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Effect of Locust Bean (Parkia Biglobosa) Pod Ash and Portland cement on Strength and Durability Properties of Compressed Earth Bricks

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Abstract: *The need for locally produced, durable and robust, readily available, inexpensive and environmentally friendly building materials has led to persistent bottlenecks in sustainable housing delivery. "The construction industry is exploring exciting new materials that are eco-friendly and perfect for construction projects." The major problem associated with compressed earth bricks is the high rate of water absorption and lack of durability properties because most soil in its natural condition needs more strength, dimensional stability, and durability, which are required for building materials. The effect of high rate of water absorption and other strength and durability issues make bricks to be soluble in water and limits its use and performance of the bricks. This experimental study assesses the effect of locust bean (Parkia biglobosa) pod ash and Portland cement on compressed earth bricks' strength and durability properties. Compressed earth bricks were tested for density, compressive strength, permeability, water absorption, shrinkage, sorptivity and abrasion resistance. The maximum compressive strength was achieved at 10%C:10%LBPA stabilization with a strength of 2.52 N/mm^2 and 2.80 N/mm^2 at 28 and 56 days, which shows a 50% and 53.21% increase in strength over the control brick samples, respectively. Bricks produced with cement and locust bean pod ash were less permeable and had high resistance to abrasion, less shrinkage, less porous and less sorptivity than 0% stabilization. In conclusion, cement and locust bean pod ash are good stabilizing agents in compressed earth bricks. The use of Portland cement and locust bean pod ash as a stabilizing material seems to be a feasible solution not only to the problem associated with compressed earth bricks but also helps in the adoption of Indigenous waste material of locust bean pod in the production of bricks which will help reduce the environmental problem. Therefore, this research recommends using cement and locust bean pod ash at 10%C:10%LBPA in compressed earth bricks, leading to robust, stabilized and durable bricks.*

Keywords: *Abrasion Resistance, Compressed Earth Bricks, Compressive Strength, Locust Bean Pod Ash, Permeability, Water Absorption, Shrinkage.*

1. INTRODUCTION

The demand for locally manufactured, long-lasting, easily accessible, affordable, and eco-friendly building materials in developing nations like Nigeria is crucial. This demand is driven by the need to fulfil the current generation's housing requirements while maintaining and ensuring that future generations can fulfil their own need [1]. Laterite, a significant material for brick production, has been used to construct shelters from time immemorial. Silveira [2] maintained that brick construction presents many cultural, social and architectural benefits. The benefits of soil as building material include its availability in large quantities [3]; economically beneficial [4]; environmentally sustainable [5] [6]; easy to design with and high aesthetical value [7] [8]; improves indoor air humidity and temperature [4] [9]; saves energy [10] [11] [12] [13]; provide better noise control [14] [15] [16] [17]; unlimited reusability of the non-stabilized soil [18] [19] [20] [21]; Its disadvantages include: extensive water absorption [22] [23] [24] [21]; poor resistance to abrasion and impact [25] [26] [27] [21]; low tensile Strength [28] [29] [30] [31]; high maintenance [32] [33] [34] [17]; and suitable only for in-situ construction [35] [36] [37] [38]. However, they are in a poor state of conservation, partly due to the lack of knowledge of the mechanical properties of earth bricks masonry.

One of the drawbacks of using earth material in construction is the lack of durability properties, which is related to its compressive strength. In its natural condition, most soil lacks the strength, dimensional stability, and durability required as a building material. The durability of a material is primarily influenced by its compressive strength. As stated by Minke [39], durability is impacted by various factors such as the composition of clay, the distribution of silt, sand, and larger aggregates, as well as any additives used and the technique employed for preparation and compaction.

Earth bricks are prone to attack by termites; they do not withstand weather effects. Often, rainstorms cause much damage to the brick walls, thereby requiring seasonal maintenance, which consumes time and labour. It needs to be stronger and has problems not desired for use as walling material. Natural disasters such as floods during the rainy season also affect earth brick buildings in rural and even in some semi-urban buildings, particularly in the middle of the rainy season; also, when excess water is released, the bricks become swollen [40] [41]. Earth brick walls have the problem of cracking due to drying shrinkage, high water absorption rate, which leads to many houses collapsing during the dry season, Rodents boring holes easily in the walls, and low compressive, tensile and shear strength. Earth bricks' poor durability and strength reduce their capacity to be an effective, sustainable building material. There is a dire need to investigate methods to enhance the properties and performance of earth bricks using environmentally friendly, cost-effective, and sustainable materials and processes.

The conventional method of using earth does not make wall construction durable enough to withstand any effects. Continuous application of this traditional method has resulted in the washing down of the wall surface by rain and eventually caused a total collapse of the building. Constant maintenance of the wall surface being washed down by rain is also a result of this old method. Worried by this ugly consequence, a new technique could be developed using the compressed earth method to improve the strength of earth bricks for more durable wall construction. The success of brick construction will mainly result from the characteristics of the existing raw materials availability. Constructions with earthen material will improve the quality of life of those who use these constructions and increase associated safety levels, mainly if effectively designed. It presents, however, essential difficulties, mainly due to the need for existing knowledge concerning properties and characteristics of the mechanical behavior of earth masonry. Technical studies of the properties and characteristics of earthen masonry are necessary and will constitute an essential instrument in support of property and strength of bricks and also in support of the design of new earth bricks constructions [42] [43] [44]. Emphasis is given to the maximum use of sustainable available earth brick materials, with significant relevance given to the design and strength of compressed earth bricks. It is essential to prioritize the development of sustainable and environmentally friendly materials without compromising the quality and standards of modern construction, as noted by Agboola et al. [1] and Obonyo et al. [45]. Therefore, a concerted effort is needed to improve the weaknesses of earth bricks associated with their strength, stability, waterproofing quality and resistance to erosion by rain. However, indigenous materials must be developed to improve specific properties of the compressed earth bricks. Significant concentration has been given to stabilization in cement/lime stabilized bricks /blocks, sundried soil blocks, burnt clay bricks, mud and straw, and lime. Based on the preceding, this research investigates new environmentally friendly and renewable chemical stabilizer sources and ensures their potency for brick production. A study conducted by Azeko et al. [46] discovered that laterite bricks, when stabilized with 20% polyethene by volume, exhibited the most favourable combination of compressive strength and fracture toughness. Compared to the traditional bricks (0.5 – 1 N/mm^2), Binici et al. [47] concluded that stabilization with plastic fibres, straws and polystyrene fabrics improved the compressive strengths of fibre-reinforced mud bricks (3.7 – 7.1 N/mm^2).

Further, Binici [47] explained that these fibre-reinforced bricks had lower dead weight, leading to lower material handling costs; however, this study needs to include more findings on the durability properties of earth bricks. Sutcu & Akkurt [48] reported that porous earthenware bricks stabilized with paper processing residues (30%) had a 50% reduction in thermal conductivity and higher compressive strengths. In their study incorporating cotton and limestone powder in a brick material, Algin & Turgut [49] obtained improved flexural strength (2.19 MPa), compressive strength (7 MPa), water absorption, and energy absorption. Rahman [50] found that rice husk-stabilized bricks had improved compressive strength, water absorption, and linear shrinkage. Agboola et al. [51] and Agboola et al. [52] found that rice husk ash as agricultural waste is an excellent pozzolanic material that aids in improving the durability of concrete properties. However, other agricultural byproducts can be assessed to see if they improve the performance of other construction materials, such as earth bricks.

Few studies have explored the use of locust bean pod ash in stabilizing compressed earth bricks, and it has also been used as a composite material of cement and LBPA, applying sustainable and cost-effective application methods. Locust bean pod ash and ordinary Portland cement were not assessed as stabilizers in compressed earth bricks. Moreover, Locus bean pod, which is a Waste Agricultural Biomes (WAB) and obtained from the fruit of the African locus bean tree (Parkia biglobosa), is a material resource that can extensively be used in adequate proportion as a soil stabilizer for the production of soil blocks to build houses. The African locust bean tree, scientifically known as "Parkia biglobosa", is a fascinating perennial tree legume belonging to the subfamily Mimosoideae and the family Leguminosae. It is a remarkable member of the plant kingdom. [6] [41] [53]. Parkia biglobosa is a versatile and vital tree native to the savannah zone of West Africa. This plant plays a crucial role in improving soil fertility and can reach a height of approximately 15 meters, featuring dark, evergreen, pinnate leaves. Its fruit is a brown, leathery pod measuring 10 to 30 cm long, containing a sweet-tasting gummy pulp surrounding several seeds.

The locust bean tree is commonly found in savanna regions and is easily identified by its bright red, drooping flowers. Its pods are edible and commonly used as livestock feed. The locust bean seeds are widely used as a food seasoning throughout Nigeria, known as Dawadawa in the north and iru in the Yoruba culture. Additionally, the fruit is sweet and can be consumed directly, and the pods are utilized in industrial gum production. Research conducted by Akabi et al. [54] revealed that Parkia biglobosa seeds are abundant in lipids, soluble sugars, carbohydrates, protein, and ascorbic acid.

According to a study by Aliero [55], these seeds contain 54% fat, 30% protein, and essential vitamins and minerals like phosphorus, potassium, and calcium. Please remember the critical findings from Okunlola et al. [56] research, which emphasize the significant role of trees in providing wind protection and shade. Tee et al. [57] conducted research showing that locust bean and ironwood tree products are essential for supporting the nutritional well-being of individuals in North-Central Nigeria. The seeds are commonly used as a seasoning and nutritious additive in soups and stews, providing essential amino acids [58]. An analysis of the fruit pulp revealed a moisture content of 8.41%, protein at 6.56%, fat at 1.80%, crude fibre at 11.75%, ash at 4.18%, and carbohydrates at 67.30% [59].

Although many look down on soil blocks today, they are one of the oldest building materials. It has been used for centuries in all parts of the world before the advent of modern building materials like concrete, but its usage can now be promoted by adding stabilizers to improve its performance [60] [61] [62]. Locust bean pod ash may serve as a cost-effective alternative if proven to be mechanically suitable, given the abundance of the raw material. This is especially relevant as the locust bean tree is extensively cultivated across various regions in the African country [63] [64]. Local builders in the country will use this material if found suitable to improve the strength and durability of bricks as a primary building material. By improving brick production, developing countries can move towards the evolution of genuinely indigenous technology and appropriate construction materials that will be available and affordable to all to achieve their housing needs. This research work, therefore, assesses the strength properties of compressed earth bricks using locust bean pod ash and cement as additives.

2. MATERIALS AND METHOD

2.1 Materials

The materials used in this experiment are laterite, cement, Locust Bean Pod ash, and water. The soil type used in these experiments was laterite obtained from Shendam local government Plateau State. The laterite sample was sieved through the 4.76 mm standard sieve size, and the particles retained were weighed. The Locust Bean Pod (LBP) was obtained from Plateau State, Shendam Local Government Area of Plateau State, Nigeria. The harvested fruits were ripped open. The yellowish pulp and seeds were removed from the pods, and the empty pod material was used. The Locust Bean Pod was sun-dried for forty-eight hours to remove moisture. It was then ground into powder and then burnt to ashes at 600^{O}C. The ashes were collected and sieved through a B.S. sieve (75 microns). Potable water was used to mix the materials and is acceptable for construction.

2.2 Method

Bricks of 150 x 300 x 80 mm were produced to study the physical and mechanical properties of the samples. All brick samples were cured for the period of (7, 14, 28, and 56 days). Seven mixes were prepared, which include the control (0%), then cement and locust bean pod ash at different ratios of 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5LBPA, and 10%C:10%LBPA, this is to enable proper utilization and optimization of sustainable alternative material in construction. Binder and water were measured in percentages by the weight of the laterite used. The bricks were air-dried. Extensive tests were conducted on the mechanical properties of brick samples, such as compressive strength test, permeability, water absorption, sorptivity, and shrinkage test. It is essential to ascertain the strength of the various soil types to determine how the material will perform in different conditions and to determine the effect of the locust bean pod and cement on the brick sample. The durability of a material depends on the pore structure and the strength of the stabilized bond. Hence, capillary absorption (sorptivity) and other properties establish the durability index. Water absorption determines the absorption rate and how the soil is stabilized at different stabilization rates. Permeability determines the rate at which water can flow through soil. The shrinkage Test determines the extent to which locust bean pod ash and cement stabilized compressed earth bricks. Table 1 depicts the standard test methods followed for carrying out various tests.

Table 1: Test method for experimental program

Test Description	Specification
Field Setting Test	BS 1377:4 [65]
Specific Gravity of Soil	ASTM D 854-02 [66]
Specific Gravity of LBPA and Cement	I.S.: 2720-Part 3. [67]
Density	BS 1924:Test 2 [68]
Compressive Strength	BS 6073 part 1 [69]
Permeability	BS 1377: [70]
Sorptivity	BS 1377 [70]
Water Absorption	BS 1377 [70]
Shrinkage	BS 1377 [70]

3. RESULTS AND DISCUSSION

3.1 Field Settling Test for Soil Sample

Table 2 shows the result of the field-settling test for the laterite used in the work. The silt test of the laterite sample indicates reasonable clay and silt content of 92.55% and 7.45%, respectively. This conformed to the BS 1377 [70] standard, which states that soil silt's maximum limit should not exceed 8%. However, the silt content is acceptable, showing that the laterite can produce compressed earth bricks.

Table 2: Field settling test result

Sample	% Clay	% Silt
A	93.22	6.78
B	92.11	7.89
C	92.31	7.69
Average	92.55	7.45

3.2 Cigar Test for Soil Sample

Table 3 shows the result of the cigar test carried out on the soil sample. The broken length was between 10.3 and 12.1, and the average length of the broken pieces was computed and found to be 11.25cm, which signifies that the soil is suitable for use since the average length falls between 5cm and 15cm. The value in this study is in the range specified by [71] that at 15cm average, the soil contains too much clay and at 5cm average, the soil contains too much sand.

Table 3: Cigar test result

Sample	Length
A	11.2
B	11.8
C	10.7
D	12.1
E	10.3
F	11.4
Average	11.25

3.3 Specific Gravity of Materials

The soil's specific gravity was found to be 2.66, which exceeds the range specified by [72], [73], [74], of 2.35 – 2.63 but falls within the range specified by BS 1377 [70] as 2.65 to 2.80. The specific gravity of locust bean pod ash is 2.18, while the specific gravity of cement is 3.15.

Table 4: Specific gravity of materials

Materials	Specific Gravity
Soil	2.66
Locust Bean Pod Ash	2.18
Cement	3.15

3.4 Density of Compressed Earth Bricks

Figure 1 presents the average density of compressed earth bricks stabilized with locust bean pod ash and cement at varying percentages of 5% to 20%; brick samples were cured and weighed at 7, 14, 28 and 56 days. The density of brick samples varies from 2420 kg/m^3 to 2640 kg/m^3, and it decreases with increased curing periods. Brick samples with a density lesser than 1966kg/m^3 are known as light-density brick samples [75]. Values obtained exceeded the 1966 kg/m^3 expected for a standard brick weight except for the control brick sample at 28 days. The result from this study is consistent with the findings of [76] and the studies conducted by [77]. This indicates that compressed earth brick stabilized with locust bean pod ash and cement favors the average weight for the brick sample produced.

3.5 Compressive Strength of Compressed Earth Bricks

Figure 2 presents the average strength of compressed earth bricks stabilized with locust bean pod ash and cement added at 0%, 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5LBPA, and 10%C:10%LBPA respectively, which recorded average compressive strength values of 0.68N/mm^2 and 1.24N/mm^2 for all percentage addition of locust bean pod ash, at 7-days curing age. This shows an increase in strength of 45.16% at 10%C:10%LBPA compared to the control specimen. The increase in compressive strength of the compressed earth brick specimens was a result of the uniform distribution of the stabilizers, which produced a strong bond between the soil and the stabilizers themselves, making a stronger material which has strength, whereas the decrease in compressive strength was a result of weak strength portrayed

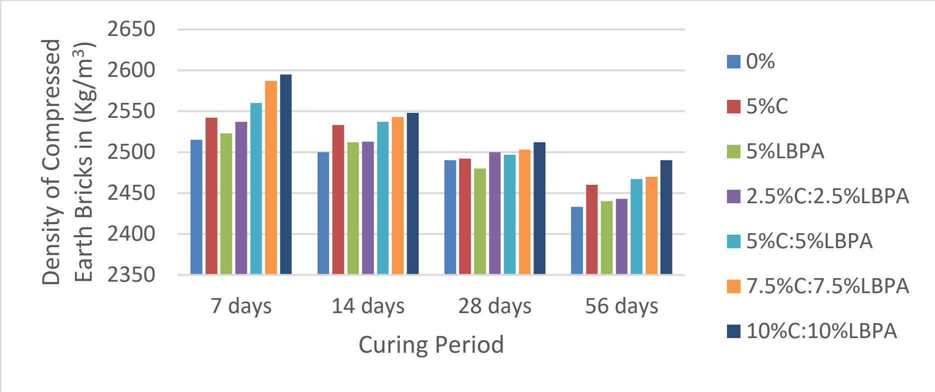

Figure 1: Density of compressed earth bricks against curing days

by soil material due to stabilizer not present in the soil. The increase in strength could also have been due to creating an isotropic matrix between the clay structure and the stabilizing agent network; such a matrix would oppose the movement of particles and create stability mainly because stabilizers appear to distribute strong bonds throughout the bulk of the material. Also, at 28 days of curing, the strength recorded was within 1.26N/mm^2 and 2.52N/mm^2. At 56 days compressed earth bricks strength recorded was within 1.31 N/mm^2 and 2.80 N/mm^2 for all percentage addition of locust bean pod ash. However, 5%C:5%LBPA, 7.5%C:7.5LBPA, 10%C:10%LBPA within the range of 1.8 to 2.5N/mm^2 as prescribed by (BS 1924, 1990), also 2.5%C:2.5%LBPA, complied with the minimal standards of 1.65N/mm^2 compressive strength for bricks [78]. All CEBs successfully met the [79] standards, making them usable for building construction.

The strength of the compressed earth bricks was above the recommended strength of 2.5 N/mm^2 for concrete blocks [80]; this means the mixing processes were fairly adequate and well observed and monitored; also, the compaction and stabilization were adequate, and its presence has maximized strength development [81]. These results indicate that stabilizers stabilize the interlocking forces between the stabilizing agent and the soil surface as adhesion properties so that the soil will not easily collapse. The external surface of the bricks, due to the presence of locust bean pod ash, offers an extra anchoring agent by which the bricks can accept stresses from the external forces and become a more effective stabilizing agent. The external surface of the bricks, due to the presence of locust bean pod ash, offers an extra anchoring agent by which the bricks can accept stresses from the external forces and become a more effective stabilizing agent. The results affirmed that cement and locust bean pod ash stabilized earth bricks have improved mechanical properties and can be adopted for important construction work, especially from a 5% stabilizer.

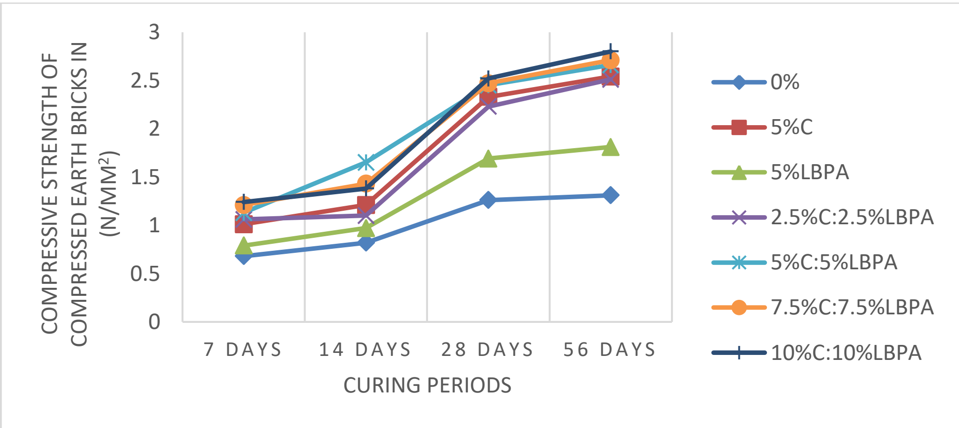

Figure 2: Compressive strength of compressed earth bricks against curing days

3.6 Permeability of Compressed Earth Bricks

The permeability of a brick indicates how porous the block is or how much it can absorb water. Since water absorption usually leads to block deterioration, the permeability of bricks is a measure of durability characteristics. The higher the permeability of brick specimens, the lower their resistance to deterioration, affecting durability properties.

Figure 3 shows the permeability at the 28 days of curing for 30min, 60min and 90min. At 30 minutes absorption, for 0%, 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5LBPA, 10%C:10%LBPA of stabilizers respectively, the highest absorption rate was observed at 0% control, while 5%C, 7.5%C:75.%LBPA and 10%C:10:LBPA show 10% absorption rate, then 5%LBPA, 2.5%C:2.5%LBPA, and 5%C:5%LBPA shows 8% absorption rate.

At 60 min, the absorption rate was maximum at 0% with a 15% absorption rate, 5%C, 7.5%C:7.5%LBPA, and 10%C:10%LBPA shows a 12% absorption rate, while 5%LBPA, 2.5%C:2.5%LBPA, and 5%C:5%LBPA shows 10% absorption rate. 0% control and 5%LBPA have the highest absorption rate, while 5%LBPA, 2.5%C:2.5%LBPA, and

5%C:5%LBPA bricks stabilization have the minimum absorption rate, as indicated in the result. The lower absorption rate of the bricks might be due to the presence of optimum LBPA in the mix, which reduces the absorptive capacity of the brick. However, permeability at 28 days of curing for 90min was maximum at 0%, with the highest absorption rate of 18%, followed by 5%C:5%LBPA, 7.5%C:7.5LBPA, and 10%C:10%LBPA with an absorption rate of 16%, 5%C having an absorption rate of 15%, while 5%LBPA and 2.5%C:2.5%LBPA having an absorption rate of 14%. 5%LBPA and 2.5%C:2.5%LBPA have a minimum absorption rate of 14%.
Figure 4 shows the permeability at 56 days of the curing period. For 30 minutes, the permeability was maximum at 0%, 5%C, and 10%C:10%LBPA with an absorption rate of 10%. 7.5%C:7.5LBPA has an absorption rate of 11%, 5%LBPA has an absorption rate of 10%, 5%C:5%LBPA has an absorption rate of 9%, while 2.5%C:2.5%LBPA has an absorption rate of 8%. However, 2.5%C: 2.5%LBPA has the minimum absorption rate.

For 60 min, permeability was maximum at 0%, with an absorption rate of 16%, then followed by 5%C, 5%LBPA, 7.5%C:7.5%LBPA and 10%C:10%LBPA with an absorption rate of 14%, respectively, while 2.5%C:2.5%LBPA and 5%C:5%LBPA have the minimum absorption rate of 12%. At 90min, permeability was maximum at 0%, with an absorption rate of 20%, followed by 5%C:5%LBPA, 7.5%C:7.5LBPA, and 10%C:10%LBPA with an absorption rate of 18%; 5%C and 5%LBPA have an absorption rate of 16%, while 2.5%C:2.5%LBPA have the minimum absorption rate of 15%. However, the absorption rate of compressed earth brick increased with the increase in the curing period and decreased with the addition of cement and locust bean pod ash. The result from this study is consistent with the findings of [82] [83] [84] [85].

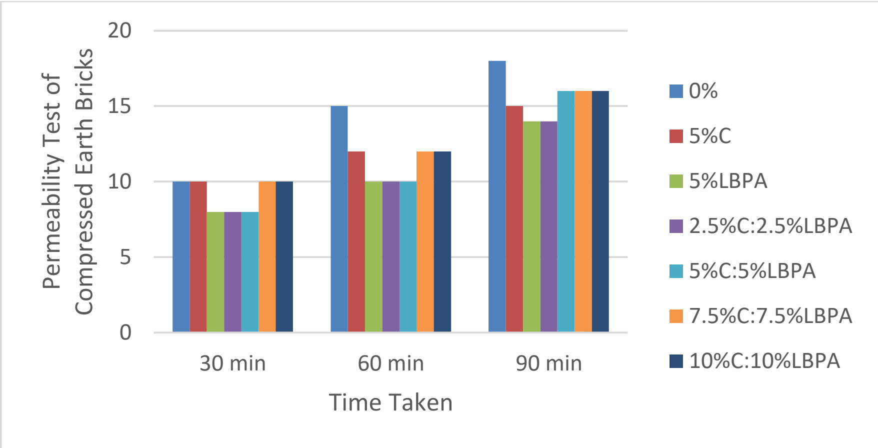

Figure 3: Permeability test for compressed earth bricks at 28 days

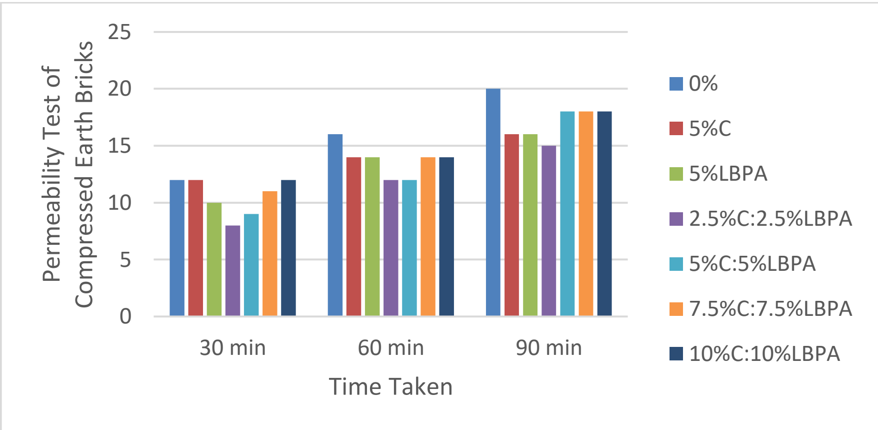

Figure 4: Permeability test for compressed earth bricks at 56 days

3.7 Sorptivity of Compressed Earth Bricks

The result of 28days presented in Figure 5 shows the rate of water rise taken at intervals of 5min; each specimen was weighed at intervals of 5min to determine the rate of water rise in the compressed earth bricks, to determine the specimen with the highest water rise and the one with lower water rise. The result shows that at 1min, 0% and 5%LBPA have the highest water absorption rate among the different stabilization levels with 16%, then 5%C with 15%, 2.5%C:2.5%LBPA with 14%, 5%C:5%LBPA with 12%, 7.5%C:7.5%LBPA with 10%, while 10%C:10%LBPA has 8% sorptivity. At 5 min, the result shows that 0% has the highest water absorption rate with 32%, followed by 5%LBPA stabilization at 30%, then 5%C at 28%, 2.5%C:2.5%LBPA at 26%, 5%C:5%LBPA with 24%, 7.5%C:7.5%LBPA with 22% and 10%C:10%LBPA with 18% sorptivity level. Also, at 10min, 0% stabilization has high absorption with 46%, 5%C and 5%LBPA with 45%, 2.5%C: 2.5%LBPA with 41% sorptivity level, 5%C: 5%LBPA with 40%, 7.5%C:7.5%LBPA has an absorption rate of 36%, 10%C:10%LBPA with 32%.

The result at 56 days, as presented in Figure 6, shows the rate of water rise taken at intervals of 5min. The result shows at 1min, 0%, 5%C, and 5%LBPA stabilization has the highest water absorption rate with 14%, followed by 2.5%C:2.5%LBPA with 12%, 5%C:5%LBPA, 7.5%C:7.5%LBPA and 10%C:10%LBPA with 10% sorptivity level. At 5 min, the result shows that 0%, 5%C, and 5%LBPA bricks have the highest water absorption rate among the different stabilization levels with 30%, 2.5%C:2.5%LBPA with 28%, 5%C:5%LBPA with 24%, 7.5%C:7.5%LBPA with 22%, and 10%C:10%LBPA with 18%. Also, at 10min, 0% stabilization has high absorption with 46%, 5%C and 5%LBPA with 45% sorptivity level, 2.5%C: 2.5%LBPA with 36%, 5%C:5%LBPA with 35%, and 10%C:10%LBPA with 34%, 10%C:10%LBPA with 29% sorptivity level. Higher absorption in control compressed earth bricks results from no stabilization, while low absorption results from stabilization in the bricks produced, and low absorption of the locust bean pod ash is used in the stabilization. The result from this study can be related to that carried out by [86] on compressed earth bricks, which shows that stabilizers influence the sorption of earth bricks. However, the findings of this study show that cement and locust bean pod ash addition reduce the sorption of compressed earth bricks.

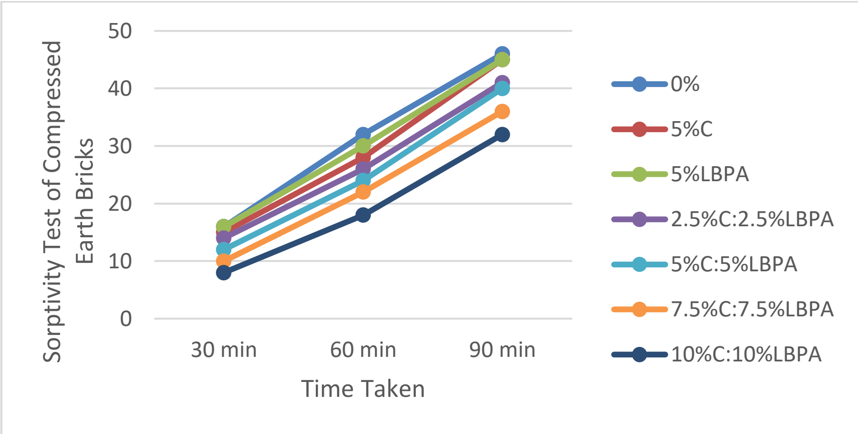

Figure 5: Sorptivity test for compressed earth bricks at 28 days

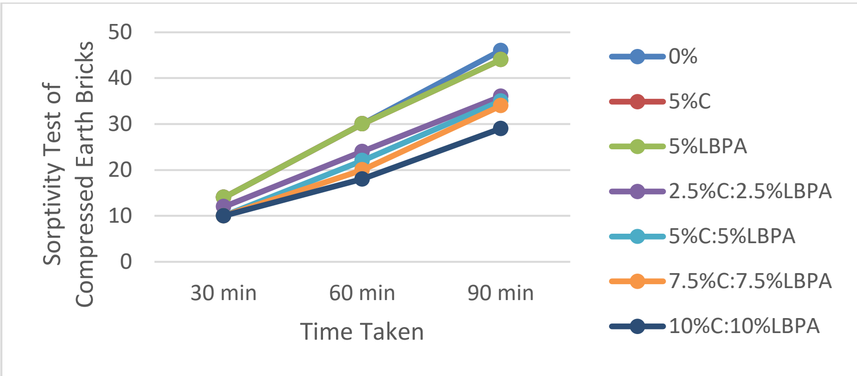

Figure 6: Sorptivity test for compressed earth bricks at 56 days

3.8 Water Absorption

Figure 7 shows the result of the water absorption test of compressed earth bricks stabilized with cement and locust bean pod ash at 28 days of curing age. It was observed that bricks with 0%, 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA and 10%C:10%LBPA absorbed 9.12%, 8.43%, 8.43%, 7.93%, 7.80%, 7.62% and 7.50%. However, compressed earth bricks stabilized with 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA, and 10%C:10%LBPA at 28 days conformed to the requirement of ASTM C 62 [79] for water absorption which states that cold water absorption of any single brick should not exceed 8%.

Figure 7 shows the result of the water absorption test of compressed earth bricks stabilized with cement and locust bean pod ash at 56 days of curing age. It was observed that compressed earth bricks with 0%, 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA and 10%C:10%LBPA absorbed 8.39%, 8.21%, 8.30%, 7.62%, 7.20%, 6.92% and 6.46%. However, compressed earth bricks stabilized with 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA, and 10%C:10%LBPA conformed to the requirement of ASTM C 62 [79] for water absorption which states that cold water absorption of any single brick of a random sample of five brick does not exceed 8%. The stabilization with 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA, and 10%C:10%LBPA has low water absorption capability due to the high content and well-distributed stabilizers, while as for the high absorption capacity of the control bricks, 5%C and 5%LBPA could be as a result of low or zero reinforcing agents in the sample since the stabilizing agent was confirmed to be responsible for reducing the rate of water absorption in brick samples. In addition, the low absorption of compressed earth bricks was due to the homogeneity mix, texture of the cement and locust bean pod ash, mode of compaction and curing style of brick. According to [87], there is a reduction in the absorption capacity of bricks as the percentage of stabilizers increases. However, this is related to the finding in this study, which shows less water absorption in the brick sample as the percentage of stabilizers increases. Also, it was observed that the silky nature of the surface area of locust bean pod ash and cement reduces the water intake absorbed by the compressed earth brick sample.

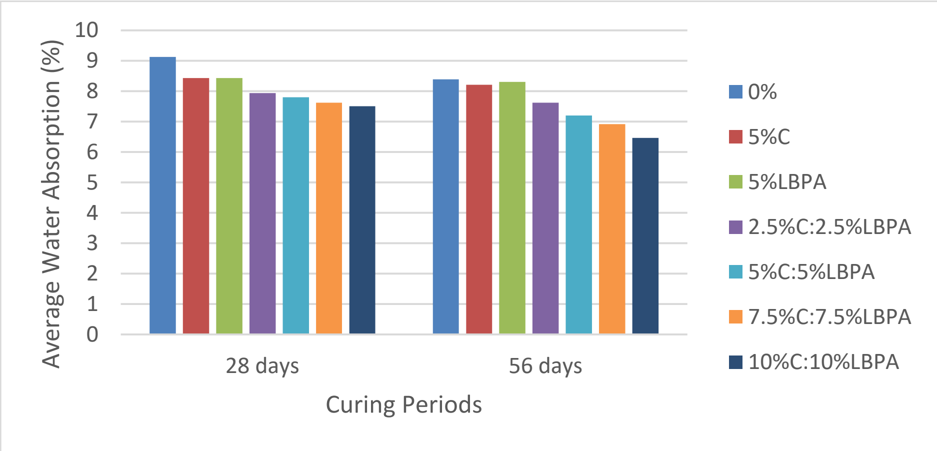

Figure 7: Water absorption test of compressed earth bricks

3.9 Shrinkage Test of Compressed Earth Bricks

The results of the shrinkage tests are shown in Figure 8 and Figure 9. The diagram shows the shrinkage in terms of the percentage of cement and locust bean pod ash added as stabilizers in compressed earth bricks. Figure 9 revealed that while non-stabilized bricks were characterized by high shrinkage of 10.56%, other stabilized bricks with 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA and 10%C:10%LBPA has shrinkage of 8.33%, 9.17%, 7.22%, 6.67%, 5.83% and 5.56% respectively. There is a progressive reduction in the percentage of shrinkage as the percentage of stabilizer increases at 28 days.

Figure 9 shows that at 56 days, the shrinkage percentage progressively reduces as the percentage of stabilizer increases from 0% control concrete to 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, 7.5%C:7.5%LBPA and 10%C:10LBPA, with shrinkage values of 10.78%, 7.78%, 9.17%, 6.67%, 6.11%, 5.56% and 5.00%, respectively.

These results provide strong evidence that stabilizing compressed earth bricks with cement and locust bean pod ash increases the stability of the brick as there is a reduction in shrinkage percentage. Stabilized compressed earth bricks are less influenced by the clay shrinkage, particularly the 10%C:10%LBPA mix. Using the 10%cC:10%LBPA brick mix reduces shrinkage by 52.65% at 28 days and 48.64% at 56 days curing period, making the 10%C:10%LBPA mix the optimum brick mix. The results from this study can be related to those carried out by [88]. In their study, bricks were reinforced with sugar cane fibre at 0.3% to 3%, and it was observed that 3%, the highest reinforcement level with sugar cane fibre, has a lower shrinkage value.

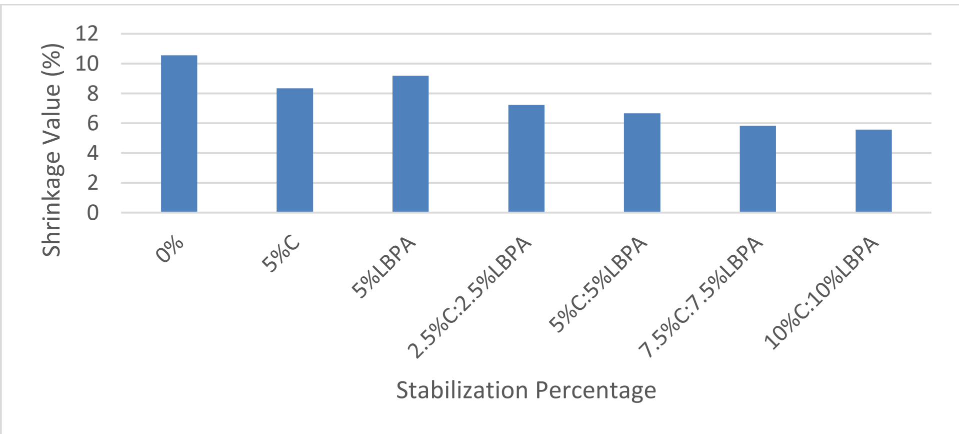

Figure 8: Shrinkage test for compressed earth bricks at 28 days

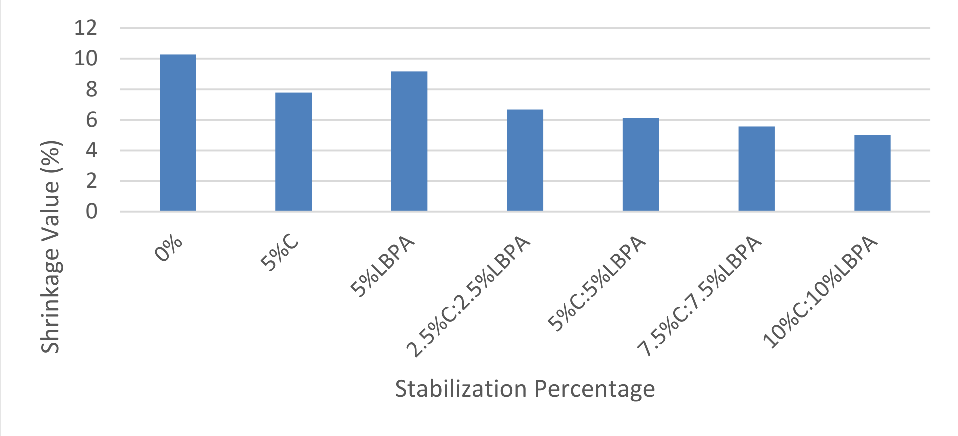

Figure 9: Shrinkage test for compressed earth bricks at 56 days

3.10 Abrasion Resistance

Figure 10 shows the abrasion resistance of compressed earth brick samples stabilized with cement and locust bean pod ash for 28 days and 56 days. There was high loss of weight of 3.61% for 0% control as compared to other stabilization addition of 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, and 10%C:10%LBPA having abrasion resistance of 3.24%, 3.43%, 3.30%, 2.95%, 2.77 and 2.63% respectively at 28days. Thus, 10%c:10%LBPA addition resists abrasion impact more than other percentage stabilization. Also, at 56days, it was discovered that 0% control had 3.23% abrasive resistance but higher than other additions at 5%C, 5%LBPA, 2.5%C:2.5%LBPA, 5%C:5%LBPA, and 10%C:10%LBPA which has a loss of weight of 2.94%, 3.00%, 3.04%, 2.75%, 2.46% and 2.34% respectively. Compressed bricks stabilized with cement and locust bean pod ash at 10%C:10%LBPA present better abrasion resistance than other additions, which may be due to the hard surface of the compressed earth brick caused by cement and locust bean pod ash at the surface, which makes it hard to brush the surface of the bricks. In addition, weight loss by other addition of stabilizing agents might be due to less stabilizing agents and coarser particles at the surfaces, which tend to be brushed out easier than those with finer particles at the surfaces. According to [89], abrasion resistance of soil bricks increases with increased stabilization in the soil materials; this is, however, related to the findings of this study, which shows that there is more resistance to abrasion of bricks when a higher percentage of cement and locust bean pod ash is present in the bricks sample.

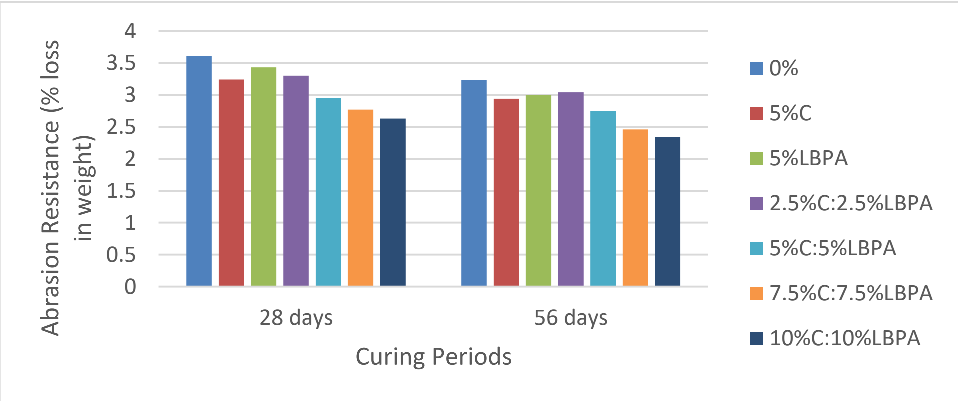

Figure 10: Abrasion resistance test of compressed earth bricks

4. CONCLUSION

The maximum compressive strength was achieved at 10%C:10%LBPA stabilization with a strength of 2.52 N/mm^2 at the 28-day curing period, with a 50% increase over the control brick sample, this was the optimum level achieved as it resulted in increased strength, enhanced durability and reduced the cost and improved the environmental benefit of sustainability compressed earth bricks. Also, at 56 days of curing age, the compressed earth bricks attained a strength of 2.80 N/mm^2, which shows an increase of 53.21% compared to the control sample. The tests confirmed that the cement and locust bean pod ash improved its resistance to moisture penetration (permeability) and shrinkage, lowering the bricks' absorption rate. There is a progressive reduction of the shrinkage percentage as the percentage of stabilization increases. The compressed earth bricks stabilized with cement and locust bean pod ash at 7.5%C:7.5%LBPA, and 10%C:10%LBPA have high resistance to abrasion impact. The locust bean pod ash and cement matrix can be stabilizing agents. The 10%C:10%LBPA stabilization level can produce durable compressed earth bricks for construction purposes in walling and where light weight is needed. In the long term, the diffusion of locust bean pod ash and cement stabilized bricks would contribute to the advancement of global housing sustainability goals, also improved stabilized compressed earth bricks will produce more durable and sustainable compressed brick structures. Compressed earth bricks produced with locust bean pod ash and cement are recommended for use in interior walling units requiring little or no load. Further tests should be conducted to determine the maximum content of locust bean pod ash and cement, beyond which the mechanical properties of stabilized compressed earth bricks will decline. Further research on the chemical constituents of locust bean pod ash should be conducted to determine the elements or compounds responsible for the water-repellent property and the strong bond in locust bean pod ash. High percentage of locust bean pod ash should be combined with other pozzolans to observe possible improvements of water repellent property of compressed earth bricks. Further studies should be done using locust bean pod ash from different sources as well as using soil type from different geological origin and different percentage ratio addition in compressed earth brick production for increased strength and durability.

REFERENCES

[1] Agboola, S. A., Idowu, F. A., Yusuf, F. M., & Musa, A. K. (2024). Barriers to sustainable green building practice in nigeria. *FUDMA JOURNAL OF SCIENCES (FUDMA),, 7*(6), 157-163. doi:https://doi.org/10.33003/fjs-2023-0706-2114.

[2] Silveira, D., Varum, H., Costa, A., & Carvalho, J. (2015). Mechanical properties and behaviour of traditional adobe wall panels of the Aveiro district. *Journal of Materials in Civil Engineering,, 27*(9), 04014253.

[3] Silveira, D., Varum, H., Costa, A., & Carvalho, J. (2015). Mechanical properties and behaviour of traditional adobe wall panels of the Aveiro district. *Journal of Materials in Civil Engineering,, 27*(9), 04014253.

[4] Minke, G. (2006). *Building with Earth: Design and technology of a sustainable architecture.* De Gruyter.

[5] Schroeder, H. (2016). *Sustainable Building with Earth (Vol. 582).* Springer.: Switzerland:.

[6] Mahamat, A. A., Linda-Bih,, N., Ayeni, O., Azikiwe Onwualu , P., Savastano Jr, H., & Oluwole Soboyejo, W. (2021). Developing sustainable and eco-friendly materials from termite hill soil stabilized with cement for low-cost housing in Chad. *Buildings,, 11*(3), 86.

[7] Peng, S. H., & Han, K. T. (2018). Assessment of aesthetic quality on soil and water conservation engineering using the scenic beauty estimation method. *Water,, 10*(4), 407.

[8] Ali, A. M., & Al-Assadi,, F. I. (2024). The aesthetic and environmental compatibility of building materials in Iraqi architecture, with brick as a model. . *In AIP Conference Proceedings. 3091(1).* AIP Publishing.

[9] Romero, A. C., Francisca,, F. M., & Giomi,, I. (2021). Hygrothermal properties of soil-cement construction materials. *Construction and Building Materials,, 313*, 125518.

[10] Arumugam, C., & Shaik,, S. (2021). Transforming waste disposals into building materials to investigate energy savings and carbon emission mitigation potential. *Environmental Science and Pollution Research,, 28*(12), 15259-15273.

[11] Esin, T., & Yüksek, I. (2008). A study on ecological properties of building materials used in traditional buildings (in Turkey). *Facilities, 26*(5/6), 229-241.

[12] Reddy, B. V., & Jagadish, K. S. (2003). Embodied energy of standard and alternative building materials and technologies. *Energy and buildings, 35*(2), 129-137.

[13] Webb, D. J. (1994). Stabilized soil and the built environment. *Renewable energy,, 5*(5-8), 1066–1080.

[14] Zou, C., Wang, Y., & Tao, Z. (2020). Train-induced building vibration and radiated noise by considering soil properties. *Sustainability,, 12*(3), 937.

[15] Yang, H. S. (2013). *Outdoor noise control by natural/sustainable materials in urban areas.* Sheffield: Doctoral dissertation, University of Sheffield.

[16] Horoshenkov, K., Khan, A., Benkreira, H., Mandon, A., & Rohr, R. (2011). The effect of moisture and soil type on the acoustic properties of green noise control elements. . *Proceedings of forum acusticum*, (pp. 845-849).

[17] Hadjri, K., Osmani, M., Baiche, B., & Chifunda, C. (2007). Attitude towards earth building for Zambian housing provision. *Proceedings of the Institution of Civil Engineers: , 160(3)*, pp. 141 – 149.

[18] Rivera-Vidal, A., & Achenza, M. (2023). Preliminary Results of Thermal Conductivity Test on Earth and Fibers Building Elements, from Waste Materials to Thermal Constructive Solution. *International Conference on Bio-Based Building Materials* (pp. 430-441). Switzerland: Springer Nature.

[19] Fabbri, A., Morel, J. C., Aubert, J. E., Bui, Q. B., Gallipoli, D., & Reddy, B. (2022). *Testing and characterization of earth-based building materials and elements.* Springer International Publishing.

[20] Bock-Hyeng, C., Ofori-Boadu, A. N., Yamb-Bell, E., & Shofoluwe, M. A. (2016). Mechanical properties of sustainable adobe bricks stabilized with recycled sugarcane fibre waste. *International Journal of Engineering Research and Application,, 6*(9), 50-59.

[21] Stulz, R., & Mukerji, K. (1988). Appropriate Building Materials: A Catalogue of Potential Solutions. Swiss Centre for Appropriate Technology,. *Skat-Publications,*. Switzerland.

[22] He, J., Luo, S. R., Li, W. J., Kang, D. Y., & Zuo,, Z. W. (2024). Capillary water absorption and strength of solidified marine soft soil. . *Construction and Building Materials,, 423*, 135729.

[23] Fabbri, A., Soudani, L., McGregor, F., & Morel, J. (2019). Analysis of the water absorption test to assess the intrinsic permeability of earthen materials. *Construction and Building Materials,, 199*, 154-162.

[24] Deboucha, S., & Hashim, R. (2011). Correlation between total water absorption and wet compressive strength of compressed stabilized peat bricks. *International Journal of Physical Sciences,, 6*(10), 2432-2438.

[25] Sujatha, E. R., & Devi, S. S. (2018). Reinforced soil blocks: Viable option for low-cost building units. *Construction and Building Materials,, 189*, 1124-1133.

[26] Erkal, A., D'Ayala, D., & Sequeira,, L. (2012). Assessment of wind-driven rain impact, related surface erosion and surface strength reduction of historic building materials. *Building and Environment,, 57*, 336-348.

[27] Atzeni, C., Pia, G., Sanna, U., & Spanu, N. (2008). Surface wear resistance of chemically or thermally stabilized earth-based materials. *Materials and Structures,, 41*, 751-758.

[28] Beckett, C. S., Augarde, C. E., Easton, D., & Easton, T. (2018). Strength characterization of soil-based construction materials. *Géotechnique,, 68*(5), 400–409.

[29] Muguda, S., Booth, S. J., Hughes, P. N., Augarde, C. E., Perlot, C., Bruno, A. W., & Gallipoli, D. (2017). Mechanical properties of biopolymer-stabilized soil-based construction materials. *Géotechnique letters, 7*(4), 309–314.

[30] Danso, H., Martinson, D. B., Ali, M., & Williams, J. B. (2015). Danso, H., Martinson, D. B., Ali, M., & Williams, J. B. (2015). Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. *Construction and Building Materials,, 101*, 797–809.

[31] Lal, A. K. (1995). *Handbook of low-cost housing,*. New Delhi, India.: New Age International Publishers,.

[32] Udoudoh, F. P., & Bassey, L. E. (2021). Traditional building materials in housing construction: usage and maintenance strategy. *PM World Journal,, 10*(4), 1-20.

[33] Fakhar, A. M., & Asmaniza, A. (2016). Road maintenance experience using polyurethane (P.U.) foam injection system and geo-crete soil stabilization as ground rehabilitation. *IOP Conference Series:, 136(1)*, p. 012004.

[34] Suffian, A. (2013). Some common maintenance problems and building defects: Our experiences. *Procedia Engineering,, 54*, 101–108.

[35] Hessouh, J. J., Eslami,, J., Beaucour, A. L., Noumowe, A., Mathieu, F., & Gotteland, P. (2023). Physical and mechanical characterization of deep soil mixing (DSM) materials: Laboratory vs construction site. *Construction and Building Materials,, 368*, 130436.

[36] Bajpayee, A., Farahbakhsh, M., Zakira, U., Pandey, A., Ennab, L. A., Rybkowski, Z., & Banerjee, S. (2020). In situ resource utilization and reconfiguration of soils into construction materials for the additive manufacturing of buildings. *Frontiers in Materials, 7*, 52.

[37] Wan, L., Wendner, R., & Cusatis, G. (2016). Wan, L., Wendner, R., & Cusatis, G. (2016). Experiments and numerical simulations are novel materials for in situ construction on Mars. *Construction and Building Materials,, 120*, 222–231.

[38] Walker, P., Keable, R., Martin, J., & Maniatidis, V. (2005). *Walker, P., Keable, R., Martin, J., & Maniatidis, V. (2005). Rammed Earth: Design and construction guidelines.*

[39] Minke, G. (2000). *Earth Construction Handbook.* South Ampton. U.K.: Wit Press.

[40] Ejidike, V. (2023). *Utilization of hydraform brick as alternative construction material for sustainable project delivery in the tropics.*

[41] Shehu, M. (2022). *Compressive strenth of re-vibrated concrete containing locust bean epicarp extract and bida natural stones.* doctoral dissertation).

[42] Miccoli, L., Müller, U., & Fontana, P. (2014). Miccoli, L., Müller, U., & Fontana, P. (2014). Mechanical behaviour of earthen materials: A comparison between earth block masonry, rammed earth and cob. *Construction and building materials,, 61*, 327-339.

[43] Hernández, R. S., Barrios, M. S., & Pozas, J. M. (2000). Characterization of ancient construction materials (mud walls and adobe) in the churches at Cisneros, Villada and Boada de Campos (Palencia). *Materiales de Construcción,, 50*(257), 33-45.

[44] Obonyo, E. T., ate, D., Sika, V., & Tia, M. (2010). We are advancing the structural use of earth-based bricks: Addressing key challenges in the East African context. *Sustainability,, 2*(11), 3561-3571.

[45] Dowling, D. (2004). *Better mud bricks to save lives: A Ph. D. project progress report. Earth building research forum.* Sydney: University of Technology.

[46] Azeko, S. T., Mustapha, K., Annan, E., Odusanya, O. S., & Soboyejo, W. O. (2015). Recycling of polyethene into strong and tough earth-based composite building materials. *J. Mater. Civ. Eng.,,* 04015104. doi:10.1061/(ASCE)MT.1943-5533.0001385,

[47] Binici, H., Aksogan, O., & Shah, T. (2005). Investigation of fibre reinforced mud brick as a building material. *Construction and Building Materials,, 19*, 313 – 318.

[48] Sutcu, M., & Akkurt, S. (2009). The use of recycled paper processing residues in making porous brick with reduced thermal conductivity. *Ceramics International,, 35*(7), 2625-2631.

[49] Algin, H. M., & Turgut, P. (2008). Cotton and limestone powder wastes as brick material. *Construction and building materials,, 22*(6), 1074-1080.

[50] Rahman, M. A. (1988). Effects of rice husks on the properties of bricks made from fired lateritic soil-clay mix. *Materials and Structures,, 21*(3), 222–227.

[51] Agboola, S. A., Yunusa, U., Tukur, M., & Bappah, H. (2022). Strength Performance of Concrete Produced with Rice Husk Ash as Partial Replacement of Cement. *African Journal of Environmental Sciences and Renewable Energy,, 5*(1), 1-15.

[52] Agboola, S. A., Bappah, H., Adamu, S. A., & Tukur, M. (2022). Effect of Rice Husk Ash on the Durability Properties of Concrete Subject to Aggressive Chemical Environment. *African Journal of Environmental Sciences & Renewable Energy. (AJESRE)., 5*(1), 16-37.
[53] Aguwa, J. I., & Okafor, J. O. (2012). A preliminary investigation is needed to use locust bean pod extract as a binder for producing laterite blocks for buildings. *International Journal of Environmental Science, Management and Engineering Research,, 1*(2), 57-67.
[54] Akabi, D. A., Akinsulire, O. R., & Sanyaolu, M. A. (2005). Qualitative determination of the chemical and nutritional composition of Parkia biglobosa (Jacq) Benth,. *African Journal of Biotechnology, 4*(8), 812-815.
[55] Aliero, B. (2004). Effect of Sulphuric acid, mechanical scarification and wet heat treatment on germination of African locust bean tree seeds, Parkia biglobosa,. *African Journal of Biotechnology, 3*(3), 179-181.
[56] Okunlola, A. I., Adebayo, R. A., & Orimogunje, O. D. (2011). Methods of braking seed dormancy on germination and early seedling growth of African locust bean (Parkia biglobosa). *(JACQ) Benth, Journal of Horticulture and Forestry, 3*(1), 1-6.
[57] Tee, T. N., Oguche, J. A., & Ikyaagba, E. T. (2009). The Role of locust bean and Ironwood trees in Human Nutrition and Income in Nigeria,. *Pakistan Journal of Nutrition,, 8*(8), 1172-1177.
[58] Hassan, L. G., & Umar, K. J. (2005). Protein and Amino acids composition of African locust bean, Tropical and Sub-tropical Agroecosystems,. *International Multidisciplinary Journals, 15*(1), 45-50.
[59] Gernmah, D. J., Atolagbe, M. O., & Echegwo, C. C. (2007). Nutritional Composition of the African Locust Bean fruit pulp, African Journal Online,. *Nigerian food Journals,, 25*(1), 190-196.
[60] Avila, F., Puertas, E., & Gallego,, R. (2022). Characterization of stabilized rammed earth's mechanical and physical properties: A review:. *Construction and Building Materials, 325*, 126693.
[61] Makul, N. (2020). Advanced innovative concrete: Review current progress, benefits, and challenges. *Journal of Cleaner Production, 274*, 122899.
[62] Sameh, S. H. (2014). Promoting earth architecture as a sustainable construction technique in Egypt. *Journal of Cleaner Production,, 65*, 362–373.
[63] Saleh, A. (2014). *Evaluating the possibility of using locust bean pod (makuba) as partial replacement of cement in sandcrete block production.*
[64] Adama, A. Y., Jimoh, Y. A., & Kolo, S. S. (2013). *Effect of locust bean pod ash on compaction characteristics of weak sub-grade soils.*
[65] B.S.-1377. (1975). Determination of granular soil's dry density/moisture content relationship (vibrating hammer method). In *BS 1377-4: Methods of test for soil for civil engineering purposes. Compaction-related tests.* London:: British Standards Institute.
[66] ASTM- D-(854)-02. (2002). Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. In *Annual Book of ASTM Standards,* (p. Vol. 04.08.). West Conshohocken, PA:: ASTM International.
[67] I.S.: 2720-Part 3. (1980). *Indian Standard Methods of Test for Soils: Determination of Specific Gravity of Fine-Grained Soils.* India: Indian Standard.
[68] BS 1924-2. (1990). *Stabilised materials for civil engineering purposes – Part 2 Methods and Lime Stabilized Material.* London: British Standard Institution.
[69] *British Standards Institution. (1981). Precast concrete masonry units. Part 1. Specifications for precast concrete masonry units. BS 6073: Part 1: BS London, England,1981.* (1981). London, England : British Standard Institution .
[70] *BSI (1990) B.S. 1377:1990: Methods of test for soils for civil engineering purposes. Parts 1–9. BSI,* . (1990). Milton Keynes, UK.: British Standard Institution .
[71] Tamta, S., Kumar, A., & Kushwaha, D. P. (2023). Potential of roots and shoots of Napier grass for arresting soil erosion and runoff of mollisols soils of Himalayas. . *International Soil and Water Conservation Research,, 11*(3), 538-548.
[72] Ibrahim, N. M., Rahim, N. L., Amat, R. C., Salehuddin, S., & Ariffin, N. A. (2012). Determination of plasticity index and compression index of soil at Perlis. *Apcbee Procedia,, 4*, 94-98.
[73] Bello, A. A., & Adegoke, C. W. (2010). Evaluation of geotechnical properties of Ilesha East Southwestern Nigeria's lateritic soil. *The Pacific Journal of Science and Technology,, 11*(2), 617-624.
[74] Badmus, B. S. (2010). Plasticity and compressibility characteristics of lateritic soil from southwestern Nigeria. *Journal of Natural Sciences Engineering and Technology,, 9*(1), 14-22.
[75] Ndububa, E. E., & Mukaddas, A. M. (2016). Mud House Failures and Mitigation Options in Bauchi, North East Nigeria. *FUOYE Journal of Engineering and Technology,, 1*(1), 26-30.
[76] Ndububa,, E. E. (2018). Stabilized lateritic bricks are an alternative to mud housing in Bauchi, North East Nigeria. *Journal of Mechanical and Civil Engineering,, 14*(5), 67-73.
[77] Salihu,, C., Paul, E. O., Patrick, O. O., Ealefoh, D. E., & Usman, S. Y. (2018). Determination of engineering properties of locust bean waste and wild vine use for construction in Nigeria. *FUTY Journal of the Environment,, 12*(2), 49-55.
[78] NBRRI. (2011). *Nigeria Building and Road Research Institute (NBRRI). NBRRI materials research and testing manual. 3rd ed. Nigeria:.* Abuja, Nigeria: Federal Ministry of Science and Technology.

[79] ASTM: C62. . (2006). *American Standard Testing Method (ASTM) C62. Standard specification for building brick (solid masonry units made from clay or shale). Annual book of ASTM; 2006.* West Conshohocken:: ASTM.
[80] NSO. (1975). *Specification for Sandcrete Blocks - Nigerian Industrial Standards.* Lagos: Nigerian Standards Organization.
[81] Uzoamaka, O. J. (1977). An Appraisal of Methods of Testing Some Physical Properties of Sandcrete Blocks. *Proceedings, institute of civil engineers, 2*(63), 625-635.
[82] Shahreza, S. K., Niklewski, J., & Molnár, M. (2021). Experimental investigation of water absorption and penetration in clay brick masonry under simulated uniform water spray exposure. *Journal of Building Engineering,, 43*, 102583.
[83] Naganathan, S., Mohamed, A. O., & Mustapha, K. N. (2015). Naganathan, S., Mohamed, A. Y. O., & Mustapha, K. N. (2015). Performance of bricks made using fly ash and bottom ash. *Construction and Building Materials,, 96*, 570-580.
[84] Othman, A. M. (2010). Experimental investigations of the effect of some insulating materials on the compressive strength, water absorption and thermal conductivity of building bricks. *Jordan Journal of Mechanical and Industrial Engineering,, 4*(4), 443-450.
[85[Lin, K. L. (2006). Feasibility study of using brick made from municipal solid waste incinerator fly ash slag. *Journal of hazardous materials,, 137*(3), 1810-1816.
[86] Ibrahim, A., Huat, B. B., Asadi, A., & Nahazanan, H. (2014). Foundation and dam construction in peat: An overview. *Electronic Journal of Geotechnical Engineering,, 19*, 10079-10094.
[87] Mbakbaye, M. R., Ronoh, E. K., & Sanewu, I. F. (2022). Potential use of Shea nutshell ash partially replaces Portland cement in interlocking earth blocks. *International Journal of Advanced Technology and Engineering Exploration, 9*(90), 687.
[88] Bock-Hyeng, C., Ofori-Boadu, A. N., Yamb-Bell, E., & Shofoluwe, M. A. (2016). Mechanical properties of sustainable adobe bricks stabilized with recycled sugarcane fibre waste. *International Journal of Engineering Research and Application,, 6*(9), 50-59.
[89] Yalley,, P. K., & Asiedu, E. (2013). Enhancing the properties of soil bricks by stabilizing with corn husk ash. *Civil and Environmental Research,, 3*(11), 43-52.