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The Comparison of Micro Mechanics Analyses to Some Empirical Properties of Ukam (Cochlospermum Planconii) Fibre Reinforced Polyester Composite

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ABSTRACT. The comparison of micro mechanics analyses to some empirical properties of cochlospermum planchonii (ukam) fibre reinforced polyester composite has been undertaken. The study developed the composites, which were characterized, and empirical values were generated. The polyester and the ukam fibre, which were used in the manufacture of the composites via weight fractions were also characterized. The properties of the polyester and ukam fibre were then used in the micro mechanics analyses of the developed composites. The study revealed that reinforcement-matrix proportion played a major role in composite property determination. This was observed from both the empirical properties measured and the micro mechanics analyses. It was also observed that micro mechanics analyses did not agree with empirical properties in all cases; this the study revealed that it was because of the complex nature of the interactions between parameters responsible for properties in composites. The study has indicated that where micro mechanics analyses agree with empirical property of the composite the law of mixtures can be used to predict the property of the composite.

Introduction. According to [11] the fabrication and properties of composites are strongly influenced by the proportions and properties of the matrix and the reinforcement. The proportions can be expressed either via the weight fraction (ω), which is relevant to fabrication, or via the volume fraction (ν), which is commonly used in property calculation. The definitions of ω and ν are related simply to the ratios of weight (W) or volume (V) as shown below.

Volume fractions:

$$\nu_f = V_f / V_c \text{ and } \nu_m = V_m / V_c \quad (1, a)$$

Weight fractions:

$$w_f = W_f / W_c \text{ and } w_m = W_m / W_c \quad (1, b)$$

where the subscripts m, f and c refer to the matrix fibre (or in the more general case, reinforcement) and composite respectively.

We note that,

$$v_f + v_m = 1 \text{ and } w_f + w_m = 1$$

We can relate weight to volume fractions by introducing the density, ρ , of the composite and its constituents.

$W_c = W_f + W_m$, which as $W = \rho V$, becomes

$$\rho_c V_c = \rho_f V_f + \rho_m V_m \Rightarrow \rho_c = \rho_f V_f + \rho_m V_m \quad (2)$$

It may also be shown that,

$$\frac{1}{\rho_c} = \frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} \quad (3)$$

And similarly,

$$W_m = \frac{W_m}{W_c} = \frac{\rho_m V_m}{\rho_c V_c} = \frac{\rho_m}{\rho_c} v_m \quad (4)$$

We can see that it is possible to convert from weight fraction to volume fraction, and vice versa, provided that the densities of the reinforcement (ρ_f) and the matrix (ρ_m) are known. Equation 2, shows that, the density of the composite is given by the volume fraction adjusted sum of the densities of the constituents. This equation is not only applicable to density, but in certain circumstances, may apply to other properties of constituents. A generalized form of the equation is

$$X_c = X_m V_m + X_f V_f \quad (5)$$

where X_c represents an appropriate property of the composite;

V is the volume fraction and the subscripts m and f refer to the matrix and reinforcement respectively.

This equation is known as the Law of Mixtures [11].

The properties of composites are very important since they determine their areas of application. Most properties of a composite are a complex fraction of a number of properties as the constituents usually interact in a synergistic way so as to provide properties in the composite that are not fully accounted for by the law of mixtures [[1], [2], [3], [7], [11]]. The chemical and strength characteristics of the interface between the fibres and the matrix, is particularly important in determining the properties of the composite. The interfacial bond strength has to be sufficient for load to be transferred from the matrix to the fibre, if the composite is to be stronger than the unreinforced matrix. On the other hand, if we are concerned with the toughness of the composite, the interface must not be so strong that it

does not fail and allow toughening mechanisms such as debonding and fibre pull-out to take place [[6], [7], [8], [9], [10], [12].

Other parameters which may significantly affect the properties of a composite are the shape, size, orientation and distribution of the reinforcement and various features of the matrix such as the grain size for polycrystalline matrices. These, together with volume fraction, constitute what is called the microstructure of the composite [[11], [13], [14], [15], [16], [17].

The use of the law of mixtures in studying the properties of composites has its basis in what is called micromechanics analyses. Because the starting point of a significant proportion of composites' manufacture is the combination of fibres and matrix, it would be very helpful if we could predict the behavior of the composite from knowledge of the properties of the constituents alone. There are however, many limitations to such micromechanics analyses [[11], [19], [20]]. However, studying performance on a micro scale is essential if we are to understand fully what controls the strength, toughness, etc. of composites. The impact strength of fibre reinforced composite increases as the fibre volume fraction increases [21]. The strength also improves with increase in fibre volume fractions, fibre treatment, fibre length, fibre orientation and the addition of additives. Rasheed *et al* [18] found that the tensile strength of the composite increases with the fibre volume fraction up to 40% and after which it decreases slightly

The objective of this research is to apply the law of mixtures in the micromechanics analyses of some properties of polyester composite reinforced with cochlospermum planchonii fibre.

Materials and Method

Materials

The materials used for this work were: polyester resin, ukam fibre (cochlospermum planchonii fibres), sodium hydroxide, acetic acid, releasing agent, methyl ethyl ketone peroxide, calcium carbonate, cobalt naphthenate and water.

Equipment

The equipment used for the study were as follows: rule, digital weighing balance, Moulds, Tensile Strength Tester, Scanning Electron Microscope, Universal Testing Machine, Flexural Testing Machine, Compression Testing Machine, Rockwell – B scale, and Impact Testing Machine

Method

The work commenced with the production of the composite using polyester as the matrix and cochlospermum planchonii as the fibres. Cut stems of the plants were soaked inside flowing water for thirty days. This enhanced the decay and removal of the thin back of the plant leaving behind, white fibrous stems (see Fig. 1). The fibres were removed from the fibrous stems with hands (see Fig. 2). The density, tensile strength, SEM analysis, and water absorption characteristics of the produced fibres were all determined. The produced fibres were then used in the development of polyester composite using various weight fractions of the fibre, which were randomly oriented in the matrix (see Table 1). The produced composites were allowed to cure for 24 hours before the commencement of their processing into standard test specimens which were used for characterization of the produced composites. Figs. 3-6 show some equipment, the developed composites, and some specimens which were used for the characterization of the produced composites.



Fig. 1. Cut stems of cochlospermum planchonii fibres.



Fig. 2. Treated and dried cochlospermum planchonii fibres.



Fig. 3. Scanning electron microscope.



Fig. 4. Developed samples of cochlospermum planchonii reinforced polyester composites.



Fig. 5. Test Specimens of cochlospermum planchonii reinforced composite for tensile test.

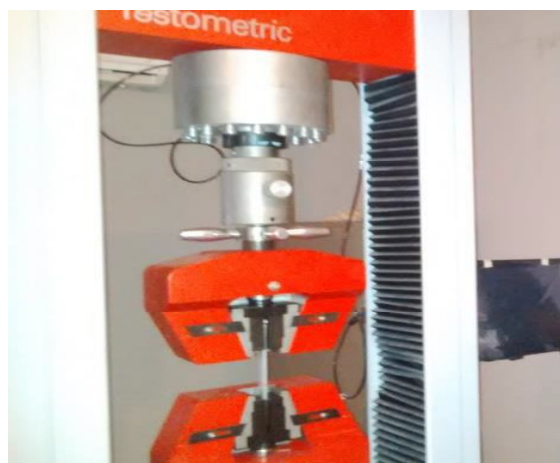


Fig. 6. Universal strength testing machine (Testometric).

Results and Discussion

Results. The results of the research are as presented in Tables 1-4. The micromechanics analyses was accomplished using equation 5.

The initial conditions:

$$\text{Density of fibres} = 1.6 \text{ g/cm}^3$$

$$\text{Tensile strength of fibre} = 1803.11 \text{ MPa}$$

$$\text{Water absorption of fibre} = 0.83\%$$

$$\text{Extension: } 0.46\text{mm}$$

Polyester properties:

$$\text{Density} = 1.45 \text{ g/cm}^3$$

$$\text{Tensile strength} = 15.59 \text{ MPa}$$

$$\text{Water absorption} = 0.38\%$$

$$\text{Elongation} = 2\%$$

Table 1. Weight and Weight Fractions of Cochlospermum Planchonii fibre and Polyester.

Wt. of Reinforcement (W_f)	wt. of matrix (W_m)	wt. fraction of reinforcement (w_f)	wt. fraction of matrix (w_m)
20	80	0.20	0.80
30	70	0.30	0.70
40	60	0.40	0.60
60	40	0.60	0.40

Table 2. Density values of the Developed Composites with the Micromechanics Analyses values.

S/no.	% Reinforcement	Density (Empirical values) g/cm^3	Density (Micromechanics analyses) g/cm^3
1	0	1.45	1.45
2	20	1.55	1.48
3	30	1.60	1.50
4	40	1.90	1.51
5	60	1.83	1.54

Table 3. Water absorption Capacity of the developed composites with the Micromechanics Analyses values.

S/no.	% Reinforcement	Water absorption capacity (Empirical values) %	Water absorption capacity (Micromechanics analyses values) %
1	0	0.31	0.31
2	20	0.31	0.46
3	30	0.38	0.49
4	40	0.38	0.52
5	60	0.53	0.57

Table 4. Tensile strength values of the Developed Composites with the Micromechanics Analyses values.

S/no.	% Reinforcement	Tensile strength (Empirical values) MPa	Tensile strength (Micromechanics analyses values) MPa
1	0	15.59	15.59
2	20	27.14	373.094
3	30	41.67	551.846
4	40	49.40	730.598
5	50	-	909.35
6	60	46.13	1088.102
7	70	-	1266.854

Table 5. Extension values of the Developed Composites with the Micromechanics Analyses values Extension.

S/No.	% Reinforcement	Extension (Empirical values), mm	Extension (Micromechanics analyses values), mm
1	0	3.07	3.07
2	20	4.70	2.548
3	30	5.63	2.287
4	40	6.90	2.026
5	50	-	1.765
6	60	6.50	1.504
7	70	-	1.243

Discussion. Table 2 shows the densities of the developed composites with the micromechanics values of the densities of the composites. The micromechanics analyses show that as the fibre reinforcement is increasing, the density property of the composite is also increasing. The same trend can be observed

in the empirical values; however, the empirical values are higher than the micromechanics values, reasons have been advanced earlier in the introducing part of this paper. Another reason is that, the law of mixtures accuracy also depends on the correct measurement of the property of the matrix and the reinforcement [[1], [2], [3], [7], [11]].

Table 3 shows the water absorption capacity values of the developed composites with the micromechanics values of the water absorption capacity of the composites. The micromechanics analyses show that the water absorption capacity increases with increase in fibre reinforcement in the composite. This trend can also be seen with the empirical values of water absorption capacity. The water absorption capacity values of the micromechanics analyses are however, higher than those of the empirical values. Again, it should be noted that the closeness or accuracy of the micromechanics values to empirical values depend on the correct measurement of the values of the matrix and the fibre in addition to other factors [[6], [7], [8], [9], [10], [12]].

Table 4 shows the tensile strength values of the developed composites with the micromechanics Analyses values. The micromechanics analyses show that as the fibre reinforcement is increasing the tensile property of the composites is also increasing. The same trend is observed with the empirical values. The empirical values are however, higher than the micromechanics values. This is not surprising because the matrix tensile strength of 15.59 MPa is quite lower than the 45 – 85 MPa range obtained from most polyesters. The micromechanics analyses values are more realistic since they are closer to strength values commonly found in polyester fibre reinforced composites (140 MPa and above) [[11], [13], [14], [15], [17]].

Table 5 shows the extension values of the developed composites with the micromechanics analyses values of the extension of the composites. The micromechanics analyses show that as fibre reinforcement is increasing, the extension property of the developed composites is decreasing.

This does not agree with the empirical values trend, which show that as the reinforcement is increasing, the extension property of the composites is also increasing. It has earlier been mentioned in the introductory part of this paper, that most properties of a composite are a complex function of a number of parameters as the constituents usually interact in a synergistic way so as to provide properties in the composite that are not fully accounted for by the law of mixtures [[11], [19], [20]].

Tables 4 and 5 have shown that it is possible to use micro mechanics analysis to predict the properties of composites. This can also be seen in previous work of Matthews and Rawlings [11]. Previous researchers [[11], [13], [14], [15], [16], [17]] have shown that the fabrication and properties of composites are strongly influenced by the proportions and properties of the matrix and the reinforcement. Several authors are also of the opinion that studying performance on a micro scale is essential if we are to understand fully what controls the strength, toughness, etc. of composites [[6], [7], [8], [9], [10], [12]]. There are however many limitations to such micro mechanics analysis. Because the starting point of a significant proportion of composites' manufacture is a combination of fibres and matrix, it would be very helpful if we could predict the behaviour of the composite from knowledge of the properties of the constituents alone [[11], [18], [21]].

Summary. The research work titled “The Comparison of Micro Mechanics analyses to some empirical properties of polyester based composition reinforced with cochlospermum planchonii fibre” was extensively undertaken and the following conclusions were drawn from the work:

1. Most properties of composites are a complex function of a number of parameters as the constituents usually interact in a synergistic way so as to provide projections in the composite that are not fully accounted for by the law of mixtures.
2. Provided the property of the matrix and the fibre has been measured correctly, micromechanics analyses can be used to predict some properties of the composite.
3. The study has shown that micromechanics analyses of the properties of polyester based / composite reinforced with cochlospermum planchonii (ukam) fibre does agree with the trend of empirical

properties for density water absorption capacity and tensile strength, but disagree with extension property.

4. Both the empirical results and micromechanics analyses have shown that proportions of the matrix and reinforcements expressed in weight fractions or volume fractions is a major determinant of cochlospermum planchonii reinforced polyester composite properties.

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