The Development and Characterisation of Recycled Polyethylene Reinforced Particulate Cockle Shell for Automobile Application

1Johnson O. Agunsoye, 2Chioma I. Madueke, *1Adela A. Bamigbaiye, 1Kenneth C. Agbakansi and 1Alice A. Oladipo
1Department of Metallurgical and Materials Engineering, University of Lagos, Akoka-Yaba, Nigeria
2Department of Metallurgy and Materials, University of Birmingham, United Kingdom

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Abstract- Polymer reinforced composites were developed from recycled polyethylene briquettes (matrix) and particulate cockle shells (reinforcement) via compounding and compression moulding technique. The objective was to use urban wastes to produce low-cost material for engineering applications as an alternative to their disposal by incineration, which can cause atmospheric pollution. The composites were characterized for wear test using spin on disk, XRD, Universal Testing Machine for Mechanical Properties and Scanning Electron Microscopy (SEM) for microstructure. Results obtained were compared with the unreinforced polymer, the composites exhibited higher tensile strength and impact energy, while the hardness reduced. More so, above 20% filler addition, the flexural strength and Young Modulus decreased. The composite can be used where rigidity is a crucial performance requirement; at 20% weight cockle shell, the composites can be used for car inner door opener where rigidity is required, while at 50% additions, the developed composite will be suitable for use in car interior dashboard where strength and fracture toughness are the most crucial property demand. Furthermore, the morphological study of the RPE/CSP composite showed a high homogeneous polymer matrix’s cockle shell particle blend. In conclusion, the study has established that particulate cockle shell waste and recycled polyethylene are suitable materials to produce polymeric composite. This is a novel material development from waste to wealth for environmental sustainability.

Keywords- Cockle shells, Recycled Polyethylene, Composite, Particulate

1 INTRODUCTION

Composite is composed of two or more materials, which are the matrix (polymer, metal, ceramic) and filler/reinforcement. Their properties depend not only on the base material, but also on the characteristics and composition of the reinforcement (Hammajam, et al., 2013). In Lagos State, Nigeria, proper disposal and general management of agro-waste have remained a significant challenge despite concerted effort by Lagos Waste Management Authority. Most of these agricultural wastes constitute a serious environmental hazard as a result of landfill gas formation, which leads to environmental pollution due to poisonous gas such as carbon monoxide (Lawal Abdu Daura, 2016). The impact of this can result in reduction of the citizenry’s life expectancy due to heavy pollution. Furthermore, a substantial gap must be filled through processing and converting some of these agricultural wastes into useful engineering materials through their recycling.

Rice husk, barley husk, eggshell, coconut shell, palm kernel shell, maize stalk, orange peel, and cockle shell are examples of agro-waste materials that have been processed as some useful filler materials for composites production. According to (Hammajam et al., 2013), the use of agro-waste in development of polymer matrix composite has increased significantly, especially in the building, construction, and automobile industries. Cockle shells (anadara granosa) is one potential filler material that has not been extensively utilised for production of composite despite its abundance along coastal line of many riverine areas and sea shores. They are obtained from cockle, which is an edible bivalve mollusk that lives in sandy and sheltered beaches. Cockle shell contains almost 96% calcium carbonate and other elements such as Magnesium, and Phosphorous (Hoque et al., 2013).

The high percentage of calcium carbonate in cockle shells makes it suitable for use as substitute material in building construction, for ceramic tiles as well as for composites production (Mohamed et al., 2012). The shell has remarkable mechanical and thermal properties attributed to its morphological (crystalline) and elemental structures (Al-Zubaidi et al., 2015). Currently, the literature on the use of cockle shell as reinforcement for polyethylene waste is readily not available to the best of authors knowledge.

The matrix of the composite used in this study is a recycled polyethylene briquette produced from water sachet. This waste is known for clogging of water ways in a metropolitan city like Lagos and resulting into flooding and consequent heavy traffic which lead to loss in man hours and low productivity. Therefore, this study focused on the use of two waste materials: recycled polyethylene and particulate cockle shell for the production of novel engineering composite for automobile application. By implication, it is anticipated that the waste will be harnessed to ultimately improve waste management and less industrial application.

2 METHODOLOGY

Table 1 represents the formulation of the matrix – filler blend in weight% for production of the composites

| Content | Weight % (g) |
|---------|-------------|
| Control | Coup. 1    |
| 2       | 3          |
| 4       | 5          |
| 6       |            |
| BRPE    | 100        |
| 90      | 80         |
| 70      | 60         |
| 50      |            |
| CSP     | 0          |
| 10      | 20         |
| 30      | 40         |
| 50      |            |

*Corresponding Author

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2.1 COCKLE SHELL PREPARATION
The cockle shells were washed and sun-dried to reduce moisture content and to eliminate impurity. The clean and dried cockle shells were then crushed, ground, and secured in a tight container to avoid air moisture. The powder was sieved to a particle size of 150 µm because it represented the particle size with the highest yield on the sieve shaker. It should be noted that the milled particulate cockle shell contained insignificant amount of impurity because the grinding media did not show a noticeable wear.

2.2 SYNTHESIS OF RECYCLED POLYETHYLENE AND COCKLE SHELL PARTICULATE COMPOSITE
Compounding and compression moulding technique was used to produce composite test coupons. The compounding process involved blending the recycled polyethylene briquettes and powdered cockle shells in a two-high rolling mill. At the same time, the rolls rotate counter-clockwise to each other for a period of (7-10 minutes) at a temperature range of (150 °C – 200°C). The cockle shell particulate percentage was varied, as shown below in Table 1, from 10% to 50% addition relative to the matrix weight. The composites’ compression was done with a one tonne hydraulic press under controlled pressure at 200°C for 30 minutes. Thereafter, the samples were cooled under sustained pressure to room temperature to cure and aid easy removal from the press.

2.3 EXPERIMENT
The phases and chemical composition of cockle shell powder was determined using XRD (X-Ray Diffraction) model Phillips Analytical Diffractometer machine and XRF (X-Ray Fluorescence), respectively at the University of Johannesburg, South Africa. Tensile test was carried out on coupons with a nominal dimension of 80 x 15 x 4 mm at a speed rate of 60 mm/min, in accordance with guidelines into ASTM D636, on a Universal Testing Machine (Instron model 3369). Hardness test was carried out following ASTM A956 guidelines using a LEEB Portable (type D) Hardness Tester, scale value HLD (HV). The impact energy of the test coupons was determined using Hounsfield Balanced Izod Impact Machine, under ASTM D6110-10 (Standard Test Method for the Impact Resistance of Notched Specimens of Plastics). The resistance to bending, which is the flexural strength, was determined according to ASTM D970 on Universal Instron Machine, Model No: 3369. A 3-Point bending configuration was used with a nominal specimen dimension of 12.84 x 4.5 mm and a support span of 65 mm.

Wear test was carried out according to ASTM D5963-04) with a DIN Abrasion Tester, Model No: FE05000 and 150 x 460mm roller type the test coupons have a nominal diameter of 16 mm. The tribological degradation was measured with P60 abrasion sheet at a speed of 0.32 m/s with and 40/mins revolution under a 10 N load. The wear rate was then determined using Equation (1).

\[
\text{Wear rate} = \frac{\text{Weight loss}}{\text{Speed} \times \text{Time}}
\]  

(1)

3 RESULT AND DISCUSSION
The major diffraction peaks of the cockle shell XRD profile are found at 32.14°, 46.6°, 31.71°, 47.998°, and 39.73°, which corresponds to 2.79Å, 1.95Å, 2.82Å, 1.90Å, and 2.27Å interplanar distances, respectively. The relative intensity of X-ray scattering is 56.46, 26.25, 100.00, 10.12, and 21.68.

The phases at these peaks are (Ca₃(SiO₃)₂ Calcium Silicate, (CaCO₃) Calcium Carbonate, (Ca₃(SiO₄)₂) Calcium Silicate, (Al₂(Si₃C)₂) Aluminum Silicon Carbide, (Mg₃SiO₄) Magnesium Silicate. The graphical representation is shown in (Fig. 1). The diffractogram also showed that calcium silicate constitutes the highest amount of all the compounds. The compositions obtained in Table 2 of the cockle shell agree with (Hemabarathy et al., 2014).

The composition analysis using XRF estimated that cockle shell powder contains oxides such as CaO, K₂O, Na₂O, Fe₂O₃, SiO₂, Al₂O₃, Na₂O. (see Table 2).

![XRD Spectrum of the Cockle Powder Particles](image)

Fig. 1: XRD Spectrum of the Cockle Powder Particles

| Element | SiO₂ | CaO | Al₂O₃ | Na₂O | Others |
|---------|------|-----|-------|------|--------|
| Normalised Value (%) | 35.00 | 44.44 | 17.80 | 2.70 | 3.92 |

3.1 MECHANICAL PROPERTY CHARACTERISATION
The average impact energy of five different samples (varying filler loading) for the control sample is presented in Fig. 2; The energy absorbed, increased from 7.52J to 9.11J with amount of the reinforcement. The filler presence enhanced the composites’ ability to absorb and dissipate more energy, thereby increasing their toughness and impact strength. Also, the uniform dispersion of the filler within the polymer matrix may have contributed to the enhancement performance.

Fig. 3 showed a decrease in the composite hardness value with increasing amount of filler. Hardness, which is a material’s resistance to localised deformation depends on the matrix’s reinforcement distribution. The attained hardness can be attributed to insufficient wetting of the particulate cockle shell by the RPE matrix, as similarly observed by Islam & Islam, 2013.

The wear rate of the RPE/CS composites at different loading rates in terms of abrasion distance is shown in Fig. 4. The presence of cockle shell particles in the polymer matrix increased the wear rate drastically from
10% to 20% filler addition. The wear rate beyond 20% was observed to be constant up to 40% filler addition. The result can be attributed to the fact that the composite at 30% and 40% is as hard as 20% (Fig. 4), which was also observed by (Agunsoye et al., 2013). The wear rate decreased from 40% to 50% filler addition because of the boundary lubricant film (debris), resulting in stress redistribution. Generally, a decrease in the hardness of material caused an increase in the wear rate. Furthermore, it was observed that particle reinforcement is more effective in decreasing the wear rate than short and long fibre reinforcements (Malhotra et al., 2012).

The tensile strength of RPE/CS composite with varying loading, as shown in Fig. 5, increased from after addition of 10 wt.% cockle shell particles and increased rapidly from 30 wt.% to 50 wt.%. This phenomenon may be attributed due to dislocation pile up of particulate within the matrix of the microstructure and thus agree with the findings of (Agunsoye et al., 2013). The composites rigidity increased up to 20 wt.% CSP addition, attaining the highest value at that reinforcement. Above 20 wt.% addition, the Young modulus of elasticity of the reinforced polymer decreased as shown in Fig. 6. The sudden decrease may be due to increased resistance to plastic deformation attributed to high stiffness of CSP relative to the polymeric material. The observation agrees with the study carried out by (Hussein et al. 2011) and the tensile strength results obtained in this study. This behaviour agrees with the tensile strength results in (Hussein et al., 2011).

Similarly, as shown in Fig. 7, the polymer’s flexural strength increased upon filler addition up to 20 wt.%. The polymer reinforced with 20 wt.% CSP has the highest flexural strength value. The decrease in the flexural strengths beyond 20 wt.% reinforcement incorporation can be attributed to interference in the mobility or deformability of the matrix by the particulate filler material under the concept of dislocation theory. The interference was due to the physical interaction and immobilisation of the polymer matrix in the presence of mechanical restraints, reducing the strength.
the boundary lubricant film (debris), resulting in stress redistribution as shown in Fig 4.

The tensile strength increased slowly from 0 to 20 wt.% filler addition and increased drastically from 20 to 50 %, this may be attributable to excellent stress propagation or distribution as shown in Fig 5. The 2221 filler content increased from 0 to 20 %. Above 20%, this property decreased due to an increase in the sample resistance to plastic deformation as shown in Fig. 6. The optimum flexural strength was obtained at the 20% filler content followed by a sudden decrease above 20%. The attained result was attributed to particles' interference in the mobility or deformability of the matrix as can be seen in Fig. 7. The morphological study of the RPE/CSP composite at 10% and 50% filler addition showed a high homogeneous polymer matrix’s cockle shell particle reinforced composites as shown in Fig. 8 a, b respectively.

In conclusion, the study has established that particulate cockle shell waste and recycled polyethylene are suitable candidate materials to produce polymeric composite. This is a novel material development from waste to wealth.

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3.2 MICROSTRUCTURAL CHARACTERISATION
The morphology of the composites containing 10 wt.% and 50 wt.% CSP RPE/CS shows that the reinforcement has smooth spherical surface suitable for maximum interaction (Figs. 8a and b). The Scanning Electron Microscopy TESCAN model equipped with Oxford INCA Energy dispersive spectroscopy (EDS) micrographs revealed finely dispersed cockle shell particles in the polymer matrix due to the improper intimate mixing of cockle shell particles with the polymer matrix in the composites. The result agrees with the observation of (Jia Ying Tong et al., 2014). The interaction between the particles and the matrix was not as good as shown in the SEM results. Probably, this is responsible for the inconsistency in the mechanical properties analysed in Fig 4. The particle-matrix interface plays a vital role in composite properties. A strong particle-matrix interface bond is critical for the high mechanical properties of composites. From the Energy Dispersive Spectrum, it is evident that the elements composed of the cockle shells are present and can also be the reason for some improved properties.

4 CONCLUSION
The following main conclusions can be drawn from the results of the study. The XRD result in Fig. 1 and Table 2 revealed that Calcium Carbonate is the predominant phase in the cockle shell. The result agrees with the literature. The impact energy in Fig 6' ability to absorb impact energy has been drastically from 10 wt.% up to 20 wt.% due to the abrasive particles in the p

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