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EFFECTS OF FIBRE-VOLUME FRACTION ON THE MECHANICAL PROPERTIES OF UKAM FIBRE-REINFORCED POLYESTER RESIN COMPOSITES

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Editorial Comment: *This article is published on the strength of the paper's potential in contributing to technological and sustainable development in Africa*

Abstract
This research is aimed at studying the composite of Ukam plant fibre-reinforced polyester resin with a view to determining the effects of fibre-volume fraction on its mechanical and physical properties. From the experimental work and the tests carried out, It was observed that increase in fibre volume fraction (V_f) reduces the hardness and the compressive strength; increases the tensile strength and the longitudinal modulus of the composites. At 10% and 30% V_f, hardness was observed to be 509.2MPa and 412.49MPa; compressive strength was 165.67MPa and 96.5MPa; Tensile strength was 34.72MPa and 83.33MPa; Longitudinal modulus was 12.6 MPa and 35.8 MPa respectively. It was observed that Ukam plant fibres are very effective in increasing the composite modulus in the longitudinal direction: As the fibre-volume fraction increases, the ratio E_c/E_m also increases. The transverse modulus of a unidirectional composite is much smaller than its longitudinal modulus. As a result, the ukam plant fibres are much less effective in raising the composite modulus in the transverse direction than in the longitudinal direction. It was also observed that the mechanical properties of the composite of ukam fibre-reinforced polyester resin were optimum at 30% V_f. Its properties were therefore determined at 30% V_f: Tensile modulus 2.78GPa; Compressive modulus 165.67MPa; Tensile strength 83.33MPa; Hardness 138.78MPa; Shear strength 27.25MPa; Ultimate strength 30.25MPa; Bending strength 68.85MPa respectively.

Keywords: *Composites, Natural Fibres, Matrix, Fibre Volume Fraction, Ukam Plant.*

INTRODUCTION

1.1 Composite technology and theory

Fibre-composite technology is expanding rapidly as progress is being made toward obtaining stiffer and lighter weight refractory fibres for reinforcing resins. Interest in these materials has been increasing at an exponential rate during the last few years. The composite technology of a polymeric matrix reinforced with man-made (synthetic) fibres such as glass has come of age especially with the advances in aerospace applications since 1950s [1] . The developments of composite materials after meeting the challenges of aerospace sector have cascaded down for catering to domestic and industrial applications.

Today, the growing environmental awareness throughout the world has triggered a paradigm shift from synthetic fibres and their composites (GFRP), which are difficult to be recycled after designed service life, towards composites of natural fibres which are compatible with the environment.

Composites (reinforced with natural fibres) – the wonder material, with light-weight, high strength to weight ratio and stiffness properties have come a long way in replacing the conventional materials like metals, woods and non-renewable (synthetic) fibres which are more expensive[5]. The natural and wood fibres derived from annually renewable resources, as reinforcing fibres, in both thermoplastic and thermoset matrix composites provide positive environmental benefits with respect to ultimate disposability and raw material utilization [6].

Composite materials consist of two or more discrete physical phases, in which a fibrous phase is dispersed within a continuous matrix phase, and the fibrous phase must retain its physical identity, such that it conceivably can be removed from the matrix intact [2]. The material properties produced are different from the properties of those constituents on their own, and cannot be predicted by summing the properties of its components. In practice, most composites consist of a bulk material (the "matrix"), and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. In the world of technology today, attention is on Natural fibres as reinforcement for resin matrices.

To fully appreciate the role and application of composite materials to a structure, an understanding is required of the constituents of the composite themselves and of the way in which they can be processed.

1.2 MATERIALS AND METHODS

The materials used in this work include:

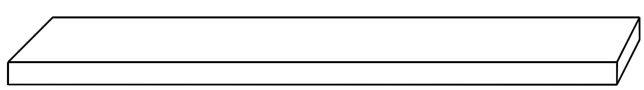
i. Ukam plant fibres (chochlostermum placoni)
ii. Polyester resin.
iii. Catalyst (methyl ethyl ketone)
iv. Accelerator (cobalt)
v. Gell coat

1.3 Experimental characterization of composites

Experimental characterization refers to the determination of the material properties through tests conducted on suitably designed specimens. The data obtained from the tests are appropriately reduced to evaluate various material properties that can later be used for analysis and design of practical structures.

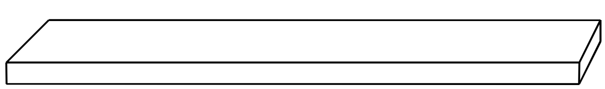
Test samples of laminates were prepared by cutting the fully cured composites into appropriate sizes. A triplicate of the test samples for each test was prepared as shown in Fig.1 to investigate the following mechanical properties: Shear modulus, tensile strength, compression strength, hardness and bending strength.

TENSILE TEST SAMPLE



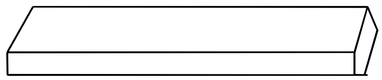
Length: 300mm
Width: 10 – 20mm
Thickness: 0 – 5mm

BENDING TEST SAMPLE



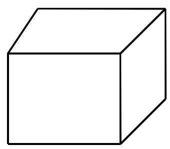
Length: 300mm
Width: 10 – 20mm
Thickness: 0 – 5mm

HARDNESS (BRINELL) TEST SAMPLE



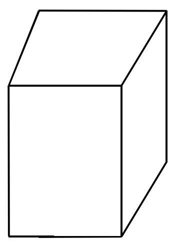
Length: 50mm
Width: 10 – 20mm
Thickness: 0 – 5mm

SHEAR TEST SAMPLE



Length: 20mm
Width: 20mm
Thickness: 20mm

COMPRESSION TEST SAMPLE



Length: 20mm
Width: 20mm
Height: 40mm

Fig.1 Schematic diagrams of Test Specimens

1.4 Procedure

The machine used for the measurement of these mechanical properties is more of a universal tester, which has various interchangeable attachments for testing of composite material. The test includes shear, tension, compression, hardness (Brinnel Indenter) and bending.

Tinius Olsen (Monsato) Tensometer (model No S/W 8889) with the appropriate attachment for each test set in place, force is then applied manually by turning the fine loading arm at the right end of the machine in a clock-wise direction. This causes the operating screw to move rightward; thus pushing or pulling, depending on the type of test been carried out. At the other end of the machine is connected a precisely grounded spring beam supported on rollers. The force is transmitted through a simple lever system to a mercury piston, which displaces mercury into a uniform plain glass tube. The reading is indicated through sliding the cursor front or back following the mercury convex head.

The movement of the worm gear which causes deformation of the specimen is transmitted through a gear train to the recording drum. The rotation of the drum is proportional to the deformation of the test piece.

Suitable gear ratio with respect to the test material include: 2:1, 4:1, 8:1, and 16:1. The gear ratio used for these tests is 4:1 the speed were fixed with the operating gear screw, which has a range, from 0.5 – 5.0 mm per minute.

1.5 RESULTS/DISCUSSION

Table 1 Shear test (along fibre grain)
Material: ukam fibre-reinforced polyester resin composite
V_f: 10%
Test piece: (20 x 20 x 20) mm
Area: 400mm^2
Length: 20mm

LOAD (N)	EXTENSION (mm)	STRESS (MPa)	STRAIN
0	0	0	0
1100	0.750	2.75	0.0375
2100	1.250	5.25	0.0625
3000	1.625	7.50	0.0813
4,100	2.125	10.25	0.1063
5000	2.500	12.50	0.1250
6000	2.625	15.00	0.1313
7000	3.000	17.50	0.1500
8000	3.250	20.00	0.1625
9000	3.500	22.50	0.1750
9300	3.625	23.25	0.1813
9200	4.750	23.00	0.2375
9200	5.000	23.00	0.2500
8900	5.250	22.25	0.2625
8400	5.375	21.00	0.2688
7400	5.500	18.50	0.2750
6300	5.750	15.75	0.2875
5800	6.125	14.50	0.3063
5300	6.500	13.25	0.3250

Table 2 Shear test (across fibre grain)
Material: ukam fibre-reinforced polyester resin composite
V_f: 10%
Test piece: **(**20x 20 x 20)
Area: 400mm^2
Length: 20mm

LOAD (N)	EXTENSION (mm)	STRESS (MPa)	STRAIN
0	0	0	0
600	1.375	1.500	0.0688
1200	2.000	3.000	0.1000
2100	2.750	5.250	0.1375
3200	3.625	8.000	0.1813
4150	5.500	10.375	0.2750
4200	5.750	10.500	0.2875
4200	6.000	10.500	0.3000
4400	6.500	11.000	0.3250
4550	7.250	11.375	0.3625
4600	7.500	11.500	0.3750
4550	7.750	11.375	0.3875
4350	8.000	10.875	0.4000

Fig. 2 Shear test graph (test along fibre grain) $V_f = 10\%$

Shear Modulus (Es) = 153.33 MPa

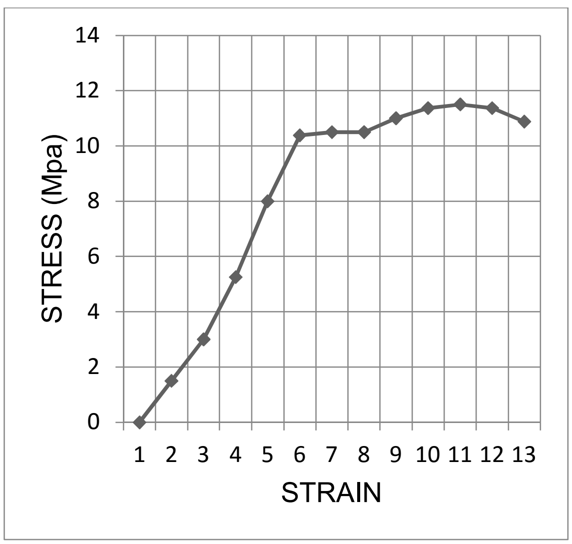


Fig.3 Shear test graph (test across fibre grain) $V_f = 10\%$

Shear modulus (Es) = 42.143 MPa
Ulyimate strength (Sy) = 11.500 MPa

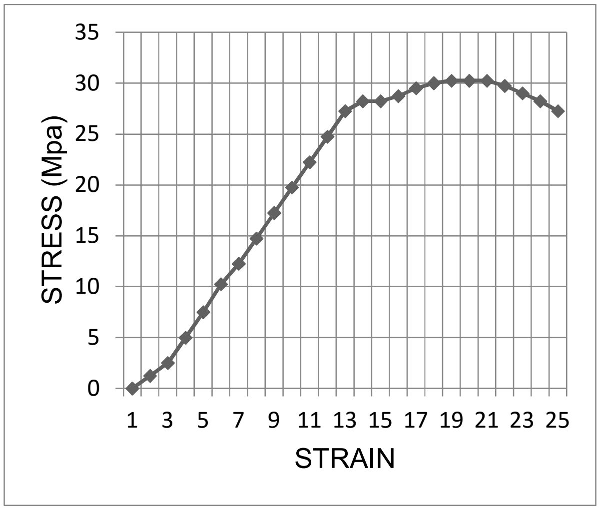


Fig. 4 Shear test graph (test across fibre grain) $V_f = 30\%$

Shear modulus (Es) = 152.857 MPa
Ultimate strength (Sy) = 30.25 MPa
Fracture strength (S_f) = 27.25 MPa

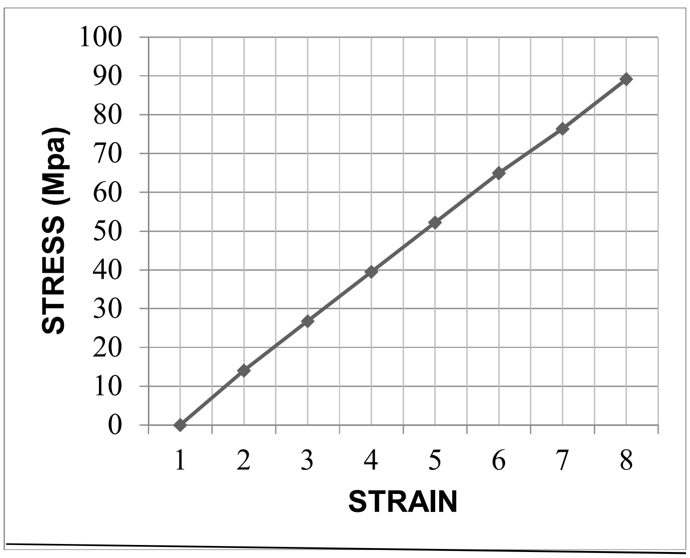


Fig. 5 Brinnel hardness test $V_f = 10\%$

Hardness (H) = 509.200 MPa

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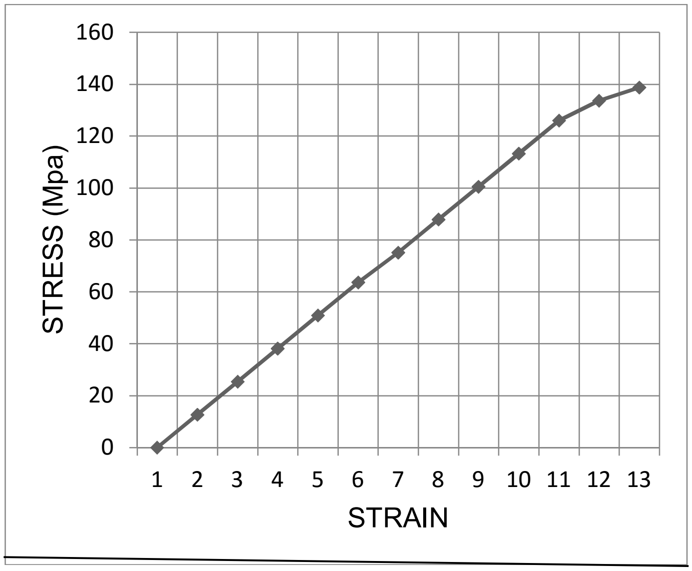

Fig. 6 Brinnel hardness test $V_f = 30\%$

Hardness (H) = 412.488 MPa

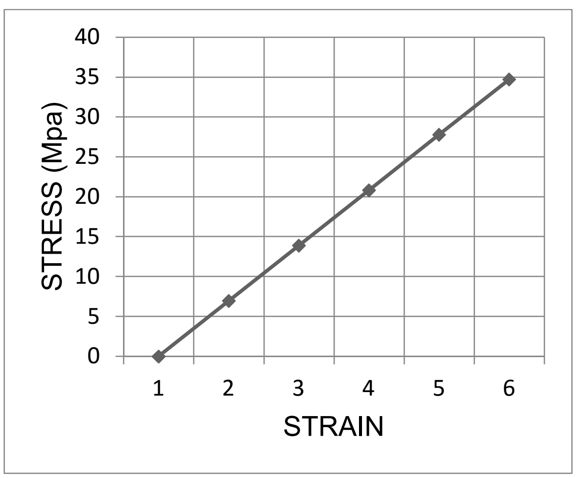

Fig. 7 Tension test. $V_f = 10\%$

Tensile modulus (Et) = 1.1323 GPa
Fracture strength (S_f) = 34.722 MPa
Tensile strength (Se) = 34.722 MPa

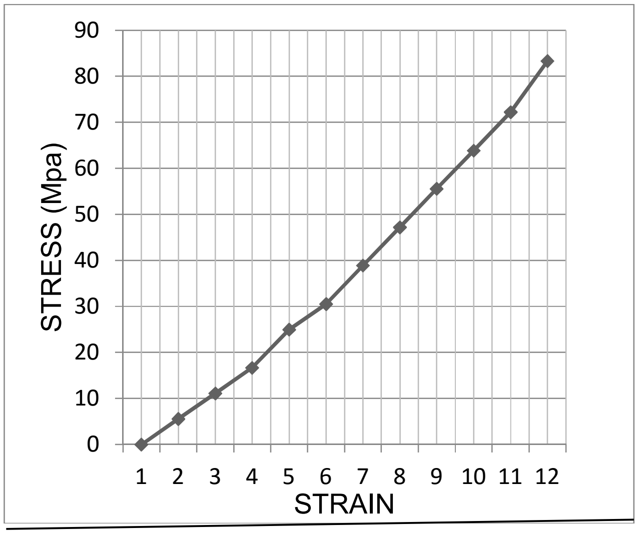

Fig. 8 Tension test. $V_f = 30\%$

Tensile modulus (E_t) = 2.777 GPa
Fracture strength (S_f) = 83.33 MPa
Tensile strength (S_e) = 83.33 MPa

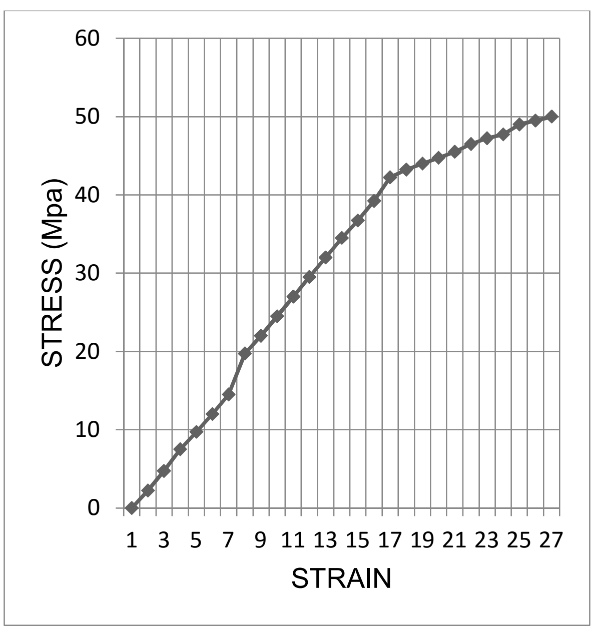

Fig. 9 Compression test. $V_f = 10\%$
Modulus of compression (Ec) = 165.667 MPa

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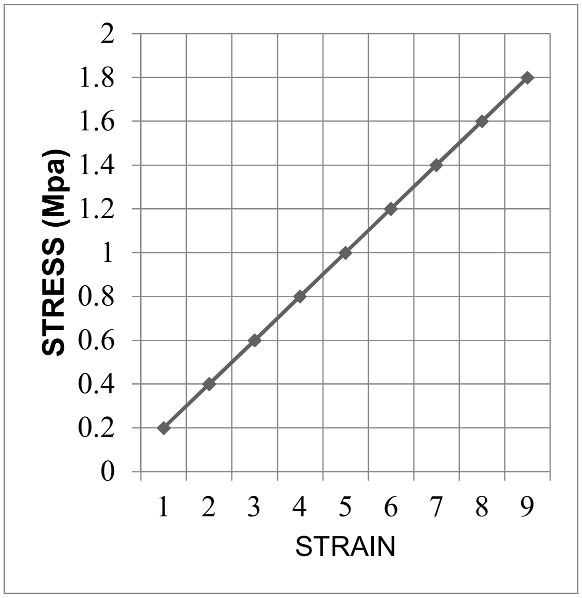

Fig. 10 Ukam plant fibre tension test

Tensile modulus (E_t) = 95.0 GPa
Fracture strength (S_f) = 1.8 GPa

1.6 Effects of V_f on the mechanical properties of ukam plant fibre-reinforced polyester resin composites

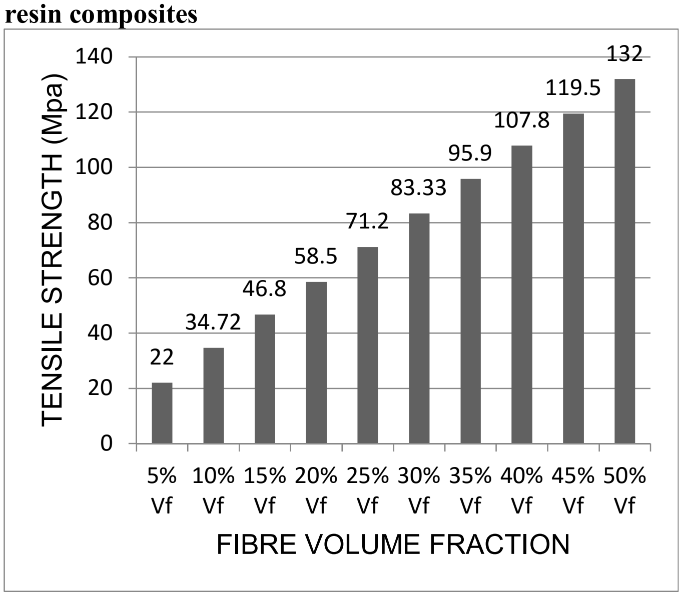

Fig. 11 Effects of volume fraction (V_f) on Tensile strength

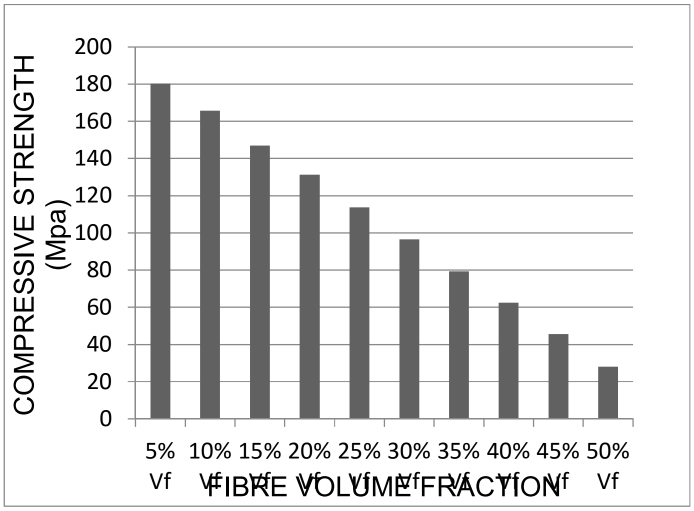

Fig.12 Effect of volume fraction (V_f) on compressive strength.

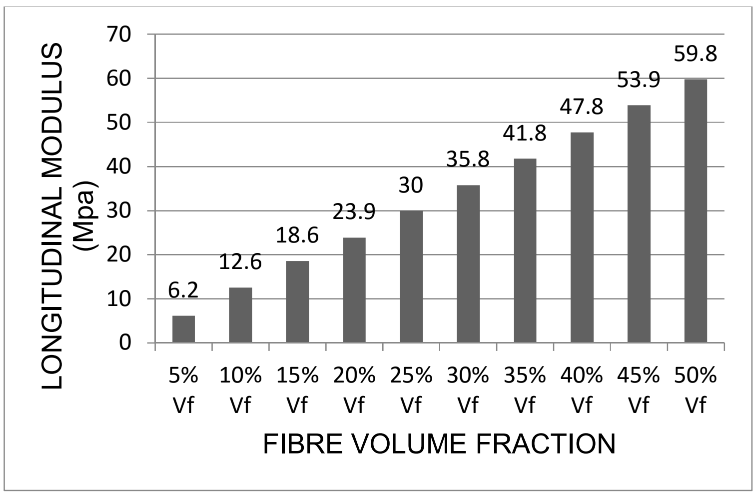

Fig.13 Effect of volume fraction (V_f) on longitudinal modulus.

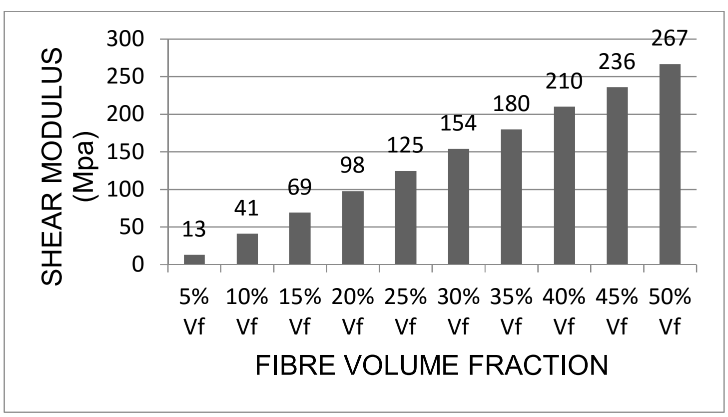

Fig.14 Effect of volume fraction (V_f) on shear modulus.

Table 3 Basic properties of ukam plant fibre-reinforced polyester resin composites at 30% V_f

MECHANICAL PROPERTIES AT 30% V_f	VALUES
Tensile Modulus	2.78 GPa
Compression Modulus	165.67 MPa
Tensile Strength	83.33 MPa
Hardness	138.78 MPa
Shear Strength	27.25 MPa
Ultimate strength	30.25 MPa.
Bending strength	68.85 MPa

1.7 Discussion

From the results above, it could be seen that:

- Increase in V_f reduces the hardness and the compressive strength, but increases the tensile strength and the longitudinal modulus of the composites.
- Ukam plant fibres are very effective in increasing the composite modulus in the longitudinal direction: as the fibre-volume fraction increase, the ratio E_c/E_m also increases.
- The transverse modulus of a unidirectional composite is much smaller than its longitudinal modulus. As a result, the ukam plant fibres are much less effective in raising the composite modulus in the transverse direction than in the longitudinal direction.
- From the experimental work carried out, it was observed that the mechanical properties of ukam fibre-reinforced polyester resin composites were optimum at 30% V_f. This is because the functional requirements of the matrix in a fibre-matrix composite (binding of fibres together; transferring stresses to fibres by adhesion and protecting them against environmental attack and damage due to handling) is satisfied up to 30%V_f. Above thirty percent volume fraction (30% V_f), the functional requirements mentioned above failed. The mechanical properties of ukam fibre-reinforced polyester resin composites were therefore determined at 30%V_f.
- Comparison between the mechanical and physical properties of E-glass fibres and ukam plant fibres shows that the specific modulus of ukam plant fibres is superior to that of E-glass fibres and therefore, where high strength is not a priority, ukam plant fibres may be used to fully replace glass fibres without entailing the introduction of new techniques of composite fabrication. The need for using ukam plant fibres in place of the traditional glass fibres as reinforcing agents in composites stems from its lower density (1320.0 kg/m^3) and higher specific modulus (72.0 GPa) of ukam plant fibres compared with those of E-glass (2500.0 kg/m^3) and (28.0 GPa) respectively. Apart from much lower cost and renewable nature of ukam plant fibres, much lower energy requirement for the production of ukam plant fibres makes it attractive as reinforcing fibres in composites.

1.8 Conclusion

An overview of the effect of ukam plant fibres on the properties of unidirectional polymer composites is presented below:

(a) **Tensile Properties:**

Ukam plant fibres are very effective in increasing the composite modulus and strength in the Longitudinal direction, but not effective in increasing the composite modulus and strength in the Transverse direction

(b) **Compression Properties:**

Under compression, ukam plant fibres have very week influence on both Longitudinal and Transverse modulus/strengths.

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