EFFECTS OF VARIATION OF PARTICLE SIZE AND WEIGHT FRACTION ON THE TENSILE STRENGTH AND MODULUS OF PERIWINKLE SHELL REINFORCED POLYESTER COMPOSITE

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Abstract

The effects of variation of particle size and weight fraction on the tensile strength and Youngs modulus of periwinkle shell reinforced polyester composite have been investigated. Particulate reinforced polyester composites incorporating varying amounts of periwinkle shell particles (10, 20, 30, 35, 40 and 45 wt %) of different particle sizes were characterized for their tensile strength and modulus of elasticity. The tensile strength and elastic modulus improved with decreasing particle size while they increased with increasing particle loading in the range of particle sizes tested. Increase in strength with small particle sizes and increased particle loading was attributed to increase in surface area which enhanced load transfer between the polyester matrix and periwinkle shell particles..

Keywords: particle-reinforced composite, weight fraction, modulus of elasticity, tensile strength, particle size

1. Introduction

Over the last three decades, composite materials, plastics and ceramics have been the dominant emerging materials. The number of applications of composites (particularly polymeric composites reinforced with synthetic fibers such as glass, carbon and aramid) has grown steadily due to their unique properties of high stiffness and strength-to-weight ratio [1]. According to Passipoularidis et al [2], high performance synthetic fiber reinforced polymer composites have been used in such diverse applications such as composite armouring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial driver shafts, and paper making rollers.

However, the widespread use of synthetic fiber reinforced polymer composites has a tendency to decline because of their high initial costs and more importantly, their adverse environmental impact [1,6]. Today, the growing environmental awareness throughout the world has triggered a paradigm shift from synthetic fibers and their composites towards composites made from natural reinforcing constituents (natural fibers and natural particulate fillers) which are more environmentally friendly [3]. In the light of this, researchers have focused their attention on composites composed of natural or synthetic resins, reinforced with mineral particulate fillers or natural fibers and manufacturing of high-performance engineering materials from these renewable resources has also been pursued by researchers since renewable raw materials are environmentally sound and do not cause health problems [4,5].

Polymer matrix composites can be reinforced with fibers (synthetic or natural), whiskers and particulate materials. Commonly used particulate fillers include: talc, calcium carbonate, kaoline, silica and carbon black [7]. These materials are not readily available, hence the need to source for other potentially suitable reinforcing constituents for polymer matrices. Whereas the use of some renewable particulate materials such as rice husk [8], coconut ash [9], wood flour [10], and palm kernel shell [11], as reinforcing phase in polymer matrices have been reported in the literature, researches on the potency of periwinkle shell particles as a reinforcing phase of polymer matrix systems are limited. Periwinkle shells have, however been reportedly used as coarse aggregates in concrete works [12].

Periwinkles are abundant in riverine areas of Nigeria and their shells are waste products of the processing of these sea animals. If (periwinkle shell) found to be good reinforcement of polymer matrices, aside from the technical benefits, our environment would be rid of some solid pollutants and our gross domestic product would improve. This work investigated the potency of periwinkle shell particles as reinforcement of polyester matrix. It also studied the effects of particle size and variation of weight fraction of each particle size on the tensile strength and Youngs modulus of a particulate reinforced polymer composite.

2. Particulate Reinforced Polymers

Particulate fillers used as reinforcements in polymer systems may be classified as natural and synthetic. Natural fillers include minerals such as calcium carbonate, koaline, mica, talc and some agricultural bye-products while synthetic fillers include processed mineral products such as carbon black, fumed silica, aluminum hydroxide [13,14]. The sizes of particulate fillers range from 0.1μm to about 2mm. However, nanosized particles have been developed. According to Leng T.P. [14] and Kim et al [15] particulate fillers impart equal strength in all directions compared to fibers that offer unidirectional reinforcement. Again their incorporation in polymers lead to increase in stiffness, higher resistance to distortion by heat, low shrinkage, low coefficient of thermal expansion and high resistance to permeation of gases and liquids [13,15].

2.1. Periwinkle shell

The periwinkle shell is a naturally occurring outer shell covering of a periwinkle (*Turritella communis*). It is an external exoskeleton which protects the winkles from their predators and mechanical damage. Structurally, the wrinkle shell has several layers and is typically made of an organic matrix (conchiolin) which is bonded with calcium carbonate precipitates. These calcium carbonate-filled organic matrix shells are impervious to water and this property makes it possible for periwinkle shells and their derivatives to have very wide applications [17].

2.2. Relationship between weight fraction and volume fraction

The volume fraction (v_p and v_m) for particle and matrix respectively and weight fraction (w_p and w_m) of particulate composite laminate is defined as follows:

$$v_p = \frac{V_p}{V_c} \quad \text{and} \quad v_m = \frac{V_m}{V_c} \qquad (1)$$

where V is volume of constituents and subscripts p, c and m refer to the particle, composite and matrix, respectively.

Similarly,

$$w_p = \frac{W_p}{W_c} \quad \text{and} \quad w_m = \frac{W_m}{W_c} \qquad (2)$$

w_p and w_m are weight fractions of particle and matrix respectively and W is the weight of constituent. A relationship between the weight fraction and volume fraction can be established by introducing the density (ρ) of the composite and its constituents. Essentially,

$$\rho_c = \rho_p v_p + \rho_m v_m \tag{3}$$

Recall that

$$w_p = \frac{W_p}{W_c} = \frac{\rho_p V_p}{\rho_c V_c} = \left(\frac{\rho_p}{\rho_c} v_p\right) \tag{4}$$

and similarly

$$w_m = \frac{W_m}{W_c} = \frac{\rho_m V_m}{\rho_c V_c} = \left(\frac{\rho_m}{\rho_c} v_m\right) \tag{5}$$

At any composite strain ε_c prior to fracture, the stresses in the matrix (σ_m) and particle (σ_p) can be obtained from:

$$\sigma_m = E_m \varepsilon_c \tag{6}$$

and

$$\sigma_p = E_p \varepsilon_c \tag{7}$$

where E_m and E_p are the Youngs moduli of matrix and particle respectively. The composite stress (σ_c) is given by:

$$\sigma_c = \sigma_p v_p + \sigma_m (1 - v_p) \tag{8}$$

and the axial Youngs Modulus of the components obtained from equation (9.0) below:

$$E_c = E_p v_p + E_m (1 - v_p) \tag{9}$$

3. Materials and Method

3.1. Polyester

Polyester is produced when dihydric alcohol like ethylene glycol reacts with an aromatic acid like phthalic acid to produce a polymeric ester. Polyester has the physical and mechanical properties shown in Table 1 [16].

3.2. Filler preparation

The periwinkle shells were sun dried, ball milled and thereafter, classified by sieving using hand sieves and the following particle sizes were obtained: 400, 600, 800 and 1000μm.

Table 1: Physical and mechanical properties of Polyester

Density (g/cm^3)	**Melting pt** (℃)	**Thermal Expansion** ($\times 10^{-6} K^{-1}$)	**Youngs modulus** (GPa)	**Tensile strength** (MPa)	**Ductility** (%)
1.21	154	120	1.3	45	30

3.3. Composite preparation

The hand lay-up technique was employed in producing the composite laminates used in this work. Four different particle sizes of ground periwinkle shell were used. Appropriate quantities of reinforcing constituents were determined and mixed with proportionate amounts of polyester resin to give: 10%, 20%, 30%, 35%, 40% and 45% weight fractions of periwinkle shell particles. The "mix" was vigorously stirred to ensure homogeneous dispersion of the periwinkle particles in the resin after the additions of methyl ethylketone peroxide and cobalt nephthenate which served as a catalyst and accelerator respectively during curing of the polyester resin to give a solid laminate.

3.4. Tensile test

The tensile test of the composite laminates was measured using a universal tensile machine. The test specimens are rectangular in shape with dimensions 150 × 15 × 3mm. A cross head speed of 5mm/minute and specimen guage length of 50mm was used.

4. Result and Discussion

4.1. Effect of particle size on Young's modulus and strength of periwinkle shell reinforced polyester composite

Young's modulus is a measure of the stiffness of a material and is defined as the ratio of stress to strain of a material at the elastic stage of a tensile test. The effect of particle sizes on the elastic modulus of polyester/periwinkle shell particle composite is shown in figure 1.0 (A - F). It is seen that there is a negligible effect on the modulus of

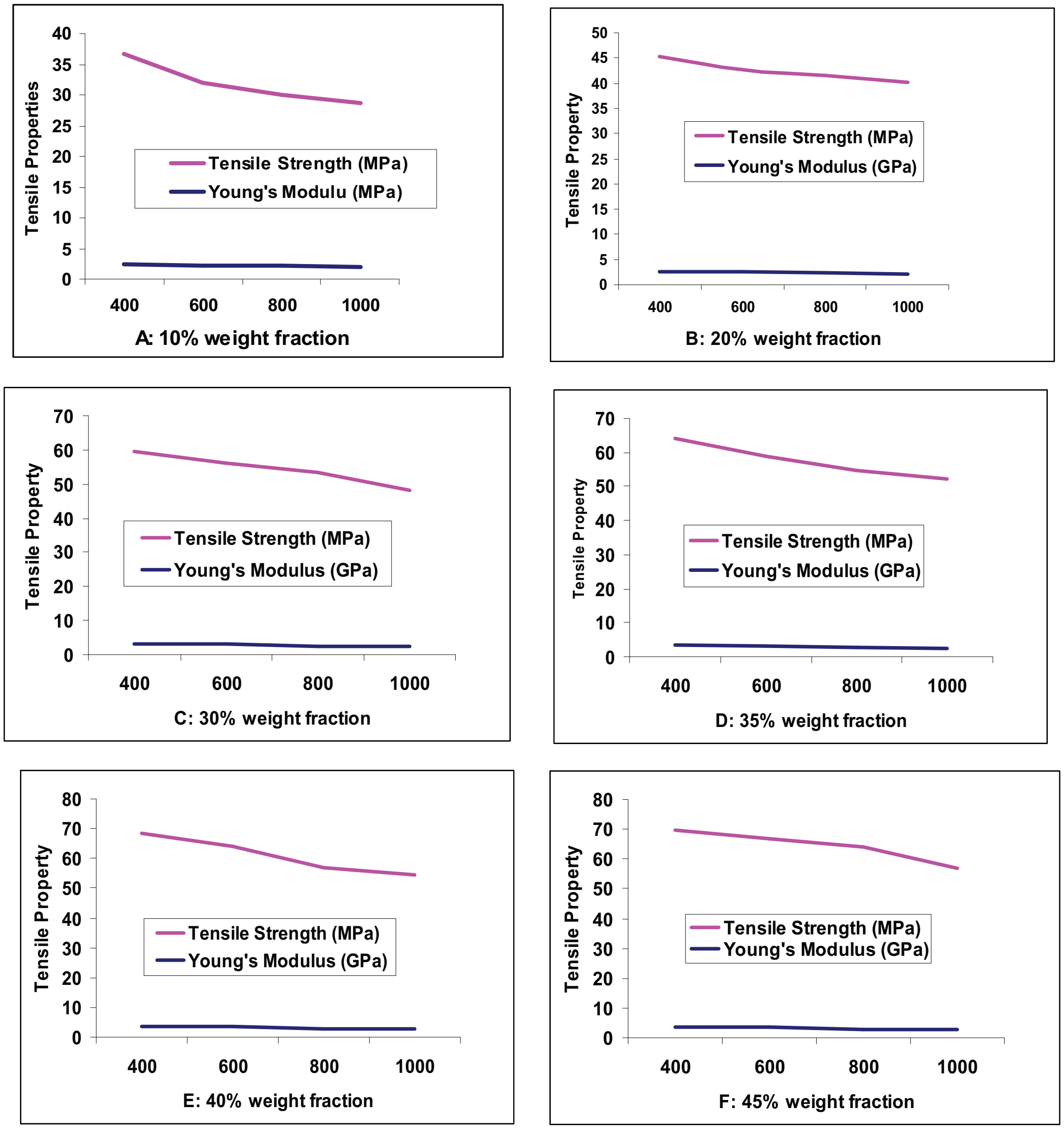

Figure 1: Effects of particle size on Young's modulus and tensile strength of periwinkle shell reinforced composite.

the composite laminate as the particle size is varied in the range of particle sizes studied.

Spanoudakie et al [18], studied the effect of particle size on the elastic modulus of epoxy/alumina trihydrate composites and reported that modulus is not very much affected by particle size. S.Y. Fu et al [19], in his work titled, "effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate polymer composite" reported that the particulate composite modulus is insensitive to particle size but when the particle decreased to a critical value (usually in the nano size range), the effect on the composite modulus is more significant with modulus increasing with decreasing particle size below this critical value.

The elastic modulus of a particulate - polymer composite is generally determined by the elastic properties of its components (matrix and particles), particle loading and aspect ratio [20, 21, 22]. Since the modulus of inorganic particles is usually much higher than that of polymer matrices, the composite modulus is enhanced by adding particles to the matrix. Many empirical equations have been proposed to predict the modulus of particulate - polymer composites, some are stated below: Einstein [24], proposed that the Youngs modulus of particulate composite may be predicted by the following equation:

$$E_c/E_m = 1 + 2.5V_p \qquad (10)$$

Where E_c and E_m are Young's modulus of composite and matrix respectively and V_p is particle volume fraction. This equation implies that the composite modulus is independent of particle size and predicts a linear relationship between E_C and V_p. Guths equation [25], stated as:

$$E_c/E_m = 1 + 2.5V_p + 1.44v_p^2 \qquad (11)$$

added a particle interaction term in the Einsteins equation. The linear term is the stiffening effect of individual particles and the second power term is the contribution of particle interaction.

The effect of particle size on the tensile strength of polyester/periwinkle shell composites is shown in figure 1 (A - F). It is clearly shown that for a given particle weight fraction, the composite strength increases with decreasing particle size. Smaller particles have a higher total surface energy for a given particle loading. Strength increases with increasing surface area of the filled particles through a more efficient stress transfer mechanism. Addition of particles leads to an increase in strength and smaller particles give better reinforcement. This is in agreement with Buggy, et al [21] who investigated the mechanical properties of kaoline filled nylon 6 composites and found that the composite strength increases with decreasing mean particle size.

4.2. Effect of weight fraction on tensile strength and Young's Modulus of periwinkle shell reinforced polyester composite

Figures 2 and 3 show the effects of weight fraction on the strength and modulus of polyester/periwinkle shell composites. The figures show that for a particular particle size, both strength and modulus increase with increase in periwinkle shell particle weight fraction. This is in agreement with Sumita et al [26] findings in their work titled, "effects of reducible properties of temperature, rate of strain and filler content on tensile yield strength of nylon 6 composites filled with ultrafine particles". According to Fu et al [23], besides particle size and loading, the particle/matrix interfacial adhesion also significantly affects the strength of particulate composites.

Fu et al [23], explained that effective stress transfer is the most important factor which contributes to the strength of two-phase composite materials. For poorly bonded particles, the stress transfer at the polymer/particle interface is inefficient. Discontinuity in the form of debonding exists because of non-adherence of particles to polymer. Thus the particle cannot carry any load and composite strength de-

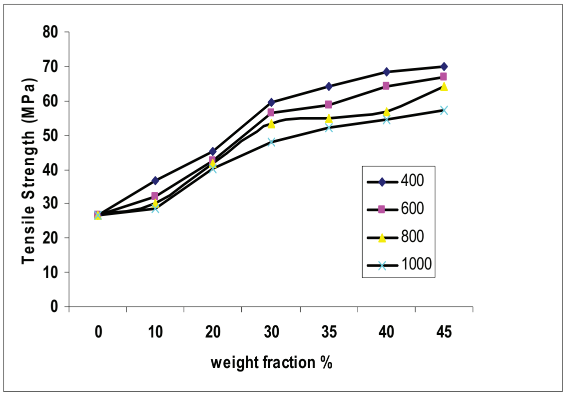

Figure 2: Effects of variation of weight fraction on the tensile strength of polyester/periwinkle shell particles composite.

creases with increasing particle loading. However, for composites containing well-bonded particles, addition of particles to a polymer leads to an increase in strength especially for nano-particles with high surface areas [23].

5. Conclusion

The following main conclusions are drawn from this work:

1. Periwinkle particle size within the range of particle sizes (400 - 1000m) studied has negligible effect on the Youngs modulus of polyester/periwinkle shell particle composite.
2. The tensile strength of periwinkle shell reinforced composite increases with decreasing particle size.
3. Both tensile strength and Youngs modulus of the composite material increase with increasing weight fraction of periwinkle particles in the composite laminate.

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