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Enhancing mechanical properties and water resistance characteristics through stabilization techniques: A study on earth blocks reinforced with wood fiber-cement composites

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Abstract

Stabilized earth blocks are attracting renewed interest throughout the world thanks to its "green" characteristics in the context of sustainable development. However, these blocks often exhibit limitations in terms of mechanical strength and water resistance properties. The current challenge lies in finding effective stabilization techniques that can enhance the performance of earth blocks. without compromising their eco-friendly nature or significantly increasing costs. This project was aimed at investigating and developing effective stabilization techniques using wood fiber-cement composites to enhance the mechanical properties (compressive strength, flexural strength) and water resistance characteristics (water absorption) of earth blocks. This project involved experimental studies such as particle size analysis, moisture content, organic content, specific gravity, dry density, plasticity index and a mix design, compressive strength test, flexural strength test, water absorption test with cement percentages of 0%, 2%, 4%, 6% ,8% and 0%, 1%, 1.5%, 2%, 2.5% wood fiber composite. The results obtained showed that increasing the cement content and the wood fiber content to 1.5% leads to an increase in the compressive strength of 64.88% and flexural strength of 41.67% compared to the reference at 0%. However, beyond 1.5% wood fiber content, the compressive and flexural strength experiences a degradation. The waster absorption capacity of the block generally decreases as the cement content increases due to a reduction in the porosity of the block. This formulation can therefore be used in construction of buildings in areas where use of locally available soil resources will promote environmentally friendly and cost-effective building practices.

Keywords: Clay; Compressed Stabilised Earth Blocks; Compressive Strength; Flexural Strength; Water Absorption.

1. Introduction

The earth has been one of the main construction materials used on our planet for almost 10.000 years. Today, more than one third of our planet's inhabitants live in earth-based habitats. The population of the town of Bamenda mostly build in adobe earth bricks, owing to the quality and availability of its red clay soil.

This material shows its current form with numerous assets necessary for the construction of sustainable, comfortable and economic accommodations (Césaire *et al.*, 2020) [1]. The use of local materials to build houses is an important strategy to counter our worsening global environmental problems (Ghorab *et al.*, 2007) [2].

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However, due to technological advancement and economic development, the practice of construction with earth has fallen by the wayside over the last few centuries, resulting in the extensive utilsation of contemporary building materials such as concrete, aluminum, glass, steel and others.

In addition to being expensive and resource-intensive, these modern building materials also leave a massive carbon footprint (Elahi *et al.*, 2020) [3]. Long abandoned in favor of materials such as concrete and steel, earthen construction is gaining traction in the current context of sustainable development (Kouame *et al.*, 2021) [4]. Using locally accessible natural materials for building construction is an effective and economical alternative that can attenuate emissions and subsequently reduce the carbon footprint of structures (Laibi *et al.*, 2018) [5].

Nonetheless, some of the disadvantages of earth construction are the lack of strength, durability and vulnerability to erosion by rain (Arooz and Halwatura, 2018) [6]. At the same time, it offers good thermal insulation properties when stabilized at ideal conditions (Elisabete *et al*., 2020) [7]. Unfortunately, due to these drawbacks, the use of earth building materials in the modern construction sector has been ignored over many years (Danja, 2017) [8] and is being extensively replaced by more durable and stronger construction materials such as fired brick and concrete (Cristiana *et al.*, 2019) [9].

Although it is important to acknowledge the contributions made by modern earth brick manufacturing and other modern earth construction to improve the overall properties of earth structures, it is equally important to consider the environmental effects of these methods. Presently, to meet the requisite comfort standards, earth building construction is also regaining its prominence in industrialized countries and becoming an integral part of "green thinking" (Lekshimi, 2017) [10].

The stabilization of soils has been performed for millennia. For instance, the Mesopotamians and Romans separately discovered that it was possible to improve the ability of pathways to carry traffic by mixing the weak soils with a stabilizing agent like pulverized limestone or calcium.

Alternatively, the presence of plant roots is a natural means of incorporating randomly oriented fiber inclusions in the soils, (Kaniraj and Gayathri, 2003) [11]. These plant fibers improve the strength of the soils and the stability of natural slopes (Wu and Erb, 1988) [12]. Therefore, the concept of fiber reinforcement was recognized more than 5000years ago. For example, ancient civilizations used straw and hay to reinforce mud blocks to create reinforced building blocks (Abtahi *et al*., 2009) [13].

There are several examples of reinforcing the soil like the Great Wall of China (the earliest example of reinforced earth using branches of trees as tensile elements), ziggurats of Babylon (woven mats of the read were used), etc. (Rao, 1996) [14]. In the modern history of soil stabilization, the concept and principle of soil reinforcement were first developed by Vidal. He demonstrated that the introduction of reinforcing elements in a soil mass increases the shear resistance of the medium (Akbulut *et al*., 2007) [15]. Consequently, efforts for using fibrous materials, as mimicry of the past, were started. Since the invention by Vidal in 1966 [16], nearly 4000 structures have been built in more than 37 countries so far using the concept of earth reinforcement (Juyol, 1994) [17]

2. Materials and methods

2.1. Sampling

2.1.1. Soil sample

The constituent materials used in the production of CSEB were: Wood fiber, Ordinary Portland Cement, soil and water.

Soil samples for the experiment were collected from a Borrow pit in Mezam Bamenda in the North West Region of Cameroon. During sampling, the organic part of the soil was removed by digging 1.00 m deep to expose the sub-soil. A large quantity of the sub-soil samples was then collected and air dried. The soil was homogenized by removing coarse fragments and sieved using a 2.5 mm mesh sieve.

2.1.2. Wood fiber

The wood fiber used was gotten from Badjoun, Bafoussam, West Region of Cameroon.

2.1.3. Cement

The cement used in the experimental work was ordinary Portland cement 42.5R from Dangote Cement.

2.1.4. Water

Regular tap water was used in all the stages of the experimental program.

2.2. Methods

2.2.1. Physical properties of the soil

The American standard test specifications were used to obtain the geotechnical properties of the soil, notably (Grain size analysis, Atterberg limit, Specific gravity, Dry density, Organic content).

2.2.2. Mechanical properties of the stabilized earth blocks

The compressive strength test was carried out in accordance with according to ASTM C109 . The Compressive strength of hardened block is the most important parameter and representative of almost overall quality of the block. It is determined by testing the cubical specimens using a compression testing machine (CTM) at the mature age of the block.

The flexural strength test was determined according to ASTM C1609 . The flexural strength test on blocks is used to determine the ability of the material to resist bending or flexure.

The water absorption was determined according to IS Code 3495 Part 2. The specimens of the blocks were preventively dried in open air at 25^0C for 28days. The test was aimed at determining the water absorption of the specimen by 24 hours immersion in cold water.

2.2.3. Formulation of the various stabilization rate

In order to better optimize the experimentation, five formulations were realized in order to revaluate the physical and mechanical parameters. In function of the results obtained, the various formulations were made;

- Formulation 1: Soil sample + (2%,4%,6%,8%) cement + 0.5% wood fiber.
- Formulation 2: Soil sample + (2%,4%,6%,8%) cement + 1% wood fiber.
- Formulation 3: Soil sample + (2%,4%,6%,8%) cement + 1.5% wood fiber.
- Formulation 4: Soil sample + (2%,4%,6%,8%) cement + 2% wood fiber.
- Formulation 5: Soil sample + (2%,4%,6%,8%) cement + 2.5% wood fiber.

3. Results and discussions

3.1. Geotechnical properties

The geotechnical parameters of the natural material used are summarized on tables 1,2 and 3 below.

Table 1 Grading particle size of soil sample

Sample	% Gravel Φ >2mm	% Sand 2> Φ >0.02mm	% Silt 0.02> Φ >0.002mm	% Clay Φ <0.002mm
Lateritic soil	20.6	32.2	13.5	33.7

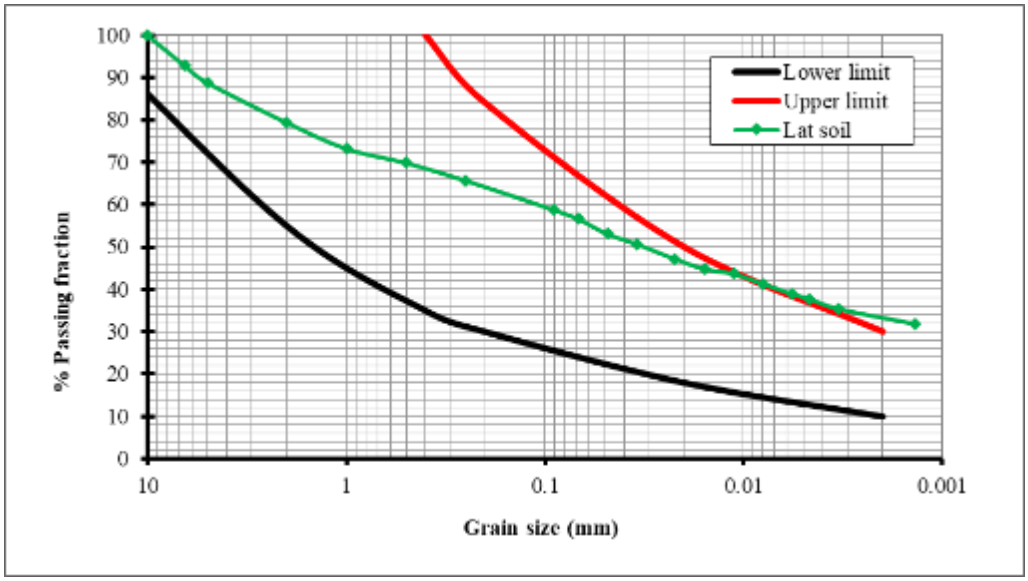


Figure 1 Grain size distribution of soil samples (Lower and upper limit curves have been established following the Cameroonian Standards for Compressed Earth Blocks (NC 102-114, 2006)).

Table 2 State parameters of soil used

Soil property	Moisture content (%)	Methylene blue value (MBV)	Specific gravity (Gs)	Dry density(γd) (g/cm^3)	Organic content (%)
Composition	21.7	2.93	2.62	1.8	7.1

Table 3 Consistence limit of natural material used

Soil property	Liquid limit (%)	Plastic limit (%)	Plasticity Index (%)
Composition	65.5	44.7	20.8

The grain size distribution (Figure 1) indicated that the soil was well graded according to the Cameroonian Standards for Compressed Earth Blocks (NC 102-114, 2006) with a wide range of particle sizes. The passing through the sieves of 0.002mm, 0.075mm, 2mm and 20mm were33.7%, 13.5%,32.2% and 20.6% respectfully. The predominant components in the gradation are sand and clay as evidenced by their notably high percentages. Based on this norm, soil containing 15% gravel, 50% sand, 15 % silt and 20% clay is considered as having the best soil composition for producing CSEB. The results obtained have a slightly greater value to that of this standard, making the soil sample suitable for making CSEB.

From table 2, the studied soil has natural moisture content of 21.7% and an organic content of 7.1%. the specific gravity and dry density are respectively 2.62 and 1.8g/cm^3. The soil also presented a Methylene blue (MBV) test value of 2.93.

Table 3 shows that the values of the liquid limit measure to 25 shocks was 65.5% and a plastic limit of 44.7% with an index of plasticity of 20.8%.

These results are consistent with previous findings that soils with liquid limits above 60% generally require stabilization to enhance their engineering performance (Amadi et al., 2015; Otoko, 2014). [17,18].

3.2. Evaluation of the compressive strength of CSEB

Table 4 Results for compressive strength after 28days with varying percentages of stabilizers

Stabilizer	**0%**	**0.5%**				**1%**				**1.5%**			
		2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%
Rc (MPa)	5.08	5.46	5.96	6.13	6.33	5.58	6.42	6.75	7.08	6.50	6.83	6.67	7.83

Stabilizer	**2%**				**2.5%**			
	2%	4%	6%	8%	2%	4%	6%	8%
Rc (MPa)	5.96	6.33	6.46	7.29	6.04	6.25	6.33	6.67

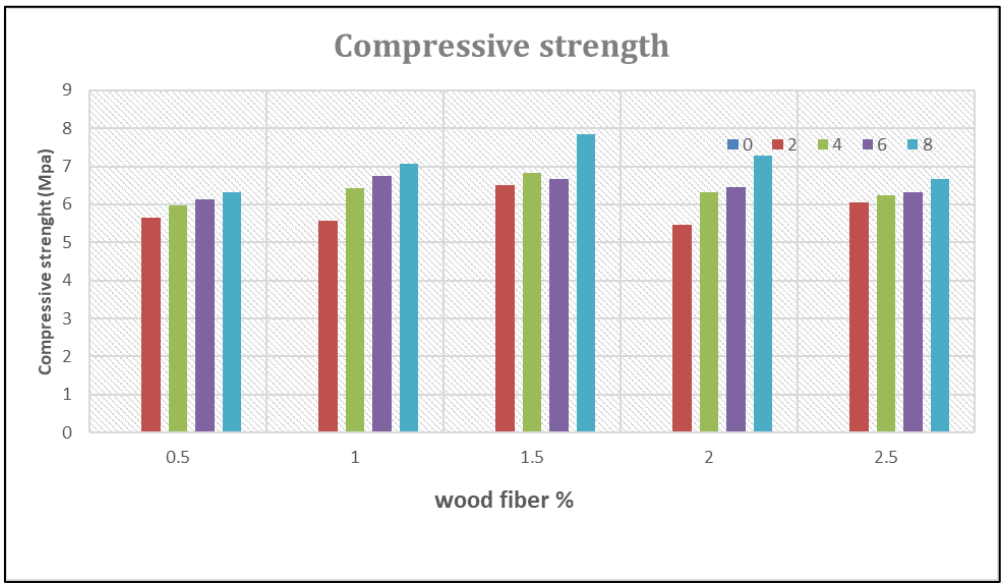


Figure 2 Diagram showing results for compressive strength testing

The results of the maximum stresses of the compressive strength tests of the CSEBs specimens are shown in the diagram in Figure 2. It is observed that, the average compressive strength of the fiber reinforced block increases with increase in cement and wood fiber content. At 8% cement stabilization and 1.5% fiber reinforcement with 28days of curing, the blocks attained an average compressive strength of about 64.88% compared to the reference taken at 0% (Figure 2). However, beyond 1.5% wood fiber content, the compressive strength experiences a degradation due to a weak interface between the earth block and the cement, reducing the overall strength. These results are in agreement with those of (Ahmed *et al*., 2004) [19] who showed that the compressive strength increases with increase in cement and fiber content, a cement ratio of beyond 7.5% by weight experienced a degradation.

3.3. Evaluation of the Flexural strength of CSEB

Table 5 Results for flexural strength after 28days with varying percentages of stabilizers

Stabilizer	0%	0.5%				1%				1.5%			
		2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%
Rf (MPa)	0.7	1.17	1.33	1.45	1.48	1.02	1.25	1.41	1.68	1.09	1.33	1.48	1.72

Stabilizer	2%				2.5%			
	2%	4%	6%	8%	2%	4%	6%	8%
Rf (MPa)	0.78	1.09	1.17	1.33	0.70	0.86	0.94	1.09

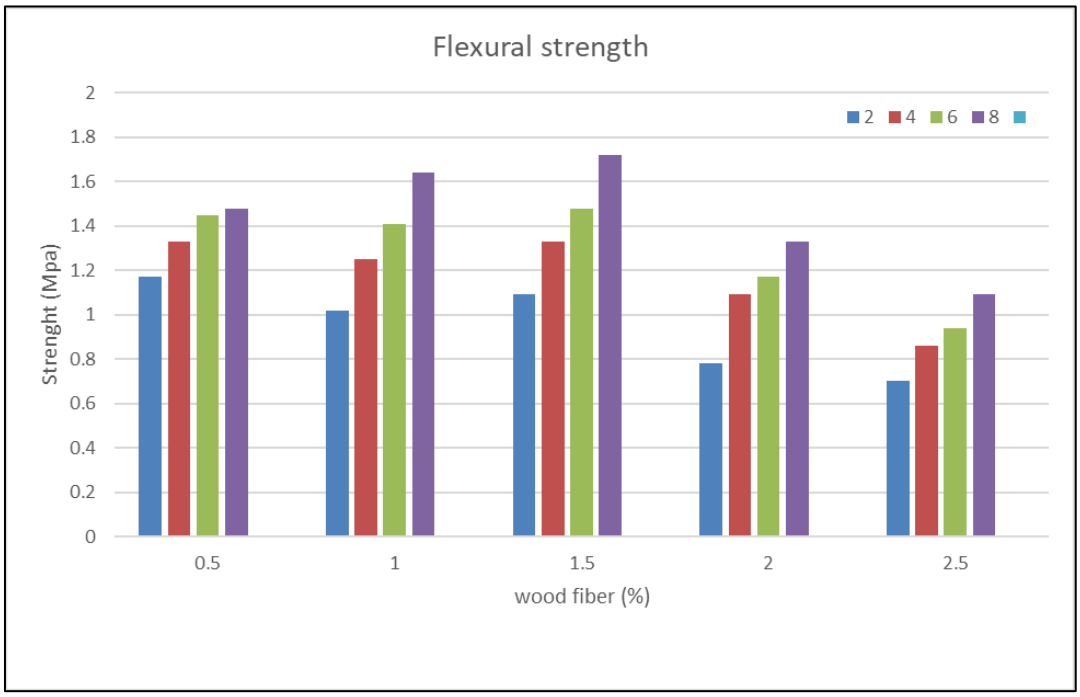


Figure 3 Diagram showing results for flexural strength testing under 28-days curing

The flexural strength of earth bricks reinforced with cement and wood fiber is presented in Figure 3. It was observed that, the flexural strength increases with an increase in the content of cement and wood fiber but experiences a decrease at 2% wood fiber content. At 8% cement and 1.5% wood fiber content a maximum flexural strength of 1.72 MPa was obtained and witnessed a decrease at 2% cement and 2.5% wood fiber with a minimum flexural strength of 0.70 MPa. According to studies by conducted by Danso (2017) [20] and Millogo et al. (2016) [21], the flexural strength of the fiber reinforced bricks increased with increase in fiber content up to 3% thereafter it decreased. At optimum fiber contents of (3% of PALF) the flexural strength was 0.64MPa and 0.92MPa respectively for bricks reinforced with N-PALF and T-PALF. The treated fiber significantly improved the flexural strength of the bricks compared to compressive strength. According to British standard code of practice for structural use of compressed stabilized earth blocks, the minimum flexural strength for CSEB used for construction is 0.35MPa. From our results and experiments conducted by Binici et al. (2005) [22] and Muntohar (2011) [23], it shows that blocks obtained with minimum flexural strength from this research can be used in for structural construction.

3.4. Evaluation of the water absorption rate of CSEB

Table 6 Water absorption rate of various clay block composition with various percentages of stabilizers

Stabilizer	0.5%				1%				1.5%			
	2%	4%	6%	8%	2%	4%	6%	8%	2%	4%	6%	8%
Absorption rate (%)		32.54	31.63	30.90	33.89	32.08	31.32	31.21	32.48	32.02	30.45	29.79

Stabilizer	2%				2.5%			
	2%	4%	6%	8%	2%	4%	6%	8%

Absorption rate (%)	33.10	32.21	31.74	30.46	36.22	31.84	29.44	29.33

The trends of water absorption of clay as shown of the bar below

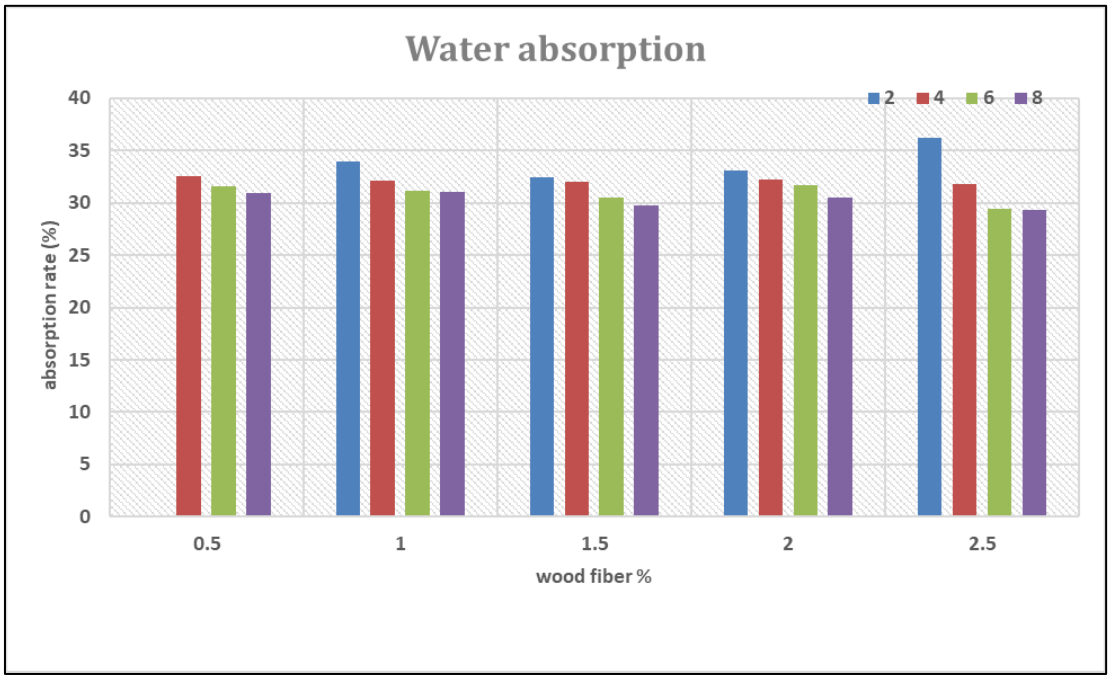


Figure 4 Diagram showing results for water absorption test

Water absorption rate for brick is of great concern as it will determine the materials workability due to the effect of weather. Although currently there is no specific standard of water absorption rate for CSEB, the actual practice in Malaysian construction industry has generally considered the rate of water absorption for bricks should be less than 15%. Figure 4 shows that the water absorption capacity of the block decreases with increase in the percentage of cement and wood fiber from 32.54% at 2% cement and 1.5% wood fiber content to 29.33% at 8% cement and 2.5% wood fiber content. This decrease in water absorption can be attributed to the reduction in porosity of the block. Lower rate of water absorption indicates that the bricks are better in terms of its quality and resilience to weather effects, particularly when exposed to rain and sunlight. Comparable reductions in water absorption with cement and fiber stabilization have been highlighted in earlier research, confirming that higher cement ratios significantly reduce porosity and enhance durability (Muntohar, 2011; Binici et al., 2005) [22,21].

4. Conclusion

This research was directed at assessing the extent to which wood fiber-cement could be used to enhance the mechanical performance of earthen masonry units and how the blocks can be used for sustainable construction. It focused specifically on investigating the influence of the incorporation of wood fiber-cement on compressive strength, flexural strength and water absorption behavior of CSEB. The samples of dimension (4x4x16) cm were produced with 0.0, 2.0, 4.0, 6.0, and 8.0% cement dosages and wood fiber content of 0.5%, 1%,1.5%,2%,2.5% by mass. The specimens were tested for water absorption according to IS Code 3495 Part 2, for compressive strength according to ASTM C109 and the flexural strength according to ASTM C1609 The strength of cement-wood fiber reinforced CSEBs is influenced by cement type and quantity, soil type, wood type, wood properties, level of compaction of the matrix, curing conditions, and testing procedures. Within the limits of the experimental program used, the main conclusions have been outlined below:

The compressive strength of the block is influenced by the balance between the cement and wood fiber content. Increasing the cement content and the wood fiber content up to a certain point leads to an increase in the compressive

strength, while further increasing the cement and wood fiber content result in a decrease in the compressive strength due to the block becoming brittle.

Blocks obtained from this research including the once with the minimum flexural strength of 0.70MPa, can be sued for structural construction purposes as they exceed the minimum flexural strength requirement of 0.35MPa specified in the British standard code of practice.

The waster absorption capacity of the block generally decreases as the cement content increases due to a reduction in the porosity of the block. However, this trend is reversed when the cement content is low (2%) and the wood fiber content is higher (2.5%), resulting in an increase in the water absorption capacity likely due to an increase in the porosity of the block.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Césaire H, Adamah M, Abdou L, Georey M. Impact of the design of walls made of compressed earth blocks on the thermal comfort of housing in hot climate. 2020;157.

[2] Ghorab H, Anter A, El Miniawy H. Building with local materials: stabilized soil and industrial wastes. *Mater Manuf Process.* 2007;157–162.

[3] Elahi T, Shahriar A, Alam M, Abedin M. Effectiveness of saw dust ash and cement for fabrication of compressed stabilized earth blocks. *Constr Build Mater.* 2020.

[4] Kouamé, A. N., Konan, L. K., & Irié Hervé Gouré Doubi, B. (2021). Microstructure and Mineralogy of Compressed Earth Bricks Incorporating Shea Butter Wastes Stabilized with Cement. *Advances in Materials*, 10(4), 67-74. https://doi.org/10.11648/j.am.20211004.13

[5] Laibi, A. B., Poullain, P., Leklou, N., Gomina, M., & Sohounhloué, D. K. C. (2018). Influence of the kenaf fiber length on the mechanical and thermal properties of compressed earth blocks (CEB). *KSCE Journal of Civil Engineering, 22*(2), 785-793. https://doi.org/10.1007/s12205-017-1968-9

[6] Arooz F R, Halwatura R U. Mud-concrete block (MCB): Mix design & durability characteristics. *Case Stud Constr Mater.* 2018;8:39-50.

[7] Elisabete R, Gilberto M, Adilson P, Christiane G. Mechanical and thermal performance characterisation of compressed earth blocks. *Energies.* 2020;29–78.

[8] Danja II. Vernacular architecture of Northern Nigeria in the light of sustainability. *Int Conf Environ Energy Eng (IC3E 2017).* 2017;63. doi:10.1088/1755-.

[9] Cristiana C, Angela C, Fernando R, Ana Velosa. The sustainability of adobe construction. *Int J Archit Herit.* 2019;13. doi:10.1080/15583058.2018.1459954.

[10] Lekshmi, M. S., Vishnudas, S., & Nair, D. G. (2017). An investigation on the potential of mud as sustainable building material in the context of Kerala. *Int. J. Energy Technol. Policy*, 13(1/2):107–122.

[11] Kaniraj S R, Gayathri V. Geotechnical behavior of fly ash mixed with randomly oriented fiber inclusions. *Geotext Geomembr.* 2003;21(3):123-149.

[12] Wu T. H., McOmber R. M., Erb R. T., & Beal P. E. Study of soil-root interaction. J Geotech Eng ASCE. 1988;114(12):1351-1375.

[13] Abtahi M, Sheikhzadeh M, Hejazi M, Y H. Compressive behavior of composite soils reinforced with recycled waste tire cords and polypropylene fibers. *1st Int. & 7th Nat. Conf. Text. Eng., Rasht, Iran.* 2009.

[14] Rao, K. S., Rao, K. S. S., Allam, M. M., & Robinson, R. G. in *Proceedings of the Institution of Civil Engineers — Geotechnical Engineering*, Volume 119, Issue 2 (April 1996), pages 123-128.

[15] Akbulut S, S A, Kalkan E. Modification of clayey soils using scrap tire rubber and synthetic fibers. *Appl Clay Sci.* 2007;23–32.

[16] Vidal, H. The Principle of Reinforced Earth. *Highway Research Record,* (1969). *No. 282,* 1-16

[17] Amadi AN, Eze CJ, Igwe CO, Okunlola IA, Jimoh MO. Assessment of the geotechnical properties of lateritic soils in Minna, North Central Nigeria for road construction. *J Civil Eng Res.* 2015;5(1):10–16.

[18] Juyal G P, Sastry G, Rama Mohan Rao M S. Rehabilitation of a mined area in Himalayas by geojute & other measures. *Proceedings of the 5th International Conference on Geotextiles, Geomembranes and Related Products*, Singapore; 1994 Sept 5-9:891-894.

[19] Otoko, G. R., & Braide, S. Stabilization of Nigerian deltaic laterites with saw dust ash. *International Journal of Scientific & Engineering Research,* (2014). *5*(2): 128-134.

[20] Ahmed, S. H., Al-Mukhtar, M., & Al-Sharify, Z. T. (2004). Hydraulic characteristics of lateritic soil stabilized with lime, cow bone ash, and polypropylene. *Journal of Materials in Civil Engineering*, 16(6), 514–519. https://doi.org/10.1061/(ASCE)0899-1561(2004)16:6(514

[21] Danso H. Effect of natural fibre reinforcement on strength and durability of soil blocks. PhD Thesis, Univ. of Portsmouth. 2017.

[22] Millogo Y, Aubert J, Séré A. Mechanical and microstructural characterization of cement–stabilized soil bricks with mineral or organic admixtures. *Constr Build Mater.* 2008;22:2450–2460.

[23] Binici H, Aksogan O, Shah T. Investigation of fibre reinforced mud brick as a building material. *Constr Build Mater.* 2005;19(4):313–318.

[24] Muntohar A, Hantoro G. Influence of rice husk ash and lime on engineering properties of a clayey subgrade. *J Civil Eng Res.* 2011;1(3):112–116.