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RESEARCH ARTICLE

EFFECT OF FILLER WEIGHT FRACTION ON THE MECHANICAL PROPERTIES OF BAMBARA GROUNDNUT (OKPA) HUSK POLYETHYLENE COMPOSITE

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ABSTRACT

The increased biomass level of bambara groundnut husk (BGH) in the environment through dumping as a refuge due to high consumption rate of bambara groundnut products has been an environmental concerned. The effect of mechanical properties of the recycled polyethylene (RPE) and recycled polyethylene with 20 percent virgin polyethylene (MPE) was investigated. The weight fractions of the BGH filler loading for this experiment were 10, 20, 25, 30 and 35 percent and processed for the reinforcement of RPE and MPE at 150MPa and 160^{0}C in an injection moulding machine to examine the mechanical properties on the composites. The tensile strength and modulus, flexural strength and modulus, and hardness of the composites increases with increased filler weight fraction of the filler up to 25 percent in the composites and impact strength of the composites decreases with increased filler weight fraction. The increased tensile strength signified that BGH filler may be used for the reinforcement of RPE and MPE. There is significant improvement on the mechanical properties of the MPE composite compared with RPE composite at $p < 0.01$ and $p < 0.05$.

INTRODUCTION

The *Vigna subterranea* commonly known as Bambara or "Okpa" groundnut originated from West Africa (Hepper, 1963). It is commonly cultivated in Sub-Saharan Africa's warm tropics (Gwekwerere, 1995). The abundance and wide spread of the bambara groundnut plants is not only due to multipurpose of its seeds but also due to human consumption. This can either be in the form of "okpa" beans pudding, milk making and bread making (Poulter and Caygill, 2006; Nwaichi *et al.,* 2010; Okeke and Eze, 2006: Akande *et al.,* 2009; Okpuzor *et al.,* 2010; Swanevelder, 1998). It is a very important crop for poorer people in Africa who cannot afford expensive animal protein Okeke *et al.,* 2009; Okeke and Eze, 2006; Baryeh, 2001) because of its high protein value so as to improve the nutrient content. A promising clean up agent for removal of heavy metal contamination of soils due to its potential cost-effective, environmentally sustainable technique and the toxicity of Bambara beans diet harvested from a contaminated soil on test animal (Nwaichi *et al.,* 2010; McGrath and Zhao, 2003) is being ensured from time to time. In fact, the rate of this bambara paste is becoming uncontrollable without considering health and microbial implication to consumers on the high ways (Oranusi and Braide, 2012). Several workers have successfully fed processed bambara groundnut to live stock animals such as poultry based on high nitrogen and phosphorus content, and suitability for livestock feeding (Arijeniwa and Omoikhoje, 2004; Joseph *et al.,* 2000; Akande, 2009). Moreover, researchers have reported the composition of both its seed floor and seed coat proximate composition with high cellulose and proteins content (Akegbejo – Samsons, 2010). The bambara groundnut husk (BGH) have become refuges on many high ways in many south-east part of Nigeria after the removal of bambara groundnut seed. The initiation of this research was not only based on the benefits using BGH as a filler for polyethylene matrix which have not been documented to the best knowledge of these researchers as a reduction of biomass level of BGH in the environment so as to reduced environmental threat that might be posed by BGH in the society but also to study the significant effect of BGH filler loading on the mechanical properties of polyethylene composites.

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MATERIALS AND METHOD

Both virgin and recycled polyethylene was used in this study. The waste polyethylene (PE) was obtained from the industrial waste of IBETO Group of Companies and crushed using the fabricated crushing machine at National Engineering Design and Development institute (NEDDI) in Nnewi, Anambra State, Nigeria. The virgin PE was obtained from chemicals line in Ugah market, Onitsha, Anambra State, Nigeria. The Bambara groundnut seed husk (BGH) was obtained from livestock feeds line in Ose Market, Onitsha, Nigeria.

Composite Preparation

The Bambara groundnut seed husk (BGH) used was sun-dried and then oven-dried at 110^{0}C for 2 days to a moisture content of almost 4.0% percent. Finally, crushed and sieved with the 18-mesh size. The composites were prepared in mixing-ratio of virgin polyethylene, recycled polyethylene and BGH as presented in the Table 1.

Table 1. Composition of the Prepared Composite

Sample	% Virgin PE	% recycled PE	% BGH Filler
A	0	100	0
B	0	90	10
C	0	80	20
D	0	75	25
E	0	70	30
F	0	65	35
G	20	70	10
H	20	60	20
I	20	55	25
J	20	50	30
K	20	45	35

Composite Processing

The BGH filler and polyethylene were fed into an injection moulding machine of the reciprocating screw type to produce the composite samples. The operating pressure and temperature of the injection moulding machine was 150MPa and 160^0C respectively. Process time for each sample was 30 – 60 seconds averagely. The following mechanical tests were carried out to assess the effects of the bambara husk filler on the mechanical properties of polyethylene. Samples of the BGH filler - polyethylene composites were cut into specified dimensions and tested at room temperature in accordance with ASTM standards.

Tensile Testing

Tensile properties were carried out on the samples using a KAOH TIEH Instron Testing Machine, in accordance with ASTM 638-90, at a cross-head speed of 200rev/min. The dimensions of each sample were 150mm (length) x 30mm (width) x 5mm (thickness). Held by the gripping heads, the specimens were pulled till failure and the respective loads and extensions noted. The values thus gathered were used to calculate the strain, tensile strengths, and modulus of the specimens A to K using the equation (1) and (2) as reported by Raju *et al*. (2012).

$$T_s = \frac{P}{bt} \quad (1)$$

T_s is the tensile strength of the sample, P is the pulling force, b is the sample width and t is the sample thickness.

$$T_m = \frac{\sigma}{\varepsilon} \quad (2)$$

T_m is the tensile modulus, σ is the stress and ε is the strain.

Flexural Testing

Flexural properties were carried out by 3-point bending tests on composite samples with dimensions 60mm (length) x 20mm (breadth = width) x 20mm (thickness) using a WP 300.4 bending device in accordance with ASTM 790 – 90. Equation 3 and 4 was used to obtain the flexural strengths and modulus respectively of the samples.

$$R_f = \frac{3FL}{2bt^3} \quad (3)$$

R_f is the applied flexural strength, F is the flexural load, L is length of the support span (mm), b is the width of the sample and t is the thickness of the composite sample.

$$R_m = \frac{mL^3}{4bt^3} \quad (4)$$

R_m is the flexural modulus, m is the slope of the tangent to the initial line portion of the load deflection curve.

Impact Testing

The unnotched impact properties were conducted on all specimens in accordance with ASTM D 256-90. Prepared specimens were subjected to fracture by a pendulum – Type Impact Testing Machine and the unnotched toughness values of the composites obtained by reading off the energy expended to rupture each specimen.

Hardness Testing

Brinell Hardness Test was conducted on flat samples of both RPE and MPE using a manually-operated Universal Testing Machine. A hardened steel ball with a diameter of 10mm was used in performing the test. The indentations on the specimens were measured (diameter-wise) and appropriate mathematical methods used for conversion to obtain the Brinell Hardness Values reference made to Figure 6. The equation for the Brinell Hardness Number (*HB*) is given as:

$$HB = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

P is the applied Load measured in kg, D is diameter of steel ball (10mm) and d is the diameter of indentation (mm)

Statistical Analysis

The statistical analysis was conducted using SPSS Version 17.0 with bivariate correlations. The Pearson's correlation coefficient test was conducted to test of significance with two tail of p-value less than 0.01 or 0.05 was considered statistically significant between RPE and MPE composites.

RESULTS

Tensile strength and Modulus

The tensile strength and modulus of both RPE and MPE composite increases from 30.33 MPa to 35.14 MPa with increased BGH filler loading up to 25 percent weight fraction and latter decreases to 27.45 MPa with increased BGH filler loading beyond 25 percent weight fraction as illustrated in Figure 1.

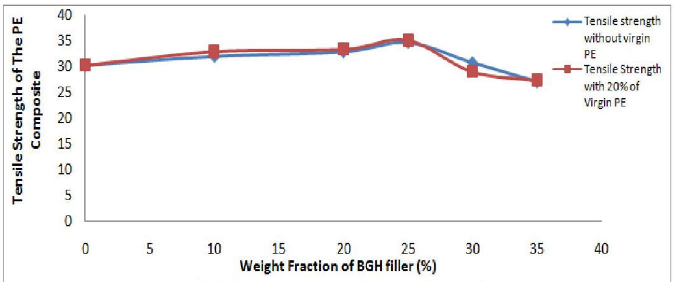

Figure1: Tensile strength of the PE composite as a function of weight fraction

The tensile modulus of the composites increases with increased weight fraction of the BGH filler loading. Based on the results obtained as shown in the Figure 2, the tensile modulus for RPE composite increases from 240.7 to 861.2 MP a which is about 257.8 percent and MPE composite increases to 924..7 MP a amounted to about 284.2 percent.

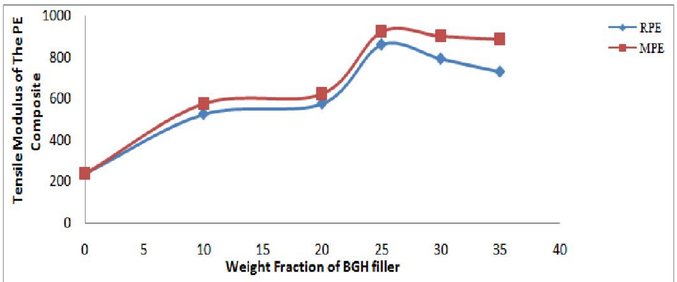

Figure2: Tensile modulus of the PE composite as a function of weight fraction

Flexural strength and modulus

The flexural strength of RPE and MPE composite increases with increased up to 35 percent BGH filler loading by 74.74 and 55.26 percent respectively. The flexural modulus of RPE and MPE composite increases with increased in filler fraction by 121.14 and 148.78 percent respectively.

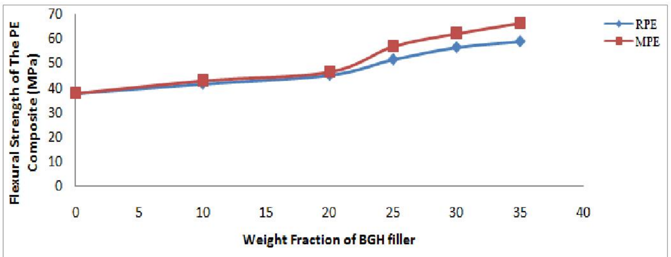

Figure 3: Flexural strength of the PE composite as a function of weight fraction

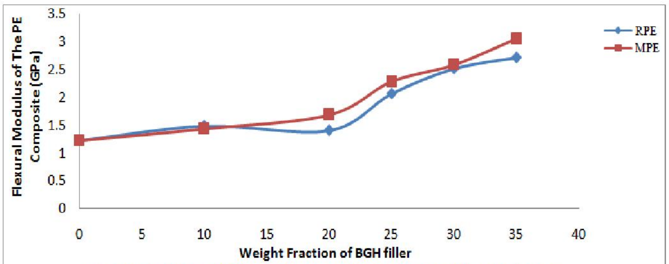

Figure4: Flexural modulus of the PE composite as a function of weight fraction

Impact strength

In contrast, the impact strength of the composite decreases from 583J/m to 40J/m and from 410J/m to 100J/m for RPE and MPE composite respectively with increased BGH filler loading as illustrated in Figure 5.

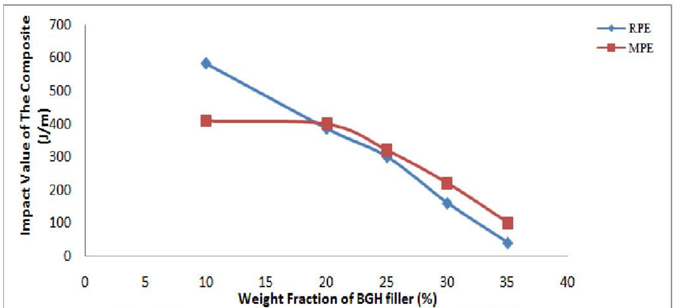

Figure 5: Impact strength of the composite with increased BGH filler

Hardness

The hardness numbers of composites increases with increased weight fraction of the BGH filler loading as shown in the Figure 6. The hardness value increases by 662.2 percent for MPE composite and 440.9 percent for RPE composite.

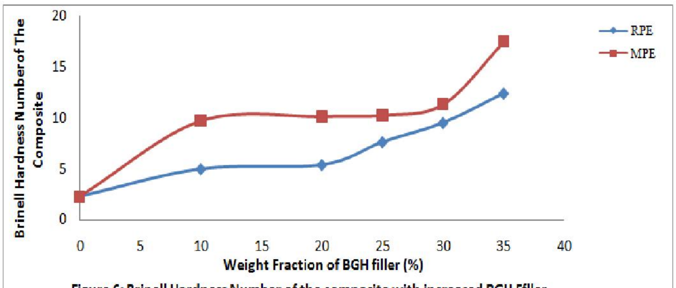

Figure 6: Brinell Hardness Number of the composite with increased BGH Ffiler

DISCUSSION

The increased tensile strength of RPE and MPE composite for 25 percent of weight fraction of the BGH filler loading was the same and amounted to 15.86 percent and latter, the tensile strength decreased by 9.5 percent for both RPE and MPE composite after 25 percent filler loading. The increased tensile strength attributed to an effective creation of an interfacial adhesion bond between filler (hydrophilic) and PE (hydrophobic), and morphological changes as reported by many researchers (Luyt, 2009; Yao *et al.,* 2008; Yang *et al.,* 2004; Ratnam *et al.,* 2010). It was also obtained that there is significant effect of 0.004 ($p < 0.01$) of BGH filler loading on tensile strength with correlation coefficient of 0.949 between MPE and RPE composites which indicated that the addition of 20 percent of virgin PE was statistically significant in the composite applications. The increased in tensile modulus of the MPE compared with RPE as shown in the Figure 2 indicated that addition of 20 percent of virgin PE significantly influenced the rigidity of the composite. Though, tensile strength and modulus decrease latter as the weight fraction of the BGH filler loading above 25 percent. The addition of 20 percent of virgin PE gave a significant effect of 0.000 ($p < 0.01$) of BGH filler loading on tensile modulus with correlation of 0.990 between RPE and MPE composites. The result of flexural test indicated that the composite increases its flexibility at increased BGH filler loading as illustrated in the Figure 3 and 4. This is a common phenomenon and similar to the report of many researchers (Zaini *et al.,* 1996; Yang *et al.,* 2004; Imoisili *et al.,* 2012). There is also significant effect of 20 percent addition of virgin PE on the flexural modulus of RPE and MPE composites at significant level of 0.001 ($p < 0.01$) with correlation coefficient of 0.981. The significant effect may be attributed to improvement on the flexibility of the composite by the effect of 20 percent of weight fraction of the virgin PE present in the MPE composite which improve the stiffness of the composite.

The decreased in impact strength could be attributed to the poor wetting of the BGH with the PE blends, which lead to poor interfacial adhesion between the fiber and polymer matrix and leads to creation of weak interfacial regions. The poor interfacial adhesion exists between hydrophobic matrix and hydrophilic nature filler usually results in decreased toughness as reported by Raju *et al*. (2012). Thus, the decline in impact strength with the increased BGH filler loading is attributed to the poor interfacial adhesion between the hydrophobic (PE) matrix and hydrophilic BGH filler**.** In addition to this, incorporation of fillers resulted in reduction in polymer chain mobility, thereby lowering the ability of the system to absorb energy during fracture propagation. There is significant effect of 0.018 ($p < 0.05$) with Pearson correlation coefficient of 0.939 on impact strength between RPE and MPE composites due to 20 percent virgin polyethylene present in MPE composite. The increased in hardness of RPE and MPE can be attributed to adhesive bonding between the polyethylene matrix and BGH filler but incorporation of 20 percent of virgin PE makes the MPE hardness to be greater than RPE. The hardness results show that MPE is significantly increased due to 20 percent virgin PE compared with RPE. Statistically, the correlation coefficient between RPE and MPE composite is 0.925 with significant value of 0.008 ($p < 0.01$).

Conclusion

The result obtained shows that the tensile modulus, flexural strength and modulus and hardness value of the composites increases significantly with increased Bambara groundnut husk filler. The tensile strength of the composite increases with increase up to 25 percent of the weight fraction of the BGH filler and decreases above 25 percent weight fraction of the BGH filler. It can also be deduced that the impact strength of the composite decreases with increased weight fraction of the filler. Moreover, there is significant improvement in the mechanical properties of the composites which could be attributed to 20 percent virgin polyethylene present in the composites with recycled polyethylene (MPE) compared with only recycled polyethylene (RPE).

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