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Modeling the Effect of Gauge Length on the Mechanical Properties of Chitin Whiskers Reinforced Composites

M.I. Ofem[1, *], P.A Ubi[2] , A. Christian[2]

[1]*Department of Mechanical Engineering, Cross River University of Technology, Calabar, NIGERIA*
[2]*Department of Mechanical Engineering, University of Calabar, Calabar, NIGERIA*
[3]*Department of Mechanical Engineering, Federal University Otuoke, Bayelsa State Nigeria, NIGERIA*

Abstract
Mechanical properties (tensile strength and modulus) of Chitin Whiskers fibre-reinforced poly(acrylic acid) with different fibre loading and different gauge lengths are compared with theories of reinforcement. The addition of random oriented Chitin Whiskers to poly(acrylic acid) matrix increased in tensile strength and elastic modulus of the composite. There was a steady increase in tensile stress and Elastic modulus within the volume fraction range investigated. The properties of the composite at different gauge lengths were studied. Within the same volume fraction, the tensile stress decreases as the gauge length increases. It is the reverse for the Elastic Modulus. Irrespective of filler loading and the theoretical modelling equations the tensile stress can be predicted at 40 mm gauge length. For the Elastic Modulus, the prediction of the property varies within the gauge lengths investigated. At higher filler loading, a smaller gauge length is required to predict the Elastic modulus. The comparative study between the tensile stresses obtained by experiment and selected theoretical models showed that the Parallel and Series models of the Rule of Mixture produced more accurate prediction, followed by Halpin-Tsai and modified Halpin-Tsai models. Guth's model was the least as the percentage deviation from the experimental data was very high when predicting the Elastic modulus. The density of the nanocomposite films were 1.08g/cm^3, 1.023, and 1.024g/cm^3 respectively, for 3%, 6%, and 9% weight filler and were in agreement with the theoretical data.

Keywords: Elastic modulus, tensile stress, volume fraction, gauge length, model equations.

1.0 INTRODUCTION

Diverse approaches have been engaged for the preparation of chitin whiskers (CHWs) based nanocomposites. These include polymer grafting [1], evaporating, and casting [2, 3] and hot-pressing and freeze-drying [4, 5]. When selecting the technique, the properties of matrix and CHWs, in addition to the end anticipated properties of the composite, should play a vital role. Starch gels from potato, sweet potato, kudzu, corn, etc. are used to form composites with collagen and chitin as fillers [6]. An increase of between 90-120% (for wheat, sweet potato, and potato) gel hardness and between 150-300% for corn as starch concentration increases was reported. The increase in gel hardness was attributed to the nature of the gel matrix, filler particle size, starch retrogression rate, and swelling nature of the particle, among others.

Properties of β-chitin/poly(vinyl alcohol) films at different fractions were investigated [7]. The tensile strength was found to decrease from 5.1 to 0.7 MPa with a decrease in β-chitin content, compared to pure PVA or β-chitin. The percentage elongation at break increased from 2.9 to 165.2 % as the β-chitin content decreased. Feng *et al.,* [7] reported an increase in tensile strength while Young's modulus decreases as the PCL content increased when chitin whisker-graft-polycaprolactone composite at different mixtures of caprolactone monomer and chitin were investigated.

The effect of chemical modification of chitin whiskers using three different reagents; alkenyl succinic anhydride (ASA), 3-isopropenyl-,α,α'-dimethylbenzyl isocyanate (TMI), and phenyl isocyanate(PI) has been reported [8]. The chemical variation resulted in a decrease in mechanical properties. The decrease was attributed to the partial or total destruction of the three-dimensional network of CHWs assumed to be present in the unmodified composites.

Research into polymer-matrix composites with natural fibres has been on the increase, recently. The focus is attributed to improved mechanical properties, low cost

***Corresponding author (**Tel:** +234 (0) 8185585383)
Email addresses: michaeliofem@crutech.edu.ng (M. I. Ofem), paschalubi@unical.edu.ng (P.A Ubi), manfredrayner456@gmail.com (A. Christian)

low density and significant processing advantages. The mechanical properties of fibre reinforced composites can be affected by the fibre length, fibre orientation, geometry of fibre, fibre dispersion within the matrix, and the degree of the interfacial bond between fibre and matrix. The efficacy of load transfer from matrix to fibre in a composite is strongly linked to the mechanical properties of the composite.

There is a wide range of literature dedicated to modelling of mechanical properties of polymers reinforced synthetic or natural fibres. The modelling is remarkably important and shed light on the bond between the composite organization and the properties of the composite. The tensile and elastic properties of polymer reinforced composites can be determined theoretically from a variety of mathematical models. The important input needed to determine these properties are the elastic modulus, tensile strength, Poisson’s ratio shear modulus and volume fractions of both matrix and fibre.

A number of theoretical models to predict these properties have been reported. These include the parallel and series model [9-11], Halpin-Tsai equation [12], Modified Halpin-Tsai equation [13], Nicolais-Narkis theory [14, 15]. Guth's Equation [14], Cox Model [16], and Hirsch’s Model [17]. The main objective of this study was to compare the experimental tensile and elastic modulus properties of chitin whiskers reinforced poly (acrylic acid) with theoretical values, using five different theoretical models at various volume fractions. It has been reported by researchers that some of the models show a good agreement with experimental data. The second objective is to determine the gauge length and volume fraction at which any of the models can predict the properties.

2.0 THEORETICAL MODELLING

There is a wide range in literature dedicated to 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 organization and the properties of the composite. The tensile strength and elastic modulus of polymer reinforced composites can be experimentally determined from a variety of mathematical models. Properties such as elastic modulus, Poisson’s ratio, 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 mixtures (Parallel and series models), Halpin-Tsai equation, Modified Halpin-Tsai equation, Hirsch’s Model, Cox Model, Guth's Equation, and Nicolais-Narkis theory.

2.1 Rule of Mixtures Model (Parallel and Series model)

The Rule of Mixtures Model (ROM), sometimes called a parallel model is the simplest model used to predict the elastic modulus and tensile properties of composite material. To calculate the elastic modulus of a composite, in one direction it is assumed that both the matrix and fibre experience the same strain due to uniform stress application over a uniform cross-sectional area. Equations 1 and 2 are the rule of mixture for modulus and tensile strength [9-11] for Parallel model and equation 3 and 4 for the Series model.

$$E_c = E_f V_f + E_m V_m \quad (1)$$

$$T_c = T_f V_f + T_m V_m \quad (2)$$

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

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

Where E_c, E_f, and E_m are the elastic modulus of composite, filler, and polymer matrix respectively, while T_c, T_f, and T_m are the tensile strength of composite, filler and polymer mat . V_f and V_m are the volume fraction of filler and polymer matrix respectively. The iso-strain or parallel model and iso-stress or series model equations from the rule-of-mixtures give the maximum and minimum possible value for E_c and T_c. For the parallel model, it is assumed that iso-strain conditions exist for both fibre and matrix, while stress is assumed to be uniform in both matrix and fibre [10]. These equations represent the case where ξ (aspect ratio) approaches infinity or zero, respectively.

2.2 Halpin-Tsai (H-T) Model

Halpin and Tsai developed a semi-empirical equation to predict the elastic properties of short fibres reinforced polymer matrix [12]. The H-T models’ assumed that the particle is isolated, the matrix is isotropic, viscosity is constant, the filler is well dispersed, has uniform shape and dimension, and is firmly adhered to the matrix [18]. In this model, the volume fraction of the filler and its orientation are accounted for by using the aspect ratio, $\xi = 2l/D$, or $2l/T$ where l is the length of the fibre and D or T the diameter or thickness of the fibre depending on the shape. The following forms of the Halpin and Tsai equation are used to predict the modulus and tensile strength of short fibres reinforced polymer matrix.

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

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

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

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

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

2.3 Modified Halpin-Tsai equation

The modified Halpin-Tsai equation takes into consideration the maximum packing fraction (ϕ_{max}) of the reinforcement [13]. ϕ_{max}, 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 [10]. The modified Halpin-Tsai equation is shown below.

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

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

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

ψ, depends on the parting fraction as seen in equation 11 while others are as defined in section 2.2

2.4 Guth's Equation and Nicolais-Narkis Theory

The modulus and yield strength of particle-filled composites can be predicted by Guth's equation [14] and Nicolais-Narkis theory [14, 15] respectively

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

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

Guth's Equation is further related to the tensile strength [10], as presented in equation 14.

$$T_c = T_m\left(1 - V_f^{\frac{2}{3}}\right) \quad (14)$$

Where, E, T, and σy 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.

3.0 EXPERIMENTAL PROCEDURE

Chitin Shrimp, poly(acrylic acid), and all chemicals were purchased from Sigma-Aldrich. Preparation of chitin whiskers, chitin film, and chitin whiskers-reinforced poly(acrylic acid) films was carried out as reported in literature[19]. Chitin and 3M HCl were mixed at a ratio of 1:30 g/ml. The mixture was heated for 6h at 120 ℃, diluted with distilled water, followed by centrifugation for 10 min. The process was repeated thrice and then dialyzed in running water for two hours, after which in distilled water overnight for three days while changing the distilled water every day. Drops of HCl acid were added to adjust the pH level to 3. The dispersion of chitin whiskers was completed by sonification for 20 minute. The solid content of the chitin whiskers suspension was approximately 0.3 wt.%.

Chitin was coarsely crushed with a domestic blender and vacuum sieved using porcelain Buchner filter funnel having an approximate pore of 1.4 mm. 0.5wt. % fibre content was made by dispersing sieved chitin in water. Few drops of acetic acid were added to adjust the pH to 3 and magnetically stirred overnight at room temperature. The suspension was vacuum-filtered and hot pressed for up to 60 min at a temperature of between 80 and 90℃ to form chitin film.

1.0 wt.% PAA solution and 0.3 wt.% chitin whiskers suspension were gently mixed in a beaker and magnetically stirred at room temperature for about 3–5 minutes, keeping the pH at 2. The solution is cast in a plastic Petri dish and allowed to dry at a fume hood for 72 h. The films were dried in an oven at a temperature of 30℃

until the film detached itself from the dish. Three variations of chitin weight fraction: 0, 3, 6, and 9 wt. % is used. The weight fraction was converted to volume fraction using equation 14 [20] as shown below, where W_f, W_m, ρ_f, ρ_m *and* V_f are the weight fractions of the fibre and matrix, the density of fibre and matrix and the volume fraction of the fibre respectively. The density of poly(acrylic acid) was given as 1.15g/cm^3 at 25° C by the manufacturer, and the density of chitin is 0.38g/cm^3

$$V_f = \frac{\frac{W_f}{\rho_f}}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}} \qquad (15)$$

3.1 Characterization

Instron 1121 tensile testing machine was used to measure the tensile strength and strain. Films were conditioned at 23 ± 3 °C, 50 ± 5RH for 48 h. The gauge lengths were 10, 20, 30, and 40 mm. Cross speed 2mm/min is used. An average of between six and nine samples was taken for each gauge length.

4.0 RESULTS AND DISCUSSION

4.1 Mechanical Properties

Results of mechanical properties were compared using ANOVA multiple comparison tests ($p < 0.05$). Mechanical properties were measured according to ASTM D882-02 (2002) standard. The CHWs-PAA composite density was measured and calculated based on the Archimedes principle, in accordance with ASTM D1037 standard. The theoretical density of the composites was determined using equation (15), [21]. The density of the nanocomposite films was calculated to be 1.08g/cm^3, 1.023, and 1.024g/cm^3, respectively, for 3%, 6%, and 9% weight filler. These results are in agreement with the theoretical data, which are 1.084, 1.025, and 1.025 g/cm^3 for 3%, 6%, and 9% weight filler, respectively.

$$\rho_c = \frac{1}{\frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}} \qquad (16)$$

Stress-strain curves for pure chitin and PAA for various gauge lengths are presented in figure 1, while the tensile stress and strain at break, the yield/ultimate stress and strain, and modulus are presented in Table 1. Using a gauge length of 10 mm as a reference starting point, the tensile strength of the α-chitin film is 65.24±4.23 MPa. The Elastic modulus is 2.98±0.83 GPa, and the % strain at break is 4.55±0.33 %. The yield stress and yield strain are the same as the stress and strain at break. As the gauge length increases, the stress at break decreases by 9.6%, 19.5%, and 28.1% for 20, 30, and 40 mm gauge length, respectively. In the same vein, the strain at break decreases by 20.9%, 37.4%, and 53.6% for 20, 30, and 40 mm gauge length, respectively, the percentage decrease in strength increases as the gauge length increases. The gradual decrease in tensile strength as gauge decreases is an indication of the presence of strength limiting defects [22]. Some of the limiting defects are voids, cracks, minor cuts, the non-uniform thickness of films due to uneven dispersion and minor cuts at the edges of films [22]

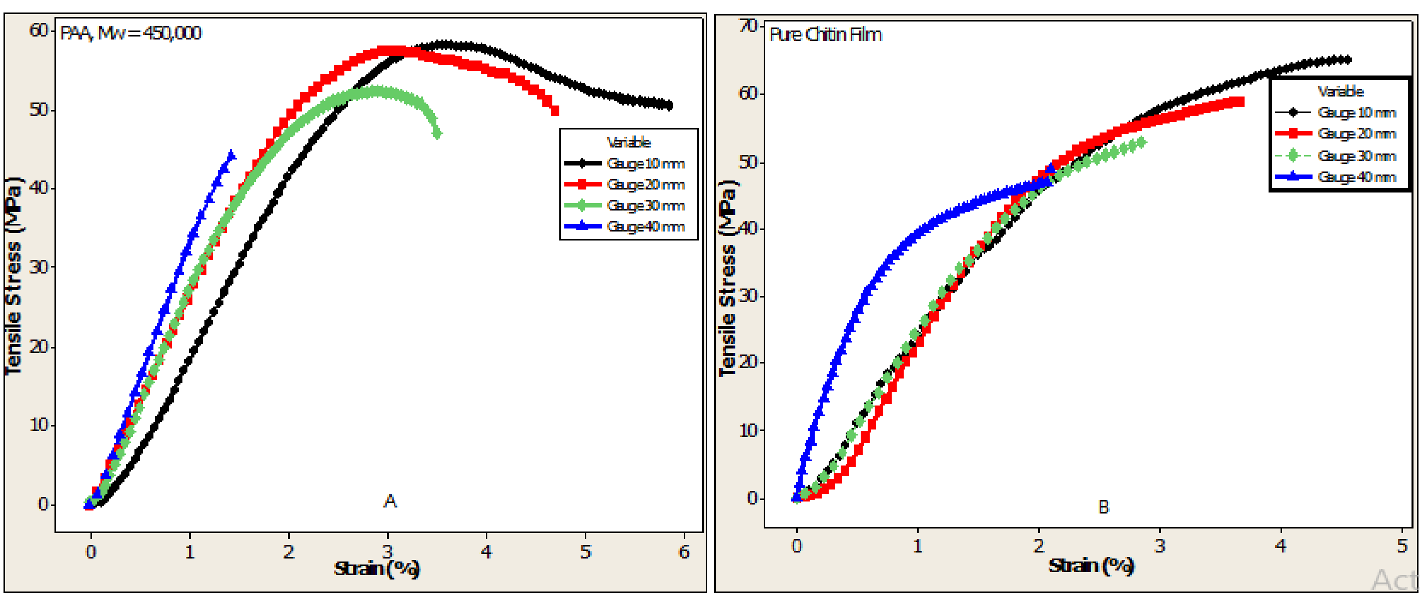


Figure 1: Stress-strain curves for (A) Pure PAA and (B) Pure Chitin at various gauge lengths

Table 1: Mechanical Properties of Pure chitin and PAA Mw =450,000

Mechanical Properties of Pure chitin					
Gauge Length(mm)	Stress at Break (MPa)	Strain at Break (%)	Young Modulus (GPa)	Yield/Ultimate Stress(MPa)	Yield/Ultimate Strain (%)
G10	65.24±4.23	4.55±0.33	2.98±0.83	65.24±4.23	4.55±0.33
G20	58.96±3.42	3.60±0.24	4.21±0.43	58.96±3.42	3.20±0.24
G30	52.61±2.32	2.85±0.42	4.67±0.34	52.61±2.32	2.75±0.42
G40	46.94±1.42	2.11±0.12	4.94±0.21	46.94±1.42	2.11±0.12
Mechanical Properties of Pure PAA, Mw =450,000					
Gauge Length(mm)	Stress at Break (MPa)	Strain at Break (%)	Young Modulus (GPa)	Yield/Ultimate Stress(MPa)	Yield/Ultimate Strain (%)
G10	52.88±2.34	5.85±0.21	2.42±0.12	58.15±3.21	3.61±0.24
G20	49.93±1.44	4.69±0.22	3.19±0.23	57.36±3.14	3.15±0.76
G30	47.13±1.67	3.50±0.24	3.39±0.31	52.27±2.85	2.90±0.23
G40	44.21±1.54	1.43±0.30	3.51±0.22	44.21±1.54	1.43±0.30

The same trend is observed for pure matrix. The percentage decrease as the gauge length increases is 5.6%, 10.9%, and 16.4% for 20, 30, and 40 mm gauge length. The lower percentage value for the matrix indicates that the limiting defects are not numerous and are evenly distributed in the films. Irrespective of the weight fraction, the trend is the same for PAA reinforced CHWs composites, as can be seen in Table 2. For 3% filler weight, the percentage decrease as gauge length increases is 6.3%, 12.1%, and 19.3% for gauge 20, 30, and 40 mm, respectively. The same percentage range was observed for 6% filler weight. For 9% filler weight, the percentage decrease drop by approximately 3% for 20 mm and 4% for 40 mm gauge lengths, respectively. The lower percentage at 9% filler weight indicates better and uniformly distributed strength limiting defects, which could be attributed to, proper dispersion of CHWs within the matrix. For Elastic modulus, there is a gradual increase as the gauge length increases. From 2.98±0.83 GPa at gauge 10mm to 4.94±0.21 GPa at 40 mm gauge length, an increase of 39.7% was obtained. The same trend was observed irrespective of the weight fraction.

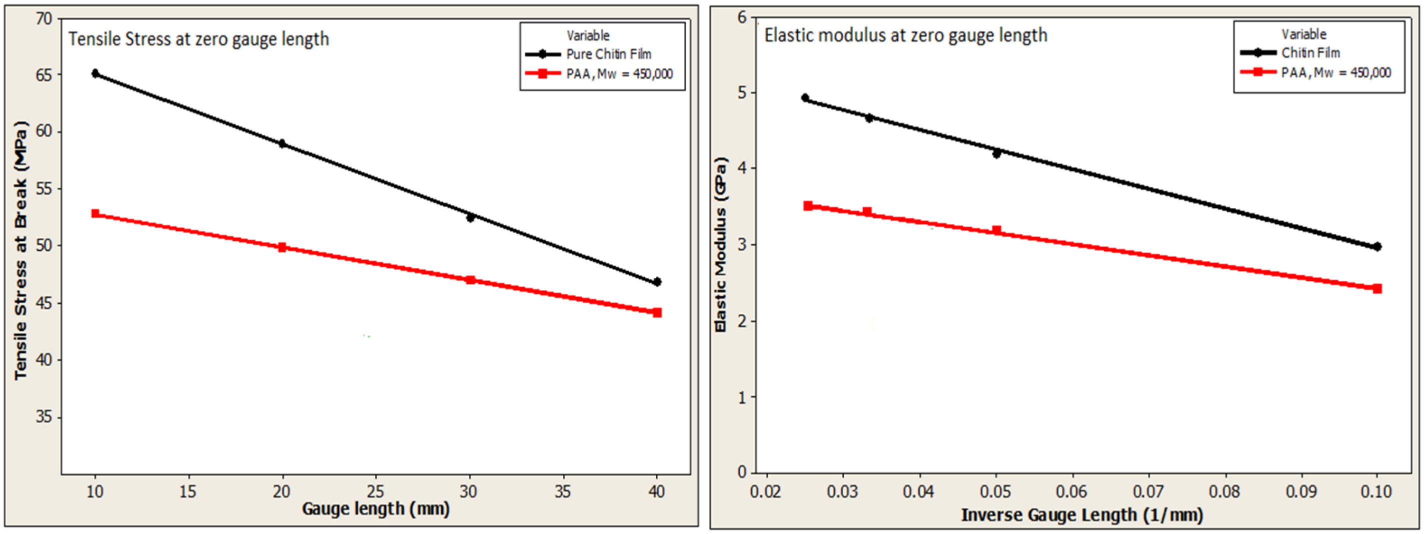
Table 2: Mechanical Properties of PAA (Mw =450,000) reinforced Chitin whiskers

% wt. of CHWs	Gauge length (mm)	Stress at break (MPa)	Strain at Break (%)	Modulus (GPa)
3% wt. chitin	G10	63.45±3.2	4.56±0.65	3.59±0.35
	G20	59.43±3.1	3.51±0.34	3.93±0.42
	G30	55.81±2.2	2.51±0.54	4.16±0.19
	G40	51.21±2.6	1.50±0.31	4.26±0.52
6% wt. chitin	G10	64.89±2.4	3.53±0.21	3.92±0.33
	G20	61.07±3.3	2.83±0.23	4.16±0.33
	G30	55.63±2.3	1.92±0.22	4.37±0.53
	G40	52.28±2.5	1.30±0.23	4.68±0.43
9% wt. chitin	G10	65.68±3.1	3.25±0.22	4.26±0.58
	G20	63.24±2.2	1.92±0.12	4.56±0.51
	G30	57.56±2.4	1.85±0.20	4.73±0.46
	G40	55.54±1.3	1.20±0.09	4.91±0.21

4.2 Modelling of the Mechanical Properties

4.2.1 Tensile Stress Modelling

Figure 2 shows the extrapolated mechanical properties of pure chitin film and PAA at zero gauge length used for the modelling of the composite. The data are presented in Table 3. Theoretical values are calculated using the various models. As shown in figure 3 it is observe that in all cases, the tensile stress increases as the volume fraction of fibre increases. There is a correlation between the experimental and theoretical values. Using a 30 mm gauge length at 0.085 volume fractions as a starting point, the curves showing parallel and series models agree the most with the experimental values while the Guth model tends to be the least. The percentage deviation from the experimental values is 3.06, 3.4, 4.35, 4.34, and 5.29 % for parallel, series, Halpin-Tsai, Modified Halpin-Tsai, and Guth models, respectively. This deviation decreases at 0.16 volume fraction to 0.9, 1.62, 3.34, 3.24 and 5.54 % respectively.



(A) (B)

Figure 2(A and B): Shows the extrapolated mechanical properties of pure chitin film and PAA at zero gauge length using for the modelling of the composite.

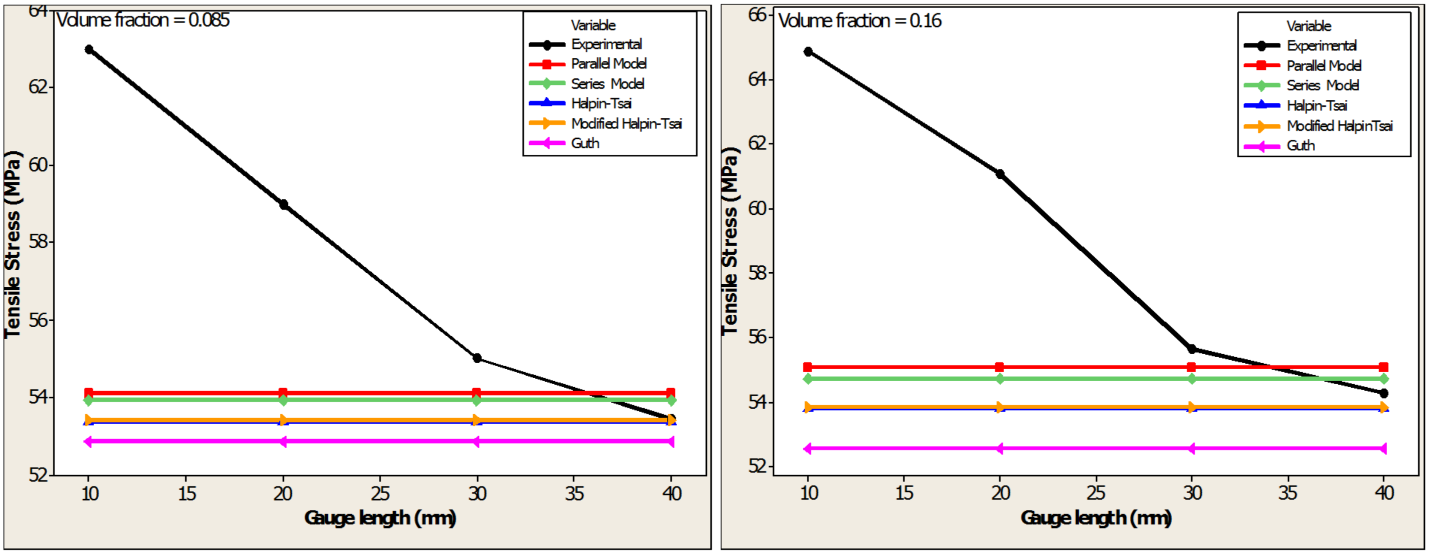
Table 3: Extrapolated Mechanical properties of chitin film, pure PAA, PAA reinforced CHWs at zero gauge length

Sample/ Gauge length	Strength at Zero gauge length (MPa)	Strain at Zero gauge length (%)	Modulus at Zero gauge length (GPa)
Chitin	66.3±3	4.6±0.2	5.21±0.2
Mw = 450,000	47.5±2	6.4±0.3	3.45±0.2

For 0.23 volume fraction, the deviation was within the range of 0.085 volume fraction. Irrespective of the gauge length, the tensile strength increases with an increase in volume fraction. As stated earlier, the curves showing parallel and series models agree the most with the experimental values. Series and Parallel models are used to describe the strength of continuous fibre reinforced composites. The assumption in the model of either uniform strain or uniform stress may have played a role in this case. There is a great difference in the stress transfer mechanism between a short fibre reinforced composites and a continuous fibre composite. In the former case, stress transfer is determined basically on the fibre orientation, critical fibre length, and stress concentration at the end of the fibre. The percentage deviation of the model values from the experimental data tends to increase marginally irrespective of the gauge length as volume fraction increases. The increase can be attributed to uniform strain and stress in the composite at low volume fraction fibre. This can only be achieved when there is evenly dispersed fibre in the matrix, leading to a better distribution of load throughout the composite. At higher volume fraction, there is an agglomeration of fibre in the matrix leading to uneven distribution of load between aggregated and non-aggregated fibre.

4.2.2 Elastic Modulus Modelling

Theoretical values for the Elastic Modulus were calculated using five models. The results with the experimental data at different volume fraction and gauge length are shown in figure 4. Compared to the other theoretical results, the Elastic modulus obtained by Guth was the highest irrespective of the volume fraction, while the Halpin-Tsai and Modified Halpin-Tsai are the least. Using gauge 30 mm, the Guth's model deviated by 35.33%, 69.1%, and 114.17% at 0.085, 0.16, and 0.23 volume fraction respectively from the experimental results.



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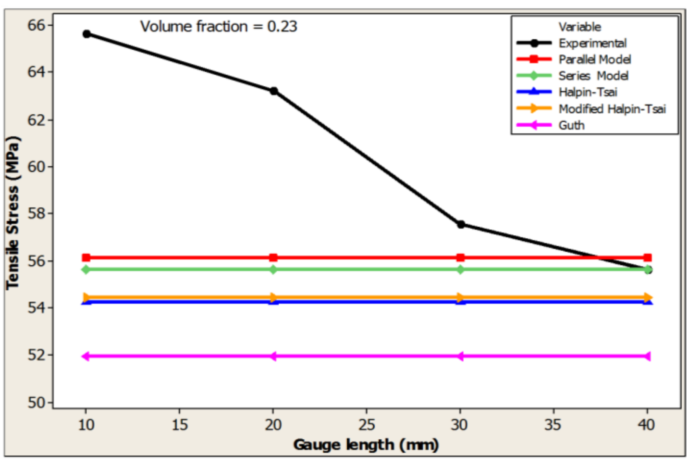


(C)

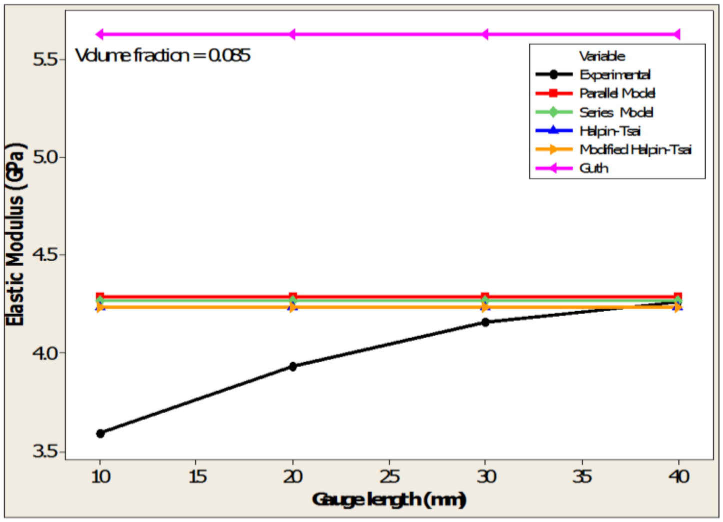
Figure 3 (A,B and C): Experimental and theoretical tensile strength values of Chitin whiskers reinforced composites using different modelling equations at different volume fractions and gauge length

The results of the Parallel model for Elastics modulus deviated 3.13%, 0.22%, and 6.13% at 0.085, 0.16, and 0.23 volume fraction from the experimental results, respectively. The results of Series models deviated 2.64%, 0.92%, and 6.77% at 0.085, 0.16, and 0.23 volume fraction from the experimental results, respectively. At 0.085 and 0.16 volume fraction, Halpin-Tsai and modified Halpin-Tsai deviated from the experimental values by 1.68 and 2.52, respectively. For 0.23 volume a fraction, the deviation is 9.3 and 8.89, respectively. It indicates that the Halpin-Tsai and modified Halpin-Tsai model are the most accurate in predicting the elastic modulus of PAA-CHWs composites. This is due to the anisotropic characteristic and aspect ratio of CHWs used in the model.

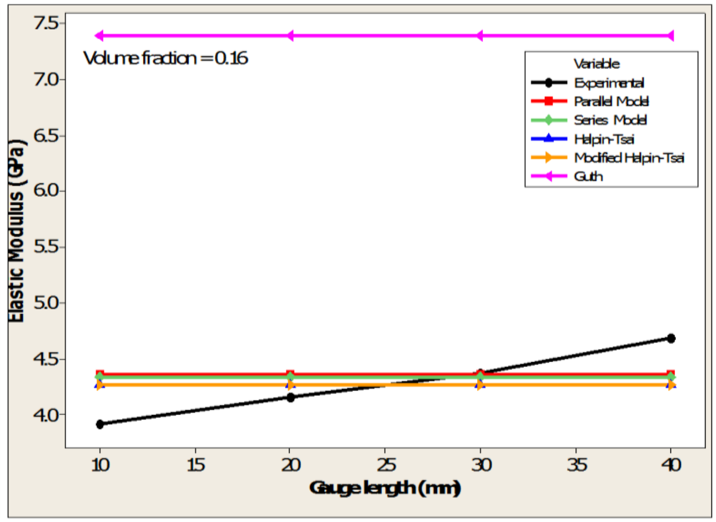
4.2.3 Effect of gauge length on the Modelling of Tensile stress and Elastic modulus

From figure 3, it can be seen that at 30 and 40 mm gauge lengths, the theoretical and experimental values tend to correlate irrespective of the volume fraction and the model equation used. At 30 mm gauge length and 0.085 volume fraction, the deviation from the experimental values are 3.06, 3.4, 4.35, 4.34 and 5.29 % for parallel, series, Halpin-Tsai, Modified Halpin-Tsai, and Guth's models respectively as against 14.73, 15.04, 15.87, 15.86 and 16.69 % for parallel, series, Halpin-Tsai, Modified Halpin-Tsai, and Guth models respectively for 10 mm gauge length and 8.96, 9.29, 10.18, 10.16 and 11.06% for 20 mm gauge length. At 40 mm gauge length and volume fraction of 0.085, the deviation decreases, which is 1.23, 0.86, 0.13, 0.11, and 1.11 % for parallel, series, Halpin-Tsai, Modified Halpin-Tsai, and Guth's models respectively. The same trend is observed at 0.16 and 0.23 volume fraction. For the tensile stress gauge, 40 mm has the least deviation from the experimental data irrespective of the Model used

For the Elastic Modulus, it can be seen from figure 4, at 40 mm gauge length, the theoretical and experimental values tend to correlate at 0.085 volume fraction irrespective of the model equation. The deviation from the experimental values are 0.70, 0.23, 0.70, 0.70 and 32.16 % for parallel, series, Halpin-Tsai, Modified Halpin-Tsai, and Guth's models respectively as against 19.50, 18.94, 17.83, 17.83 and 56.83 % for parallel, series, Halpin-Tsai, Modified Halpin-Tsai, and Guth's models respectively for 10 mm gauge length and 9.16, 8.65, 7.63, 7.73 and 43.26% for 20 mm gauge length. At 0.16 volume, fraction only 30 mm gauge length was able to predict the Modulus, while gauge 10 and 20 mm could predict the theoretical values at 0.23 volume fraction depending on the model used. It can be concluded that the higher the volume fraction, the lower the gauge length that can predict the theoretical values



(A)



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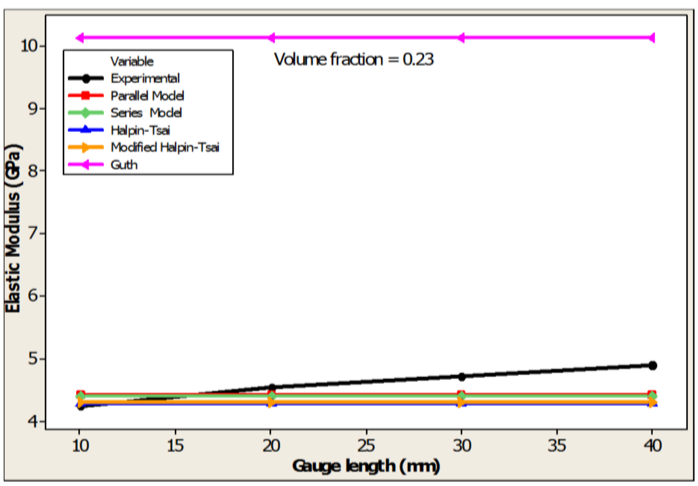

(C)

Figure 4(A,B and C): Experimental and theoretical Elastic Modulus values of Chitin whiskers reinforced composites using different modelling equations at different volume fractions and gauge length

The gauge length to predict the elastic modulus changes from 40 mm at 0.085 volume fraction to 10 and 20 mm gauge lengths at 0.23 volume fraction depending on the model equation and 30 mm for 0.16 volume fraction. Halpin-Tsai and modified Halpin-Tsai model are the most accurate in predicting the elastic modulus of PAA-CHWs composites at 30 mm gauge length of 0.085 and 0.16 volume fractions. Notwithstanding different gauge length can predict the elastic modulus at different volume fraction

5.0 CONCLUSION

Tensile strength and elastic modulus of CHWs fibre-reinforced PAA at different fibre loading and gauge lengths were compared with theories of reinforcement. Here evaluation was made between experimental data and five different theoretical models, namely; parallel series, Halpin-Tsai, modified Halpin-Tsai, and Guth's theories. It was observed that irrespective of the volume fraction and the modelling equation used, the tensile stress can be predicted at gauge 40 mm.

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