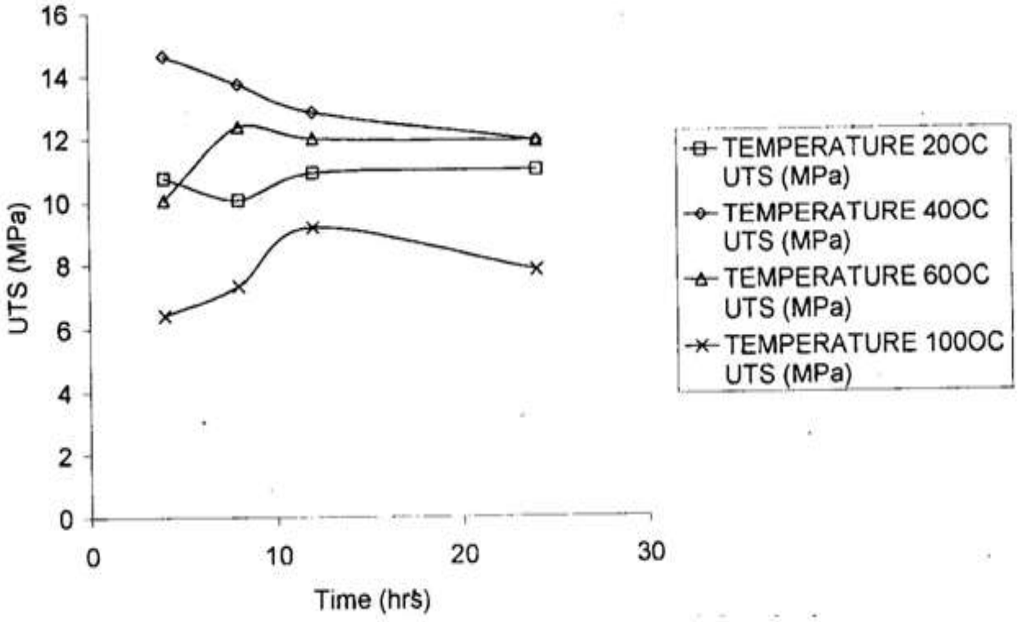
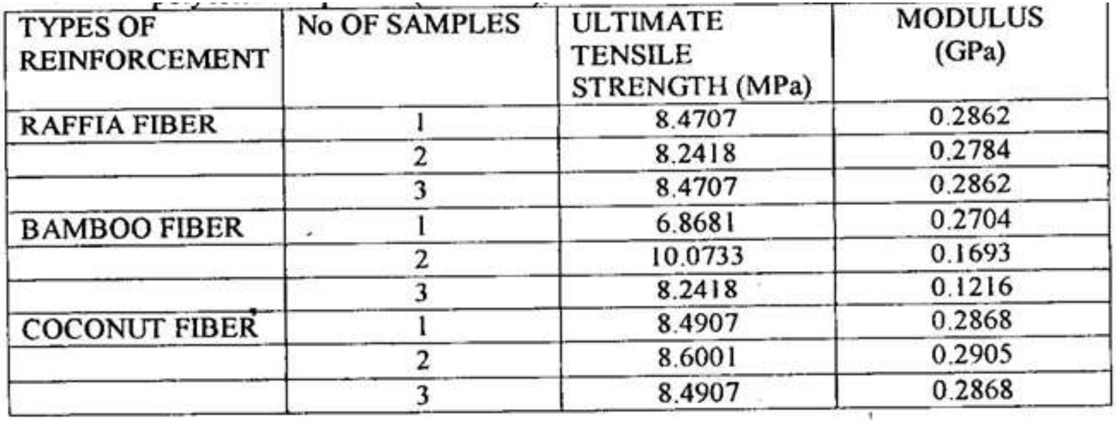


Fig 3.3 Ultimate tensile strength vs time graphs of coconut fiber-reinforced-polyester composites (treated), $V_f = 0.35$.

Table 3.4 Mechanical properties of raffia, bamboo, and coconut fiber-reinforced-polyester composites (treated), $V_f = 0.35$.



TYPES OF REINFORCEMENT	No OF SAMPLES	ULTIMATE TENSILE STRENGTH (MPa)	MODULUS (GPa)
RAFFIA FIBER	1	8.4707	0.2862
	2	8.2418	0.2784
	3	8.4707	0.2862
BAMBOO FIBER	1	6.8681	0.2704
	2	10.0733	0.1693
	3	8.2418	0.1216
COCONUT FIBER	1	8.4907	0.2868
	2	8.6001	0.2905
	3	8.4907	0.2868

From Table 3.3, it was observed that at the temperature of 40^{o}C and at the conditioning time of 4 hours the modulus of elasticity is 0.4322 and the ultimate tensile strength is 14.6520MPa while at 60^{o}C temperature and at the same conditioning time, the modulus of elasticity is 0.1401 with the ultimate tensile strength given as 10.0733 MPa. This goes a long way to portray that water in the of moisture and heat leads to the de-bonding the fiber matrix.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The effects of moisture and temperature on the mechanical properties of raffia, bamboo, and coconut fiber-reinforced-polyester composites were investigated. The following conclusions are drawn from the research results:

- De-bonding at the fiber-matrix interface bundle is caused after the amount of absorbed moisture increases with temperature and soaking time, and this results to the decrease of the mechanical properties (ultimate tensile strengths and elastic moduli) of the composites.
- The fractured surfaces revealed de-bonded surfaces between the reinforcements and the matrices, especially for samples subjected to increased temperatures.
- The presence of defects, imperfections, blowholes, porosity, and induced stresses during sample sizing weakened the mechanical properties of the composites.
- 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.
- The investigations involving raffia, bamboo, and coconut fibers, and their mechanical behaviours when used as reinforcements for polyester resins show that these plant fibers, just like synthetic fibers possess acceptable mechanical properties, with room for improvement(s) with better fiber modification system(s).
- 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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