Statistical Prediction of the Creep Distribution for Hibiscus Esculentus Fibre – Reinforced Polymer Composites

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ABSTRACT
The paper highlights the results of experimental evaluation of the mechanical properties of hibiscus esculentus fibre reinforced polymer composite which were fabricated using the hand moulding process. The sample fibre was treated with various chemical solutions including alkali treatment and the tensile strength, youngs modulus and ultimate elongation for the treated sample was found to be 171.6, 1653 N/mm^2 6.5% respectively as against the values 89.49N/mm^2, 1492N/mm^2 and 7.25% respectively for tensile strength, youngs modulus and ultimate elongation for the untreated sample. This shows that the mechanical properties of the sample are higher than that of the untreated one. This is due to the increase in fibre-matrix bond and adhersibility properties as a result of the alkali treatment. The minimum creep rates occur for polymer composite sample which has 1cm fibre length and 50% fibre volume fraction. This is due to the high fibre content of the composite sample. The statistical model of the creep rate was developed from the experimental data and the adjusted R^2 was found to be greater 0.5 as observed from table 6.0 which shows a good correlation between experimental data.

Keywords: Polymer, Composite, Properties, Fibre, Fabrication.

1.0 INTRODUCTION
Increased environmental awareness and consciousness throughout the world has developed an increasing interest in natural fibres and its application in various fields. Natural fibres are now considered as serious alternative to synthetic fibres for use in various field [Drzal et al, 2003] and [Arifuizzaman et al, 2009]. Use of natural fibres as reinforcing materials in both thermoplastic and thermoset matrix composites provides positive environmental benefits with respects to ultimate disposability and best utilization of raw materials [Lee et al, 2009] and [Li et al, 2007].

In 1989, the German DRL Institute of Structural Mechanics developed an innovative idea of embedding natural reinforcing fibre, example flax, hemp and ramie into bio-polymeric matrix made of derivatives from cellulose, starch; lactic, new fibre reinforced materials called bio-composites were created and are still being developed. Bio-composite consist of biodegradable polymer as reinforcing element. Bio-fibers (natural polymer) generally have thermal and mechanical properties desirable for engineering plastics. A lot of research and development work has been carried out in increasing the necessary thermal and mechanicals properties of the bio-fibre (natural fibre) [Maya and Rajesh, 2008]. The mechanical, chemical and physical properties of the bio-fibers are strongly influenced by climate, location, weather conditions and soil characteristics. These properties are also affected during the processing of fibre such as retting, scotching, bleaching and spinning [Moshamsul and Arifuzzaman, 2007].

Quality and properties of fiber depends on factors such as size, maturity and processing method adopted for the extraction of fiber properties such as density, electrical resistivity, ultimate tensile strength and initial modulus, high durability, low bulk density, good mouldability and recyclability.

2.0 CLASSIFICATION OF COMPOSITE MATERIAL BASED ON MATRIX MATERIAL
Matrix materials are classified into three (3) types:
- Polymer matrix material
- Ceramic matrix material
- Metal matrix material

2.1 Polymer Matrix Composite

Polymer Matrix Composite (PMC) is the material consisting of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase. Polymer Matrix Composites are very popular due to their low cost and simple fabrication method. Use of non-reinforced polymers as structure materials is limited by low level of their mechanical properties. In addition to relatively low strength, polymer materials possess low impact resistance.

Polymer Matrix Composite (PMCs) is characterized by the following properties.

- High tensile strength
- High stiffness strength
- High fracture toughness
- Good abrasion resistance
- Good puncture resistance
- Good corrosion resistance
- Low cost

The main disadvantages of Polymer Matrix Composition (PMCs) are:

- Low thermal resistance
- High coefficient of thermal expansion.

Two types of polymers are used as materials for fabricating composite; Thermosets (epoxies, phenolic) and thermoplastics (Low Density Polyethylene [LDPE]) [High Density Polyethylene [LDPE], Polypropylene, nylon). But the mechanical properties of polymers are inadequate for many structural purposes. In particular their strength and stiffness are low compared to metal and ceramics. These difficulties are overcome by reinforcing other materials with polymer. Also the processing of polymer matrix composites need not involve high pressure and does not require high temperature. Equipment needed for manufacturing polymer matrix composites are simpler. For this reasons polymer matrix composites developed rapidly and soon become popular for structural applications [Srinivasababul et al, 2009].

Composites have a greater modulus than the polymer component but they are not as brittle as ceramics. Composites are used because overall properties of the composites are superior to those of individual components for example polymer and ceramic.

2.2 Ceramic Matrix Composites

Ceramic matrix Composites (CMC) is a material consisting of a ceramic matrix combined with a ceramic (oxides, carbides) dispersed phase. Ceramic Matrix Composites (CMC) is designed to improve toughness of conventional ceramics, the main disadvantage of which is brittleness. CMCs are reinforced by either continuous (long) fibers or discontinuous (short) fibers. Short fibers (discontinuous composite are produced by conventional ceramic processes from an oxide (alumina) or non-oxide (silicon carbide). CMC reinforced by whiskers of silicon carbide (SiC), Aluminum nitride (MN) and other ceramic fibers. Most CMCs are reinforced by silicon carbide fiber due to their high strength and stiffness (modulus of elasticity). Long-fiber (continuous) composites are fabricated by chemical vapor deposition (CVD) of silicon carbide on a substrate made of carbon (C) fibers. Monofilament fibers produce stronger interfacial bonding with the matrix material improving its toughness. Failure of long-fiber ceramics matrix composites is not catastrophic. [Nabisahab and Jog, 1999].

Typically, properties of long-fiber ceramics matrix composites include:

- High mechanical/strength even at high temperature
- High thermal shock resistance
- High stiffness
- High toughness
- High thermal stability
- Low density

- High corrosion resistance even at high temperature.

2.3 Metal Matrix Composition (MMC)

When the matrix is a metal, the composite is a metal matrix composite (MMC) in (MMC), the reinforcement usually takes the form of particles, whiskers, short fibers, or continuous fibers. Metal Matrix Composites (MMC) is generally distinguished by characteristics of the reinforcement: the aspect ratio of the reinforcement is an important quality, because of the load transferred from the matrix to the reinforcement is directly proportional to the reinforcement aspect ratio. This, continuous fiber typically provide the highest degree of load transfer, because of their very high aspect ratio, so they exhibit lower strengths than their reinforced metals have a much lower aspect ratio, so they exhibit strength than their continuous fiber counterparts, although the properties of these composites are much more isotropic. They have advantages over monolithic metals like higher specific modulus, higher specific strength, better properties at elevated temperatures, and lower coefficient of thermal expansion. Due to the quality metal matrix composite possess they are under consideration for wide range of application example of their applications are combustion chamber nozzle (in rocket, space shuttle) housing, lubing, cable, heat exchangers, structural members [Ramakrislma et al, 2009].

3.0 MATERIALS AND METHODS (COMPOSITE CREEP TEST)

The use of metals at high temperature introduces the possibility of failure in-service by a mechanism knows as creep. As name suggest this is a slow failure mechanism in that it occurs in a material exposed for a protracted length of time to a load below its elastic limit, the materials increasing in length in the direction of the applied stress. At ambient temperature deformation is so slow that it is not significant. A creep-testing machine measures the creep (the tender ability of a material after being subjected to high levels of stress to change its form in relation to time of the composite exposure). The tensometer machine used for okro (hibiscus esculentus) fiber does the polymer composite creep test. The specimen of 5% cm/10% fiber volume was placed vertically in the grips of any spillage with gripe length. As the force is recorded with its deformation in length, this is continued until distortion of the specimen occurs. This machine shows how much strain (load) of an object can handle under pressure.

3.1 Construction of Creep Model

As described earlier, the creep behavior of the barrier-material is time dependent and is rather complex. It is subjected to many perimeters such as volume fraction. The modified time hardening creep analysis method where the time hardening rule for the creep strain-stress curve was employed.

The general quadratic equation for creep rate for time hardening is given by equation (1):

$$PY = a_0 + a_1x_1 + a_2X_2 + a_3X_1X_2 + a_4X_1^2 + a_5X_2^2 \qquad (1)$$

Where

X_1 = modulus fiber length

X_2 = modulus volume fraction

a_0 = modulus constant

$a_1 \ldots a_5$ = modulus coefficient

Table 1: Evaluated properties of Untreated Sample

Tensile Strength N/mm^2	Young's Modulus N/mm^2	Failed Strength N/mm^2	Ultimate Elongation (Elongation at Break
89.489	1492	80.540	7.25%

Table 2 Evaluated Properties of treated Sample

Tensile Strength N/mm^2	Young's modulus N/mm^2	Failed Strength N/mm^2	Ultimate Elongation (Elongation at Break
171.605	1653	-	6.5%

3.3 Simple Factorial Design

This involves reducing the variation in the process through robust design of experiment that is, it is based on 3 levels and 2 properties (design parameters) to give up to nine samples $3^2 = 9$.

Table 3: Factorial Design

Fiber length (mm)	10.0000	30.0000	50.0000
Fiber volume fraction	10.0000	30.0000	50.0000

Table 4: Composite creep test

	Time (Sec)	Force (N)	Extension (mm)	Stress (N/mm^2)	Strain (%)	Creep (s^{-1})
1cm/10%	0.0000 0.6000 1.3400 2.6000 3.4500	0.0000 175. 0000 300.0000 425.0000 500.0000	0.0000 0.5000 0.9750 1.6250 2.3750	0.0000	00.00000 0.0050 0.0090 0.0160 0.0240	0.006605
1cm/30%	0.0000 3.4300 5.0000 5.6000 5.8300 8.8800	0.0000 25.0000 445.0000 700.0000 950.0000 1,175.0000	0.0000 0.7500 1.5000 2.5000 3.0000 3.4500	0.0000	0.0000 0.0080 0.0150 0.0250 0.0300 0.0350	0.005104
1cm/50%	0.0000 5.2300 11.2300 15.5100 20.0200 25.0000	0.0000 200.0000 425.0000 675.0000 1,050.0000 1,450.0000	0.0000 0.1250 1.0000 2.0000 3.0000 3.7500		0.0000 0.0001 0.0100 0.0200 0.0300 0.038	
3cm/10%	0.0000 2.2600 5.5300 9.5300 11.0300	0.0000 325.0000 425.0000 575.0000 650.0000	0.0000 0.7000 1.2500 2.2500 3.0000	0.0000	0.0000 0.0080 0.0130 0.0230 0.0300	0.002524
3cm/30%	0.0000 2.4200 7.8000 14.6800 16.6900	0.0000 25.0000 275.0000 375.0000 475.0000	0.0000 0.0250 0.4750 1.3750 3.2500	0.0000	0.0000 $2.5*10-^{+}$ $5.0*10^{-3}$ 0.0150 0.0325	0.001697
3cm/30%	0.0000 3.3800 7.2700 11.6300 15.9100 15.9100	0.0000 225.0000 375.0000 522.0000 650.0000 700.0000	0.0000 0.1250 0.4750 1.3750 2.8750 3.5000	0.0000	0.0000 $1.25*10^{-4}$ $4.75*10^{-3}$ 0.01375 0.02875 0.0350	0.002154
5cm/50%	0.0000 2.5000 3.0600 5.9000 9.0800 10.3900	0.0000 175.0000 325.0000 525.0000 725.0000 945.0000	0.0000 0.2500 0.7500 1.2500 1.7500 2.0500	0.0000	0.0000 0.0030 0.0080 0.0130 0.0180 0.0210	0.0021
5cm/30%	0.0000 2.4300 7.1100 12.5100 16.2700	0.0000 150.0000 225.0000 305.0000 350.0000	0.0000 0.2500 0.5000 1.5000 3.0000	0.0000	0.0000 0.0030 0.0050 0.0150 0.0300	0.001698
5cm/50%	0.0000 3.1600 6.2700 9.1200	0.0000 205.0000 350.0000 610.0000	0.0000 0.4500 0.7500 1.2500	0.0000	0.0000 0.0050 0.00.80 0.0130	0.001829

Table 5: Creep Value

Fiber Length (cm)	1	1	1	3	3	3	5	5	5
Fiber Volume	10	10	10	30	30	30	10	30	50
Creep (sec^{-1})	0.006605	0.005104	0.001655	0.002524	0.001697	0.002154	0.0021	0.001698	0.00829

Table 6: Statistical Modeling of Creep Rate

Variables	**Coefficients**	**Se**	**T_{stat}**	**P_{val}**	**Fstatistics**
	0.0104	0.0020143	5.1605	0.01412	Sse=2.6269e^{-6}
X_1	-3.0823e^{-4}	0.0001069	-2.8809	0.063482	dfe = 3
X_2	-1.3105e^{-4}	0.0001699	-1.2248	0.30803	dfr
$X_1 X_2$	2.924e^{-6}	1.1697e^{-6}	2.5001	0.087679	Ssr = 2.825e^{-5}
X_1^2	2.6004e^{-6}	1.6542^{-6}	1.572	0.21399	F = 5.2133
X_2^2	-5.4583e^{-8}	1.6542e^{-6}	-.032997	0.97575	Pval = 0.102232
	R^2 = 0.8968	Adj R^2=0.7284	Mst=8.7563e-7		

4.0 DISCUSSION

In tensile test of the fiber, the most properties can be represented by young's modulus and tensile strength. The result of analysis of both the treated and untreated fiber show that the young modulus and tensile strength of the treated fiber is higher than that of the untreated fiber as shown in table 1 and table 2. This is because introduced of alkaline treatment in the natural fiber reinforced polymer composite help to improve both tensile strength and young modulus of the fiber. Because the treatment are dependent on the concentration of the NaOH and saline solution, the young modulus and tensile strength of the treated fiber varies from the observation, the optimum fiber loading which yield the highest young's modulus was at ratio or 20.80 (treated A) of NaOH and saline. The fiber served as a reinforcement because the major share of load has been taken up by the crystalline fibrils resulting in extension of the helically wound fibrils along with the matrix (Singha and Vijay, 2009). The ultimate stress break of the untreated is 7.25% compared to treated fiber which carries with the treatment concentration.

The fiber length varies from 1 cm, 3cm and 5cm and be fiber volume 10%, 30% and 5%. The minimum creep rate of the composite has 1cm fiber length and 50% fiber acted as flaws and crazing occurred. Thus creating stress concentration area (in time and forces), which is lowering the stiffness of the composite. This may be attributed to the strong stress fields developed at the ends of the fibers in the composite beyond 1cm fiber length which made the composite sample less tough and shorter fiber are said to be more to optimized position in a composite than longer fiber. Beside at this 50% volume fraction of fiber was a bit excessive, that the polymer matrix was hard enough of flow through every fiber leaving voids and fibers are more easily exposed to environmental degradation.

CONCLUSION

These fibers are abundant, cheap and renewable. The chemical composition of the material fiber depending upon the type of fiber varies, Plant fibers are materials designed by nature. The fibers are basically rigid, crystalline cellulose micro-fibril-reinforced amorphous lignin and or with hemi cellulosic matrix. Most plant fibers, except for cotton, are composed of the cellulose, hemicelluloses, lignin, waxes and some water soluble compound were cellulose, hemicelluloses and lignin are the major constituent. A new natural fiber named okro (hibiscus esculentus) was introduced in this work. The effect of chemical treatment on the tensile properties and the characterization of fiber reinforced polyester composites showed that treated okro fiber has higher tensile strength and modulus than that of the untreated. This is to say that treatment in the natural fiber reinforced polymer composites improve the adhesions between the matrix and fiber and activate the OH group of the cellulose and lignin in the fiber. The minimum creep rate of the composites has 1cm fiber length and 50% fiber volume fraction because of high volume fraction of the fiber as could be observed from table 4 and table 5.

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