COMPUTATIONAL MODELING OF HYGROTHERMAL RESPONSE OF COCONUT FIBRE REINFORCED COMPOSITES

Dr. Chukwu Too .C. Ihueze

Abstract

Hydrothermal behaviour of non-uniform size fibre of coconut husk was investigated and the thermal and hygroscopic effects of changing environmental conditions during manufacture and use of plant fibre reinforced polymer matrix composites (PFRP) were considered and modeled. Coconut husk fibres were extracted, treated and laminated by hand-layup method. Tension tests were conducted on replicated samples of composites of coconut husk fibre reinforced polyester matrix composites subjected to different environmental conditions. Mechanical properties such as strength and modulus were modeled. The study found PFRP properties to be temperature and moisture dependent, the moisture absorption increasing with temperature and time. Power law and polynomial regression models are used to model stress-strain responses of coconut husk of non-uniform fibre reinforced polyester. The models show that the strengths and module of respective composites after a particular optimum strength decrease parabolically.

Introduction

Natural fibres may be used in the form of particles, fibre bundles, or single fibres and may act as filler or reinforcement for plastics, Osswald (1999). Natural fibres refer generally to lignocellulosematerials derived from wood or agricultural materials, Kunz (1989). Short-fibre composites have low strength and toughness relative to continuous fibre- composites. This is an intrinsic problem caused by discontinuities at fibre ends and interfacial debonding Zhu etal (in press).

Numerous discontinuities provided by fibre ends can produce stress concentrations on nearby fibres and promote matrix micro cracking, which occur even prior to fibre failure and often coalesces to form a large main crack.

Again, the fibre/matrix interface is often a limiting factor for improving mechanical properties of short fibre composites, Mark and Rowlands (2003).

The application of short fibre composites has far been limited primarily to light-load-bearing components because of their low strength and toughness, Mikell (2007).

Low knowledge of plant fibre composite durability and lack of life prediction methods for evaluating plant fibre reinforced composite material durability and damage and tolerance under hygrothermal environment constitute mitigating factors against the use of PFR? in the marine and .civil infrastructure. Again the absence of a unified theory for complete characterization of fibre-reinforced plastic systems is a major challenge facing the composite industry, Crawford (1998) .The growing interest in the application of composite material in the infrastructure sector has begun a more rigorous approach *in* the evaluation of these materials to ensure that they perform within expected hygro-thermal-mechanical environment, Gillat and Broutman (1981).

.....The .Qprrosion of ^fibres,. Jhe_disso.lution of_ soluble compounds in matrices, increased interlaminar stresses, and the reduction in strength and modulus are moisture-related events that affect composite materials durability and damage tolerance, Crawford (1998).

Moisture absorption in composite materials is influenced by many factors, Crawford (1998) and Gibson (1994). The nature and distribution of voids in composite materials dictate the volume of moisture it can retain. The presence of moisture also increases the equilibrium moisture concentration and the diffusion coefficient, Mikell (2007).

Gillat and Broutman (1981) found that micro cracks in composites allow the absorption of more moisture due to the capillary action of the voids.

The study of moisture absorption characteristics of composites is of paramount importance in establishing a priori the performance characteristics of composites under marine comiitkitis._

Gibson etal (1982), reported two principal effects of hygrothermal canraMment on mechanical behavior of polymer composites as:

- Matrix dominated properties such as stiffness and strength are altered, increased temperature causes a gradual softening of the polymer matrix materials up to a point. Plasticization of the polymer by the absorbed moisture causes a reduction in the glass transition temperature and a complete degradation of composition properties.

- Hygrothermal expansions or contraction changes the stress and strain distribution in composite. Increased temperature and or moisture content causes swelling of the polymer matrix, whereas reduced temperature or moisture content causes contraction.
- Hygrothermal responses of plant fin re composites of coconut husks fibres were investigated and modeled.

Above all, the hygrothermal properties of **PFRP** are affected by, discontinuities at fibre breaks and degree of extraction of fibres, Mikeil (2007) .The smaller the cross sectional area of fibre, the greater is the strength of composites.

The properties of **PFRP** therefore greatly depend on the size of uniform fibre loads used. Specification of properties for **PFRP** will he greatly based on the size of fibre and orientation of fibre. Mikeil (2007), also reported that the smaller the cross sectional area of fibre the greater is the tensile strength of composites. With this it is very difficult to specify the actual property of plant fibre composites. Studies are still on this topic to characterize the property based on the fibre size.Fibre diameter is in the range 0.0025mm to 0.33mm. Discontinuous shot fibres have the Aspect Ratio of 100, Mikeil (2007).

Materials and Extraction

Materials

The materials needed are:

(i) Fibre materials. Plant fibres (coconut husk fibres) used as reinforcements.

(ii) Chemical.

- Catalyst. Methyl Ethyl kctone peroxide **(MEKP)** is used here. This compound initiates the chemical reaction of the unsaturated polyester in styrene monomers.
- Accelerator. Cobalt derivative is used here to promote the catalysts at a lower temperature.
- Resins .Gel coat to conceal the fibres, Release agents for removal of Laminate after cure [Examples are wax and polyvinyl Alcohol **(PVA)|.**
- Fillers which include treated calcium carbonate, hydrated alumina and clay.
- Binders, the commonly used ones are polyvinyl acetate emulsion or polyester powder.

(iii) Tools. Pair of scissors. Rubber gloves, Paintbrush.

Fibre Extraction Coconut
(cocos **nucifera)**

The shell is separated from the nut and the outer covering of the husk is removed, the remaining fibrous husk is fermentated and washed.

Fibre Load Formation

This ensures consolidation of the natural fibre before fabrication or moulding. Before fibre load formation the fibres are treated or modified with appropriate coupling agent in order to improve the fibres' mechanical properties.

- **Fibre Treatment.** Saline solution (obtained by mixing 0.6% of vinyl triethxy with ethanol solution) and 2 molar solution of sodium hydroxide **(NaoH)** are appropriate coupling agents. Neatly separated fibres were cut and soaked in silane solution for 48hrs after which the fibres were removed, washed in clean water and then dried in air filled environment for 24 hrs to ensure complete drying. For use of **NaoH,** clean separated fibres were soaked in 2 molar solution **of NaoH** for 48hrs. Large quantity of water is used for washing to ensure that fibres are free from alkali. The fibres are then dried in air filled environment for another 24 hrs.

Fibres load Formation or Matting. The treated fibres were cut to 50mm length to conform to chopped strand mat arrangement. The chopped fibres are distributed on surface with PVA binder to form a mat. The combination is then pressed on with a roller to ensure better loading of the fibres. The fibres are distributed randomly on the **PVA** binding surface. So random chopped strand mat is formed.

- **Moulding or Composite Formation**
- The usual hand lay-up method was used to form the composites of coconut fibre reinforced polyester resin using the respective fibre loads, polyester resin, gelcoat resin, release agent,

catalyst, accelerator, scissors and roller. The moulding processes are found in Crawford (1998).

Methodology

This covers tension tests, compression tests and absorption experiments with replicated samples of composites at varying environmental conditions.

Experimental Procedure

Tensile specimens were prepared from composite of coconut fibre reinforced composites untreated and treated. The replicated samples of the composites were subjected to various hygrothermal conditions. The respective replications were tested with Monsanto lensometer to evaluate the load-deformation responses of the composites.

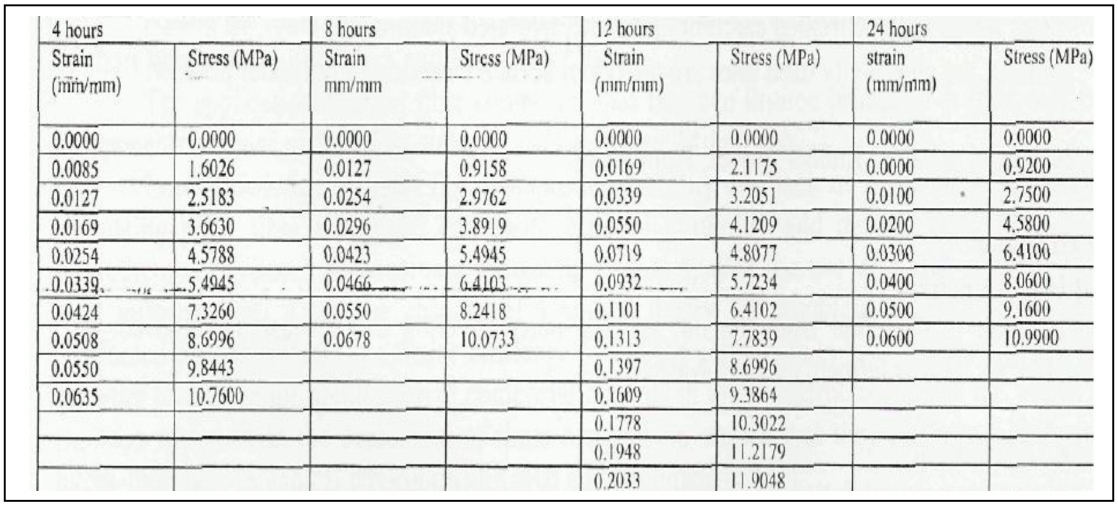
Results and Presentation

The load deformation (extension) responses of treated and untreated coconut fibre composites of polyester matrix at various conditions recorded at the orthographic graph sheet were used to compute the stress-strain responses of respective samples for tension and compression tests.

The critical stress, strain and the moduli of samples of respective composites were estimated from excel graphics and by using computational model optimization. The results of respective experiments are presented in tables for the various conditions.

Hygrothermal Tension Stress-Strain Responses

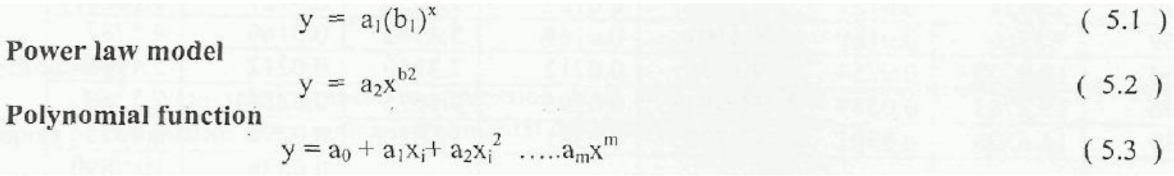
Table I Tensile Test Stress-Strain Response Of 300*21*5.2mm^3 **for Coconut Fiber Reinforced Polyester Composite Sample** *(a)*, 20"c **(Treated)**



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		

Computational Modeling Techniques

Tables.! to 3 and their graphics show nonlinear responses of composites samples. Both power law model, exponential models and Gauss-Newton iterative models can then be fit to the data to establish computational models. Fitting model is selected by plotting the data first and observing the nature of the curves. The stress-strain responses that can be optimized for evaluation of strength and modulus of composites show nonlinear relation of stress and strain with time and temperature. The hygrotherrnal properties may be modeled as **Exponential model**



$$y = a_1(b_1)^x \qquad (5.1)$$

Power law model

$$y = a_2x^{b2} \qquad (5.2)$$

Polynomial function

$$y = a_0 + a_1x_i + a_2x_i^2 \; \ldots\ldots a_mx^m \qquad (5.3)$$

The data obtained suggest a second order or quadratic or parabolic response so that we can express polynomial model as.

$$y = a_0 + a_1x_i + a_2x_i^2 \qquad (5.4)$$

Matrix equation obtained by fitting p.J) to data using polynomial regression method as in Ihueze (2005), Stroud (1995) and Chapara and Canale (1998) is expressed

as:

$$\begin{matrix} n & \Sigma x_i & \Sigma_i^2 \\ \Sigma x_i & \Sigma x_i^2 & \Sigma x_i^3 \\ \Sigma_i^2 & \Sigma x_i^3 & \Sigma x_i^4 \end{matrix} \quad \begin{matrix} a_0 \\ a_1 \\ a_2 \end{matrix} \quad = \quad \begin{matrix} \Sigma y_i \\ \Sigma x_i y_i \\ \Sigma x_i^2 y_i \end{matrix} \qquad (5.5)$$

and

Gauss-Newton Iterative Model

y-f(x) = ao(l-e-^{a}!^{x}) (5.6),

is also appropriate model that is fit to the hyrothermal responses.

-WJiere-for-all the cases .-_—__,_._ .__.___.. __

y,x = dependent and independent variables respectively

ao - a_2, bi - b2 = composite material constant dependent on soaking time, temperature and type of fibre orientation and number of reinforcement combinations

Rv Power law Kouation.

$$y = a_2x^{b2}$$

(5.2) is linearized to evaluate a_2 and b_2 as

$$\log y = \log a_2 + b_2 \log x$$

The parameters of samples on which the model is linear can be evaluated. A plot of log y on the vertical axis and log x on the horizontal axis defines log a_2 as intercept and b_2 as slope. Eq (5.8) is compared with classical relation of equation of best line,

$$y = a + b\,x_i \qquad (5.9)$$

So that the estimators

a_2 = log a_2, b = b_2,and a and b is evaluated from classical relation of statistics,

$$b = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \qquad (5.10)$$

$$a = y^1 - bx^1 \qquad (5.11)$$

Eq (5.10) and Eq (5.11) are computed as

$$b = \frac{n\,\Sigma \log x \log y - \Sigma \log x\, \Sigma \log y}{n\,\Sigma (\log x)^2 - (\Sigma \log x)^2} \qquad (5.12)$$

and

$$a = \log y^1 - b \log x^1 \qquad (5.13)$$

Where

n = number of data points.

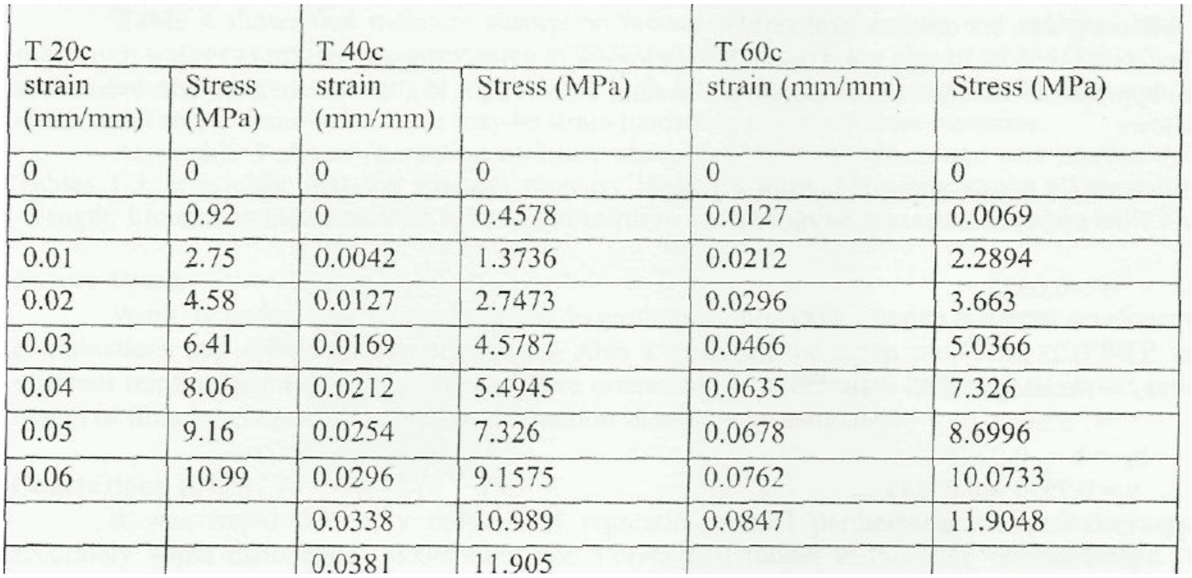
$$\log y^1 = \frac{\Sigma \log y}{n} \qquad (5.14)$$

$$\log x^1 = \Sigma \log x \qquad (5.15)$$

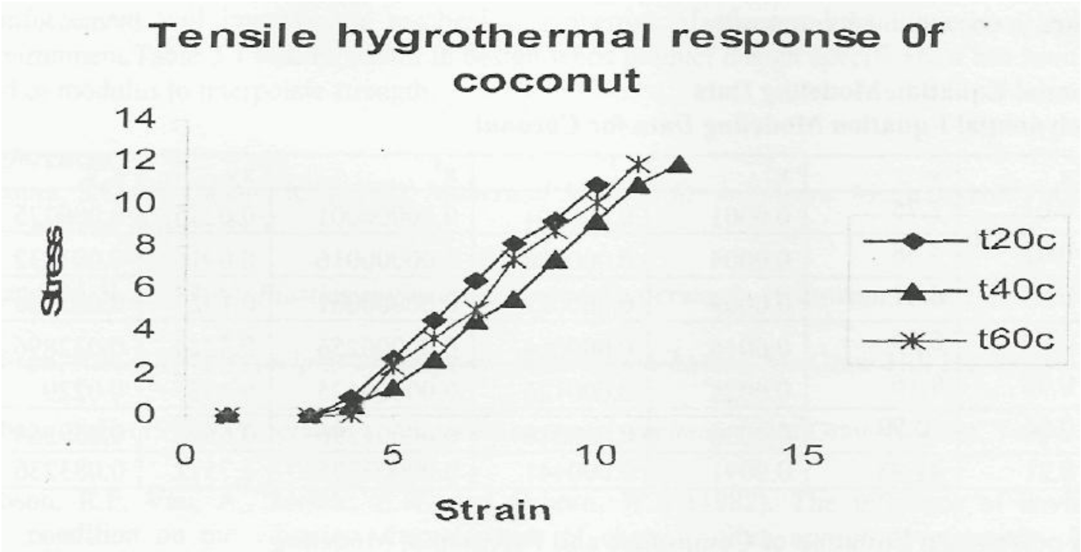
These relations of (5.1) Eo (5,! 5) are also derived from Ihueze (2005), Stroud (1995) and Chapara and Canaie(l998).

Hygrothermal Responses at 24liours Soaking Time

Table 5 Coconut **Hygrothermal** Responses at 24hours Soaking time



T 20c		T 40c		T 60c	
strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)	strain (mm/mm)	Stress (MPa)
0	0	0	0	0	0
0	0.92	0	0.4578	0.0127	0.0069
0.01	2.75	0.0042	1.3736	0.0212	2.2894
0.02	4.58	0.0127	2.7473	0.0296	3.663
0.03	6.41	0.0169	4.5787	0.0466	5.0366
0.04	8.06	0.0212	5.4945	0.0635	7.326
0.05	9.16	0.0254	7.326	0.0678	8.6996
0.06	10.99	0.0296	9.1575	0.0762	10.0733
		0.0338	10.989	0.0847	11.9048
		0.0381	11.905		



5.2 Power law Equation Modeling.

Table 6 Power Law Equation Modeling Data for Coconut

x	JL__^ __	Logx	Hlogy	LogxLogy	LogxLogx
0.01	2.75	-2	0.43933269	-0.878665388	0.193013216
0.02	4.58	^ L 6 9 8 9 7 _	0.66086548	-1.122790624	0.43674318
0.03	6.41	-1.5228787	0.80685803	-1.228746944	0.65101988
0.04	8.06	-1.39794	0.90633504	-1.267002016	0.821443208
IL,2^	9.16	-1.30103	0.96189547	-1.251454864	0.925242902
r006	10.99	-1.2218487	1.04099769	^L2JM94|729_ I	1.083676196
sum		-9.1426675	4.81628441	-7.020601564	4.111138582

The following data are obtained from table6

£ log x = -9.1426675,2 log y = 4.816285,S logx logy - -7.0206,S (logx)^2 = 4.4111139

When appropriate summations of table 6 are used in Eq (5.10 -5.15), the line of best fit is established as follows

n - 6

b = 6C-7.Q206) - (-9.1426675-X4.816284)

$6(4.4111139)-(-9.I426675)^2$

= -0.0324 a =
0.8027-0.0324(1.524)
...-......... =-0.2533 . _ . . _ . - . . „ _ .
a_2 - Antilog 0.7533 = $I0^{0,7533}$
» 5.6663 b_2 =b =
-0.0324
y = 0.7533 - 0.0324* (5.16)

The power law model becomes
$y = 5.6663x''^{0,0324}$ (5.17),

The ultimate strength of the non-uniform fibre size coconut predicted with fibre strain of 0.06 gives with power law model, strength of 6.207 MPa .

This value is less than that of raffia because of high number of impurity fibers (fibers less than 2.5mm in composites in coconut husk composites).

5.4 **Polynomial Equation Modeling Data**

Table 7 Polynomial Equation Modeling Data for Coconut

i	x	y	x^2	x^3	x4	*y	X^2y
1	0.01	2.75	0.0001	0.000001	0.00000001	0.0275	0.000275
2	0.02	4.58	0.0004,	0.000008	0.00000016	0.0916	0.001832
3	0.03	6.41	0.0009	0.000027	0.00000081	0.1923	0.005769
4	0.04	8.06	0.0016	0.000064	0.00000256	0.3224	0.012896
5	0.05	9.16	0.0025	0.000125	0.00000625	0.458	0.0229
6	0.06	10.99	0.0036	0.000216	0.00001296	0.6594	0.039564
sum	0.21	41.95	0.0091	0.000441	0.00002275	1.7512	0.083236

5.5 **Matrix polynomial Equation of Composites and Polynomial** Modeling

The matrix polynomial equation obtained from table7for Coconut is

6.00000 0.21000 0.00910 ao 41.95000 =
0.21000 0.00910 0.00044 a_1 1.75)20
0.00910 0.00044 0.00002 a_2 0.08324

The polynomial coefficients are obtained by **LU-decomposition** as
$a_{(}$, = 1.344498, a, = 160.7863, a. = 12.9539,
with these in (5.4)
y_t = 1.34498 + 160.7863x + !2.<W>x^2 (5.18)

Discussion of Results,..,

Table 2 - 4 , show that hygrothermal degradation increases with temperature and time, water absorption increases with increasing temperature and time. Also the elasticity of material decreases with increases in water absorption and elongation decreases and material may fail at high strain level.

Table 1 - Table 3 show that coconut treated on 20 °C and 24hr soaking has strength up to 12.82 MPa while treatment on 40°C . 60 "C and 24hr has up 9.15 MPa.

The influence of treatment is observed when we compare the strengths of untreated that is lower that of treatment at20"C, which means that the ambient temperature of the untreated composites is higher than 20^{C1}C, this is obvious

Table 4 shows that moisture absorption increases with temperature and soaking time. The maximum water absorption at temperatures of 20 "C, 40 "C and 60 "C are also in table 4.Table 5 shows that at low temperature strength is high and at high temperature the strength is low depending on strain rate.Table 1-3 show that there may be strain hardening as temperature increases.

Also table 4 shows increasing moisture absorption as temperature and tine increase. From Tables 1-3, it is clear that the strength property increases with increasing strain till the ultimate strength.

Elongation increases with moisture absorption and strength increase as shown in table 5

Future Work

Work is under way to evaluate the hygrothermal properties under different reinforcement combinations and different fibre orientation. Also a study on the creep properties of **PFRP** under different reinforcement combinations and fibre orientation is under way. Influence of aspect ratio or length of fibre in composites as well as orientation should be investigated.

Conclusions

It was found that only polynomial regression model predicts the composites response accurately while exponential model does not. Polynomial model is therefore recommended. This response is attributed to random properties of plastics composites.

This study showed that since the strength of composite at 60°c is higher than strength at 20°c, the composite of coconut fibre can be used in a hygrothermal environment of 6Q°c. Also increased reinforcement will improve the mechanical properties of coconut husk fibre in a hygrothermal environment.Table 5.1 will be useful in design when product design specification has limit for strain and or modulus to interpolate strength.

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