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Influence of Air-dried Soil Types and Compaction on Eco-bricks Performance Under Uniaxial Compressive Loading

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Abstract

Researchers have considered the potential utilization of waste plastics in concrete and mortar production. However, there is paucity of research on the use of waste plastic as an encapsulate in the manufacture of eco-bricks. This paper assesses the characterization of eco-bricks under uniaxial compressive loading with respect to soil materials and compaction. Three compaction layers and three types of soil materials (laterite, sharp sand, and stone dust) were used to produce 81 specimens of eco-bricks. The study reveals that the compressive strength of eco-bricks made with laterite has a positive linear relationship with the number of compaction layers, but eco-bricks that are made with sharp sand and stone dust as filler material have a negative linear relationship with the number of compaction layers. The compressive strength of laterite-filled eco-bricks for one, two and three layers of compaction was 31.92 N/mm^2, 40.91 N/mm^2 and 46.79 N/mm^2, respectively. In comparison, stone dust has a density of 12.18 N/mm^2, N/mm^2, and 6.51 N/mm^2 and sharp sand have a density of 3.38 N/mm^2, 2.42 N/mm^2, and 2.17 N/mm^2. The study revealed that at a high level of compaction, laterite bottle bricks are suitable for use as masonry units for construction of walls, while sharp sand and stone dust bottle bricks are only suitable for use as masonry units at a low level of compaction. It is advised to choose filler materials and compaction layers carefully while manufacturing bottle bricks because the performance of eco-bricks depends significantly on these parameters.

Keywords: Bottle bricks, Compressive strength, Poisons ratio, PET, Waste plastic

Introduction

The management of waste plastics indiscriminately disposed into the built environment, landfills, and water bodies is becoming a global issue (Bjerregaard and Meekings, 2008; Khoo, 2019; Petersen, 2004; Wang et al., 2019). In 2016 alone, over 7.3 million tonnes of waste plastic were generated around the globe (Geyer et al., 2016). Worldwatch (2018) reported that approximately 43% of plastic waste ends up in landfills, 52% in low environmental regulation countries, and 5% is disposed into water bodies. Brooks et al. (2018) also asserted that higher-income countries in the Organization for Economic Cooperation export 70% of plastic waste to lower-income countries in East Asia and the Pacific. The plethora of waste plastic that is carelessly dumped into the built environment in numerous cities in developing nations is not included in this statistic. When there is a flood, waste plastic from the built environment that has been recklessly discarded can sometimes make its way into the ocean, clog waterways, and damage marine life.

The situation has continued to degenerate and Wilson (2015) raised concern that if the current trend persists, there will be more plastic than fish in the sea by 2050. Mousa et al. (2016) remarked that if the rising demand for plastics, indiscriminate disposal, and the inability of governments at every level to efficiently manage plastic disposal continue for the next few decades, the earth will be buried under a pile of disposable plastic materials. Disposal of plastic waste into landfill and incineration contributes to the depletion of the environment and carbon dioxide emissions from incineration plants ultimately lead to global warming.

Numerous studies have been conducted to discover a long-term solution to the threat posed by the massive environmental issues caused by the indiscriminate disposal of nylon and waste plastics. Ameri and Nasr (2017) investigated the performance properties of devulcanized waste PET-modified asphalt mixtures. Khoo (2019) presented a new perspective on the Life Cycle Assessment (LCA) of plastic waste treatment by including waste treatment plant capacities. Badejo *et al*., (2017) studied the application of waste plastic as a strength modifier in asphalt for pavement. Jassim (2017) investigated the recycling of polyethylene waste to produce plastic cement. A similar study examined the utilisation of waste plastic for the manufacture of bricks and paver blocks (Thorneycroft et al., 2018). Several studies have explored the use of waste plastic in the production of concrete and mortar (Ge et al., 2013; Wang and Meyer, 2012). A few studies have investigated the use of waste plastic bottles (PET) as an encapsulate in the production of bricks (Mokhtar *et al.*, 2016; Taaffe, et al., 2014). The adoption of eco-bricks for the construction of houses in Yelwa, Nigeria has been reported also (Edike et al., 2021). Utilizing PET as an encapsulate offers significant benefits to developing and low-tech countries since extensive refining and reprocessing are not necessary for the production of eco-bricks.

Also, to enable the characterization of eco-bricks, further research on the use of waste PET in eco-brick production is necessary due to the variability of the findings of the existing studies. Existing studies have employed plastic waste and other materials as infill material with no systematic filling methods, which have produced different results. Most significantly, eco-bricks are utilised as infill materials for the construction of affordable homes, some structural elements, and eco-parks in various places and regions of Nigeria and Latin American nations, utilising locally available soil. However, the quality of the infill materials used in various areas may differ, which will have an impact on the performance of the finished eco-bricks. This study examines how soil types and compaction affect the mechanical characteristics of eco-bricks to determine which soil types and manufacturing techniques will yield satisfactory performance.

Materials and Methods

Three types of soil materials—stone dust, sharp sand, and laterite—were used as infill materials for the PET bottles. 75 cl PET bottles of the same shape and products retrieved from the streets were used as encapsulate for the infill materials. The infill materials were air dried in the laboratory for three months. PET bottles were filled with either of the soil types at various compaction layers. Each compaction layer involves 12 rounds of vibration on the floor with a round displacement height not exceeding 150 mm. The vibration was manually done and the lifting height was limited to 150mm to avoid damaging the PET bottles. The bottle bricks were compacted into three different layers as indicated in Table 1. Nine specimens were tested for infill material type and layers of compaction.

Table 1: Soil Types, Compaction Layers and Specimen Code

Soil Types	Single Layer	Two Layers	Three Layers
Stone dust	SD_1	SD_2	SD_3
Sharp Sand	SS_1	SS_2	SS_3
Laterite	LT_1	LT_2	LT_3

SD-Stone dust; SS-Sharp sand; LT-Laterite

The single layer involves filling the PET bottles with soil material without compaction. In the two-layer compaction, PET bottles were half filled and compacted, then filled, compacted again and levelled up before corking. The bottle bricks were filled and compacted in three layers for the three-layer compaction. The load-bearing surface area of the bottle bricks was computed by shredding PET bottles into five parts of measurable shapes, which were then calculated and summed up.

A 1500kN capacity Technotest compression testing machine was used for the compressive strength test. To increase the uniformity of stress distribution on the bottle bricks and to make up the lifting height of the compression machine, a platen measuring 450 X 225 X 25 mm^3 and a metal disc measuring 300 mm in diameter by 150 mm in thickness were added to the machine as indicated in Figure 1. The platen was placed on the specimen and the metal disc was positioned at the compression machine's bottom disc. The eco-brick samples were crushed at a machine loading rate of 15 kN/s.

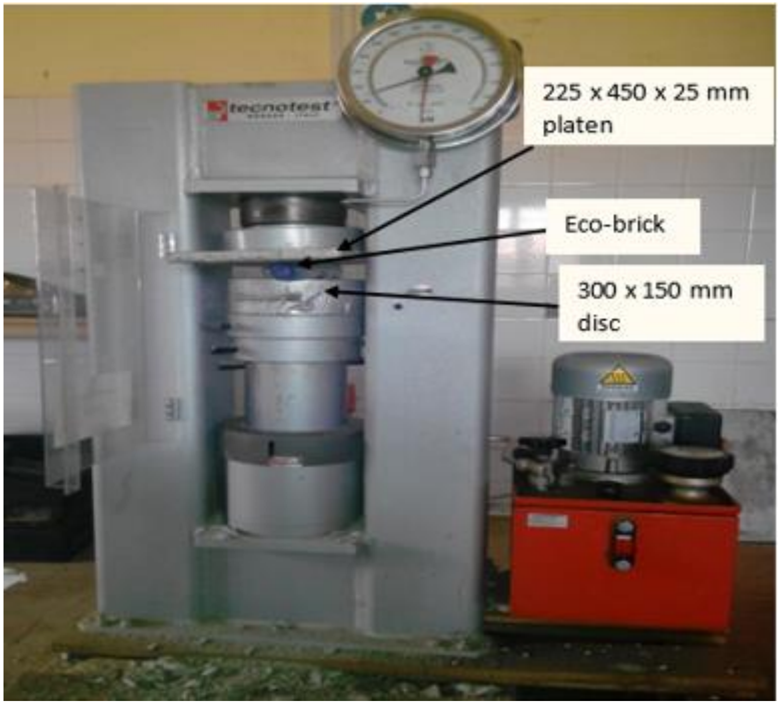

Figure 1: 750 ml Bottle Brick under Compression Load

Results and Discussion

Mass of Eco-bricks and duration of loading to failure

The mass of the bottle bricks and compression loads at failure for the various infill soil materials are presented in Table 2. The bottle bricks are 750 ml in size but have a varied mass since the infill soil components have varying specific gravities and layers of compaction. Bottle bricks packed with laterite (LT bottle bricks), sharp sand (SS bottle bricks), and stone dust (SD bottle bricks) have all shown an increase in mass with increasing levels of compaction. Also, the duration of crushing increased with compaction layers. For the sharp sand bottle bricks with a single compaction layer (SS_1), two layers of compaction layer (SS_2), and three layers of compaction (SS_3), 1.19 kg, 1.26 kg, and 1.32 kg, respectively, were recorded and an increase in crushing time from 9.09 minutes to 10.01 minutes as compaction layers increased from one to three was also observed.

Table 2: Effect of Compaction on Crushing Time and Mass of Bottle Bricks

S/N	Samples	Mass (kg)	Crushing Load (kN)	Crushing Time (minutes)
1	SS_1	1.19	90.83	9.09
2	SS_2	1.26	65.00	9.22
3	SS_3	1.32	58.33	10.01
4	SD_1	1.31	327.50	8.72
5	SD_2	1.41	250.00	10.45
6	SD_3	1.45	175.00	11.23
7	LT_1	0.92	858.33	13.28
8	LT_2	1.00	1100	13.36
9	LT_3	1.10	1258.33	14.49

SD_{1-3}-Stone Dust samples for compaction layers 1-3; SS_{1-3}-Sharp Sand samples for compaction layers 1-3; LT_{1-3}-Laterite samples for compaction layers 1-3

Similarly, the mass of the bottle bricks manufactured with sharp sand increases with increasing layers of compaction, and hence, the duration of the load-bearing capacity of eco-bricks produced using sharp sand increases with an increase in mass and compaction layer. Similar trends were observed in eco-bricks made with laterite and stone dust. Bottle bricks filled with stone dust achieve a maximum average mass of 1.45 kg at a load-bearing duration of 11.23 minutes for the three compaction layers.

The increase in mass from the single layer to the three-layer compaction in stone duct bottle bricks is due to the increase in the compaction layer as soil particles replace voids in the bricks, resulting in enhanced load-bearing duration. However, the enhancement of load-bearing duration due to compaction does not translate into an increase in load bearing capacity of the stone dust bottle bricks.

The duration of loading to failure increased with compaction layers for the eco-bricks produced with laterite. A maximum average load-bearing duration of 14.49 minutes at an average mass of 1.10 kg was recorded for the three compaction layers of eco-bricks produced with laterite infill material. Unlike the sharp sand and stone dust eco-bricks, the eco-bricks produced with laterite indicated a positive relationship among the mass, compaction layers, duration of loading to failure, and load-bearing capacity. The sharp sand and stone dust eco-bricks showed an inverse relationship between load bearing capacity and the other parameters: mass, compaction layers, and duration of loading to failure.

Compressive Strength

The results of the compression strength test are shown in Figure 2 to illustrate the impact of soil types and compaction on the compressive strength of eco-bricks. For single-layer compaction, two-layer compaction, and three-layer compaction, the average compressive strength of bottle bricks packed with sharp sand is 3.38 N/mm^2, 2.42 N/mm^2, and 2.17 N/mm^2 respectively. The result is consistent with Taaffe *et al.*'s (2014) study that obtained a compressive strength of 2.96 N/mm^2 with eco-bricks produced with waste plastic as infill material. The results do not meet the BS 3921 minimum requirement of 5 N/mm^2 for external works. The compressive strength of the sharp sand-filled bottle bricks is low compared to the results obtained for sharp sand-filled eco-bricks in Edike, Ameh and Dada (2020). The differences could be attributed to the compaction technique and the moisture content of the infill soil materials.

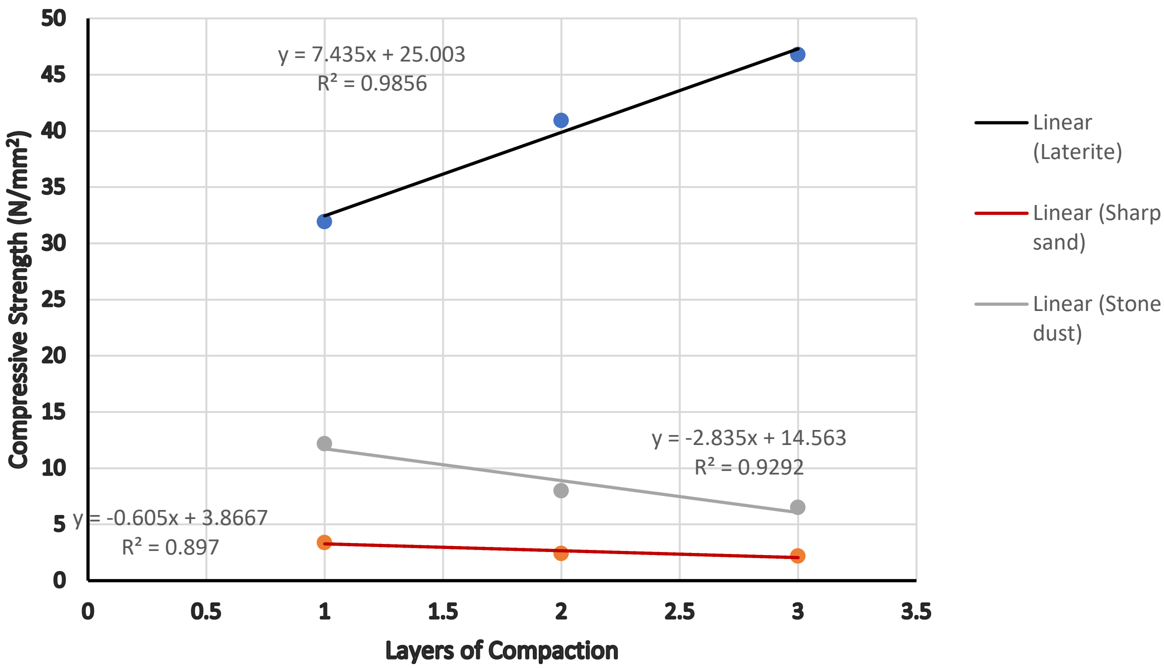

Figure 2: Variation of Compressive Strength with Compaction

In Figure 2, the results indicate that the compressive strength is linearly decreased with an increase in compaction due to the decrease in air void of soil material and consequently reduced space needed to accommodate the elastic behaviour of the encapsulate material—PET bottle. A similar trend was also observed with bottle bricks filled with stone dust. The average compressive strength of stone dust for single-layer, two-layer, and three-layer compaction is 12.18 N/mm^2, 7.99 N/mm^2, and 6.51 N/mm^2, respectively. The SD bottle bricks satisfied the 5 N/mm^2 compressive strength limit recommended by BS 3921, 1985. However, the graph in Figure 2 shows that the compressive strength is linearly decreased with an increase in compaction due to the decrease of air void of stone dust, resulting in reduced space for elastic behaviour of the PET bottles.

For the laterite-filled bottle bricks (LT bottle bricks), compressive strength linearly increased with compaction layers. The average compressive strength of LT bottle bricks for single-layer compaction, two-layer compaction, and three-layer compaction is 31.92 N/mm^2, 40.91 N/mm^2, and 46.79 N/mm^2, respectively. This result corroborates Mokhtar *et al.*, (2016) that achieved maximum stresses of 38.34 N/mm^2 and 27.39 N/mm^2 with 250 ml and 1.5 L plastic bottles, respectively. The results of the compression strength also indicate a linear relationship with the mass of LT bottle bricks, which is consistent with the remarks of Taaffe *et al.*, (2014) that the weight of a bottle brick and the compressive force it can support appears to be linearly correlated to each other. However, the results of the SS and SD bottle bricks show that the compressive strength decreases with the compaction layer and consequently the mass of the bricks shows that the assertion is dependent on the infill material.

Specific Strength

To determine the resistance of the encapsulate material (PET bottle) under uniaxial compressive loading, compaction layers and soil types, the specific strength of the eco-bricks was computed using the formula in equation (1), which was derived by dividing the stresses at failure by the eco-brick's density. The units of specific strength are Pam^3/kg or kN.m/kg and the result is presented in Figure 3.

$$SpS = \frac{\sigma v}{m} \qquad \text{------------------} \qquad (1)$$

Where SpS is specific strength (kN.m/kg), σ is stress at failure (kN/m^2), v is volume of bottle brick (m^3), m is mass of bottle bricks (kg).

The specific strength of LT bottle bricks, as shown in Figure 3, ranges from 26.02 kN.m./kg to 31.91 kN.m./kg. Edike *et al.*, (2020) obtained higher specific strength values for eco-bricks filled with laterite at less than 15% moisture content. The specific strength of eco-brick in the present study is higher than the specific strengths of copper (24.7 kN/kg) and concrete (5.22 kN/kg), but lower than the specific strength of PET (57–62 kN/kg) alone.

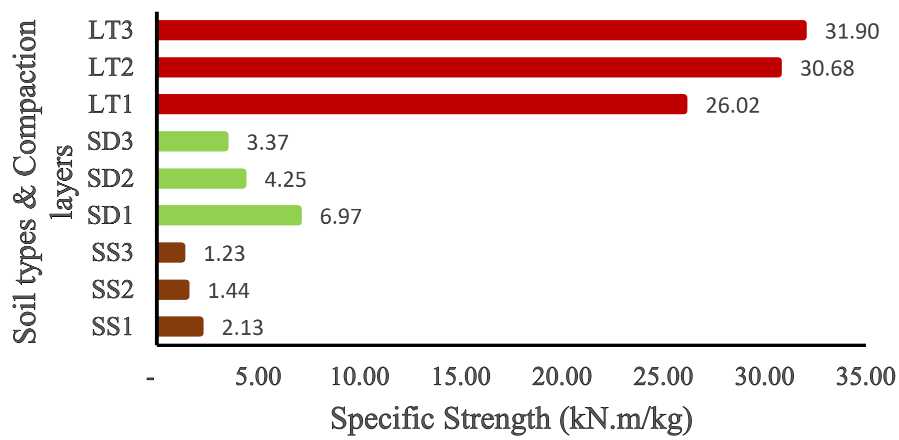

Figure 3: Effect of Soil Type and Compaction on Specific Strength of Eco-bricks

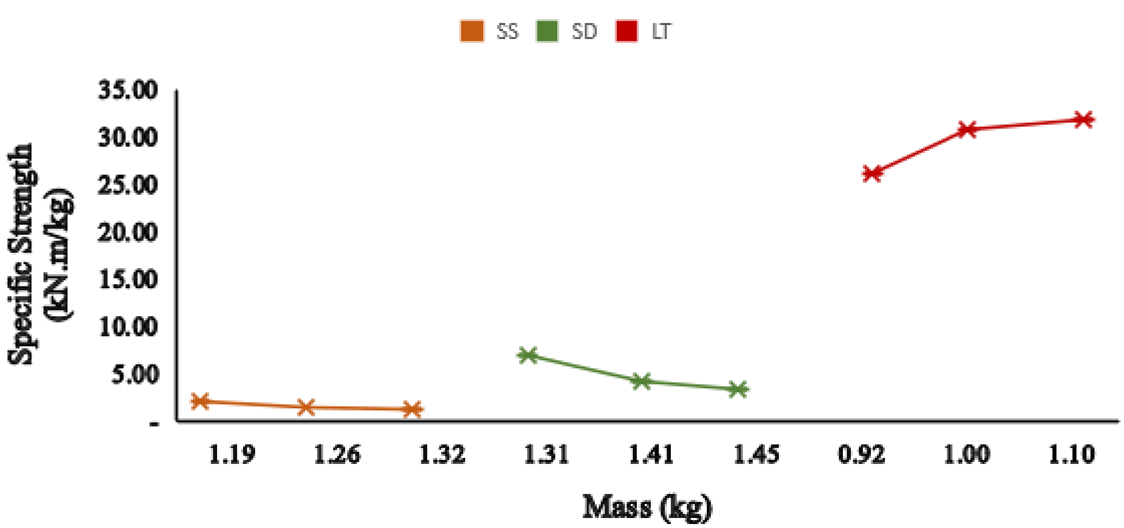

Figure 4: Specific Strength of Eco-bricks as a Function of Soil Material Mass

For the SD bottle bricks, specific strengths of 3.37 kN.m/kg, 4.25 kN.m/kg, and 6.97 kN.m/kg were recorded for three-layer compaction, two-layer compaction, and single layer, respectively. Taaffe *et al.*, (2014) got a comparable series of values between 5.17 kN.m./kg and 5.69 kN.m./kg for the specific strength of bottle bricks using waste plastics as infill material. The SD bottle bricks' specific strength reduces with an increase in layers of compaction. The decrease in specific strength with layers of compaction is in agreement with the compressive strength performance of the SD bottle bricks. A comparable decrease in specific strength with respect to compaction layers was also observed in the SS eco-bricks. The specific strength of sharp sand and stone dust bottle bricks decreases with mass, whereas the LT bottle bricks increase with mass (see Figure 4). The results revealed that LT bottle bricks have considerable resilience under compressive uniaxial loading compared to SS and SD bottle bricks.

Poisson's Ratio

To calculate the Poisson's ratio, the specimens were compressed in the direction of the applied load during the compressive strength test, and the corresponding extensions in directions perpendicular to the applied load were noted. The ratio between the axial strain and transverse strain was computed as Poisson's ratio shown in Figure 5. To prevent inaccurate readings caused by the eco-brick's residual elastic energy, measurements were conducted when the compression machine's upper disc was still on the specimen.

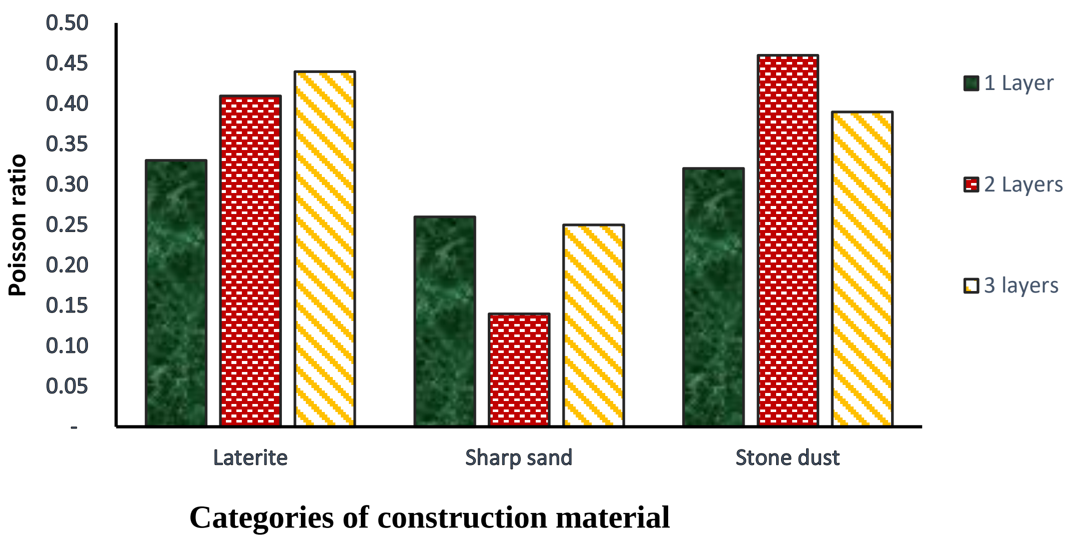

Figure 5: Poisson's Ratio of Bottle Bricks

Figure 5 shows an increase in Poisson's ratio of LT bottle bricks with compaction layers. Poisson's ratios of 0.33, 0.41, and 0.44 were found at the single compaction layer, two layer, and three compaction layers, respectively. This revealed an enduring and resilient property of LT bottle bricks, which could contribute to the enhancement of the probability of survival of LT bottle brick masonry under load. It may also necessitate the conduct of further research into the relationship between Poisson's ratio and the compressive strength of eco-bricks given the increase in Poisson's ratio of the LT bottle bricks with compaction layers. On the contrary, SS and SD bottle bricks show no particular trend between Poisson's ratio, compressive strength, and layers of compaction.

Conclusions

The study has established the suppositions of the application of air-dried laterite, stone dust, and sharp sand to the manufacture of eco-bricks. The study also demonstrated how compaction affected the performance of eco-bricks made with laterite, stone dust, and sharp sand as infill materials. The study reveals the feasibility and suitability of eco-bricks applications for the construction of building structures. The following conclusion is drawn from the study.

i. Bottle bricks made with laterite as the infill material have remarkable specific strength and compressive strength, but a low Poisson's ratio. The high specific strength attribute of laterite bottle bricks presents the potential to facilitate the use of eco-bricks in multi-story building construction, where weight reduction and significant strength performance are crucial as the number of storeys increases.
ii. The compaction layers have a positive linear relationship with the compressive strength performance of laterite eco-bricks. This reveals that air-dried laterite bottle bricks require substantial compaction during production for the attainment of optimal strength.
iii. On the contrary, the study found that compaction is not required in the manufacture of bottle bricks using air-dried sharp sand or stone dust as infill material due to the negative linear relationship between the compaction layers and the compressive strength of the eco-bricks. The negative relationship is attributable to the reduction in internal elastic movement of the encapsulate material with more coarse soil particles.
iv. Sharp sand bottle bricks only achieve the minimum 2.9 N/mm^2 compressive strength specified in BS EN 771-3 (2011) when the bottle brick is not compacted adequately. Irrespective of the layers of compaction, stone dust bottle bricks satisfy the minimum compressive strength. However, considerable performance is enhanced with reduced compaction layers.
v. The performance of bottle bricks is dependent on the infill material and the layers of compaction; thus, the study advises careful selection of the infill material and consideration of the layers of compaction in the manufacture of eco-bricks.

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