DEVELOPMENT OF FIRE RETARDANT BIOCOMPOSITE ROOFING SHINGLES FROM RECOVERED POLYMER WASTE

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ABSTRACT

The present work is on the development of flame retardant roofing shingles using recycled Low-Density Polyethylene (rLDPE), Coconut Shell particle-fibre and Rice Husk Ash (RHA). The test samples were prepared by compounding and hot compression molding in a plastic compression molding machine. Ten samples were produced from various filler loadings in order to obtain a mix ratio with the best mechanical properties. The best sample was then selected for further analysis on its thermal and morphological characteristics. Water absorption characterization of all samples was also carried out to determine percentage equilibrium of water absorption. Sample 'E' has the highest tensile strength of 8.54MPa, highest flexural strength of 16.16MPa, highest flexural modulus of 415.44MPa, impact strength of 2.60J/m and hardness value of 48.20HV. Sample 'E' showed an increase in glass transition temperature, T_g by 3.53% when compared to neat recycled Low-Density Polyethylene and also presence of microscopic voids resulting from filler agglomeration. The water absorption content of the sample E is 0.91%. The results obtained and analysis carried out revealed that Sample 'E' with a composition of 5% coconut shell particle-fibre, 20% Rice Husk Ash and 75% recycled Low Density Polyethylene was adopted in this work based on its better performance in regards to mechanical properties. Results obtained are in agreement with findings of Ziyad *et al*, Chira *et al*, Khan *et al*, Atuanya *et al*, Koay *et al* and Porabka *et al.*

Keywords: Biocomposite, Recycled Low-Density Polyethylene (rLDPE), Coconut particle fibre, Rice Husk Ash (RHA), Glass transition temperature (T_g).

1. INTRODUCTION

A waste material can be defined as any substance which is discarded after primary use or is worthless, defective and of no use. Waste generated by industrial, domestic and agricultural activities have been accelerated over the years owing to population growth, increasing urbanization and rising standard of living due to technological innovations [1].

According to information by United Nations Environment Programme in 2019, the world produces an estimated 300 million tons of plastic waste each year. To date only about 9% of plastic waste ever generated have been recycled, and only 14% is collected for recycling [2]. These figures however vary geographically, according to plastic types and applications [3].

The major concern about plastics is its longevity whether or not they truly biodegrade. It is estimated that it takes 500 to 1000 years for plastics to break down into its organic components. As a result of this longevity coupled with low recycling and recovery rates, most plastics end

up in landfills or eventually find their way into the ocean where they directly or indirectly affect marine life in our ecosystem [4]. As a solution to this vexing problem of plastic waste management, plastic recovery presents a realistic and feasible option of cleaning up trillions of pieces of waste plastic building up in our environment.

Resource recovery entails using wastes as an input to create valuable products as new outputs. Recycling on the other hand is limited by serious technical and economic barriers, but with advances in processing mixed waste plastics has led to the development of innovative Polymer Matrix Composite materials [5]. One of such innovations is Polymer Biocomposites.

Polymer Biocomposites are composite materials comprising one or more phase(s) derived from biological origin. There is need to make composites from plastics because most plastics by themselves are not suitable for load bearing applications due to their lack of sufficient strength, stiffness and dimensional stability [6].

Coconut shell is an agricultural waste available in large quantities throughout tropical countries worldwide with Nigeria not being an exception [7]. Moreover, agricultural waste such as rice husks which are the outer protective coverings of paddy which is separated from the seeds. Rice Husk Ash (RHA) is the major by-product left after the burning of rice husk, which is profusely present throughout rice processing facilities where paddy is processed into rice. RHA, in turn causes more environmental pollution and its disposal becomes a difficult problem, hence requiring serious attention from the scientific community regarding its disposal and proper reuse if possible [8]. Use can therefore be made of these agricultural wastes by using a combination of coconut shell particle-fibre and RHA as filler material in the development of polymer bio-composites.

In this work, fire retardant biocomposite roofing shingles is being developed from recovered polymer wastes.

2. Review of Related Works

Ghani et al in 2014 conducted an investigation on the effects of rice husk content on mechanical and morphological properties of recycled polymer biocomposites. Two types of recycled plastic High-Density Polyethylene (rHDPE) and Polyethylene terephthalate (rPET) were mixed with various amount of rice husk content. Tensile and flexural tests demonstrated that rHDPE/rPET/RH biocomposites present improved mechanical performances comparatively to the unfilled polymer blend. The addition of RH in the polymer blend drastically reduced the impact strength. Microstructure analysis was carried out on the composite fracture surface using a Scanning Electron Microscope (SEM) to investigate interfacial bonding between the polymer blends and rice husk [9].

Askanian et al in 2015 carried out an investigation on the potentials of different agro-wastes as reinforcements for thermoplastics as an alternative to wood fibres. Olive pits flour, walnut nutshells flour and cherry pits flour were used as filler for Polylactic Acid. Thermal behaviour of the composites was studied to investigate the nucleation effect of the lignocellulosic flour. The effects of filler loading on the mechanical properties, as well as viscoelastic behaviour were also studied. The results indicated that these agricultural by-products can be used as filler in production of biocomposites without any further treatment, especially in the case of walnut nutshells flour and cherry pits flour [10].

Lazrak et al in 2018 investigated the stability, mechanical properties and the microstructure of Wood–Plastic Composites, which were fabricated using recycled High-Density Polyethylene (HDPE) with pine wood flour used as fillers. Composite panels were obtained using hot-press moulding. The tensile and flexural properties of the composites based on recycled HDPE revealed that the strength properties of the composites can be improved by increasing the polymer content, also the composite formulation significantly improved the morphology and the stability. Scanning Electron Microscope (SEM) was used to characterize the morphology of the wood particulate/HDPE interface. It was clearly proved from the results that Wood-Plastic Composite (WPC) based on recycled High-Density Polyethylene (HDPE) can be successfully utilized to fabricate stable and strong WPCs [11].

Sampathkumaran et al in 2014 reported the preparation of fly ash cenospheres bearing polymer composites, using various polymer matrix materials namely, Low-Density Polyethylene, Polystyrene and Polymethylmethacrylate followed by evaluation of properties. The investigation revealed that the addition of fly ash cenospheres to various polymer matrices resulted in reduction of density. Also, further improvements in slide wear resistance and decrease in co-efficient of friction values were noticed. Hardness properties increased while compression strength and impact energy decreased with inclusion of cenospheres in all four types of samples investigated [12].

Sanusi et al in 2013 investigated the role of wood ash as an additive in the formulation of Polymer Matrix Composite (PMC) in varying percentages. On comparative basis, the inclusion of wood ash in the formulation of Polymer Matrix Composite (PMC) resulted in significant increase in impact and tensile strength. While the impact resistance was improved by two times as a result of incorporating wood ash, tensile strength of the PMC was enhanced by more than thirty-six percent (36%). The hardness of the formulated PMC increases progressively with the increase in the wood ash content. The microscopic analysis revealed that the wood ash particles were uniformly distributed in the matrix without evidence of segregation [13].

Mohammed et al in 2015 was able to show that higher content of silica derived from Rice Husk Ash (RHA) in geopolymer coating results in better thermal properties. [14].

Ahmad et al in 2017 in a study incorporated Rice Husk Ash (RHA) and RHA derived silica aerogel into Low-Density Polyethylene (LDPE) as a filler. The effect of percentage by weight of the different fillers on the thermal properties was also determined. Both fillers show improvements in terms of the thermal stability of the composite when compared to unfilled LDPE but comparisons between the silica aerogel and RHA shows that silica aerogel's performance slightly edges the performance of RHA. The incorporation of silica aerogel as filler shows better thermal stability when compared to RHA with a slight increase in onset degradation temperature as the filler percentage increases. In terms of thermal conductivity, the addition of silica aerogel as filler shows an increase in thermal insulation strength when compared to RHA [15].

Chuenkhwan et al in 2020 investigated Polylactic Acid (PLA) samples containing a Layered Double Hydroxide modified with Sodium Dodecyl Sulfate (PKL_DS), silica from Rice Husk Ash (SiRHA) and a combination of the two nano-fillers. TGA showed only the addition of SiRHA significantly improved the thermal stability of PLA. Also, the flammability performance of PLA nanocomposites was investigated using Limiting Oxygen Index (LOI) and UL-94V type measurements. It was found that there was synergism between PKL_DS and SiRHA, and this was very effective in improving the flame retardant performance of PLA [16].

Agunsoye et al in 2012 investigated the morphology and mechanical properties of coconut shell reinforced polyethylene to establish the possibility of using it as a new material for engineering applications. The results obtained shows that the hardness of the composite increases with increase in coconut shell content though the tensile strength, modulus of elasticity, impact energy and ductility of the composite decreases with increase in the particle content. Scanning Electron Microscopy (SEM) of the composites (with 0% - 25% particles) surfaces indicates poor interfacial interaction between the coconut shell particle and the Low-Density Polyethylene matrix [17].

Porabka et al in 2015 investigated the possibility to modify Low-Density Polyethylene (LDPE) with Fly Ash (FA). The influence of amount and the particles size of filler on morphology, mechanical properties, thermal stability and flammability of the composites were investigated. The results show that composites with the addition of FA in the amount up to 20 wt% are characterized by good mechanical properties and processibility, and also less flammable when compared to neat LDPE [18].

Currently, recycling, recovery or reuse of raw materials has made it possible to reintegrate raw materials from steadily increasing waste streams back into the manufacturing process. Agricultural wastes such as rice husk and coconut shell are valuable raw materials for lignocellulosic-based production. However, to the best of the researcher's knowledge, the flame retardation properties of the rice-husk ash and coconut shell reinforced recycled polyethylene has not been fully investigated and documented.

3. Materials, Equipment and Methods

3.1 Materials

The following materials were used for the research work;

Recycled Low-Density Polyethylene (rLDPE) from waste water sachet as matrix, Chlorine water (HClO), Iron (III) oxide (Fe_2O_3) as colorant, Rice Husk (RH) and Coconut particle fibre as fillers.

3.2 Equipment

The major equipment used in this research are: Tensometer, Universal Materials Testing Machine, Microvickers Hardness Tester, Charpy Impact Testing Machine, Dynamic Mechanical Analyzer, Scanning Electron Microscope, Compounding Machine, Hot-compression moulding machine, Furnace, Shredding machine, Grain milling machine, Weighing scale, Grain sieve. All the equipment are available at Nigerian Defence Academy Kaduna, Ahmadu Bello University Zaria, Nigerian Institute of Leather and Science Technology Zaria and Umaru Musa Yar'adua University, Katsina.

3.3 Methods

3.3.1 Processing of Recycled Low-Density Polyethylene, Coconut particle fibre and Rice Husk Ash

The collected rice husk and the coconut shells were sorted separately, washed thoroughly with water and dried in oven at a temperature 150^{o}C until the moisture content was greatly reduced. The rice husk was calcinated using a furnace temperature of 700^{o}C for 3hours [19]. The coconut shells were milled into particulate form. The milled coconut shell particles were then sieved using ASTM sieve size 72μm and then treated with prepared Chlorine water. Plate 3.1 (a) and (b) below shows untreated and treated coconut powder respectively while plate 3.2 shows a picture of Rice Husk Ash (RHA).

Plate 1 (a), (b), and (c) below shows samples of untreated coconut particle fiber, treated coconut particle fibre and Rice Husk Ash (RHA) respectively.

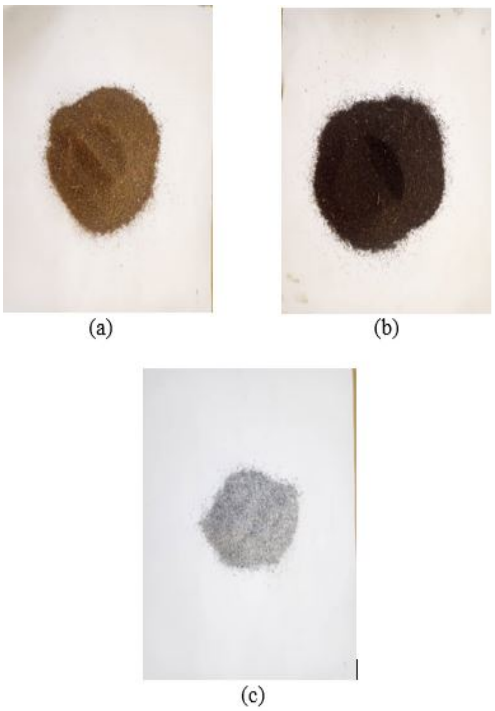


Plate 1: (a) untreated coconut particle fiber, (b) treated coconut particle fibre and (c) Rice Husk Ash (RHA).

The recycled Low-Density Polyethylene (waste water sachets) were shredded using a shredding machine so as to ease the formulation process.

Plate 2 below shows shredded recycled Low-Density Polyethylene from waste water sachets.

Plate 2: Shredded waste water sachets.

3.3.2 Fabrication of Composites

The composite test samples were produced by a mixing process involving the introduction of the pre-cleaned recycled Low-Density Polyethylene (rLDPE) of measured weight while the rolls of the Two Roll Mill machine were in counter clockwise motion. Softening and

subsequent melting of the polymer matrix for a period of 5 minutes at a pre-set temperature of 150°C occurred.

Upon achieving a band formation of the rLDPE on the front roll, the required percentage by weight of fillers (RHA/Coconut shell powder) were manually added to the band as the rolls rotate at a rate of 500 rpm.

The compounded composite was drawn out and designated A, B, C, D, E, F, G, H, I, J and K respectively according the formulation in table 1 below.

Table 1: Formulation of Biocomposite test samples.

Sample	Rice husk Ash (g)	Coconut Shell Particle-fibre (g)	rLDPE (g)
A (Control)	0	0	100
B	5	5	90
C	10	5	85
D	15	5	80
E	20	5	75
F	25	5	70
G	30	5	65
H	35	5	60
I	40	5	55
J	45	5	50
K	50	5	45

3.3.3 Compression Molding Process

The composite obtained from the mixing process were filled into a metal mold of dimensions 200mm x160mm x 10mm designed for Slate prototype and were then placed on the hydraulic hot press for compression at a temperature of 130°C and pressure of 2.5MPa or 25bar for 5mins. Plate 3 below shows compounded composite material prepared for hot compression in a mold while plate 4 shows the various composites after hot compression.

Plate 3: Compounded composite material.

Plate 4: Compounded composite material after hot compression.

3.4 Experimentation

The following tests and analysis were conducted on the various specimens using various international standard procedures; Tensile Test (ASTM D638), Three-Point Flexural Test (ASTM D790), Impact Test (ASTM D256) and Hardness Test (ASTM D2240), Water Absorption Test (D2842) and Thermal Test (ASTM D7028).

Shown below in plate 5 are prepared composite specimens for the various tests.

Plate 5: Composite specimens prepared for the various tests carried out.

3.5 Roofing Slate Production

Prototype samples of a roofing slates were produced using the optimum composition that gave the best mechanical properties. This was done using a mix ratio of 1:4:15 of coconut shell particle-fibre, RHA and rLDPE respectively.

Compounding was done by introducing rLDPE while the rolls of the two roll mill machine were in counter clockwise motion. Softening and subsequent melting at a pre-set temperature of 150°C for a period of 5 minutes. Also at this stage, 5g of Fe_2O_3 was added as colorant for each sample.

Upon achieving a band formation of the rLDPE on the front roll, the required ratio of fillers RHA/Coconut shell particle-fibre were manually added to the band as the rolls
rotate at a rate of 500 rpm. The compounded composite was drawn out.

The composite obtained from the mixing process were filled into a metal mold of dimensions 400mm x 340mm x 5mm designed slate prototype and were then placed on the hydraulic hot press for shaping at a temperature of 130^{o}C and pressure of 2.5MPa or 25bar for 5mins.

Plate 6 below shows five prototype roofing slate samples produced using the optimum mix composition (Sample E).

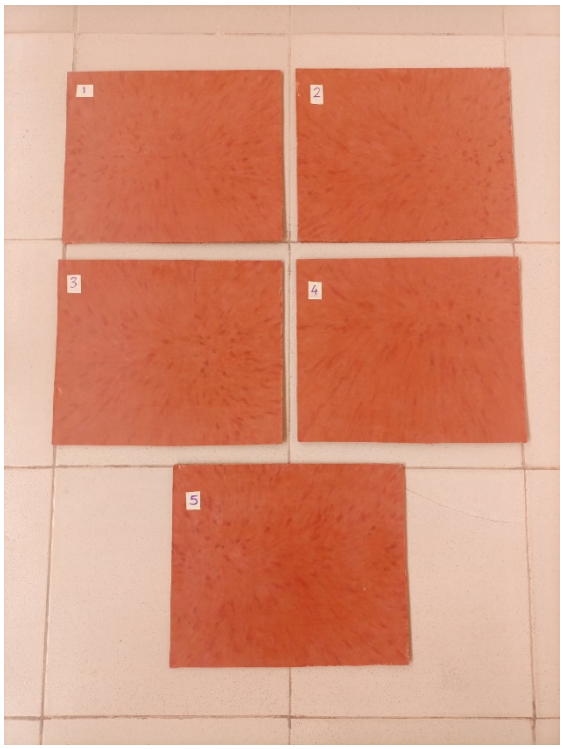


Plate 6: Prototype samples produced using the optimum mix composition (Sample E).

4. Discussion

4.1 Discussion of Results of Experiments

4.1.1 Tensile Strength properties of rLDPE Composites.

Figure 1 below shows the effects of filler loading on the tensile properties for rLDPE.

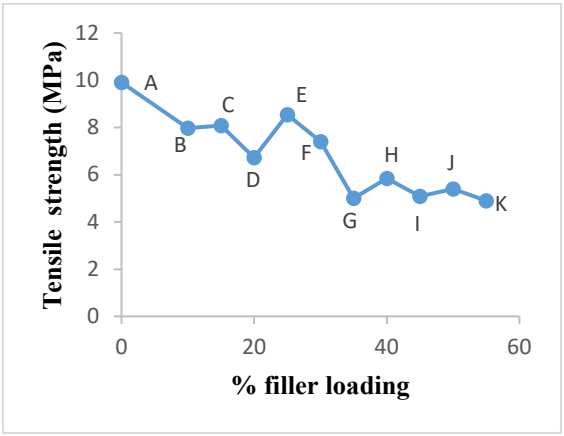


Figure 1: Variation of tensile strength of rLDPE with varying filler loading.

From the results, it is evident that tensile strength of the samples A to K decreases from 9.91Mpa for neat rLDPE down to 4.90MPa. Sample E produced the highest tensile strength for the reinforced composite with a value of 8.54MPa at 25wt% filler loading.

The decreases recorded in tensile strength properties after reinforcement of the matrix with filler material confirms the fact that increasing ash content results in the reduction of tensile strength characteristics of rLDPE. This is because the filler particle agglomerates resulting to a lower dispersion, reduced compatibility as result of poor interfacial bonding and hence ultimately weakening the tensile strength characteristics of the composites. This postulation is congruent to findings made in a research by Khan *et al* [20], Ziyad *et al* [21] and Zikri *et al* [22].

4.1.2 Flexural Strength properties of rLDPE composites

Flexural strength, also known as rupture strength or bending strength is defined as the maximum stress in a material just before it yields under bending load. The effects of filler loading on the flexural strength for neat rLDPE and Reinforced rLDPE is shown in figure 2 below.

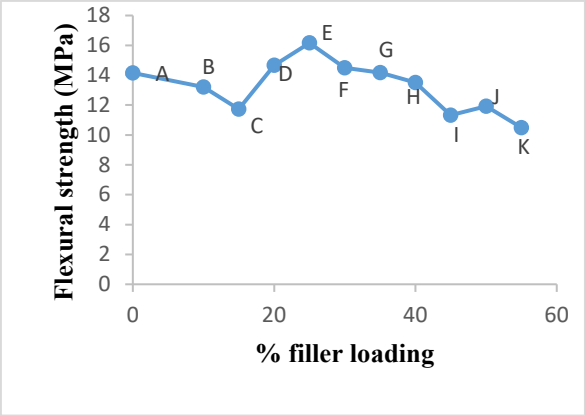


Figure 2: Variation of flexural strength of rLDPE with varying filler loading.

The results obtained from flexural test shows that the value of flexural strength of neat rLDPE is 14.15MPa. After reinforcing the matrix with filler material, a decrease to 13.21MPa and then 11.74MPa respectively was noticed. After this initial decrease, an increase is then noticed as the flexural strength increases to 14.67MPa before finally reaching a peak value of 16.16MPa at 25wt%. Beyond this peak value, further increasing the ash content results in a decline flexural strength. This is as a result of the RHA saturating the matrix (rLDPE) and therefore producing a weaker composite. This postulation is congruent to findings made by Adeosun *et al* [23] and Chira *et al* [24].

4.1.3 Flexural Modulus of rLDPE Composites

Flexural modulus or bending modulus is an intensive property that is computed as a ratio of stress to strain in flexural deformation. It depicts a materials ability to resist bending. The effects of filler loading on flexural modulus for neat rLDPE and Reinforced rLDPE is shown in figure 3 below.

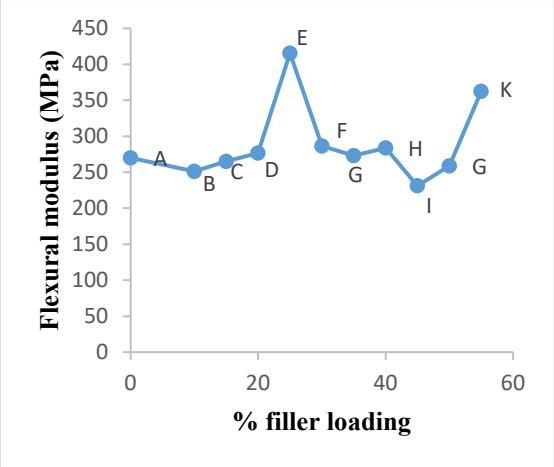


Figure 3: Variation of flexural modulus of rLDPE with varying filler loading.

From the results, it can be seen that the flexural modulus of neat rLDPE is 270.24MPa. After reinforcing the matrix with filler material, a marginal decrease in flexural modulus was initially noticed with values 251.37MPa and 265.35MPa after which it increases to 276.91MPa before reaching a peak value of 415.44MPa at 25wt%. Beyond this peak value, further increasing the ash content results in a decline of flexural modulus. This postulation is in agreement with findings made in a research by Khan *et al* [20] and Ahmad *et al* [25].

4.1.4 Hardness properties of rLDPE Composites

Hardness can be defined as the resistance of material to permanent deformation of the surface through scratching, abrasion, cutting indentation or penetration. The effect of filler loading on hardness values of neat rLDPE and reinforced rLDPE is shown in the plot on figure 4 below.

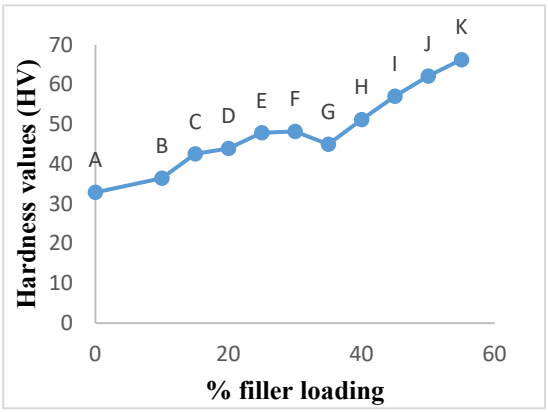


Figure 4: Variation of hardness values of rLDPE with varying filler loading.

Hardness values increased with increase in loading of filler material from a value of 32.9 HV up to 66.3HV at 55wt%. This result correlates with the works of Nanonenyi *et al* [26] and Ogbonna *et al* [27].

4.1.5 Impact properties of rLDPE Composites.

Impact strength can be defined as the ability of a material to absorb energy during plastic deformation. It is a measure of toughness of a material. The effect of filler loading on impact strength for neat rLDPE and reinforced rLDPE is shown in figure 5 below.

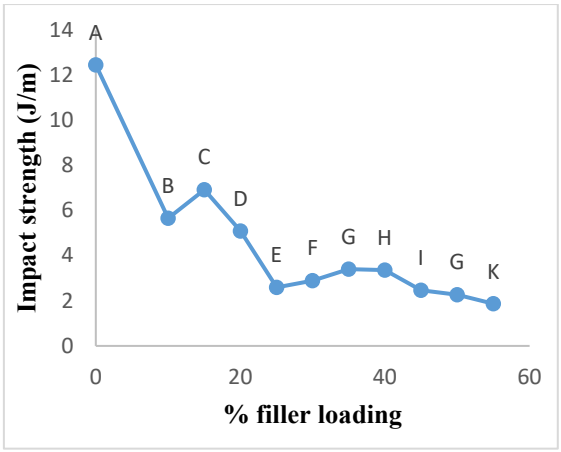


Figure 5: Variation of impact strength of rLDPE with varying filler loading.

From the results, it is observed that impact strength decreases with increase in content of filler material from a value of 12.47J/m to 1.87 J/m at 55wt%. Sample E recorded a value of 2.6J/m This result is in agreement with the works carried out by Atuanya *et al* [28] and Darunee *et al* [29].

4.1.6 Thermal properties of rLDPE Composites

Thermal test was carried out using Dynamic Mechanical Analysis (DMA). Figure 6 below shows the DMA trace of neat rLDPE (sample A) showing the storage modulus (E′), loss modulus (E″), loss factor (tanδ) and static length change (dL) against temperature.

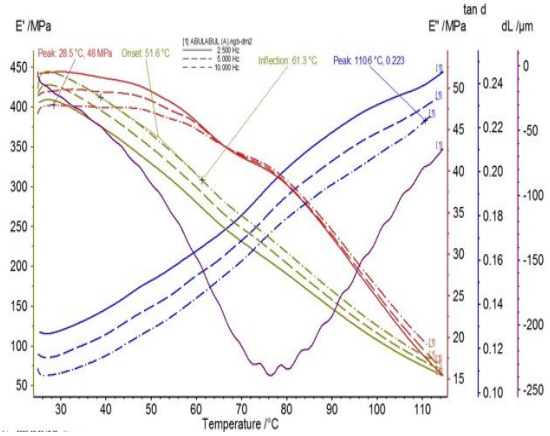


Figure 6: DMA trace of neat rLDPE showing E', E", tan d and dL against Temperature.

DMA measurement was carried out between 25ºC to 120ºC at a heating rate of 6.0K/min and at frequencies of 2.5, 5.0 and 10Hz. Depicted in the plot above are the storage modulus (E′), loss modulus (E″), loss factor (tanδ) and static length change (dL).

The points of DMA trace for the neat recycled LDPE can be observed on E′ at 51.6ºC (onset) and 61.3 º C (inflection). E″ at 28.5ºC(peak) and stress 48MPa. Tanδ at 110.6ºC (peak) and loss factor of 0.223. dL at 76.4ºC is -239.0µm.

Figure 7 below shows DMA graph of composite formed by 5% coconut particle-fibre, 20% RHA and 75% rLDPE (sample E) Showing E′, E″, tan d and dL against temperature.

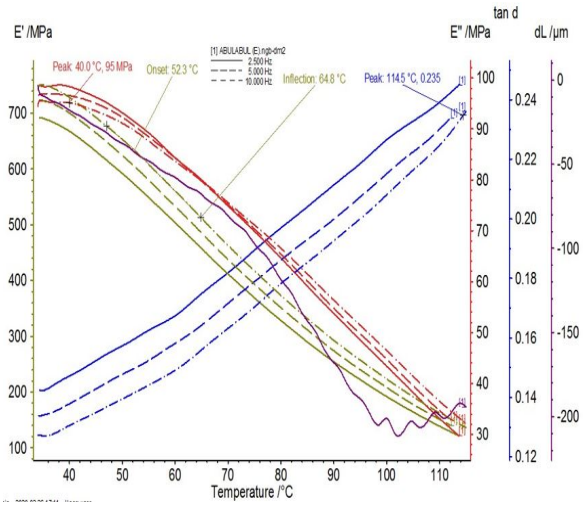


Figure 7: DMA trace of sample E Showing E′, E″, tan d and dL against Temperature

The DMA measurement was carried out at 33°C to 120°C at a heating rate of 6.0K/min and at frequencies 2.5, 5.0 and 10Hz. The points of DMA trace for reinforced rLDPE can be observed in E' at 52.3°C (onset) and inflection at 64.8 ° C. E" at 40.0°C (peak) and stress 95MPa. Tanδ at 114.5°C and loss factor 0.235. dL at 102.2°C is -211.3µm [30].

Figures 6 and 7 show that E′ increased after matrix reinforcement by 3.5°C (taken at the points of inflection) which signifies a 5.71% increment. This is an indication of increase in stiffness of the reinforced polymer which is also confirmed by a corresponding increase in the glass transition temperature, T_g (taken at the peak of tanδ curve) which increased by 3.9°C signifying a 3.53% increment. Also, the loss factor increased by 0.012 signifying a 5.38% increase.
This can be attributed to the fact that addition of fillers/fibers to polymer matrix increases its stiffness or reduces movement of the polymer chains hence, causing an increase in glass transition temperature (T_g). This postulation is in agreement with that made by Ilori *et al* [31].

4.1.7 Water Absorption properties of rLDPE Composites

Figure 8 below is a plot of variation of equilibrium % water absorption against filler loading.

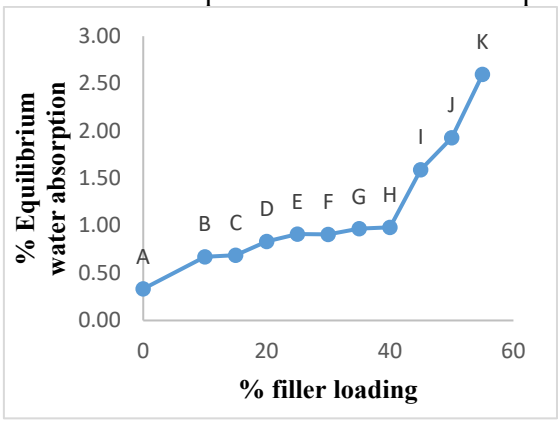


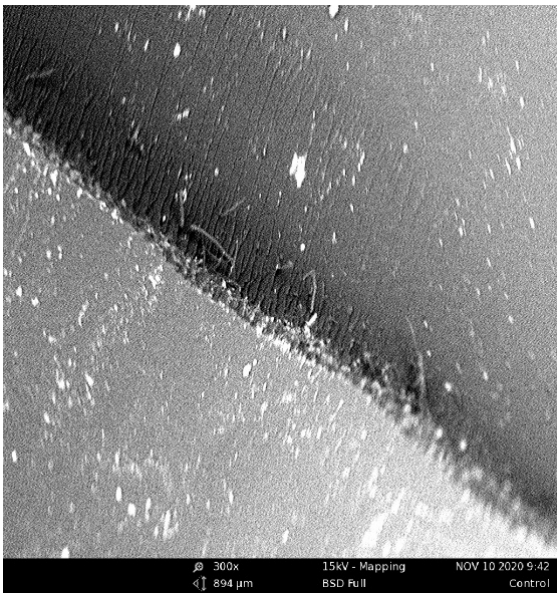
Figure 8: Variation of equilibrium % water absorption of rLDPE with varying filler loading.

From the results, it can be observed that water absorptivity is found to increase with increase in content of filler material. The value for water absorptivity for neat recycled LDPE is found to be 0.33% and increased to a peak value of 2.60% at 55wt% after reinforcement. Sample E recorded a value of 0.91%.

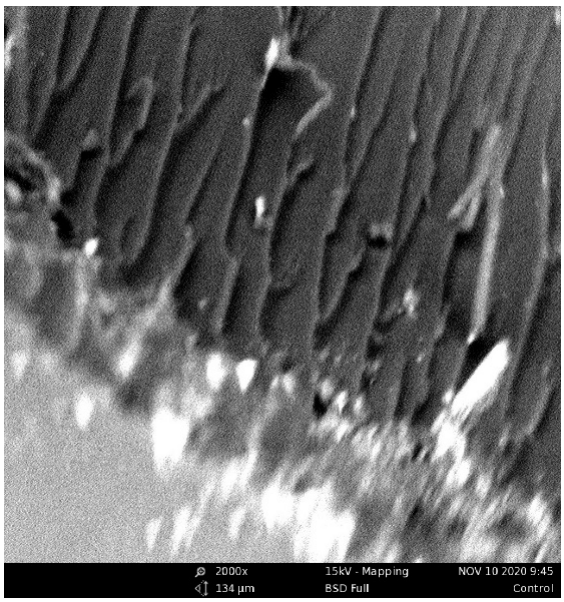
This increase in water absorptivity can be attributed to the hydrophilic nature of both coconut shell particles and rice husk ash (RHA). On the other hand, neat recycled LDPE is hydrophobic in nature but the slight increase in water absorptivity observed can be as a result of microscopic voids present in the sample which allows water uptake by capillary effect. This results are in agreement with findings made by Koay *et al* [31], Duangdao *et al* [33] and Chowdhury *et al* [34].

4.1.8 Microstructure Examination

Plates 3 (a) and (b) shows the SEM micrograph of tensile fracture surface of rLDPE at magnification 300X and 2000X respectively.



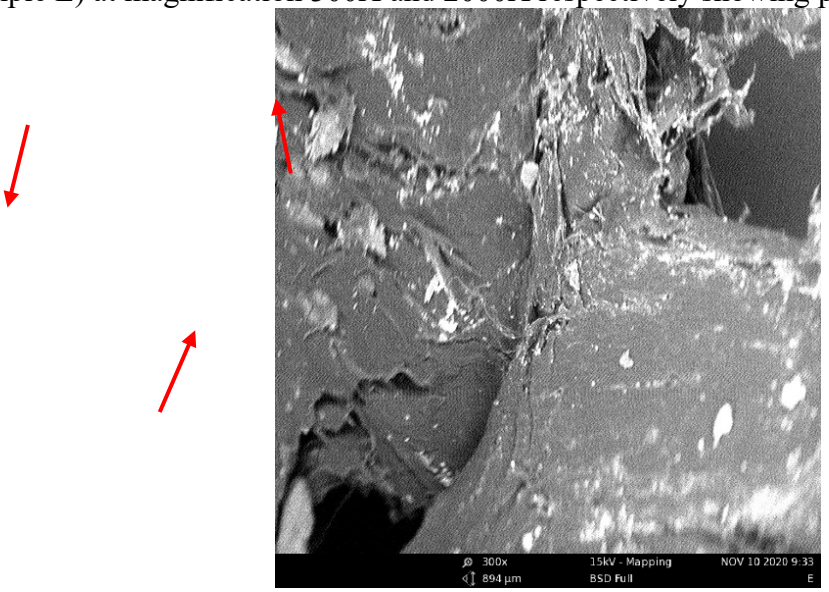
Magnification: 300X
(a)



Magnification: 2000X
(b)

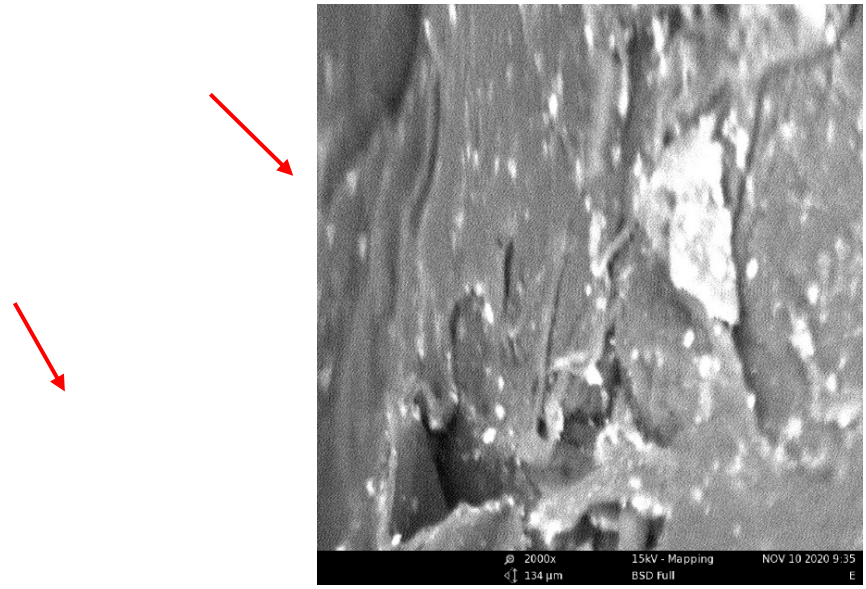
Plate 3: SEM micrograph of tensile fracture surface of neat rLDPE at magnification 300X. (b) Same image at 2000X.

Plate 4 (a) and (b) show SEM micrograph of tensile fracture surface of the optimized sample (sample E) at magnification 300X and 2000X respectively showing presence of voids.



Magnification: 300X

(a)



Magnification: 2000X

(b)

Plate 4: (a) SEM micrograph of tensile fracture surface for sample E, at magnification 300X. (b) Same image at 2000X.

In morphology properties, it can be seen in plate 3 above that the fracture surface of neat rLDPE is wavy with presence of fibrils which is an indication of ductile failure mode.

From plate 4, it can be seen that the reinforced matrix has many textures and is less homogenous when compared with neat rLDPE with fairly uniform filler dispersion and a rougher surface showing presence of voids which can be attributed to the agglomeration of filler material within

the matrix. Agglomerated fillers may act as stress concentration points to reduce tensile or elongation property of the composite material. This explains the reduced tensile strength observed after filler reinforcement and these findings are in agreement with that made by Wen *et al* [35] and Supri *et al* [36].

5. CONCLUSION

The aim of this research is to develop biocomposite shingles for roofing applications derived from recovered polymer waste and some agricultural waste. The identified waste materials are recycled Low-Density Polyethylene (LDPE), coconut shell fibre and Rice Husk Ash (RHA). Ten samples were produced from various filler loadings in order to obtain a mix ratio with the best mechanical properties. The best sample was then selected for further analysis of its thermal and morphological characteristics.
The following conclusion can be drawn from the development carried out:

i. Low-Density Polyethylene (LDPE) polymer waste was identified as matrix for use in the development of polymer biocomposite.
ii. Polymer biocomposites with varying filler loading were formulated using hot compression moulding method.
iii. The mechanical properties of the optimum mix (sample E) shows that tensile strength is 8.54MPa, flexural strength is 16.16MPa, flexural modulus is 415.44MPa, hardness value of 48.20HV and impact strength of 2.60J/m.
iv. The glass transition temperature (T_g) increased by 3.53% for the optimum mix when compared with that of the unreinforced material.
v. Water absorption property shows that sample E has a percentage water absorption content of 0.91%.
vi. Microstructure examination shows agglomeration of filler material and also presence of voids for the reinforced composite.
vii. Prototype of roofing slates were produced using the optimum mix ratio of 1:4:15 coconut particle fibre, RHA and rLDPE respectively.

6. RECOMMENDATIONS

This research work has revealed that biocomposite made of LDPE, coconut shell particle-fibre and RHA can be used for producing flame retardant roofing material, however, further work in the following areas is hereby recommended:

i. A more extensive heat transfer work should be carried out on the mould in order to improve on the performance and avoid defects like burning and distortion as evident from this work.
ii. The effect of aging, weathering and ultraviolet radiation should be investigated on the developed biocomposite.
iii. Investigation should be carried out on how to incorporate other streams of polymer wastes like e.g. Styrofoam in the production of biocomposite for possible roofing applications.

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