MECHANICAL AND THERMAL PROPERTIES OF SUSTAINABLE COMPOSITE BUILDING MATERIALS MADE FROM REPROCESSED LOW-DENSITY POLYETHYLENE, BIOCHAR, AND OTHER MATERIALS WASTES OF CALCIUM PHOSPHATE AND PHOSPHOGYPSUM

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ABSTRACT

The mechanical and thermal properties of laterite composites mixed with reprocessed low-density polyethylene waste (LDPE), calcium phosphate (CaP), and phosphogypsum wastes, as well as biochar to make brick composites, are presented in this work. Compressive strength, flexural strength, and fracture toughness were found to be outstanding in bricks containing 20% LDPE, 15% CaP, and 15% gypsum by volume. After sintering for 24 hours, the composites with 1% by volume LDPE and 15% by volume biochar had the optimal combination of mechanical properties, such as flexural strength and fracture toughness. There was a linear association between the strength and the weight loss of the bricks. Scanning electron microscopy and optical microscopy images revealed evidence of crack bridging by LDPE particles. The laterite–LDPE composite mixed with 5%, 10%, and 15% by volume biochar had sintering temperatures of ~850°C, ~720°C, and ~710°C, respectively, after undergoing softening, cold crystallization, and cooling.

Keywords: *Laterite; Reprocessed Low-density polyethylene waste (LDPE); Biochar; Phosphogypsum; Strength; Fracture toughness; Thermal properties*.

INTRODUCTION

Alternative building materials such as artificial and/or natural wastes, as well as earth-based composites, have been investigated as potential alternatives to cement in construction (Azeko et al. 2015a, c; Mustapha et al. 2016a, b; Flomo et al.2021). The composites have also made it possible to recycle agricultural waste (natural fibers), industrial waste (Phosphogypsum (PG)), and human-made waste materials (plastics) into building materials with appealing mechanical qualities (Azeko et al. 2015a, c; Srijaroen et al. 2020; Flomo et al.2021). As a result, there is the possibility of incorporating various types of waste materials into the production of durable and long-lasting building materials. The yearly global output of 80 million polyethylene supports the possible use of polyethylene as a building material. Polyethylene waste has a usefulness of about 12% (Azeko et al. 2015c), making it challenging to create an effective disposal system. As a result, appropriate methods for reusing or recycling polyethylene trash for a variety of sustainable building uses are required. Phosphogypsum, an industrial waste, is frequently thrown in bulk without being processed, resulting in annual volumes of 300–400 Mt (Tayibi et al. 2009; Hanan et al. 2009). These wastes are frequently precipitated. Macas et al. (2017) studied metals. Rashad (2017) demonstrated that the heavy isn't always a bad thing. The metals in PG are safe to utilize in building, especially in low-cost housing.

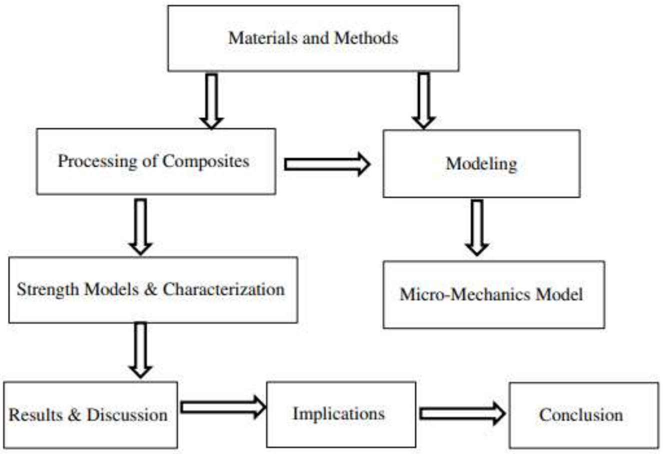

Fig. 1. Flowchart of research approach.

Biochar is a carbon-rich material made from organic materials that burn under low or no oxygen conditions as a result of pyrolysis, hydrothermal carbonization, or gasification (Cha et al.2016), torrefaction (Nunoura et al. 2006), and flash carbonization (Nunoura et al.2006). Water cleansing and energy storage are two applications of biochar (Yang et al. 2017). Because the use of cement in modern buildings is both costly and ecologically unfriendly, there is a need to partially replace it with other natural and artificial wastes such as slags (Savastano et al. 2001), straws (Mustapha et al. 2016), and banana peels (Mustapha et al. 2016). fibres (Savastano et al. 2000), waste tyres (Sukontasukkul and Sukontasukkul and Sukontasukkul and Sukontasukkul and Sukontasukkul and termite soil (Mahamat et al. 2006), and ash (Chaikaew 2006). Azeko et al. 2015b, 2018; Flomo et al. 2021), and polyethylene (Azeko et al. 2015b, 2018; Flomo et al.2021) without adding to pollution levels. The mechanical properties of sustainable building materials that combine recycled plastics, calcium phosphate, and phosphogypsum into laterite are studied experimentally and theoretically in this research (clay with high iron oxide content). Materials that are made up of several different components. Powdered low-density polyethylene (LDPE) was combined with laterite in various concentrations. The strength and fracture toughness of the resulting composites were studied using a combination of experiments and micromechanical models. The implications of the results were discussed for the development of sustainable building materials.

MODELING

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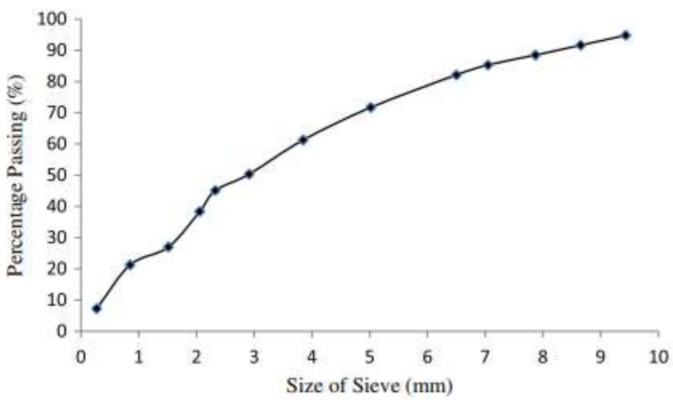
The modified mean field (M-T) was the basis for the development of the micromechanical composite model (Weng 2011; Guo et al. 2014). This model was used in estimating the overall stress and strain in bimodal LDPE bricks. The secant elastic modulus and secant Poisson's ratio for the jth phase can be expressed as:

$$E^{S(j)} = \frac{E^{(j)}}{1 + \frac{E^{(j)}\varepsilon^{(j)}}{\sigma_{\text{flow}}^{(j)}}\left(\frac{\sigma_{11}^{(j)}}{\sigma_{\text{flow}}^{(j)}}\right)^{m_0-1}}$$

$$v^{S(j)} = \frac{1}{2} - \left(\frac{1}{2} - v^{(j)}\frac{E^{S(j)}}{E^{(i)}}\right)$$

Materials and Methods Formulation and Processing of Composite

The Building and Technology Department at Tamale Technical University (TaTU) in Tamale, Northern Ghana, provided Formulation and Processing of Composite Laterite. The decreased particle size of about crushed/milled 900 0.03 m is a value that can be used to calculate the distance between two points. The distributions of particle sizes in laterite following Figure shows the results of the sieve analysis.



In one composite, the matrix material (a combination of laterite and cement) was mixed with LDPE particles and calcium phosphate; in another composite, the matrix material was mixed with LDPE particles and gypsum; and in a third composite, the matrix material was mixed with LDPE, gypsum, and calcium phosphate in various proportions. The LDPE particles were mechanically blended in proportions of 10%, 15%, and 20% by volume. For 5 minutes, these were combined with 150 mL water. The mixed materials were moulded into rectangular-shaped samples of 100 x 25 x 12.5 mm in size. For 5 minutes, the moulds were subjected to a consistent pressure of roughly 20 kN. For flexural strength and fracture toughness tests, the prepared samples were cut into pieces with dimensions of 60 10 5 mm and compressive strength measurements with dimensions of 20 20 20 mm.

Composite Preparation for Thermal Energy Storage:

The Below Table lists the various formulas of composites used for thermal energy storage in buildings. This involved combining various weight percentages of pure laterite, biochar, gypsum, and LDPE to test the strength and thermal energy storage capacities of the material for sustainable building applications. Biochar is made from wood biomass that has been gasified. The biochar was pulverised and sieved to a particle size of around 160 m on average. The biochar was then combined in volume percentages of 5%, 10%, and 15% with LDPE at 1% and 2% by volume, and gypsum was mixed uniformly at 20% by volume.

Table 2. Composition of laterite and biochar

No.	Laterite (% by volume)	Laterite (g)	Biochar (% by volume)	Biochar (g)
1	95	285	5	15
2	90	270	10	30
3	85	255	15	45

X-Ray Diffraction Analysis:

The XRD data was collected using a Phillips P-analytical X'pert Pro MPD diffractometer (Malvern Panalytical S.A.S, Palaiseau, France). Copper (Cu) was used as the radiation source ray. The wavelength K is 1.543 nm. To remove nickel, a nickel filter was utilised. The CuK ray is a type of ray. The apparatus's working conditions were as follows: The voltage is 45 kV and the current is 40 mA. From 10° to 20°, the diffractogram was recorded. In 2q, heat to 75°F. In 2q, the scan step-time was 0.017° and the steps were 0.017°. The phase identification was done from the beginning.

Thermogravimetric Analysis and Differential Scanning Calorimetry:

Thermogravimetric analysis (TGA)/DSC equipment (SDT Q600, TA Instruments, Guyancourt, France) was used to conduct thermal assessments of the formed composite samples. Approximately 50–100 milligrammes of the solid was heated at 5°C/min from room temperature to 1,100°C. After then, there will be a 30-minute isotherm. All of the TGA/DSC tests were completed.

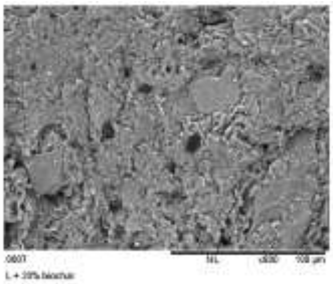
Thermomechanical Analysis:

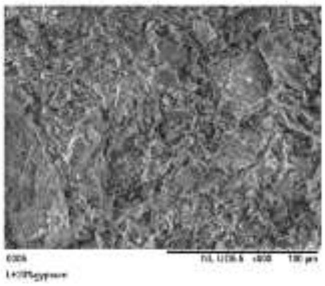
TMAs (thermomechanical analyses) were performed using a TMA Setsys (Setaram, Caluire-et-Cuire, France). A sample weighing 10 g was heated at 5°C/min from 30°C to 1,100°C, then cooled. The crucible used for the analysis of the samples was made from alumina, and the reference was an empty alumina pan.

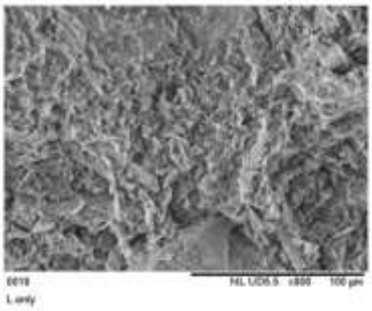
Results and Discussion:

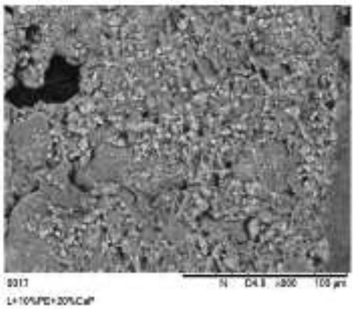
Microstructural and XRD Analysis:

Figures 1(a–d) and 2(a–d) show micrographs of the laterite/cement matrix and the PE, gypsum, and calcium phosphate composites. These SEM photos show how various particles interact. Each composite microstructure interacted with one another. Figures 2(a) and 2(b). Porous microstructures may be seen in 3(c and d), indicating that the microstructures are porous. At the microscopic scale, particles are weakly linked. This reduces the overall strength of the composite. Figures 3 and 4 show that this is not the case (d) and 4(a and b) show particles that are tightly bound within them. Figures 5(a–c) show the XRD data obtained for the composites. The diffractograms produced when laterite was mixed with gypsum, PE, or charcoal were unaffected [Figs. 6(b and c)]. Laterite, PE, and biochar, on the other hand, had unique diffractograms.



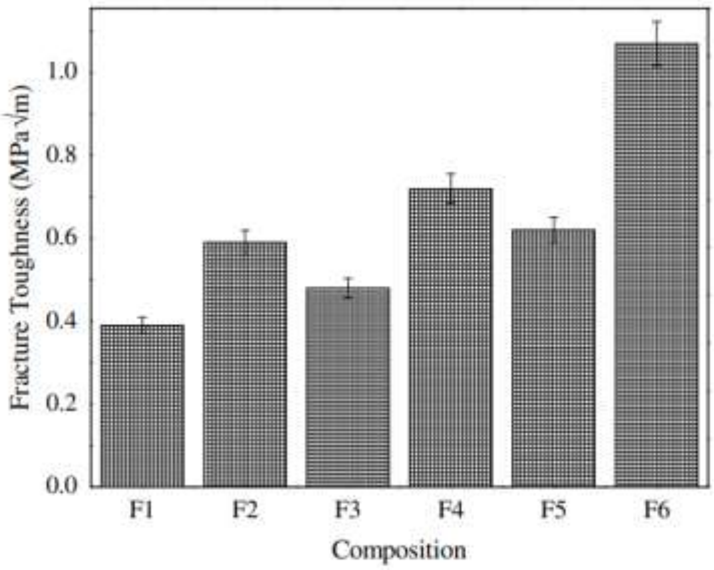






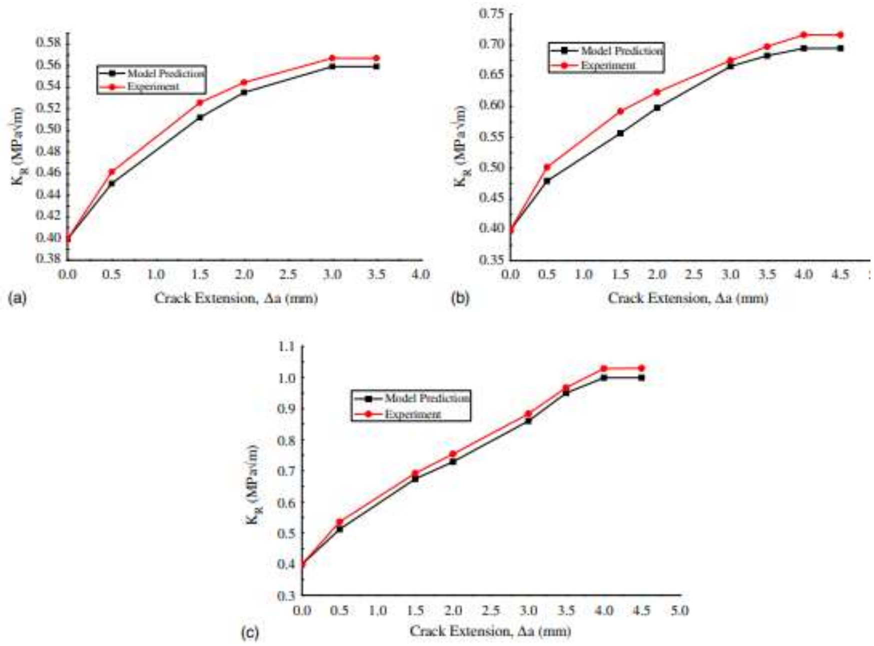
Compressive Strength:

Figure shows the measured compressive strengths for all of the materials that were tested. The results of the compressive strength tests revealed that the 100% laterite composition had a compressive strength of 24 hours of drying in an oven, the pressure was 2.822 0.01 MPa. The capability of the composites increased to 3.5 0.032 MPa and 3.6 MPa, respectively.



Flexural Strength:

Figure shows the flexural strengths obtained for all of the tested formulated composite samples. The flexural strength results show that the 100% laterite sample had a flexural strength of 4.1 0.02 MPa after drying in an electric oven for 24 h. This value increased significantly to ~6.0 0.02 MPa for mixtures of 50% by volume laterite, 20% by volume LDPE, 15% by volume gypsum, and 15% by volume calcium phosphate after drying for 24 h in an electric oven.



Mechanical Strength Analysis

The regression model linking the mechanical strength to the weight loss of the composites is illustrated in Fig. 13. The model predicts a linear relationship between strength and weight loss of the resulting composites. The R − squared adjusted value of nearly 98% indicates a strong correlation between the strength and weight loss of the composites. This indicates that the strength of the composite increases when more weight is lost. This was attributed to the fact that more weight reduction strengthens the bonds in the composite. The linear association between the strength and weight loss of the composite identified in this work is a major scientific contribution to the web of knowledge.

Statistical Analysis of Cracks

Table 3 shows the findings of the statistical analysis of composite cracks. The Student's t-test was used to conduct this study at a 95 percent confidence interval (CI). The p-values for the different brick composites' crack forms and extensions were all less than 0.05. This signifies that the null hypothesis is rejected, and the test statistic for fracture creation and extension is statistically significant.

Scientific Contribution

Environmental contaminants and waste materials, such as low-density polyethylene and phosphogypsum, were employed in multifunctional earth-based bricks for use in sustainable structures in this study. The recovered waste low-density polyethylene functioned as a toughening material for crack-tip shielding in the composite by crack bridging.

Table 3. Statistical analysis of cracks

Variable	Laterite only	Laterite with PE and biochar	Laterite with gypsum	Laterite with PE, CaP, and gypsum
N	8	8	8	8
Mean	1.699	1.087	1.051	0.391
Standard deviation	2.114	1.290	1.247	0.384
Standard error mean	0.748	0.456	0.441	0.136
95% CI	(−0.069, 3.467)	(0.008, 2.165)	(0.008, 2.093)	(0.070, 0.712)
T	−3.08	−4.19	−4.42	−4.48
P	0.018	0.004	0.003	0.003

CONCLUSIONS

1. Gypsum waste and low-density polyethylene bags can be recycled into laterite composite reinforcements for use in the building and construction sector. The LDPE–laterite–gypsum composite and the laterite–LDPE–biochar composite that resulted both had outstanding mechanical properties as well as thermal properties.

2. The composite was strengthened with LDPE at 1% by volume and 15% by weight. Biochar exhibited the best combination of flexural strength, flexural strength, and flexural strength by volume.

3. Because of its higher stacking regularity, the addition of the compound AlSiO2OH2 to the kaolinite group contributed to the overall strength of the composite. The fact that it exists Mg2.35Fe0.13Al0.52 offered quick setting and hardening, resulting in the composite's total strength, which is a significant scientific contribution following sintering, fracture toughness, and thermal behaviour 850°C, which is higher than that found in earlier research. This Composites could be used in infrastructure construction materials like sustainable housing and thermal energy. Biochar, on the other hand, aids in the absorption of thermal energy.

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