Science World Journal Vol 14(No 1) 2019
www.scienceworldjournal.org
ISSN 1597-6343
Published by Faculty of Science, Kaduna State University

Full Length Research Article

MECHANICAL AND DYNAMIC MECHANICAL CHARACTERIZATION OF GROUNDNUT SHELL POWDER FILLED RECYCLED HIGH DENSITY POLYETHYLENE COMPOSITES

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ABSTRACT

Groundnut shell powder (GSP) reinforced recycled high density polyethylene composites were developed via melt mixing and compression moulding techniques. GSP was alkaline treated to increase its compatibility with the polymer matrix. The developed composites were subjected to mechanical properties test and thermal characterization using 242E dynamic mechanical analyzer. Results obtained indicated an enhancement in mechanical properties of the recycled high density polyethylene composites compared to the unreinforced (control sample). Similarly, dynamic mechanical properties results showed that the storage modulus of all the composites increase with increase in weight percentage of GSP incorporated. The energy dissipation in form of heat (loss modulus) and damping peaks (Tan ∂) values were found to be reduced with the incorporation of alkaline treated GSP which implies an improvement in thermal stability and load bearing capacity of the composites.

Keywords: Composites, Dynamic Mechanical Analysis, Groundnut Shell Powder, Mechanical Properties, Recycled High Density Polyethylene.

1. INTRODUCTION

Recent years have witnessed an increased application of biodegradable materials in form of fibres, particulates, and laminates as reinforcement in polymer composites. Natural fibres offer many technical and ecological benefits and therefore present more advantages over synthetic fibres as reinforcements in composite materials. Low cost, readily available, easy to use, biodegradability and eco-friendly are some of the advantages of natural fibres that have attracted the interest of researchers both in the academia and in the industries to investigate their feasibility of reinforcement purposes and to what extent they satisfy the required specifications of a good reinforcement in polymer composite for different applications (Jacob *et al*., 2018).

High density polyethylene (HDPE) is one of the important grades of polyethylene (PE) that exhibits excellent properties such as chemical stability barrier, good thermal resistance and mechanical strength. These properties make HDPE a versatile material in the manufacture of many products and packaging such as milk jugs, detergent bottles, margarine tubes, garbage containers (Klyosov, 2007), water pipes (Vasile and Pascu, 2005) and bottle caps resulting in a large volume of waste. In this study, groundnut shell powder was used as reinforcement in the recycled high density polyethylene (RHDPE) matrix.

Groundnut shell is a waste product obtained after the removal of groundnut seed from its pod, and there has not been considerable demand for the utilization of groundnut shell for the benefit of mankind (Usman *et al*., 2016). Groundnut shell is a valuable product in composite production process due to its high availability in Northern Nigeria and scarce interest in other industrial sectors. It was treated with sodium hydroxide to improve fibre matrix interaction and thermo-mechanical properties of the produced composite.

The current trend of research in the field of natural fibre 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 viscoelastic nature when stimulated by dynamic loading. Time temperature superposition (TTS) principle is also an important parameter that could be determined by the use of DMA technique. TTS principle is usually used to predict the long term performance of material by the use of the Williams-Landel-Ferry (WLF) equation.

Some recent works on the development and characterization of polymeric composites have been reported and have thus been summarized. Dan-asabe *et al.* (2016) determined the dynamic mechanical analysis of aluminium reinforced PVC composite as a feasible alternative material for automotive bumper application. Dan-asabe (2016) also determined and characterized the thermo-mechanical properties of banana particulate reinforced PVC as piping material. Dynamic mechanical analysis and crystalline analysis of hemp fibre reinforced cellulose filled epoxy composite was investigated by Palanivel *et al*. (2017) and reported that alkali and benzoyl chloride treated fibres has resulted in enhanced DMA results. Chris-Okafor *et al.* (2018) also investigated the reinforcement of high density polyethylene with snail shell powder and reported that incorporation of the filler material improved the mechanical properties of HDPE.

The effect of variation in frequencies on dynamic mechanical properties of jute fibre reinforced epoxy composites has been studied by Gupta (2018) 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. The quest to clean up the environment and produce economically viable materials from HDPE waste using cheap and readily available reinforcement has promoted the need for the present investigation.

2. MATERIALS AND METHODS

2.1 Materials
Materials were selected based on availability and ease of processing. Materials used are water bottle caps made from high density polyethylene identified by the resin code "2" (Society of Plastic Industry, 1987), groundnut shell, plantain peel, sodium hydroxide, benzoyl chloride, distilled water and mild steel mould.

2.2 Methods

2.2.1 Materials Preparation
The RHDPE waste was washed thoroughly with water, dried and shredded into smaller sizes using shredding machine. The groundnut shell used as reinforcement was pulverized into powdery form and sieved to 150 µm. It was immersed in 10 % NaOH for 6 hours with continuous stirring after which the solution was decanted off, washed several times with distilled water until the solution becomes neutral. Finally, the fibre was dried in an oven at 80 °C for 6 hours.

2.2.2 Composite Production
The materials were compounded via melt mixing at a temperature of 170 °C to obtain a homogeneous mixture. The % weight fraction of reinforcement was varied from 0-25 % (0, 5, 10, 15, 20, and 25. Curing of the samples was then carried out using hydraulic press at a temperature of 160 °C and a compression pressure of 4 Pa for 10 minutes. Samples obtained were cooled and machined in preparation for characterization tests.

2.3 Mechanical property test

2.3.1 Tensile test
The tensile testing of the samples was done at Engineering Materials Development Institute, Akure, Ondo State, Nigeria in accordance with (ASTM D638, 2014) standard. The samples were machined to dumbbell shape and then placed in Instron universal tensile testing machine 3369 model and the tensile strength and elastic modulus were evaluated.

2.3.2 Flexural strength
Flexural strength was measured under a three-point bending approach using a universal testing machine according to (ASTM D7028-2015). The distance between the spans was 40 mm and the strain rate was 5 mm/min. The flexural strength (MPa) and flexural modulus (MPa) was calculated using equations (1 and 2) respectively.

$$\frac{3PL}{2bt^2} \qquad (1)$$

$$\frac{3PL^3}{4bd^3D} \qquad (2)$$

L is the gauge length of support span (measured in mm)
P is the applied load (k N)
b is the width of the specimen (measured in mm)
t is the thickness of specimen (measured in mm)
D is the deflection (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. Samples of 30 mm x 30 mm x 5 mm were tested for shore hardness values with a 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.

2.4 Dynamic Mechanical Analysis (DMA)
DMA was carried out using DMA 242E machine in strength of materials laboratory, Mechanical Engineering Department, ABU Zaria according to (ASTM D7028, 2015). 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 °C, dynamic load of 4 N, frequency range of 1-10 Hz and heating rate of 3 K/min were configured. 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.

Table 1: The designation of symbol and their meaning as used in this work.

Symbol	Meaning
G0	unreinforced RHDPE (control)
G10	5 wt % groundnut shell powder reinforced polyethylene composite
G15	15 wt % groundnut shell powder reinforced polyethylene composite
G20	20 wt % groundnut shell powder reinforced polyethylene composite
G25	25 wt % groundnut shell powder reinforced polyethylene composite

3. RESULTS AND DISCUSSION

3.1 Mechanical properties

3.1.1 Tensile strength and elastic modulus
Figure 1 depicts the ultimate tensile strength (UTS) of the composite with increasing weight of reinforcement. The tensile strength increases and then decreases steeply. 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 GSP. Similar observations have been reported by other authors (Salmah *et al;* 2005; Raju *et al*., 2012; and Dan asabe, 2016).

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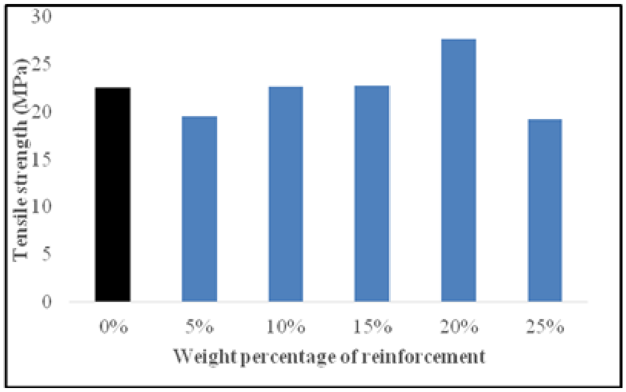

Figure 1: Effect of GSP on the tensile strength RHDPE composites.

Figure 2 shows the elastic modulus (stiffness) of the composite against weight of reinforcement. A similar trend of increase in modulus of elasticity with weight fraction of reinforcement (GSP) could be observed. The elastic modulus of the composites increases from 53.1 MPa to 77.3 MPa which could be attributed to better interaction between RHDPE and the GSP. An increase in elastic modulus with weight fraction of reinforcement has been reported by other authors (Khalaf, 2015).

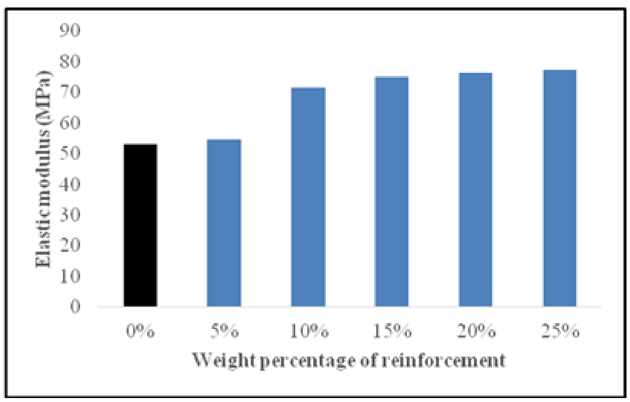

Figure 2: Effect of GSP on the stiffness of RHDPE composites.

3.1.2 Modulus of rupture (MOR) and modulus of elasticity (MOE) of the composites
Figure 3 depicts the modulus of rupture of the composites. From the figure, the MOR of ground nut shell powder reinforced RHDPE composites increases with weight fraction of reinforcement and then decreases, with the maximum value of 31.58 MPa at 20 % wt of reinforcement. This is an indication of improved interaction and stress transfer between the particles. Further increase in weight fraction of reinforcement to 25 % however decreases the MOR value due to weak fibre-matrix adhesion. Similar results have been reported by (Raju *et al.,* 2012; Chris-Okafor *et al*., 2018).

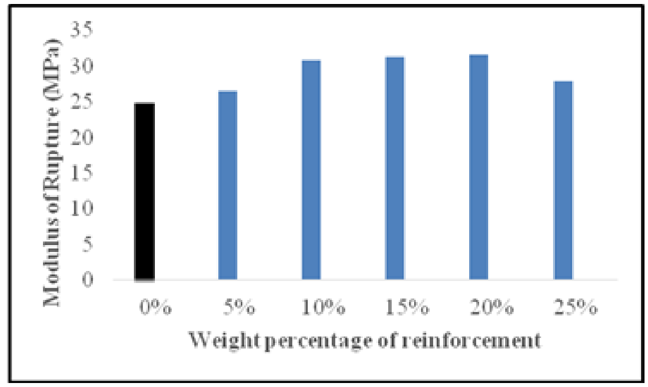

Figure 3: Effect of GSP on the modulus of rupture of RHDPE composites.

Figure 4 shows the MOE of the composites in the range 252.7-448.1 MPa. It is interesting to note that maximum MOE value was achieved at 15 % weight of reinforcement. The flexural strength and flexural modulus of the all composites were observed to be higher than the control sample which indicates that incorporation of treated groundnut shell powder into RHDPE matrix enhanced the material's resistance to bending.

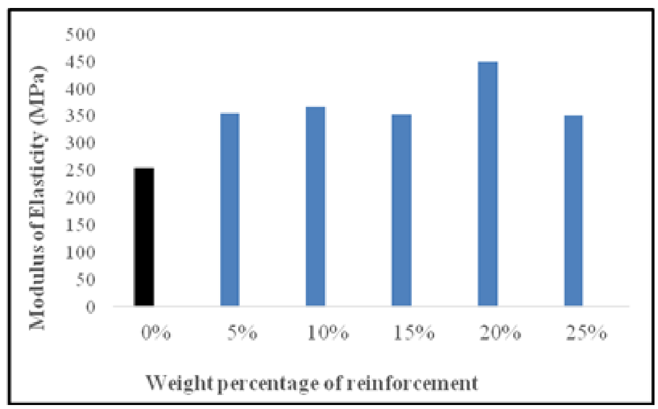

Figure 4: Effect of GSP on the modulus of elasticity of RHDPE composites.

3.1.3 Hardness
Hardness is defined as the resistance of material to localized deformation induced by mechanical indentation or abrasion. Figure 5 shows the hardness value of the control sample and the composites. It is 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 fibres incorporated into the polymer matrix. Fibres are usually added to polymeric materials to improve their rigidity and strength. The higher the percentage of fibres incorporated, the harder the material, and more rigid it becomes.

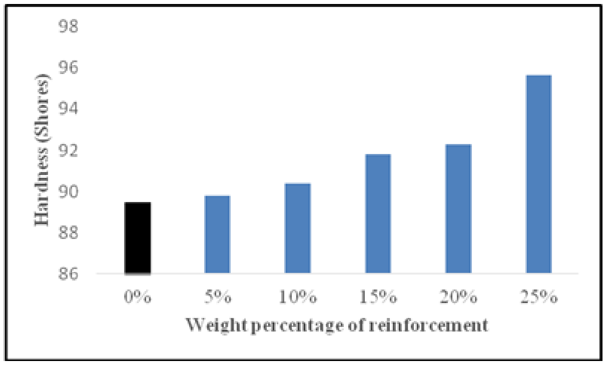

Figure 5: Effect of GSP on the hardness value of RHDPE composites.

3.2 Water absorption

Water absorption, which is an important property used in selecting material for outdoor applications was only 3.4% after 10 days of immersion as depicted in Figure 6. This may be attributed to lower void content in the composite arising from better interfacial bonding between the treated GSP and the RHDPE matrix. Chemical treatment removes non cellulosic materials like lignin, pectin, hemicelluloses and natural fats which make natural fibres prone to water absorption. However, an increase in water absorption with weight fraction of reinforcement could be observed due to void content created at higher fibre fraction leading to increased number of pores. It could also be observed that after 168 hours of immersion, there was no further increase in water absorption, which is evident from the linearity of the plots after 168 hours. This could be attributed to the fact that the pores created may have been saturated with water, thus giving rise to such behaviour. Similar observations have been reported by other authors (Raju *et al.*, 2012; Agunsoye *et al.*, 2012).

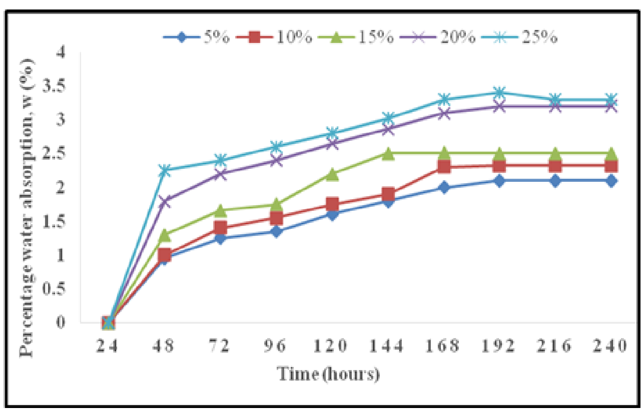

Figure 6: Percentage water absorption of recycled HDPE composites

3.3 Dynamic mechanical properties

3.3.1 Storage modulus

It is the real part of complex modulus; defined as the amount of maximum energy stored by material during one cycle of oscillation (Gupta, 2017; Rana *et al.*, 2017). It also gives an estimate of temperature-dependent stiffness behaviour and load bearing capability of the polymer composites. Figure 7 depicts the variation of storage modulus with temperature of the control sample (G0) and the composites. There is a clear increase in storage modulus with weight fraction of reinforcement and the maximum value was obtained for the composite with the optimum GSP content. This could be attributed to the strong fibre/matrix interaction and the elastic modulus of the treated GSP. However, as the temperature increases, storage modulus decreases for all composites and this may be due to molecular mobility of the polymer chains (Paiva & Frollini, 2006).

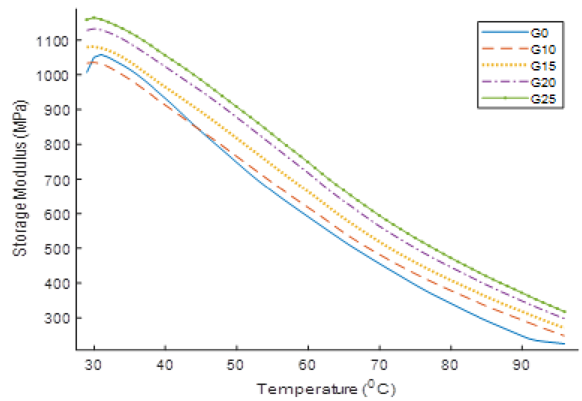

Figure 7: Variation of Storage modulus with temperature of GSP reinforced RHDPE composites at 1 Hz.

3.3.2 Loss modulus

The imaginary part of the complex modulus is called loss modulus; defined as amount of energy dissipated in form of heat by materials during one cycle of sinusoidal load (Gupta, 2017; Rana *et al.*, 2017). It also represents the viscous response of the polymer composites. Figure 8 shows the variation of loss modulus with temperature of the unreinforced sample and the composites. From the curve, it is evident that the energy dissipation of the control sample was higher than the composites; which implies that incorporation of treated GSP into RHDPE matrix inhibited the energy dissipation of the polymer matrix and thus increases its thermal stability (Jacob *et al.*, 2018). At higher temperatures, loss modulus was found to decrease for all the materials.

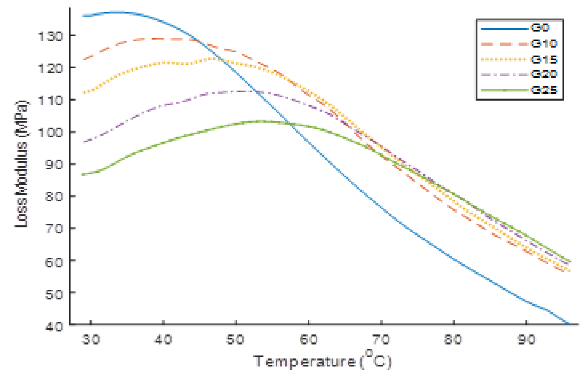

Figure 8: Variation of Loss modulus with temperature of GSP reinforced RHDPE at 1 Hz

3.3.3 Damping

The ratio of loss modulus to storage modulus is known as damping (Gupta, 2018). Damping parameter also called tan ∂ or loss factor is expressed as a dimensionless number. Figure 9 depicts the damping parameter with increasing weight fraction of reinforcement indicated a decrease in damping with weight of GSP in the RHDPE matrix. The trend of decrease in damping with weight fraction of reinforcement shows that composite G25 has good load bearing capacity of all the composites. This could be attributed to good interactions between the fibres and the RHDPE matrix. The sharp drop in tan ∂ curve of the control sample at temperature above 90 °C indicates that the energy dissipation of the material decreases at higher temperature.

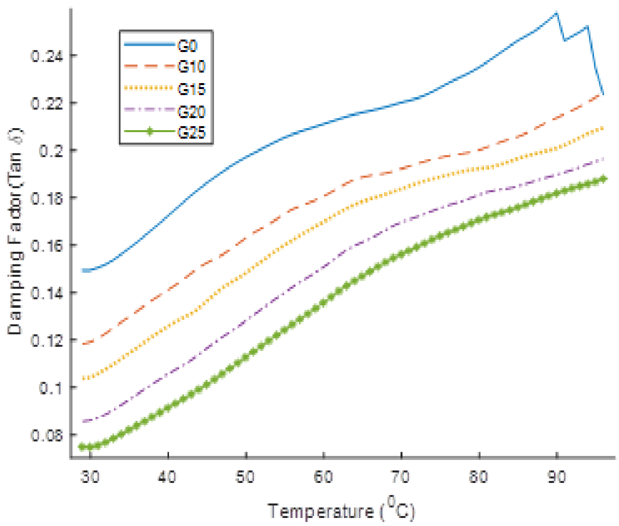

Figure 9: Variation of Tan ∂ with temperature of GSP reinforced RHDPE at 1 Hz

4. Conclusion

Groundnut shell powder filled RHDPE composites were successfully developed and characterized and the following conclusions are made:

- Environmental friendliness, cheapness, low density and good thermo-mechanical properties have made GSP as a good reinforcing material in the development of composites.
- It has been found that composite materials possess appreciable mechanical properties compared to the unreinforced (control) sample.
- Percentage weight fraction of GSP has been found to affect the magnitude of the composites.
- Optimum thermo-mechanical properties were obtained at 20% and 25% weight fraction of reinforcement
- Dynamic mechanical properties such as storage modulus, loss modulus and damping parameter were found to improve with the incorporation of treated GSP.

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