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Properties of Cassava Peels Reinforced High-Density Polyethylene

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ABSTRACT
Cassava Peels Powder (CaPP) of size less than 750μm was reinforced with high-density polyethylene (HDPE). The results of tensile test show that the yield strain, yield strength, strain at break and strength at break decreased as powdered cassava peels increases. For the elastic modulus, it increased with cassava peels content. Pure HDPE, under tensile conditions, deform with the formation of a collar or neck. The width of the neck gradually increases and tends to collapse as the CaPP increases. Yield strength of pure HDPE is 22.15 MPa, increased to 24.05 MPa at 6% wt. and dropped to 22.02 MPa at 12% wt. of CaPP. HDPE elongation at yield is 22.98% and 54.81% at break. Addition of CaPP decreases elongation both at yield point and break to 7.19 and 12.78% respectively at 12% loading. The maximum percentage decrease is 68. 71 % for elongation at yield point and 76.68 % at break. For pure HDPE the tensile strength at break is 19.50 MPa, this value dropped to 17.53 MPa at 12 %wt. The decrease in tensile strength as CaPP increases is attributed to high hydrophilic nature of cassava peels. Six standard equations were used to predict the mechanical properties of the composite. From the six equations, the best correlation between the theoretical and experimental tensile strength was seen in the model predicted using Halpin-Tsai, while Guth and Series agree the least with experimental values. For Hirsch model at χ = 0.9, the

theoretical and experimental values have a marginal agreement at all volume fractions. For Halpin-Tsai and modified Halpin-Tsai models, the tensile strength values are not the same. The Halpin-Tsai equation gave the best correlation for the tensile strength while modified Halpin-Tsai equation made a marginal agreement.

Keywords: Elastic modulus, tensile strength, volume fraction, model equations.

1. INTRODUCTION

The addition of fillers to polymer matrices as additives is intended to improve some of the mechanical and physical properties of the material in addition to reducing the cost of production. Some of the properties to improve upon are stiffness, yield strength, hardness, tensile strength, elastic modulus, percentage elongation, flame resistance, viscosity and thermal conductivity. Organic fillers from natural fibres, wood flour, starch, cassava peels have been used to improve on the properties of composite materials produced from biodegradable materials [1-5].

The interest in producing biodegradable films has been on the increase. Among the reasons for such interest are renewability sources and environmental awareness. Non-biodegradable materials such as synthetic plastic, a common environmental contamination cannot be easily disposed of as they last for years [6].

In order to reduce environmental contamination of synthetic plastic, the need for the production of ecologically friendly materials become unavoidable [5, 7-8]. There has been increased interest from Engineers and Scientists in developing biodegradable plastics from agricultural by-products. Some of these renewable natural materials include natural fibres, starch and proteins [6,7,9].

Thermoplastic starch is a typical example of a biopolymer derived from natural sources. Depending on the source of starch, they are carbohydrate polymers made of a combination of polysaccharides amylose and branched polysaccharide amylopectin [10]. The renewability, availability and cost-effectiveness of starch cannot be overemphasised [11]. In spite of these advantages, they are hydrophilic in character and perform less mechanical and thermal behaviour when compared with traditional industrial polymers [12]. To overcome some of these problems, blending with synthetic polymers, chemical modification and addition of plasticizers have been recommended by Swanson et al. [13].

Cassava peels a natural fibre has attracted scientists to explore its mechanical properties. Versino et al. [14] prepared a cassava starch/peel composite film. Using glycerol as a plasticizer, the percentage of cassava peels varies between 0.5 and 1.5%. The addition of cassava peels improved the properties of the composites. Using starch as a matrix, and cassava peels as fillers Edhirej et al. [15] obtained a biodegradable composite. The addition of cassava peels results in increased thickness, water content, and water absorption of the films, while density and water solubility decreases. At 6% cassava peels weight, the tensile stress and elastic modulus increased to 9.62MPa and 449.74, respectively. DMA test confirmed the increase in tensile strength and modulus.

The performance of gelatinized starch plasticized with glycerol using low-density polyethylene (LDPE) as matrix has been reported by St. Pierre, et al. [16]. The result shows that morphological control can be achieved with respect to the size and shape of the dispersed filler. Elongation at the break did not follow a pattern in failure. At 8% starch filler, it is 345% as against 321% for pure LDPE and dropped to 244% at 22% filler. The modulus decreased from 152MPa for neat LDPE to 109 at 22% filler. The yield stress follows the same pattern as the modulus while yield strain increases as filler increases. The effect of various concentrations of plasticizers on the mechanical properties of corn-starch based films has been reported [17]. Irrespective of plasticizer, the tensile stress and Young's modulus of plasticized films decreased as the plasticizer concentrations increased. In summary, the concentrations and type of plasticizers significantly affect the properties and performance of the corn-starch based film.

There is little research in literature relating to the characterization of bio-composites using cassava peel as filler. However, there is no information for the preparation and characterization of HDPE/cassava peels composite. Most authors report LDPE/starch; therefore, the main objective of this study is to investigate the effect of cassava peels on the mechanical properties of its composite. Using HDPE as the matrix, six model equations will be used to predict the tensile strength and elastic modulus of the composite.

Theoretical modelling of Mechanical Properties

There is wide-ranging literature dedicated to the modelling of mechanical properties of polymers reinforced natural or synthetic fibres. The modelling is exceedingly significant and sheds light on the relationship between the composite structure and the properties of the composite. The mechanical properties (tensile and elastic) of polymer reinforced composites can be experimentally determined from a variety of mathematical models. Properties such as Poisson's ratio, elastic modulus, shear modulus, tensile strength, and relative volume fractions of both matrix and fibre are the important input properties needed to predict the mechanical properties of the composite. In some models, aspect ratio and orientation of fibre play a significant rule. A number of theoretical models have been reported to model the tensile strength and Young's modulus of composites. These include Rule of mixture (Parallel or Series) model, Halpin T-sai equation, modified Halpin T-sai equation, Hirsch's model, Einstein and Guth equations, Cox Model and Guth's Equation and Nicolais-Narkis theory. In this research, we will limit ourselves to Rule of mixture (Parallel or Series) model, Halpin T-sai equation, Modified Halpin T-sai equation, Hirsch's Model, Einstein and Guth equations.

Rule of Mixtures Model *(Parallel and Series model)*

The Rule of mixtures model (ROM) comprises of the parallel model and the series model. They are the simplest models used to predict the elastic and tensile properties of a composite material. They can be applied for both particulate and fibrous reinforcement. The iso-strain or parallel model and iso-stress or series model equations gives the maximum and minimum possible values for E_c and T_c. The parallel model (ROMP) assumes iso-strain conditions for both matrix and fibre while series models (ROMS) assume uniform stress in both matrix and fibre. Equations 1 and 2 are the Rule of mixture for modulus and tensile strength [1-3]. The rule of mixture assumes that the aspect ratio ξ approaches infinity or zero.

Parallel model

$$E_c = E_f V_f + E_p V_p \quad 1$$

$$T_c = T_f V_f + T_p V_p \quad 2$$

Series model

$$E_c = \frac{E_m E_f}{E_m V_f + E_f V_m} \quad 3$$

$$T_c = \frac{T_m T_f}{T_m V_f + T_f V_m} \quad 4$$

Where E_m, E_C and E_f are the elastic moduli of matrix, composite, and filler, respectively. V_f the volume fraction of filler, and V_p is the volume fraction of polymer matrix. T_c, T_f and T_p, are the Tensile strength of composite, filler and polymer matrix, respectively.

Halpin-Tsai (H-T) Model

A semi-empirical equation to predict the elastic properties of short fibres reinforced polymer matrix was developed by Halpin and Tsai [18]. The H-T models' assumed that the particle is isolated, the matrix is isotropic, viscosity is constant, filler well dispersed, has uniform shape and dimension, and is firmly adhered to the matrix [19]. The volume fraction of the filler and its orientation are accounted by using the aspect ratio, $\xi = 2l/D$ where l is the length of the fibre and D the diameter or thickness of the fibre depending on the shape. The Halpin and Tsai equations are given in equations 5-8.

$$E_c = E_m \left\{\frac{1+\xi\eta V_f}{1-\eta V_f}\right\} \quad 5$$

$$T_c = T_m \left\{\frac{1+\xi\eta V_f}{1-\eta V_f}\right\} \quad 6$$

$$\eta = \frac{E_f/E_m - 1}{E_f/E_m - \xi} \quad 7$$

$$\eta = \frac{T_f/T_m - 1}{T_f/T_m - \xi} \quad 8$$

Where
E_c = composites' modulus
E_m = the matrix modulus
T_c = composites' Strength
T_m = the matrix Strength
ξ = the shape factor which relates with the filler aspect ratio
V_f = the volume fraction of the filler

Modified Halpin-Tsai equation

The modified Halpin-Tsai equation takes into consideration the maximum packing fraction (ϕ_{max}) of the reinforcement [20]. ϕ_{max}, the maximum packing fraction has a value of 0.785 for a square arrangement of fibre, 0.907 for a hexagonal array of fibres and 0.82 for random packing of fibre [3]. The modified Halpin-Tsai equations are shown below:

$$E_c = E_m \left\{\frac{1+\xi\eta V_f}{1-\eta\psi V_f}\right\} \qquad 9$$

$$T_c = T_m \left\{\frac{1+\xi\eta V_f}{1-\eta\psi V_f}\right\} \qquad 10$$

$$\psi = 1+\left\{\frac{1-\phi_{max}}{\phi_{max}^2}\right\} V_f \qquad 11$$

Nicolais-Narkis Theory and Guth's Equation

The modulus and yield strength of particle filled composites can be predicted by Guth's equation [21] and Nicolais-Narkis theory [21, 22].

$$E_c = E_m\,(1 + 2.5\,V_f + 14.1 V_f{}^2) \qquad 12$$

$$\sigma_{yc} = \sigma_{ym}\,(1 - 1.21\,V_f{}^{2/3}) \qquad 13$$

Guth's Equation is further related to the tensile strength [3], as presented in equation 14.

$$T_c = T_m\,(1 - V_f{}^{2/3}) \qquad 14$$

Where, E, T, and σ_y are Young's modulus, tensile strength, and yield strength respectively; subscripts *m*, *f*, and *c* denote matrix, filler, and composite, V_f is the volume fraction of filler.

Hirch's Model

Hirsch's model is a combination of series and parallel models. Hirsch's model is applicable to particulate and fibrous reinforcements. The Young's modulus and tensile strength can be calculated using the following equations [3,23].
Series model

$$E_c = \chi(E_f V_f + E_p) + (1-\chi)\,V_p\,\frac{E_m E_f}{E_m V_f + E_f V_m} \qquad 15$$

$$T_c = \chi(T_f V_f + T_p) + (1-\chi)\,V_p\,\frac{T_m T_f}{T_m V_f + T_f V_m} \qquad 16$$

where χ is the stress transfer parameter. X is 0.1 for randomly oriented fibres composite.

2. MATERIAL & METHODS

Materials

The following are the major materials used; High-density polyethylene (HDPE), Cassava peel, Weighing device, Magnetic stirrer, Hot and Stirrer Device, Laboratory Oven, Injection moulding machine, Instron Universal Testing Machine (Zwick Roell model Z005), Micrometre screw gauge, dumbbell cutter. The high-density polyethylene used in this research was obtained from Petrochemical store Calabar Nigeria. The melt flow index (MFI) and the density of the polymer are 2.2 g/10 min and 0.97 g/cm^3, respectively. The cassava peels were washed thoroughly with distilled water to remove dust and impurities, then sun-dried, and dried in an oven at 200^0 C for four hours. It was later crushed to a fine powder and sieved to 750μm size.

Preparation of Composite

Cassava roots obtained from the local market were first washed thoroughly and then peeled to remove the edible part. The cassava peels were washed thoroughly with distilled water to remove dust and impurities, then sun-dried, and dried in an oven at 150 °C for four hours to reduce the moisture content. Chemical activation of sieved cassava peels was performed by mixing the dried cassava peels with 10% KOH solution at an impregnation ratio of 5:2 (mass KOH: mass cassava peels) and stirring at 150 °C for 2 hrs. The obtained slurry was dried in an oven for at least 24 hrs at 200 °C. It was later crushed to a fine powder and sieved to 750 μm. 400, 388, 376, 364 and 352g of high-density polyethylene was measured and put in beakers. 600 ml of water was added to each beaker and then placed on the hot plate (with the magnetic stirrer inside the beaker) and stirrer at 150 °C to dissolve the matrix and obtain a homogeneous mixture. 100 % High-Density Polyethylene sample, which serve as a control measure and, HDPE blended with cassava peels powder (CaPP) at different filler contents were mixed. The blends of HDPE and cassava peel powder composites were prepared by thoroughly mixing various weight of HDPE (400, 388, 376, 364 and 352 g) with the filler quantities of 12, 24, 36, and 48 g respectively. The high-density polyethylene and filler were homogenised in an injection moulding machine. The resultant composites were then extruded as sheets of dimensions approximately 4.5 x 20.2 x 300 mm. Table I shows the compositions of the bio-composites prepared.

Table I: Composition of HDPE Composites with CP

S/No.	Formulation	HDPE content wt. %	Filler content wt. %
1	HDPE	100	0
2	CaPP3	97	3
3	CaPP6	94	6
4	CaPP9	91	9
5	CaPP12	88	12

Characterisations of Composite

Scanning Electron Microscopy Analysis

The fracture surface of HDPE-CaPP composites was examined by scanning electron microscopy (SEM) to investigate the cause and mechanism of fracture. An EVO 60 scanning electron microscope was used to study fracture surfaces. Using a low-vacuum sputtering machine, samples were coated with gold mounted on a silver-paint holder before insertion into the SEM chamber. SEM imaging was employed using an accelerating voltage of 5kV. To prepare specimens for SEM, fracture surfaces were first flushed with distilled water to remove any debris.

Mechanical Analysis

Mechanical properties were appraised using Instron Universal Testing Machine (Zwick Roell model Z005), fitted with a 10KN load Cell. The tensile test was performed at a crosshead speed of 50 mm/min. Prior to the test, the samples were conditioned at 25±1°C, 50±5 % relative humidity for 48 hours. A micrometre screw gauge was used to measure the thickness. Measurements were taken from four different positions, and an average value was used. Between 4 and 5 specimens were tested for each filler gauge. The mechanical properties were measured according to ASTM D-638. The dimensions of the specimen were as follows; Specimen length

(Lo) = 300 mm, Specimen thickness (a)≈ 4.5 mm, Specimen width (b)≈ 20.2 mm, Cross-section area (Ao) ≈ 90.9 mm^2. The specimens were stretched in the testing machine. Equations 17 and 18 are used to calculate the stress (σ) and strain (%), respectively.

$$\sigma = \frac{F\,(N)}{A(\,m^2)} \quad 17$$

$$\varepsilon = \frac{\Delta l\ X\ 100}{l} \quad 18$$

where

F= force, A= cross-sectional area, Δl= change in length, l=original length. Six modelling equations; Parallel and Series model of Rule of mixtures, Halpin-Tsai equation, modified Halpin-Tsai, Guth's Equation and Nicolais-Narkis Theory and Hirch's Model were used to predict the elastic and tensile properties of the composite material.

3. RESULTS AND DISCUSSION

Mechanical Properties

The averaged stress-strain for pure HDPE and HDPE/CaPP are presented in Fig. 1. It can be seen that the addition of cassava peels particles changes the characteristics curves and mechanical behaviour of the composites. Pure HDPE, under tensile conditions, deform with the formation of a collar or neck. The width of the neck gradually increases and tends to collapse as the CaPP increases. Fig. 2 shows the mechanical properties of HDPE, and its composites at different filler loading. It should be noted that all attempt to produce films from cassava peels particles failed. From the figure, the yield strength of pure HDPE is 22.15 MPa, and this value increases to 24.05 MPa at 6% wt., and decreases to 22.02 MPa at 12% wt. of CaPP. The final percentage increment is 8.58%. HDPE elongation at yield is 22.98% while at break is 54.81%. Addition of CaPP decreases elongation both at yield point, and at break to 7.19 and 12.78% respectively at 12% loading. The maximum percentage decrease is 68.71 % for elongation at yield point and 76.68 % at break. In synthetic polymer composites, the addition of an immiscible phase to a ductile matrix material normally significantly reduces the elongation at break [16]. The decrease, in elongation at break is an indication that the synthetic polymer blends with a ductile matrix is extremely sensitive to the state of the interface between the matrix and the immiscible filler. Tensile strength at break decreases as CaPP increases. For pure HDPE the tensile strength at break is 19.50 MPa, this value dropped to 17.53 MPa at 12 % wt. The decrease in tensile strength with increase in filler contents may be attributed to the likely heterogeneous dispersion of cassava peels particles within the HDPE matrix and the resulting incompatibility of cassava peel particles and HDPE. This heterogeneous dispersion of cassava particles could enhance structural defects leading to lower mechanical behaviour [24].

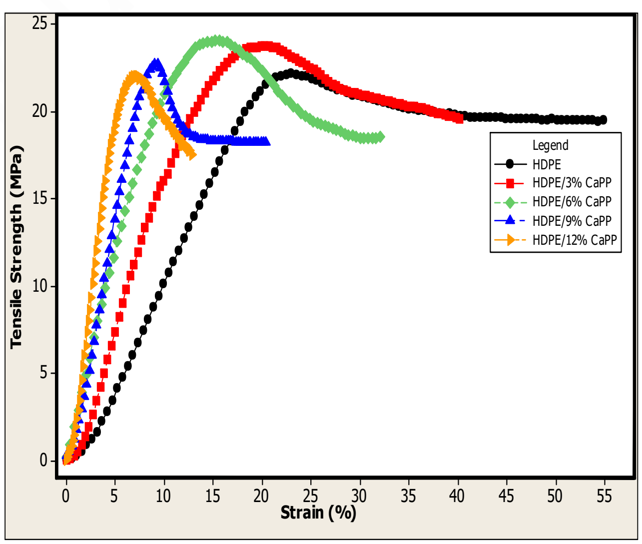


Figure 1: Stress-strain curves of HDPE reinforced cassava peels powder

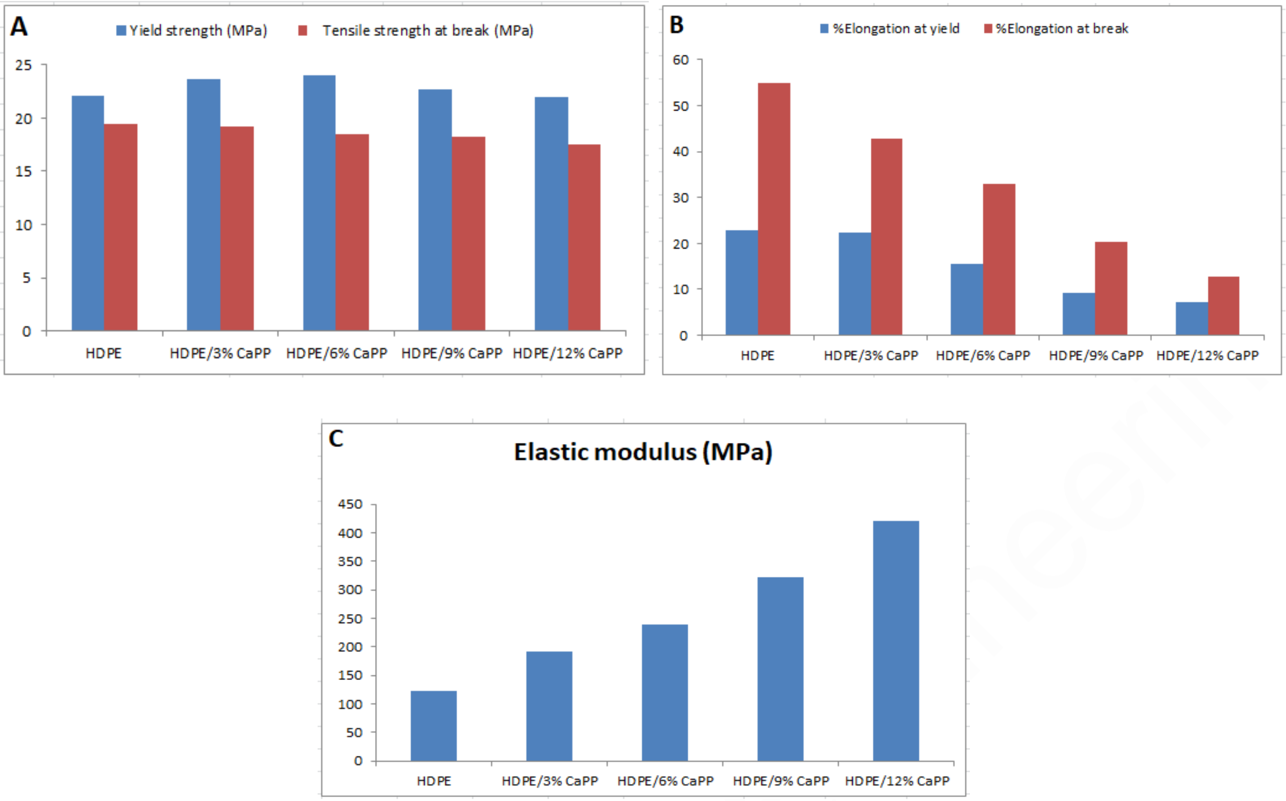


Figure 2: Mechanical properties of HDPE reinforced cassava peels powder

Different results have been reported by different authors depending on the filler used. In their report, Rozman et al. [25] observed decreasing tensile stress at higher filler loading when oil palm fruit bunch was used as reinforcement with polypropylene composite. The same trend was reported for the elongation at break. Thakore et al. [26] reported decreasing elongation at break as starch particles increase when using low-density polyethylene as matrix. In synthetic polymer blends, the addition of the immiscible component to a ductile matrix generally decreases the elongation properties of the blends considerably at the breakpoint. Contrary to the report of Thakore et a.l and Rozman et al., Kusuktham and Teeranachaideekul [27], reported a divergent result for the tensile strength at different loading of HDPE/modified calcium silicate composites subject to a maximum of 8%wt. calcium silicate. St-Pierre et al. [16] did not observe any improvement on the tensile behaviour when LDPE/starch blends were investigated. The result of Rozman et al. and Thakore et al. is in line with the data obtained in this research. Starch-polymer interaction can be increased by reducing the hydrophilic nature of starch, leading to improved or higher tensile strength [26]. The decrease in tensile strength as CaPP increases could be attributed to the high hydrophilic nature of starch. Chemical treatment of 10% KOH solution at an impregnation ratio of 5:2 (mass KOH: mass cassava peels) was not enough to reduce the high hydrophilic nature of starch.

The Young modulus of the composites increases from 122.22 MPa to 419.78 MPa a percentage increase of 243.46 %, and this could be attributed to the brittleness of cassava peels. Khalaf [28] and Dan-asabe [4] reported an increase in Young modulus with an increase in weight fraction. The mechanical behaviour of thermoplastic starch based biopolymers is strongly determined by numerous factors, such as ambient conditions (temperature and humidity), the botanical source of starch (that is amylose/amylopectin ratio), the processing technique as well as concentration and type of plasticiser [29, 8]. Particles size can also affect the mechanical properties of the composite [15, 30-31]. The cassava peel with two different particles sizes (P1 < 300 μm and 300 μm < P2 <600 μm) were used as fibre at different loadings of 3, 6, and 9% of dry starch [15]. Irrespective of loading P1 < 300 μm performs better than 300 μm < P2 <600 μm. Powdered carbonised cassava cortex with different microns (150μm, 300μm, and 600 μm) were reinforced with polyester resin [31], the tensile and elastic modulus of 150μm were reported to be the best of the three. Tables 2 and 3 are the properties of HDPE and cassava starch.

Table 2. Physical and mechanical properties of high-density polyethylene (HDPE)

Density (g/cm^3)	Tensile strength at break (MPa)	Elongation at break (%)	Modulus of elasticity (MPa)
0.951±0.0055	19.5±2.3	54.55±4.2	122.22±6.2

Table 3. Mechanical properties of Cassava starch

Density (g/cm^3)	Tensile strength at break (MPa)	Elongation at break (%)	Modulus of elasticity (MPa)
2.43	5.6	35.41	196

Modelling of Mechanical properties

Composites containing 750 μm particles size of cassava peels were examined in this study. Fig. 3 shows a comparison of the difference in theoretical and experimental tensile strength values of cassava peels composites. Theoretical values were calculated using six different models, as shown in the figure. It can be observed that, in all cases, tensile strength decreases with an increase in the volume fraction of CaPP. The best correlation between the theoretical and experimental observed tensile strength is seen in the model predicted using Halpin-Tsai, followed by the Hirsch equation, Parallel and modified Halpin-Tsai model. Guth and Series models agree the least with the experimental values. Typically, Series and Parallel models are used to describe the strength of both particulate and fibrous reinforced composites [3]. Parallel and Series model equations gives the maximum and minimum possible values for tensile strength and the modulus. One of the assumptions of Series model is uniform stress and uniform strain for Parallel model. It is well known that the stress transfer mechanism for continuous fibre reinforced composite is not the same as that of short or particulate composite. A short fibre composite mainly depends on the stress concentration at the ends of the fibre, critical length fibre and orientation of fibre, among others. From Fig. 3 irrespective of the volume fraction, Parallel and MH-T models show marginal agreement with experimental values, an indication that uniform strain or stress has been achieved in the composite. This is not the case for Series model, at a volume fraction of 0.068 the difference is 4.85 % as against 2.14% for 0.016 volume fraction. At higher volume fraction of CaPP (0.068) some of the particulates will be agglomerated in the matrix, hence the uneven distribution of load between aggregated and non-aggregated particulates.

Hirsch model is another equation that combined the Series and Parallel models, with the inclusion of a parameter χ. Like Series and Parallel models, the Hirsch model is compatible with particulate and fibrous reinforcements. The theoretical and experimental values can only have a marginal agreement at all volume fractions when the value of χ in equation 15 is 0.9. Bearing in mind the assumption made for Series and Parallel models which are applicable here, it will be right to conclude that at χ= 0.9 uniform stress and strain have been achieved, that is χ is a parameter which defines the level of stress transfer between matrix and fibre. For a short fibre, the governing indices for the value of χ are fibre orientation, fibre length and stress concentration at the ends of fibre [3]. The lower the amount of χ the higher stress concentration at the fibre ends. Stress concentrations at the end of the fibre are influenced by chemical modification carried out prior to composite formation.

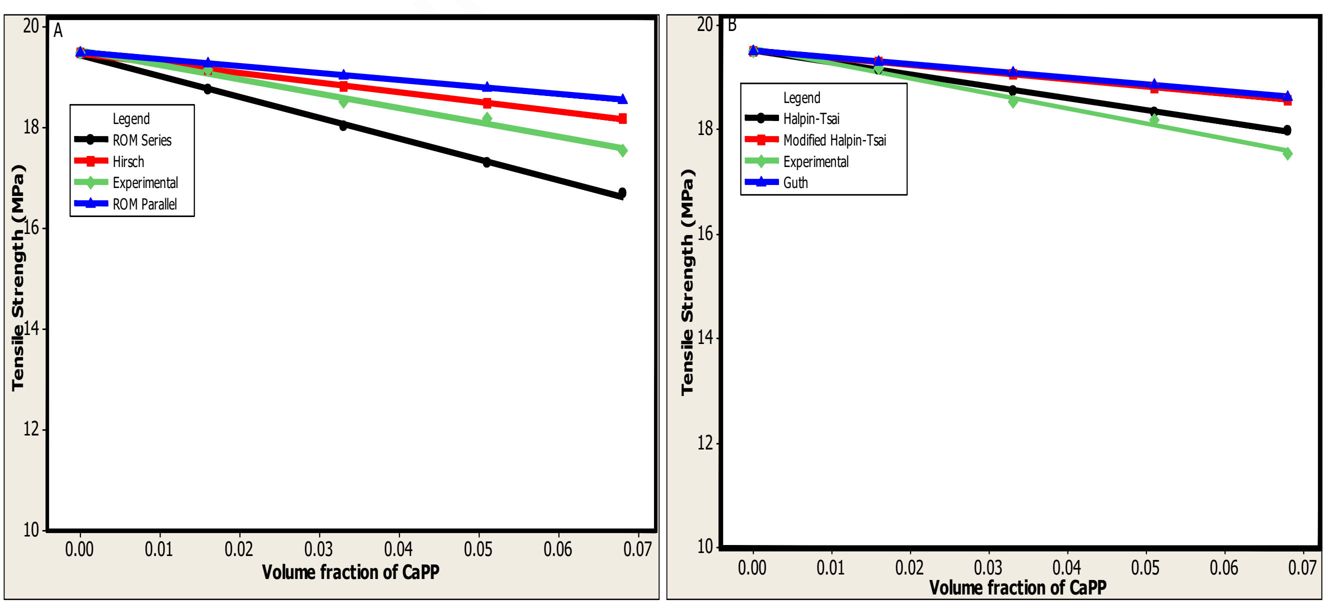


Figure 3. Tensile strength of CaPP-HDPE composite modelled by Parallel, Series, Hirsch, Halpin-Tsai, modified Halpin-Tsai and Guth

The curves showing the tensile strength values for Halpin-Tsai and the modified Halpin-Tsai equations are shown in Fig. 3. It can be seen that in both cases, tensile strength values are not the same. It has been reported that Halpin-Tsai is useful in predicting the properties of composites that contain discontinuous fibres [3]. The Halpin-Tsai equation is the best correlation equation to predict the tensile strength, while modified Halpin-Tsai equation made a marginal agreement. Irrespective of the volume fraction the percentage deviation from the experimental value is less than 1% compared to 5.8 % at 0.068 volume fraction for modified Halpin-Tsai equation. The differences in value are an indication that the introduction of a factor which determines the maximum packing fraction of fibres has an effect on tensile strength of particulate fibres. In the same figure, three curves showing the tensile strength values for Guth equation is presented. Guth equation is used for particulate reinforced polymer composites. Quite clearly, the predicted tensile strength values are larger than the experimental values. At 0.016 volume fraction the percentage deviation from experimental value is 0.63, this value rose to 6.21% at 0.068 volume fractions.

Fig. 4 shows a comparison of the difference in theoretical and experimental elastic modulus values of cassava peels composites. From the figure it is seen that none of the six model equations could give a correlation between theoretical and experimental values. Contrary to the tensile modelling, the Guth model made an attempt. The difference in percentage between model equations and experimental values is 64.04% for Guth model and 70.27% for MH-T model. The constraint of the models used here mainly depends on different factors among which is micro-voids between fibre and matrix during composites formation; this factor is not taken care of in the cause of the model formulation.

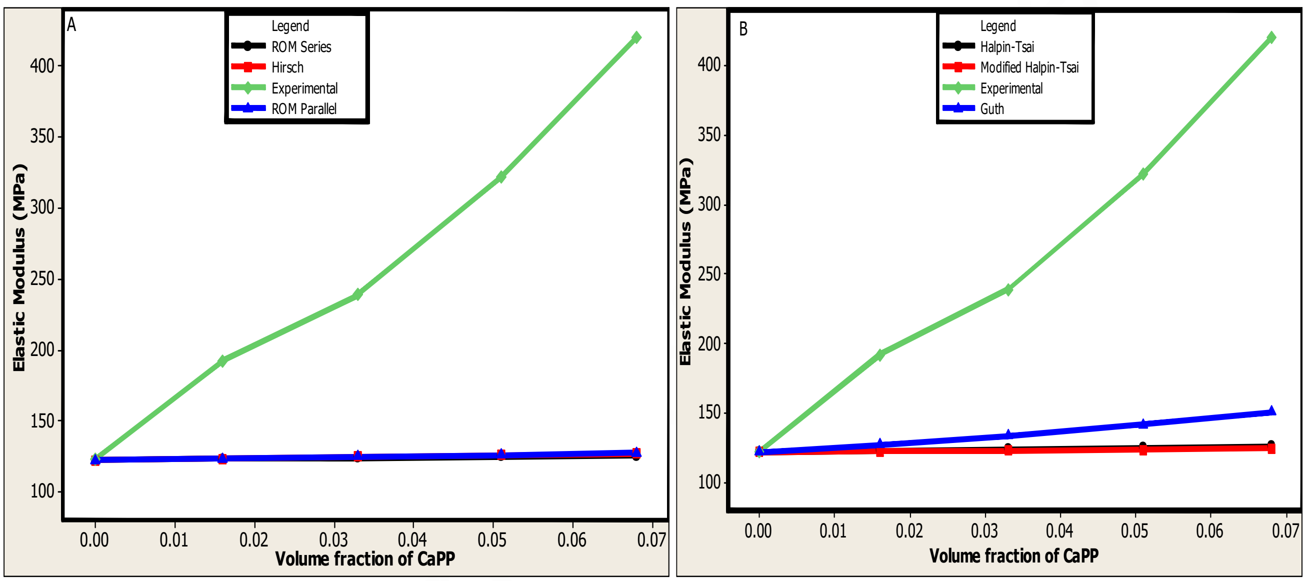
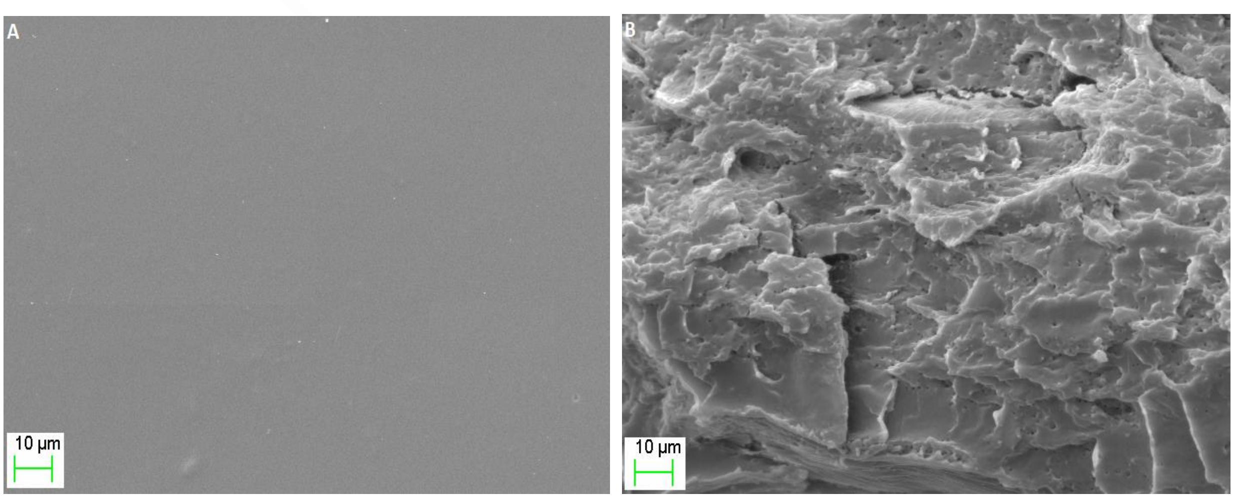


Figure 4. Elastic modulus of HDPE-CaPP composite modelled by Parallel, Series, Hirsch, Halpin-Tsai, modified Halpin-Tsai and Guth

Morphology



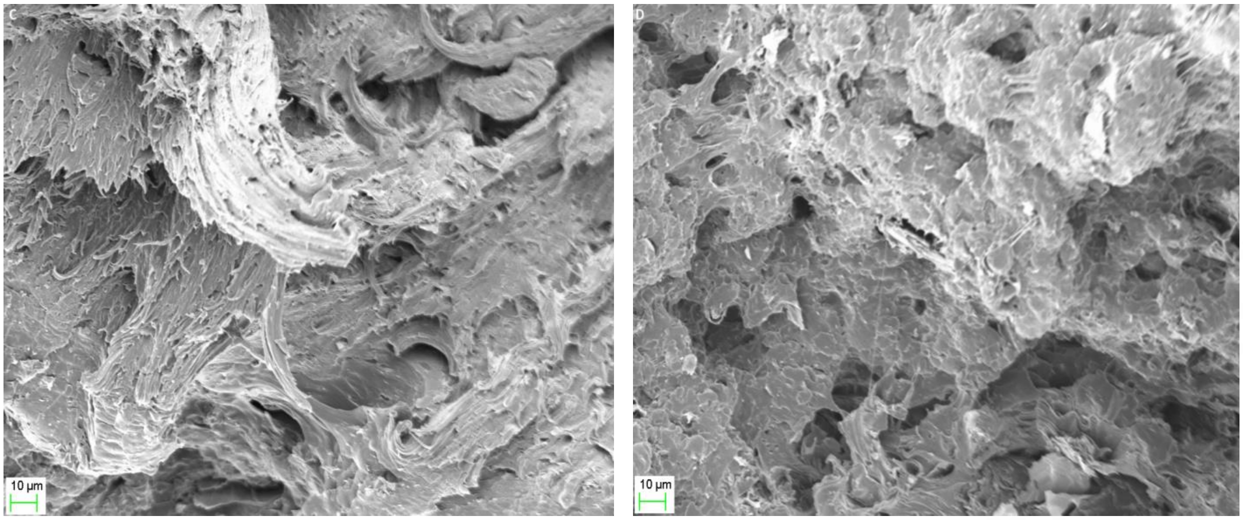


Figure 5. SEM images of cassava peels powder/HDPE composite film

The SEM images are shown in Fig. 5. It can be observed that pure HDPE film presents a smooth surface without pores with a compact structure. Fractured surface of HDPE is rough but looks ductile in nature with few voids. The fracture surfaces become gradually more irregular as the CaPP content increases. The sample with 12 % CaPP showed a less dense structure. Traces of agglomeration of CaPP could be seen at higher loading (Fig. 5D) suggesting that CaPP granules was not thoroughly disordered. It has been reported by Luduena et al. [32], that agglomeration does not allow the correct matrix–filler interaction, resulting in poor mechanical behaviour due to weaker polymer–filler interfacial adhesion. The fractured surface of 9 and 12% weight composites has trivial pores or voids spread throughout the matrix (Fig. 5 C & D). The voids cannot be associated with CaPP granules due to their irregular shape. The pores can be attributed to the formation of water or steam during moulding.

4. CONCLUSION

The tensile test results of powdered cassava peels and HDPE-based showed that the strain and stress at break and yield decreased with powdered cassava peels contents while the elastic modulus increases with CaPP content. The addition of 3 to 12% cassava peels increases the elastic modulus from 122.22 MPa for pure HDPE to 419 MPa at 12% CaPP content. The tensile strength decreases from 19.5MPa for pure HDPE to 17.53 MPa for 12% content. Addition of CaPP decreases elongation both at yield point and at break to 7.19 and 12.78% respectively at 12% loading. The maximum percentage decrease is 68.71 % for elongation at yield point and 76.68 % at break. Six model equations were used to predict the mechanical properties of the composite. From the six equations used, the best correlation between the theoretical and experimental tensile strength was seen in the model predicted using Halpin-Tsai, followed by the Hirsch equation, Parallel and modified Halpin-Tsai model. The Guth and Series models agree the least with the experimental values. None of the six equations could correctly predict the elastic modulus of the composite when compared with the modulus obtained experimentally, with Guth equation been the closest. The decrease in tensile strength is attributed to the high hydrophilic nature of cassava peels.

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Conflict of Interest:
The author declares that there are no conflicts of interests.

Peer-review:
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Data and materials availability:
All data associated with this study are present in the paper.

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