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Rice Husk Ash/Recycled Low Density Polyethyelene Composites for Pavers' Block Production

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The performance of Rice Husk Ash (RHA)/Recycled Low Density Polyethylene (water sachets) composites was investigated for its suitability for pavers' block production and applications without using cement. The rice husk was properly dried, burnt in open air and collected for use. The raw materials were collected, sorted, and cleaned preparatory for use. The water sachets (LDPE) was melted using a steel pot on an open hearth furnace. Samples with RHA (0, 5, 10, 15, 20 and 25%), LDPE (100, 80, 75, 70, 65, 60 and 55%) and sand (20% constant) by weight were thoroughly mixed to ensure a homogeneous paste which was then poured into prepared moulds to produce the composite blocks (200×160×80 mm). Three samples of each batch were used to perform physical/durability, mechanical and surface morphological tests. The results for the physical tests shows that water absorption was 0.92%, thickness swelling 0.06%, and density 1.27 g/cm^3. For the mechanical tests, the compressive, impact and flexural strengths were 0.81 N/mm^2, 8.8 J/mm^2 and 2.68 N/mm^2 respectively. The surface morphology of the blocks was carried out to ascertain their integrity, and it indicated good distribution, and retention between the RHA particles and the resins. The results show that the blocks compare well with those used for light traffic and non-traffic pavements and this provides a good option for handling solid waste and converting waste to wealth.

Keywords: Composites; non-biodegradable; recycled low density polyethylene; rice husk ash; Paver's block.

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1. INTRODUCTION

The search for new materials for engineering applications is a continuous exercise as new materials are needed for emerging needs. Historically, the development and advancement of societies have been intimately tied to the members' ability to produce and manipulate materials to fill up their needs [1]. Advancement in the understanding of a material type is often the forerunner to the stepwise progression in technology. Material sources are not inexhaustible and one way of ensuring sustainability is through recycling, as recycling requires less energy than producing materials from primary sources, enabling reduction in energy consumption with the attendant benefits.

More than a billion tons of plastic materials have been made since the 1950s, and the vast majority of it has been thrown in the trash, according to a study by Robert [2]. This particular study found that as at year 2015, only 9 % of the plastic waste produced ended up recycled, another 12 % was incinerated, and the remaining 79 % has been built up in landfills or ended up elsewhere in the environment. Therefore, in this present study, the use of plastics as construction materials could reduce the percentage of plastic waste dumped in landfill areas.

Due to inadequacy in supply of portable drinking water from public sources in Nigeria, drinking water is packaged and sold in sachets made from Low Density Polyethylene (LDPE). As a result of the high patronage of this important source of drinking water, popularly referred to as "Pure water", it has become common to see waste polyethylene sachets littering every space in Nigeria. These disposed sachets constitute about 50 % of most of the domestic waste generated [3]. These sachets are non-biodegradable and are harmful if left in the soil for years. The most common method of disposing this waste is by burning, which has its own harmful impact on the environment as it emits greenhouse gases into the atmosphere. Therefore, LDPE was used as one of the materials in producing paver's block composites in the present study thereby attaining waste to wealth conversion.

Rice husk is an agricultural waste obtained from milling of rice. With the current upsurge in rice production through the Federal Government of Nigeria Rice Value Chain Programme, there is increased level of rice cultivation translating into huge amount of rice husk which is a by-product from the head rice. These huge quantities of rice husk also create solid waste management problem to the environment. It is well known that rice husk could produce high silica element with burning process and improvement of binder properties. Hence, the use of the material could highly enhance the properties of the paver's block.

The construction industry relies heavily on conventional material such as, cement, and granite for building structures. The demand for concrete materials for today's infrastructural development is on the increase. With increasing population, there is the need for a sustainable exploitation of these natural resources for the benefit of future generations.

Recycling and reuse, as well as substitution with cheaper alternatives therefore become the obvious choices that must be followed [4]. Several attempts have been made to replace cement and fine aggregates in the concrete mix thereby saving cost. Mall et al. [5] replaced cement with fly ash by up to 25% by weight and found out that there was negligible effect on any physical and mechanical properties.

Several researchers have investigated on RHA as a construction material to enhance the properties of concrete and pavement blocks. Premalal et al. [6] added RHA powder to various concretes mixes and concluded that the use of RHA with cement improves workability and strength, reduces heat evolution, thermal cracking and plastic shrinkage. RHA also minimizes alkali aggregates reaction, refines pore structure and hinders diffusion of alkali ions to the surface of aggregates. Besides, LDPE was also found to be one of the materials used in producing pavement blocks. Mohan et al. [7], produced pavement blocks from plastic bags, fine aggregates and quarry dust, thereby eliminating the use of cement. They obtained cheaper blocks with reduced weight of up to 15%, and blocks could be used in low load carrying applications. Sohani et al. [8] also replaced cement in pavement blocks with recycled LDPE waste. They used only LDPE and Sand in various ratios and obtained blocks with properties comparable with conventional concrete pavement blocks.

In this work, cement was completely replaced with LDPE wastes and RHA for pavers' block production. This is aimed at converting waste to wealth, tackling environmental pollution and solid waste accumulations and reducing material and energy cost.

2. MATERIALS AND METHODS

Rice husk was obtained from Wurukum Rice mill in Makurdi, Benue State, Nigeria, while water sachets (LDPE) were collected from trenches, drainages and dump sites within the town. Sand of size 3.35 mm were collected from the bank of the River Benue also in Makurdi. Soluble oil D was purchased from a lubricant retailer in Makurdi.

2.1 Preparation of Materials

The Rice husk was properly washed with clean water and sun-dried for 3 days, after which it was burnt in the open air at an average temperature of 60°C to convert it into ash. It was further carbonized in a furnace at 30ºC for 20 minutes. The ash was properly mixed to ensure a homogeneous distribution of particles. The composition of the RHA shown in Table 1 was determined using Atomic Absorption Spectrometry (ASS). The water sachets were also sorted, washed and shredded manually. The sand were equally washed and dried under the sun for 24 hours for further removal of moisture. The sun-dried sand were sieved using a mechanical sieve shaker and a nominal particle sieve size of 10 mm diameter was selected for fine finishing of the composite paving blocks.

2.2 Pavers' Block Production

The stainless steel pot was placed on the Electric hot plate for 15 seconds and the shredded waste polyethylene water sachets were poured into it and heated to a temperature of 170°C to obtain a homogeneous mixture. The shredded material (dry condition) was allowed to melt completely inside the heated steel container causing a breakdown of the long plastic polymer chain forming a paste, stirring was carried out continuously using a long metal stirrer. The sand (dry condition) and RHA (wet condition) were then added to the mixture progressively with vigorous stirring to achieve homogeneity. The mixture was then poured into the predesigned metallic mould whose interior had been lined with lubricant (Soluble Oil D), as mould facing material. The edge of the mould was gently tapped continuously using a mallet, to allow for even spread of the molten material which also aided the escape of gases as that could cause cracks in the composite. The mould's cover was placed in position and gently pressed (using hydraulic press) to obtain a well compacted pavers block. Curing was carried out for 24 hours by completely cooling in air and tested for 14 days. The composite pavers block was finally released by up-turning the mould.

The percentage by weight of sample of the RHA, LDPE and the fine aggregates were varied in the proportions shown in Table 2. The sample were labeled as A, B, C, D, E, F and G.

Table 1. Chemical composition of RHA

S/N	Chemical properties	Test Value % w/w
1	Silica (SiO_2)	83.6
2	Calcium Oxide (CaO)	0.84
3	Magnesium Oxide (MgO)	0.40
4	Alumina (Al_2O_3)	0.76
5	Ferric Oxide (Fe_2O_3)	0.64
6	Loss on ignition	14.2
7	Sulphuric Anhydride (SO_3)	0.69

Table 2. Composition of LDPE/RHA composite paving blocks

Sample code	LDPE (wt %)	RHA (wt %)	Sand (wt %)
A	80	0	20
B	75	5	20
C	70	10	20
D	65	15	20
E	60	20	20
F	55	25	20
G	100	0	0

2.3 Physical/Durability Tests

The water absorption test (cold testing) was carried out in conformity with BSI 6730. The weight of the RLDPE composite paving block before immersion into cold water was taken using a digital weighing scale and recorded as Wt_1 . The sample was then completely immersed in water for 72 hours. The specimen was removed from the water and allowed to drain for 5 minutes and was wiped with a damp cloth, and then reweighted and recorded as Wt_2. The percentage of water absorbed was then calculated using equation 1.

$$\% \, \mathrm{WA} = \frac{\mathrm{Wt_2} - \mathrm{Wt_1}}{\mathrm{Wt_1}} \times 100 \quad (1)$$

Where,

% WA = the water absorption expressed in percentage,
Wt_1 = Initial weight of sample before immersion and
Wt_2 = final weight of sample after immersion.

The thickness swelling test was carried out in accordance with BSI 6717. The thickness of the composites samples were first measured using vernier calipers and recorded as T_0. The samples were then immersed in beakers containing distilled water and allowed to stay for 72 hours after which the thickness was again measured and recorded as T_f. The thickness swelling (TS) was then determined using equation 2.

$$\text{Thickness swelling (TS)} = \frac{\mathrm{T_f} - \mathrm{T_o}}{\mathrm{T_o}} \times 100 \quad (2)$$

Where,

T_f = the thickness of the composites after 72 hours of immersion and
T_o= the original/initial thickness of the composites before immersion.

The density of the RLDP composite pavers' blocks was determined in accordance with ASTM C693. The sample was weighed using a digital weighing balance to obtain the mass of the sample (m). The produced RLDPE composite block was immersed into water in a vessel and the displacement (difference between the final water volume in the immersion vessel and the initial volume of water in it) representing the water displaced by the sample and the volume of the sample (v) by Archimedes' Principle. The density of the sample was obtained using equation 3.

$$\text{Density}, \rho = \frac{\text{Mass (m)}}{\text{Displaced Volume (v)}} \quad (3)$$

Where,

ρ = density (kg/m^3),
m = the mass of the test sample (kg), and
v = the volume (m^3).

2.4 Mechanical Tests

The compressive strength (crushing) test was performed in accordance with ASTM D695. The plane area (A) of the pavers' block was determined. The specimen was placed on the machine bearing plate and load was applied continuously until there was a noticeable fracture in the sample indicating that no greater load can be sustained. The maximum load was noted as P. The apparent compressive strength was then calculated using equation 4.

$$\mathrm{C}s = \frac{\mathrm{P}}{\mathrm{A}} \quad (4)$$

Where,

Cs = compressive strength (N/mm^2),
P = applied load (N), and
A = area (mm^2).

The charpy impact test was carried out on the composite samples. The composite specimen was supported horizontally as a simple beam on the impact testing machine. The pendulum arm of the machine was raised and held at a height of 0.14 m and was then released. The swinging arm hits the sample and broke it, and the energy absorbed by the sample was recorded as its impact energy.

The flexural strength test was conducted under three-point bending approach using a Universal Testing Machine in accordance with ASTM D790. The thickness (t) and width (b) as well as the length (L) in mm of the sample were noted. The load was applied from the top of the specimen in the form of a simple beam loading through a roller placed midway between the supporting rollers at a uniform rate for an average thickness. The load was gradually increased until the specimen failed. The maximum load applied (P) was noted. The flexural strength (MPa) was then calculated using equation 5.

$$\text{Flexural Strength, } \sigma = \frac{3}{2}(\mathrm{PL}/\mathrm{bt}^2) \quad (5)$$

Where,

σ = flexural strength (MPa),
L = span length (mm),
P = maximum applied load (kN),
b = average width of the specimen (mm) and
t = average thickness (mm).

2.5 Scanning Electron Microscopy (SEM)

Scanning Electron Microscope (SEM) was employed to examine the surface morphology of the composites in order to observe particle distribution in the composites and interfacial interaction between particles and polymer resin. A 40×12×5 mm size of sample was cut from the various composite samples and properly cleaned with emery paper to remove dirt particles. The samples were air-dried and coated with nanometers thick gold sputter ion coater. The electron beam of 15 kV was focused on the surface of the sample and the energy exchanged between the electron beam and the sample resulted in the reflection of high energy electrons. The beam current absorbed by the specimen was detected and used to create images of the specimen which were displayed on the computer monitor where the morphology image of the produced composite samples was viewed and captured.

3. RESULTS AND DISCUSSION

The result of water absorption against percentage composition of the produced pavers blocks are presented in Fig. 1. It was observed that sample G with 100% LDPE had the least water absorption of 0.92%. Water absorption increased with increase in percentage RHA. This is because RHA particles are highly hydrophilic due to hydroxyl group of polysaccharides found in cellulose that are capable of forming hydrogen bond between water molecules and the RHA. The increase in the number of voids with increasing RHA loading which occurs between RHA and LDPE/sand also permits more water to be absorbed. This observation agrees with Mohammed et al. [9] who established that as the filler content increases, water intake also increases. The water absorption in this case is negligible and in not likely to affect the stability of the pavers blocks. The result is also similar to that obtained by Er Atul et al. [10].

The result of thickness swelling against percentage composition of the produced composites with LDPE and RHA matrix is presented in Fig. 2. The result indicates that sample G with 100% LDPE has the least thickness swelling of 0.06%. As the filler content increases, the percentage thickness swelling of the samples increases. This is attributed to moisture build-up in the particle cell wall, leading to dimensional changes in the composite as stated by Ogah et al. [11]. These changes in thickness due to absorbed moisture are not significant enough to affect the stability of the pavers blocks when put in place with provision for minimal expansion.

The result of density against percentage composition of the produced composites pavers' block is presented in Fig. 3. The result indicates that sample B with 75% LDPE and 5% RHA had the highest density of 1.27 g/cm^3 as compared with the rest of the compositions. There was remarkable decrease in density as the percent tage content of RHA increases, decreasing from 1.27g/cm^3 (75:5; LDPE/RHA) to 1.07 g/cm^3 at (55:25; LDPE/RHA), representing around decrease 15.7% in density. The decrease in densities could be attributed to the fact that the RHA particles are lighter in weight but occupies substantial space [12].

The result of the compressive test carried out on the pavers' blocks produced is as shown in Fig. 4. It was observed that sample E with 60% LDPE and 20% RHA has the highest compressive strength of 0.81 N/mm^2. The result shows that as the RHA content increases the compressive strength also increases, indicating that there is an increase in adhesive strength between the surface area of the LDPE molecules and the neighboring RHA aggregate particles as suggested by Sahil and Jaspreet [13]. Also this could be as a result of the high silica content in the RHA which provides strength to the composites. The compressive strength after this point began to fall, implying that any further increment will rather reduce the strength [14].

The result of impact strength against percentage composition of the pavers block composite specimens is presented in Fig. 5. Sample E with 60% LDPE and 20% RHA had the highest impact strength of 8.8 J/mm^2. The result showed a steady increase in impact strength from 8.1-8.8 J/mm^2, with increasing RHA content and then dropped to 7.7J/mm^2 (100:0:0). Concerted improvement in impact energy with RHA additions could be attributed to the presence of particles well bonded by the resins which leads to increase in impact energy [3].

The result of flexural strength against the percentage composition of the produced composite pavers' block is presented in Fig. 6. Sample C with 70% LDPE and 10% RHA recorded the highest flexural strength of 2.68 N/mm^2 compared to other samples. As the RHA increases the flexural strength also increases, though there was a minimal change in flexural strength with RHA additions. The result shows irregular pattern and minimal difference in the flexural strength. High flexural strength are required for pavers' blocks. The irregular result pattern in flexural strength as the RHA increase could be attributed to the inter play between strong interfacial bond between the RHA and LDPE matrix, the presence of voids, and poor dispersion of RHA particles in the RLDPE matrix in some samples [9,15]

The scanning electron micrographs (morpho logies) of the pavers' blocks produced at various compositions are presented in Fig. 7 (a-f). Morphological analysis from SEM clearly showed variations of morphology images with varying RHA content. It was observed that RHA particles are not detached from the resins surface even as the weight fraction was increased showing good interfacial bonding between LDPE and the particles. The SEM also showed good wetting and retention of the RHA [16].

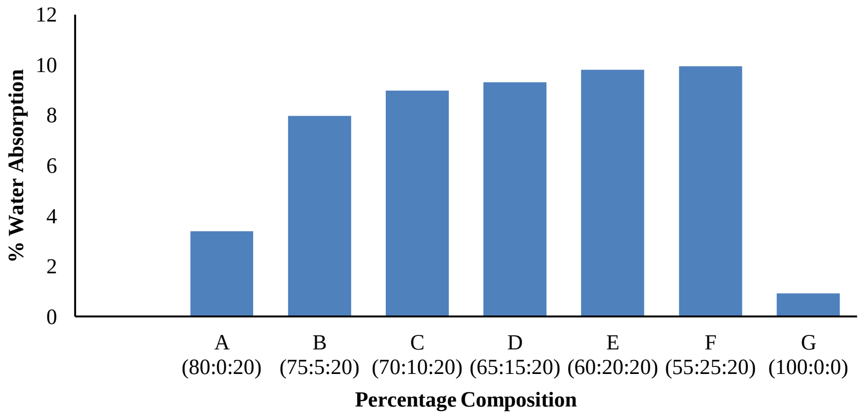

Fig. 1. Water absorption against percentage composites composition after 14 days

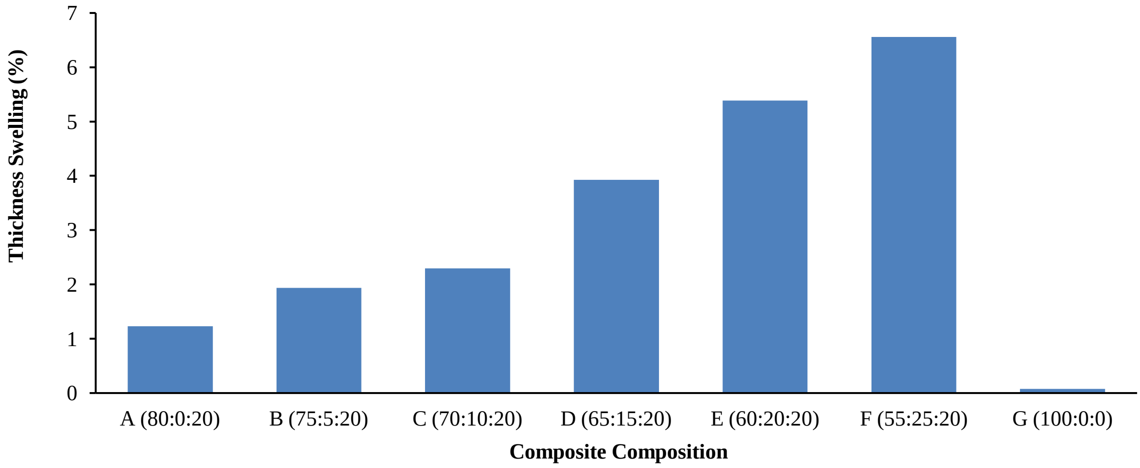

Fig. 2. Thickness swelling against percentage composite composition after 14 days

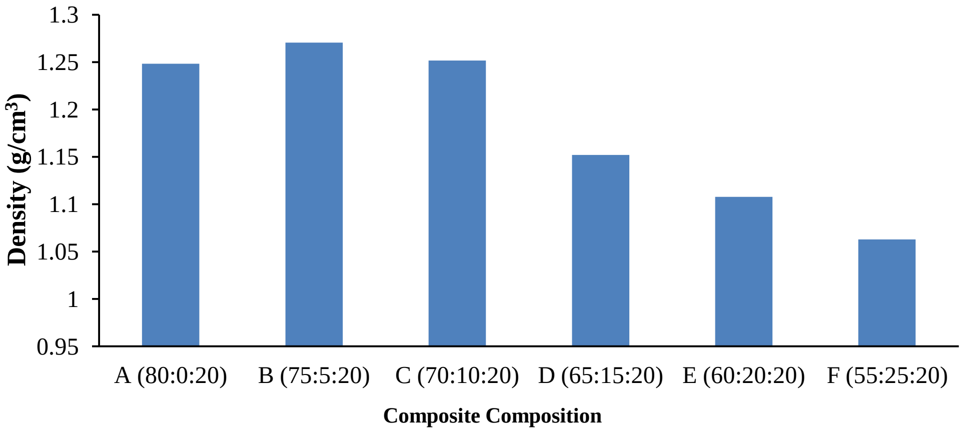

Fig. 3. Graph of density against percentage composite composition after 14 days

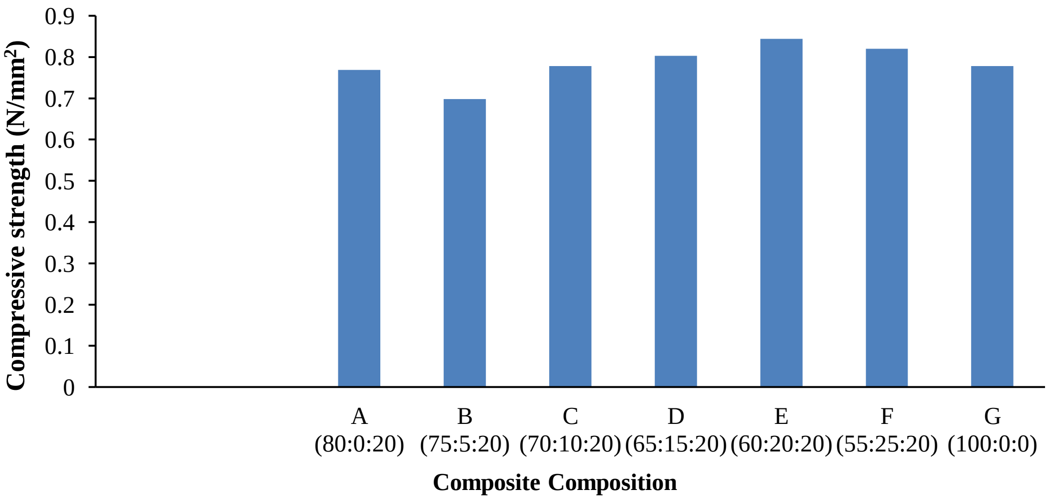

Fig. 4. Compressive strength against percentage composite composition after 14 days

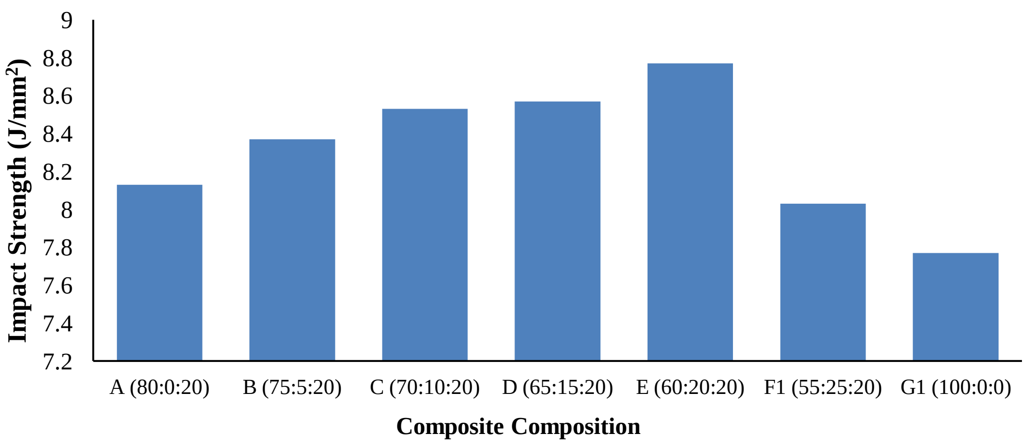

Fig. 5. Impact strength against percentage composite composition after 14 days

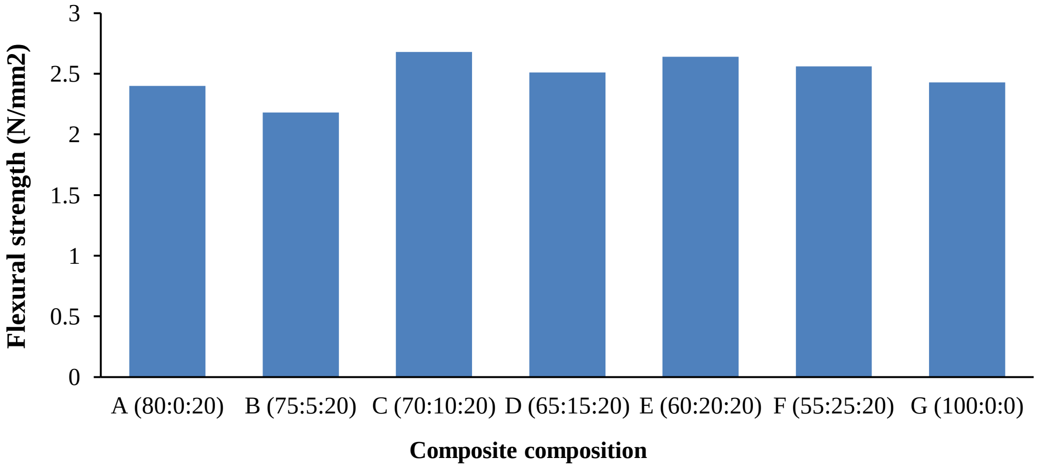

Fig. 6. Flexural strength against percentage composite composition after 14 days

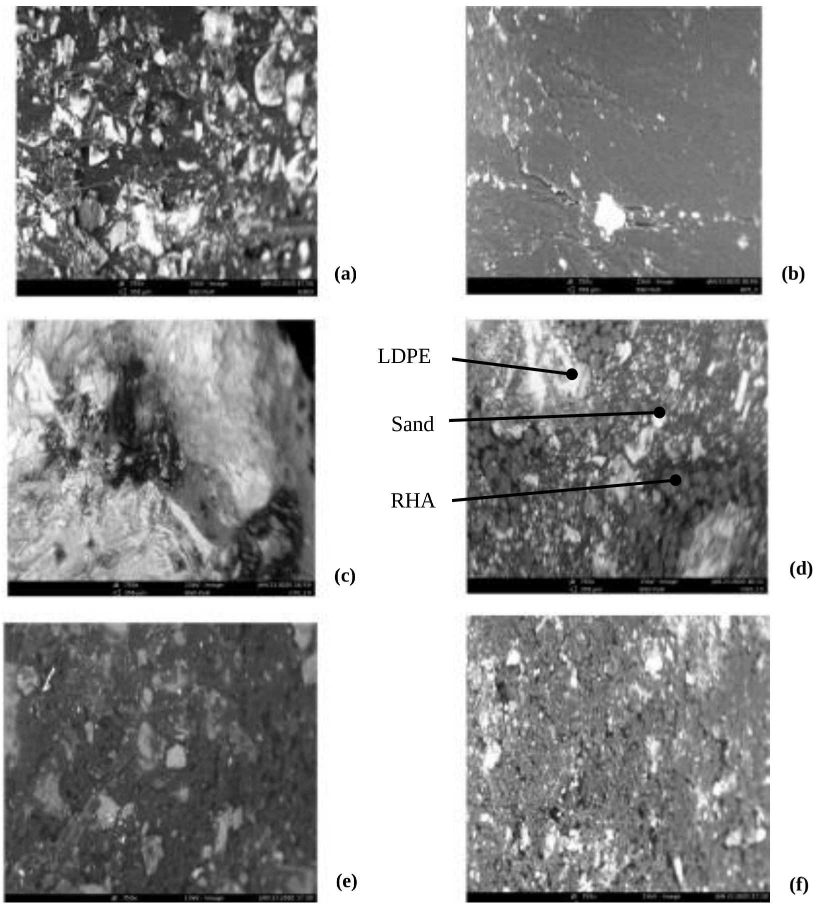

Fig. 7. Scanning electron micrographs of the samples × 2000 with: (a) 80:0:20; (b) 75:5:20; (c) 70:10:20; (d) 65:15:20; (e) 60:20:20; and (f) 55:25:20 RLDPE/RHA/Sand after 14 days

4. CONCLUSION AND RECOMMENDATIONS

Based on the experiments and the result obtained, the best compositional mixture in terms of the required properties is the 65:15:20 RLDPE/RHA/Sand. It can be concluded that composite pavers' blocks can be successfully produced from recycled LDPE, RHA and sand in various proportions. Also, the pavers' blocks have good compressive and impact properties within acceptable range for use in light traffic areas and residential premises. Furthermore, the morphology of the composites show good retention of the particles and surface binding between the RHA and the resin. From the results and analysis, it can conveniently be recommended that pavers' blocks produced from LDPE/RHA can be used for pavement of light traffic and non-traffic areas.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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