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Mechanical and thermal behavior of plantain peel powder filled recycled polyethylene composites

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Abstract. In the arduous search for ways to clean up the environment and produce viable materials from waste plastics; plantain peel powder filled low density polyethylene wastes (wLDPE) were developed through melt mixing and compression moulding techniques. Optimum properties were determined at 15, 55 and 30 % formulation of plantain peel powder, and *Kankara* clay respectively. Composition with optimum properties has tensile strength of 55.5 MPa, flexural strength of 50.45 MPa and elastic modulus of 2.30 GPa with corresponding minimal water absorption of 0.95% after 30 days immersion period at room temperature. The thermal properties investigated by Dynamic Mechanical Analysis showed that the composite has better thermal stability at higher temperature than wLDPE. Similarly, through creep analysis, the composite was observed to have better load bearing capability at elevated temperature than waste low density polyethylene material. These results indicate that incorporation of treated plantain peel powder and *Kankara* clay into wLDPE enhanced the mechanical, thermal and creep resistance of wLDPE. This implies load bearing capability and potential suitability for different wall tiles applications.

***Keywords*:** creep; dynamic mechanical analysis; low density polyethylene; plantain peel powder; waste low density polyethylene.

1. Introduction

The quest to develop economically viable materials from plastic wastes using locally sourced natural fibers has been on the increase in recent years. Low density polyethylene (LDPE) is a low-cost material with good processability, excellent electrical insulation properties, chemical resistance, high toughness and flexibility even at low temperature [1]. These properties make LDPE the most widely used class of polyethylene in various packaging and functional applications [2]. LDPE currently enjoys ubiquitous application in packaging of sachet water popularly known as pure water in Nigeria, resulting in a large volume of waste [2, 3]. Polymer composite development via reinforcement with natural fibers is one of the best options in which these wastes could be re-utilized [4-6].

Low cost, readily available, easy to use, biodegradability and eco-friendly are some of the advantages of natural fibers that have attracted the interest of researchers both in the academia and in the industries [7]. This has prompted the need to investigate their feasibility for reinforcement purposes, and to what extent they satisfy the required specifications of a good reinforcement in polymer composite for different applications [2].

Traditionally, polymer composites are made up of the matrix and the fiber. However, a third component known as the non-reinforcing filler may be added not necessarily to improve the mechanical or thermal property, but rather to create a new material for desired consideration [8]. *Kankara* kaolin clay is important filler that could be used in a three-component polymer composite. *Kankara* kaolin is in abundance in *Kankara,* Katsina State of Northern Nigeria. The clay is available and accessible in most market in Northern Nigeria. Naturally, clay types are corrosion resistant [8]. Natural and synthetic constituents are used extensively in composite development.

The current trend of research in the field of natural fiber-based composites is the application of dynamic mechanical analysis (DMA) technique. DMA depicts the stiffness stability of the composites with increasing temperature, its glass transition temperature and its visco-elastic nature when stimulated by dynamic loading [5].Creep is also an important parameter that could be determined using the dynamic mechanical analyzer. Some recent works on the development and characterization of polymeric composites have been reported and have thus been summarized: Jacob *et al*. [7] investigated thermo-mechanical characterization of plantain particulate reinforced waste high density polyethylene as composite wall tiles. Through DMA and creep curves, the composites were observed to have better stiffness stability and load bearing capability than the unreinforced waste high density polyethylene.

The effect of variation in frequencies on dynamic mechanical properties of jute fiber reinforced epoxy composites has been studied by Gupta [9] and reported that the acceptable dynamic mechanical properties of jute composite indicates that it can be used in making the casing of electronic instruments such as mobiles, laptops, and so on.

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Dan-asabe [8] also determined and characterized the thermo-mechanical properties of banana particulate reinforced PVC as piping material. Through dynamic mechanical analysis, the composition with optimum mechanical property of 42 MPa was estimated to have a long stress value of 25 MPa corresponding to 40% loss in strength over a period of 32 years. The need to evaluate the influence of plantain peel powder addition on the mechanical and thermal properties of waste low density polyethylene composites with a view in determining its suitability for different applications becomes expedient.

2. Experimental

2.1. Sample collection and preparation

Wastewater sachets made from low density polyethylene were collected from refuse dumps. These samples were thoroughly washed with water, dried and shredded into particles of smaller sizes which constitute the polymer matrix [10].The plantain peel used as reinforcement was also sourced from local vendors in Samaru, Zaria-Nigeria. It was sun-dried, pulverized and sieved to 100 µm. The *Kankara* kaolin (non-reinforcing filler) was obtained from *Kankara* town in Katsina State, Nigeria. It was also sieved to 100 µm particle size.

Plate I. LDPE waste used for the study

Plate II. Treated plantain peel powder

The sodium hydroxide used in chemical modification of fibers was obtained from BDH Supplies, England. Chemical treatment of fibers in composite development is carried out to reduce potential surface hindrances and bring about better adhesion between the hydrophilic plantain peel powder and hydrophobic polymer matrix [2]. The plantain peel powder was initially alkaline pre-treated by suspending the fibers in 5% NaOH for 8 hours with continuous stirring after which the solution was decanted off, washed several times with distilled water until the solution becomes neutral. This was done to activate the hydroxyl groups of the cellulose and lignin in the fiber, after which the samples were then treated with benzoyl chloride for 15 minutes. The isolated fibers were then soaked in ethanol for 1 hour to remove excess benzoyl chloride. Finally, the fiber was dried in an oven at 80 ^{o}C for 6 hours [2, 4, 6].

2.2. Composite production

The materials were compounded via melt mixing at a temperature of 160℃ to obtain a homogeneous mixture. The composition of the plantain peel powder and wLDPE was varied from 5, 10, 15, 20 and 25 % respectively. Shredded LDPE waste was varied accordingly from 0, 65, 60, 55, 50 and 45 % respectively. The *Kankara* kaolin was kept constant at 30 %. Curing of the samples was then carried out using hydraulic press at a temperature of 150 ^{o}C and a compression pressure of 3 Pa for 10 minutes. Samples obtained were cooled and machined in preparation for characterization tests [4].

2.3. Mechanical property test

2.3.1. Tensile test

The tensile testing of the samples was determined using the ASTM D638 [11] recommended method. The samples were machined to dumbbell shape and then placed in computerized Instron universal tensile testing machine 3369 model, which measured the tensile strength and elastic modulus were evaluated [6].

2.3.2. Flexural strength

Flexural strength was measured under a three-point bending approach using a universal testing machine according to ASTM D790 [12].The distance between the spans was 40 mm and the strain rate was 5 mm/min [7, 6].The flexural strength (MPa) was calculated using equation (1):

$$\sigma = \frac{3Pl}{2bt^2} \qquad (1)$$

Where: l = length of specimen span between support (mm); P = maximum deflection force (N); b = width of specimen (mm); t = thickness of specimen (mm)

2.3.3. Hardness test

The hardness test of composites is based on the relative resistance of its surface to indentation by an indenter of specified dimensions under a specified load [2]. Samples of 30 mm x 30 mm x 5 mm were tested for shore hardness values with Durometer Shore A. Five measurements were performed on the sample at different spots and the average of the values was taken as the hardness of the sample [2, 6].

2.4. Water absorption

Water absorption test was carried out according to ASTM D570 [13] method. The test sample was an oven dried specimen of dimension 76 × 25 × 5 mm immersed in water at ambient temperature for 24 hours. After immersion period of 24 hours, the specimens were removed and patted dry with a cloth (lint free) and then reweighed using a Sartorius ED 224S digital Analytical balance. In order to evaluate long term moisture absorption on the composites, the process was repeated at 48, 72, 96, up to 720 hours exposure. The dried weight before ($W_{initial}$) and after weight immersion (W_{final}) were noted. Similar method has been reported [6, 7].The water absorption was determined as follows:

$$W = \frac{W_{final} - W_{initial}}{W_{fina}} \ (\%) \qquad (2)$$

2.5. Thermal properties

2.5.1. Dynamic Mechanical Analysis

DMA was carried out using DMA 242E machine according to ASTM D7028 [14]. The test parameters: storage modulus (E'), loss modulus (E") and tangent of delta (Tan ∂) were first configured via the Proteus software using personal computer. Instrument set up included the sample holder (3-point bending), furnace temperature range of 30-110 ºC, dynamic load of 4 N, frequency range of 1-10 Hz and heating rate of 3 K/min were configured [4]. Sample dimension of 60 x 12 x 5 mm were produced for each test. The test specimens were loaded into the machine using a three- point bending and locked into the furnace [8].

2.5.2. Creep

Creep is one of the supplementary characterizations that can be done using the Dynamic Mechanical Analyzer. The creep test was conducted for 60 min at a load stress of 100 kN/m^2 at 70 ºC [7].

3. Results and discussion

3.1. Mechanical properties

3.1.1. Tensile strength

Fig. 1 depicts the tensile strength (UTS) of the composites with increasing weight of reinforcement. The tensile strength increases and then decreases gradually. This could be due to weakening of the interfacial attraction of the constituent composition as the fraction of the RHDPE is reduced with increasing weight fraction of reinforcement. Similar observations have been reported by other authors [2, 4].

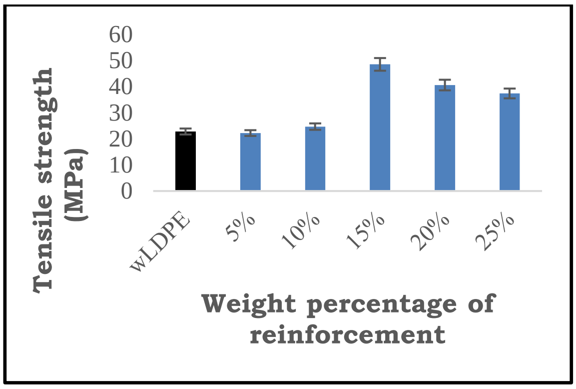

Figure 1. Effect of plantain peel powder on the tensile strength of waste LDPE composites

3.1.2. Elastic modulus

Fig. 2 depicts the elastic modulus (stiffness) of the composite against weight of reinforcement. An increase in modulus of elasticity with weight fraction of reinforcement (plantain peel powder) could be observed. The elastic modulus of the composites increases from 0.5 GPa to 2.55 GPa which could be attributed to better interaction between wLDPE and the PPP. An increase in elastic modulus with weight fraction of reinforcement has been reported by other authors [8, 15].

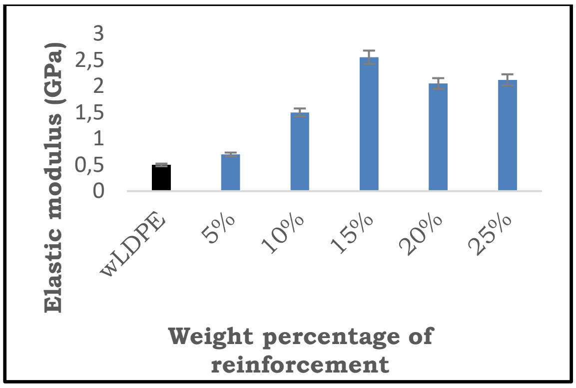

Figure 2. Effect of plantain peel powder on the elastic modulus of waste LDPE composites

3.1.3. Flexural strength

Fig. 3 shows the flexural strength of the composites. The flexural strength of plantain peel powder reinforced wLDPE composites increases with weight fraction of reinforcement and then decreases, with the maximum value of 85.65 MPa at 15 % wt of reinforcement. This is an indication of improved interaction and stress transfer between the wLDPE and plantain peel powder particles. It was observed that further increase in weight fraction of reinforcement to 20-25 % however decreases the flexural strength value due to weak fiber-matrix adhesion. Similar results have been reported [16, 17].

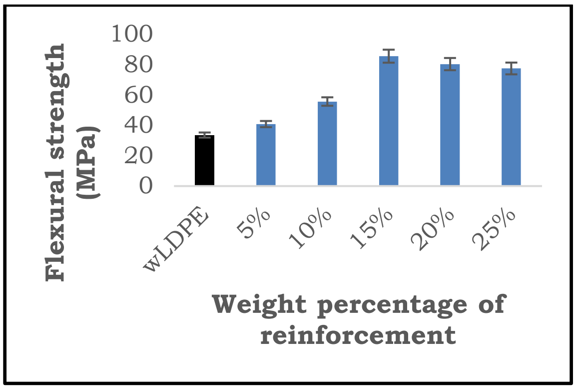

Figure 3. Effect of plantain peel powder on the flexural strength of waste LDPE composites

3.1.4. Hardness

Hardness is defined as the resistance of material to localized deformation induced by mechanical indentation or abrasion [4]. Fig. 4 depicts the hardness value of wLDPE and the composites. It could be observed that the hardness increased with increase in weight fraction of reinforcement. The increase in hardness may be attributed to the strengthening effect of the fibers incorporated into the polymer matrix. Fibers are usually added to polymeric materials to improve their rigidity and strength. The higher the percentage of fibers incorporated, the harder the material, and more rigid it becomes. Similar results have been reported [4].

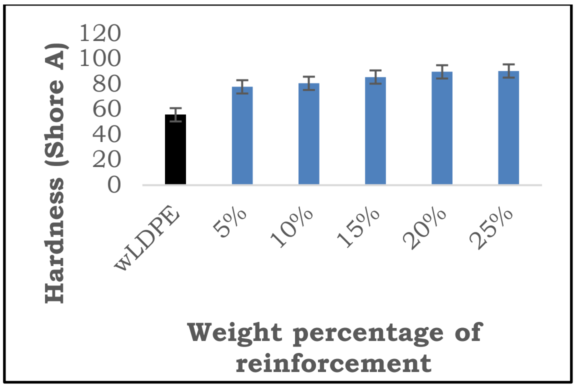

Figure 4. Effect of plantain peel powder on the hardness value of waste LDPE composites

3.2. Water absorption

Fig. 5 depicts the % moisture absorption against the square root of time for plantain peel powder reinforced wLDPE composites immersed at room temperature (RT) for 720 hours (30 days). The water absorption process for all composite samples (except wLDPE, which was observed not to absorb) was initially linear before slowing down with time towards the point of attainment of saturation after prolonged time. Therefore, the observed trend follows the Fickian diffusion process. Both the initial and maximum rate of water absorption was observed to increase for all PPP-wLDPE composite samples as the weight fraction of reinforcement increases. Both the initial rate of water absorption and the maximum were observed to increase with weight percentage of reinforcement. Similar results have been reported [6, 15, 18, 19].

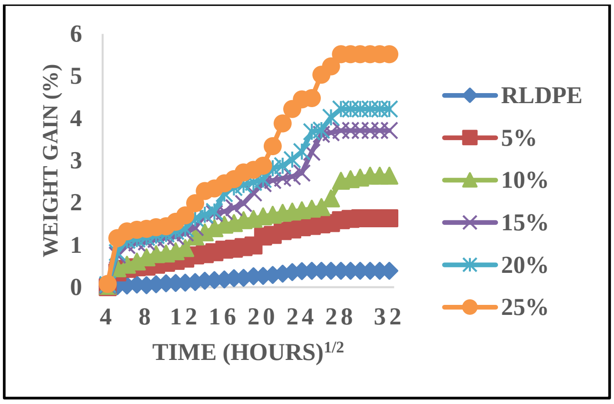

Figure 5. Water absorption curves of the composites immersed at RT for 30 days.

3.3. Dynamic mechanical properties

3.3.1. Storage modulus

Storage modulus (E') describes the stiffness of materials [9]. In other words, it represents the energy stored in the system which depicts the elastic portion [7]. Fig. 5 shows the storage modulus of unreinforced LDPE waste at frequencies of 1, 5 and 10 Hz respectively. The curve shows that the material is unstable at temperatures below 40 °C. The maximum stiffness of 0.12 GPa could be observed with glass transition temperature of 35.8°C. Similar observation has been reported by Jacob *et al.* [7] who reported the thermo-mechanical characterization of plantain peel particulate reinforced waste HDPE as composite wall tiles.

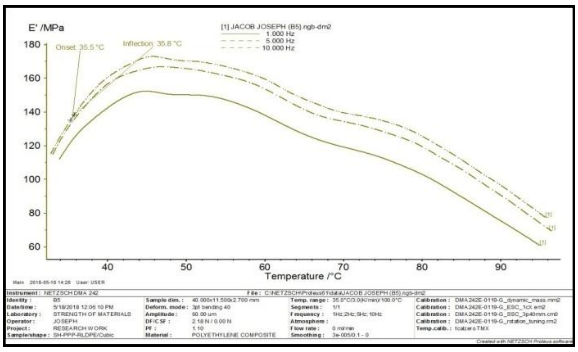

Figure 6. Storage modulus curve of waste LDPE at 1, 5 and 10 Hz.

Fig. 7 shows the storage modulus of the composite of plantain peel powder at frequencies of 1, 5 and 10 Hz respectively. The curve shows that the composite is stable under dynamic loading with increasing temperature up to 45 ºC before its point of inflection of 49.6 ºC. Similar result has been reported by [8]. The curve also shows loss in stiffness from 0.33 GPa to 0.01 GPa at 45 ºC This indicates the suitability of the material up to 45 ºC [7, 10].

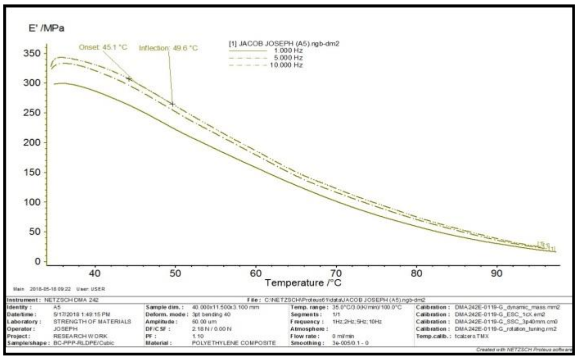

Figure 7. Storage modulus curve of 15% wt plantain peel powder reinforced waste LDPE composite at 1, 5 and 10 Hz.

3.3.2. Damping parameter

Tan delta (Tan ∂) or damping is the measure of visco-elasticity of materials. A high value of damping is indicative of a material with high non-elastic strain behavior while low value of damping indicates that the material is more elastic. Fig. 8 depicts the damping curve of 15 % plantain peel powder reinforced waste-LDPE composite. The visco-elasticity of the composite of plantain peel powder is eminent at tan delta value of 0.13 at 38.5 °C up to a maximum of 0.153 at 44.2°C. Similar results have been reported by other authors [7, 20].

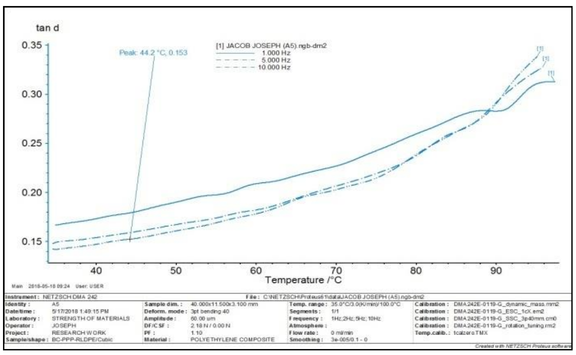

Figure 8. Damping curve for 15 % wt plantain peel powder reinforced waste LDPE composite at 1, 5 and 10 Hz

3.4. Creep

Creep is the deformation of material under constant stress; dependent on time, stress, temperature, and material properties, etc. [10]. Creep deformation can exceed the creep limit and cause product failure, especially in applications with long-term loading. Fig. 9 shows the creep result of 15 % plantain peel powder reinforced waste LDPE composite at 70℃. The initial large vertical strain was due to the applied constant load after which the strain rate decreases with time up to 46.8 min where the strain rate was very small known as the equilibrium strain rate. This stage is known as secondary creep and must be considered in load bearing capability of the composite. Similar results have been reported by other authors [7, 8].

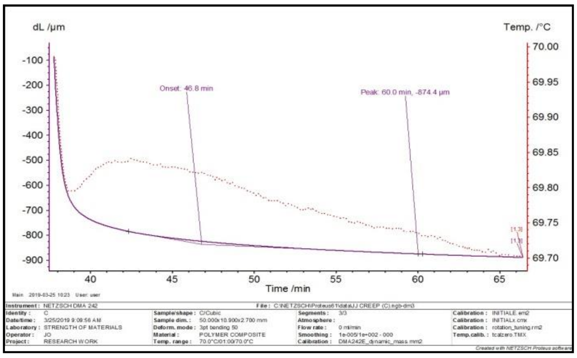

Figure 9. Creep curve of 15 % plantain peel reinforced waste LDPE composites at 70 ℃

Fig. 10 depicts the creep curve of the control sample (waste LDPE). The equilibrium strain rate occurred at 41.3 min which is lower than that of the composite. This indicates that the load bearing capability of waste LDPE has been improved with the incorporation of plantain particulate [7].

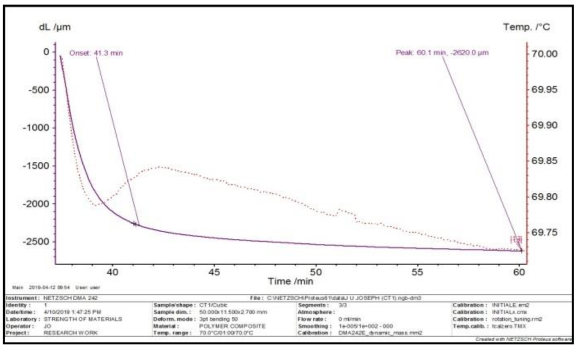

Figure 10. Creep curve of unreinforced wLDPE at 70 ℃

4. Conclusions

- The composites were developed with low cost and readily available materials having an overall light-weight and good mechanical, thermal properties.
- Optimum mechanical property was determined at 15 % , 55 % and 30 % formulation of plantain peel powder, wLDPE and *Kankara* kaolin respectively, having elastic modulus of 2.30 GPa, tensile strength of 55.5 MPa, flexural strength of 50.45 MPa and minimal water absorption of 0.95 % over 30 days immersion period at ambient temperature.
- Dynamic mechanical analysis curve showed that the composite has better stiffness stability at higher temperature under dynamic loading than the unreinforced (wLDPE).
- The creep curve indicates that the composites have better creep stability at elevated temperatures than the wLDPE material under constant loading. This implies the load bearing suitability for different wall tiles applications.

List of abbreviations

ASTM: American Standard of Testing Material; DMA: Dynamic Mechanical Analysis; GPa: Giga Pascal; HDPE: High Density Polyethylene; LDPE: Low Density Polyethylene; MPa: Mega Pascals; PPP: Plantain peel powder; PVC: Polyvinyl Chloride; RT: Room temperature; wLDPE: waste Low Density Polyethylene.

Plate III. Some of the developed potential composite wall tiles.

Conflict of interest

The authors confirm that this article content has no conflicts of interest.

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