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Sustainable Earth Bricks: Characterisation of Milled Glass and Cissus Producta Fibre as Stabilisers and Reinforcement

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Abstract

This study focused on evaluating the properties of earth bricks incorporating milled glass as a binder and Cissus producta fibre as reinforcement. The investigation began with an assessment of the soil's physical characteristics through particle size distribution and compaction tests. Earth bricks were then produced using a constant 15% milled glass content and varying fibre contents of 0.25%, 0.50%, 0.75%, and 1%. These bricks were tested for density, water absorption, compressive strength, split tensile strength, and erosion resistance over curing periods of 7, 14, 21, and 28 days. The test results indicated that the soil had medium moisture content and a well-graded particle distribution, while the milled glass was significantly finer, making it suitable as a pozzolanic material. The enhancement was observed with the addition of Cissus producta fibre, with optimum results achieved at 15% glass powder and 0.75% fibre content. Compressive strength values of 1.315 N/mm², 1.834 N/mm², and 2.135 N/mm² were recorded for the sample without milled glass, the sample with 15% milled glass, and the 15% milled glass and 0.75% fibre-reinforced sample, respectively. Corresponding tensile strength values were 0.103 N/mm², 0.137 N/mm², and 0.233 N/mm². The study concluded that the incorporation of milled glass and Cissus producta fibre significantly enhances the performance of earth bricks, improving their mechanical strength, durability, and structural integrity. It is therefore recommended that the use of earth bricks be promoted as an environmentally friendly approach to managing agricultural and glass wastes.

Keywords: *Recycled Glass Powder, Cissus Producta Fibre, Compressed Earth Block, Density, Water Absorption, Compressive Strength, Tensile Strength, Erosion Resistance*

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I. INTRODUCTION

In 2021, the Ghana Statistical Service [1] established that 64.1% of dwelling units in Ghana have their walls constructed of cement blocks or concrete. This record shows an increase from 39.1% in the year 2000 to 57.5% in the year 2010 and 64.1% in 2021. In contrast, the use of earth or mud bricks declined over the same period, from 50.0% in the year 2000 to 34.2% in the year 2010 and 29.6% in the year 2021. The primary challenges associated with using earth as a construction material include shrinkage cracking and low strength [2]. Additionally, unstabilised earth is known to have poor resistance to erosion and high-water absorption. Importantly, if the low uptake of earth as a building material remains unchanged in Ghana, it could lead to extreme environmental destruction risks with dire socio-economic impacts for the country.

The common walling materials used today (fired clay bricks, sandcrete blocks, and concrete) have unique properties. However, the manufacture of these conventional materials is environmentally unfriendly and costly, particularly due to the use of high energy and the significant carbon dioxide (CO_2) emissions released into the atmosphere. In order to reduce these negative environmental impacts, it is important to use resources with lower embodied energy and prevent waste from going into landfills [3].

Notably, recent studies have investigated the properties of various stabilised earth bricks and blocks, revealing significant potential for their use. However, some of these studies have relied on certain conventional materials and unsustainable production processes without adequately addressing the issue of environmental impacts. For instance, [4] studied the design and fabrication of a sustainable construction brick, the results show improvements in compressive strength. Nevertheless, the bricks were fired in a kiln at very high temperatures, which can increase production costs and carbon emissions. Similarly, prior research on clay and earth bricks incorporated materials such as quarry dust or granite powder [5], [6], cement [7], and lime [8], all of which are unsustainable and not eco-friendly.

Materials such as coconut fibre, sugarcane fibres, oil palm fruit fibres [9], straw [10], and palm kernel oil residue [11] have been used to stabilise earth to improve its density and

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mechanical properties. However, in a review of literature on the application of agro-waste for sustainable construction materials, [12] established that water absorption is a significant issue for most of the products reviewed, which calls for further investigations. This finding was confirmed by [13], who noted that the use of jute fibres in earth blocks can improve strength properties and erosion resistance, as well as increase the rate of water absorption.

Furthermore, recent studies [14], [15] show that the use of glass powder (GP) in bricks can reduce water absorption and increase compressive and tensile strengths. However, [16], [17], [18] stabilised clay with GP, but their clay bricks were produced using unsustainable production processes, without addressing energy-saving considerations.

In a literature review on possible recycling of waste glass in clay bricks, [19] recommended a comprehensive study on combining waste glass with other materials. Materials such as cissus producta fibre and waste glass are common and readily available in Ghana. However, to date, the current author has not found any comprehensive study on the use of these materials in combination to stabilise earth for earth brick manufacturing. This gap hinders the full adoption of sustainability and the use of eco-friendly materials in the construction industry in Ghana. Therefore, this study seeks to extensively and comprehensively investigate the properties of earth bricks stabilised with milled glass and cissus producta fibre for sustainable construction. The durability and easy accessibility of the raw materials, the low production cost, and the environmental sustainability—due to the use of waste and agricultural fibres as the main stabilising agents—are the major motivations behind this current search for knowledge.

II. Materials And Methods

A. Materials

1 Water

The water used was potable water drawn from the tap at the construction laboratory of AAMUSTED, Kumasi campus, supplied by the Ghana Water Company Limited.

2 Earth

The earth used for this study was manually excavated from Kumasi in the Ashanti region. The soil was spread out in thin layers and air-dried continuously under a shed for 14 days, then sieved using a 5 mm square-mesh sieve. Sieve analysis and the Standard Proctor Compaction test were conducted in the laboratory in accordance with BS 1377:2022 [20]. The particle size distribution curve for the earth is shown in Fig. 3.

3 Milled Glass (MG)

The type of glass used in this study is untreated soda-lime glass sourced from broken colourless bottles. The waste glass bottles were collected from Asesewa in the Upper Manya Krobo Municipality, washed with potable water, and then sun-dried for one hour. The glass was subsequently broken into pieces, manually milled, and sieved to obtain powder with particle sizes smaller than 425 µm. The particle size distribution curve for the MG is shown in Fig. 3.

4 Cissus Producta Fibre

Cissus producta fibre (CPF), locally known as “hejuu kotsa,” is a very strong fibre. The material was cut into 3-meter lengths from farmland in Asesewa, located in the Upper Manya Krobo Municipality, and then lightly burned with flames at a temperature below 50°C for 60 seconds to facilitate easy removal of the bark. The material was placed on a large rock and manually beaten with a wooden rod to extract the fibres, which were then intermittently sun-dried for twenty hours at a temperature not exceeding 30°C. The extracted fibres were subsequently cut to a length of 50 mm, following the procedure used in similar studies [21]. Fig. 1 (c) shows the CPF.

B. Methods and Procedure

1 Preparation of Specimens

One hundred and eighty earth bricks measuring 130 mm × 100 mm × 100 mm were made using water, CPF, earth, and 15% MG content by weight of soil, as recommended by [14], [18]. Fibre contents of 0.25%, 0.5%, 0.75%, and 1% by weight of soil were used to prepare the brick specimens, following the method described by [9]. The fibre was soaked in water for 24 hours before use.



(a)	(b)	(c)

Fig. 1: (a) Earth (b) Milled Glass (c) Cissus Producta Fibre

The quantities of materials for each mixing batch are presented in Table I. The required quantity of soil for each batch was weighed and spread on a platform. The required quantity of MG was also weighed and spread over the soil as shown in Fig. 2 (a). The raw materials were manually mixed until a uniform colour was obtained. The mixture was spread and the required CPF quantity was added. Water was sprinkled on the mixture in bits and mixed uniformly. A fraction of the mixture was weighed and placed in each of the six compartments in the hydraulic Brepak block machine and manually tamped with a wooden rod and levelled.

The bricks were made using a BREPAK brick mould with a constant pressure of 10 MPa. The moulded bricks were air-dried for 24 hours and then cured by sprinkling for up to 28 days to prevent excessive loss of moisture from the brick specimens. Batching, mixing, and moulding of the bricks were done for three different groups: two control groups ($CP_{0/0}$ and $CP_{15/0}$) and one treatment group ($CP_{15/0.25}$, $CP_{15/0.50}$, $CP_{15/0.75}$, $CP_{15/1.0}$). The specimens were labelled in the following order as presented in Table I: $CP_{0/0}$ denotes earth bricks without CPF and MG. $CP_{15/0}$ denotes earth bricks with 15% MG and 0% CPF. $CP_{15/0.25}$ denotes earth bricks with 15% MG and 0.25% CPF. $CP_{15/0.50}$ denotes earth bricks with 15% MG and 0.50% CPF. $CP_{15/0.75}$ denotes earth bricks with 15% MG and 0.75% CPF. $CP_{15/1.0}$ denotes earth bricks with 15% MG and 1.0% CPF.

TABLE I: MIX PROPORTIONS FOR MATERIALS

Quantity of Materials - (kg)

	Cissus Producta Fibre Percentages						
Materials	**$CP_{0/0}$**	**$CP_{15/0}$**	**$CP_{15/0.25}$**	**$CP_{15/0.50}$**	**$CP_{15/0.75}$**	**$CP_{15/1.0}$**	**Total (kg)**
MG (15%)	0.00	11.33	11.33	11.33	11.33	11.33	56.64
Laterite	75.52	64.19	64.19	64.19	64.19	64.19	396.47
CPF	0.00	0.00	0.16	0.32	0.48	0.64	1.60
Water (OMC 13.79%)	10.41	10.41	10.41	10.41	10.41	10.41	62.46

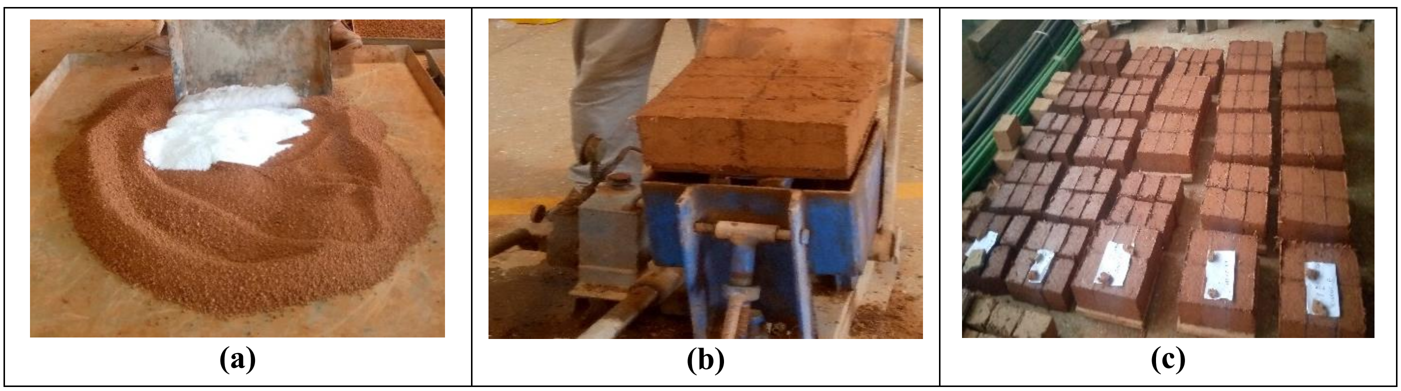

Fig. 2; Preparation of earth bricks: (a) mixing of raw materials (b) moulding of bricks, (c) curing of bricks

C. Testing of Specimens

The specimen testing was performed in three categories of properties: physical properties (density and water absorption), mechanical properties (compressive strength and split tensile strength), and durability properties (erosion test).

1 Density

The test was conducted in accordance with BS EN 771-1:2011 [22]. After curing the brick specimens by sprinkling for 7, 14, 21, and 28 days, the mass of each brick was measured, and the corresponding density was calculated using (1).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (1)$$

2 Water Absorption by Capillary

The water absorption test was conducted to determine the rate at which the stabilised earth bricks absorb water through capillary action. The test was performed in accordance with BS EN 772-11:2011 [23]. The weight of each brick specimen was measured and recorded as M_1, after which the specimens were placed in an oven at a constant temperature of 105°C for twenty-four hours. The weight of each oven-dried specimen was then measured and recorded as M_2. The 130 mm x 100 mm side of each oven-dried brick specimen was partially immersed in water to a depth of 5 mm for 10 minutes. After capillary water absorption, the weight of each specimen was recorded as M_3. The rate of water absorption (W) was calculated using (2).

$$W = \left(\frac{M3-M2}{M2}\right) \times 100 \quad (2)$$

Where W is water absorption; M_3 is the wet mass of the specimens, recorded in kilograms (kg); and M_2 is the oven-dried mass of the specimens, also recorded in kilograms (kg).

3 Compressive strength Test

The compressive strength test was carried out with reference to BS EN 772-1:2011 [24] using the ELE Non-Automatic Compressive Test Machine, which has a maximum capacity of 2000 kN. The weight of each brick was measured, and the brick was placed directly on the rammers of the test machine. A load was applied at a rate of 0.05 kN/mm²/s until failure occurred, and the load at which each brick failed was recorded and the maximum compressive strength was calculated using (3).

$$\text{Compressive Strength} = \frac{\text{Load (F)}}{\text{Area (A)}} \qquad (3)$$

4 Split Tensile Test

The split tensile strength test was carried out in accordance with ASTM C1006 [25] using the ELE Non-Automatic Compressive Test Machine, which has a maximum capacity of 2000 kN. The weight of each brick was determined, and the brick was then placed centrally on the lower and upper jigs of the test machine. A load was applied at a rate of 0.05 kN/mm²/s until the brick failed. The failure load (F), the length (L), and the width (d) of each brick specimen were recorded. The maximum split tensile strength was calculated using (4).

$$\text{Split Tensile Strength (ST)} = \frac{2F}{\pi \text{Ld}} \qquad (4)$$

5 Erosion Test

The erosion test was conducted using the Geelong method (drip test), following the procedures of NZS 4298, 1998 [26], to evaluate the erosion behaviour of earth bricks under specific environmental (weather) elements, such as rain drops. After curing the earth brick specimens for 28 days and recording their weights, the test equipment was set up having a transparent glass container filled with water, marked at the 100 ml level from the top. A 16 mm diameter Wettex (J-Cloth) was placed inside the container to absorb and transmit water onto the test brick. The brick was positioned on an inclined plane set at a 27° angle relative to the base of the test apparatus, located 400 mm below the tip of the Wettex. Water dripped from the glass container through the Wettex onto the 130 mm x 100 mm face of the specimen for sixty minutes. After erosion, the depth of the pit formed on the brick was measured and recorded, and the erodibility index was noted.

III. RESULTS AND DISCUSSION

A. Properties of the Materials Used

The test results for the lateritic soil indicated it comprised 34.86% gravels, 64.50% sand, and 0.64% silt and clay, while the MG consisted of 98.08% sand and 1.92% of silt and clay. It shows 100% passing through sieves down to 0.6 mm, with over 50% passing through the 0.3 mm sieve, which classifies it as a very fine powder. The MG is uniformly fine and poorly graded; however, with its fineness, it is more suitable as a pozzolanic additive.

Laterite soil exhibits a broader particle size distribution, with much lower percentages passing through finer sieves (e.g., only 11.43% through the 0.3 mm). The particle size distribution analysis showed that the lateritic soil demonstrates a well-graded composition suitable for the production of compressed earth bricks. This assessment aligns with the grading criteria outlined in BS 1377 [20], which defines well-graded samples as those containing a wide range of particle sizes. Such soils are preferred in construction due to their ability to achieve better compaction and superior strength compared to uniformly fine materials. The particle size distribution curves for the laterite and MG are shown in Fig. 3.

The result of the Standard Proctor compaction test on the laterite soil is presented in Table II. This shows that the soil achieves optimum compaction at a moisture content of 13.79%, with a maximum dry density (MDD) of 1980.84 kg/m³. At this 13.79% optimum moisture content (OMC), the soil particles achieved the best packing arrangement under the applied compaction effort. Beyond OMC (≥18.75%), increasing moisture results in a drop in dry density, as excessive water fills pores and displaces air without contributing to densification. Conversely, below the OMC (≤11.24%), there is insufficient water to lubricate the particles for close packing, resulting in lower dry densities.

This result shows a degree of consistency with prior research by [27] who observed an OMC of 12.0% with an MDD of 1.76 Mg/m³. Similarly, [9] reported OMC values of 17.59%, 19.02%, and 11.9% with corresponding MDD values of 1.779 Mg/m³, 1.791 Mg/m³, and 1.835 Mg/m³ for soil samples R, B, and HI, respectively. The identified OMC in this study was subsequently used in the preparation of the earth bricks for further testing in this study.

TABLE II: COMPACTION TEST RESULT

Dry density kg/m³	**OMC (%)**
1741.04	9.32
1978.51	11.24
1980.84	13.79
1869.27	18.75
1805.18	21.80

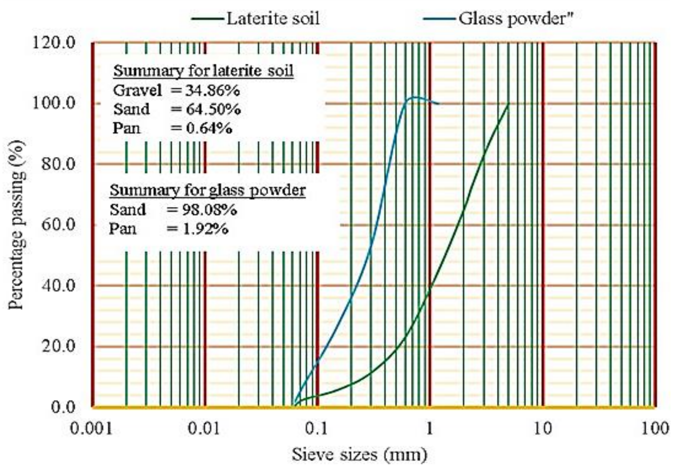

Fig. 3: Particle Size Distribution Curve

B. Physical Properties of bricks

1 Density

The results of the density test performed in this study are presented in Fig. 4. The findings indicate that the average density decreases over time across all mix proportions.

The study revealed that control specimens containing MG as a binder ($CP_{15/0}$) exhibited higher density compared to control specimens without MG ($CP_{0/0}$). The density of the control brick without MG ($CP_{0/0}$) was 1665.9 kg/m³, while that of the control brick with 15% MG ($CP_{15/0}$) increased to 1724.62 kg/m³, representing 3.50% increase in density. This increase could be attributed to the mass of the MG used in the mix.

However, the addition of CPF caused the density to decrease more rapidly. The study found that incorporating up to 0.75% CPF slightly improved density; nevertheless, density decreased across all mixes over time. This reduction in density could be attributed to the increased fibre content and moisture loss from both the fibres and bricks during prolonged curing periods.

Similar results were reported by [28], who found that the inclusion of waste glass powder (WGP) increased brick density due to improved particle packing. Additionally, [29] concluded that fibre-reinforced soil blocks consistently exhibit lower density values because of the low mass of natural fibres and the associated moisture loss over time. These findings suggest that the reduction in density observed in the current study aligns with previous research. Despite these changes, the densities remained within the acceptable range for high-density bricks as defined by BS EN 771:2011 [22]. These findings also agree with previous studies by [30].

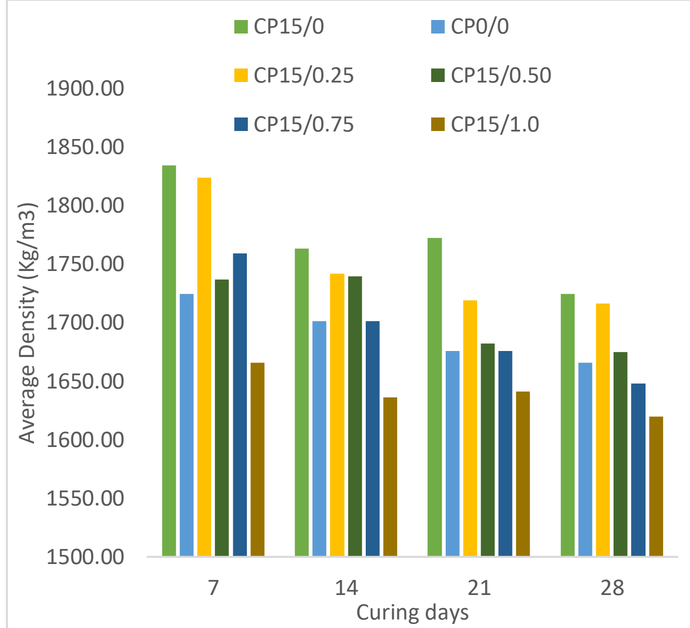

Fig. 4: Average Density of the Specimens

2 Water Absorption by Capillary

Fig. 5. presents the water absorption percentages of earth bricks after 28 days of curing for different fibre replacement levels and a constant amount (15%) of MG. The results indicate that the control samples without fibre and MG ($CP_{0/0}$) exhibited the highest porosity, with a water absorption rate of 6.79%, while the control samples containing only MG ($CP_{15/0}$) showed lower porosity, recording an absorption rate of 4.84%. The reduction in water absorption could be attributed to the fine particles of the MG, which are closely packed, thereby reducing pore volume and blocking pathways through which fibres might absorb water in the bricks. These findings are consistent with those of [31], who observed that water absorption decreased with increasing glass content (particle size <0.4 mm) when the substitution level was below 35 wt.%. Bricks incorporating both MG and CPF at varying percentages demonstrated reduced water permeability, with absorption rates of 4.18%, 2.67%, 2.25%, and 2.51% for fibre replacements of 0.25%, 0.50%, 0.75%, and 1%, respectively, indicating a positive impact of this combination.

The lowest water absorption rate (2.25%) was recorded at 0.75% fibre replacement, indicating the highest resistance to water absorption. However, beyond this 0.75% threshold, a slight rise in water absorption was noted, suggesting that excessive fibre content may reduce the compactness of the earth bricks, creating more voids that facilitate water ingress. This trend aligns with the findings of [32], who studied earth blocks reinforced with jute fibre and observed that water absorption increased with higher fibre content, attributing the rise to the presence of cellulose and the porous nature of natural fibres. Similarly, [29] reported that higher sugarcane bagasse fibre content led to greater water absorption due to increased voids within the brick matrix. These findings suggest that MG alone enhances the water resistance of earth bricks, but the addition of CPF further improves their resistance to moisture penetration.

However, an optimal fibre dosage of 0.75% is necessary to achieve the best performance, as excessive fibre content may negatively impact water absorption properties. Overall, the water absorption rates recorded in this study, ranging from 2.25% to 6.79% for both control and test bricks, fall well within the acceptable limits of 7% specified by BS EN 771:2011 [22]. These results confirm the suitability of the developed earth bricks for construction purposes.

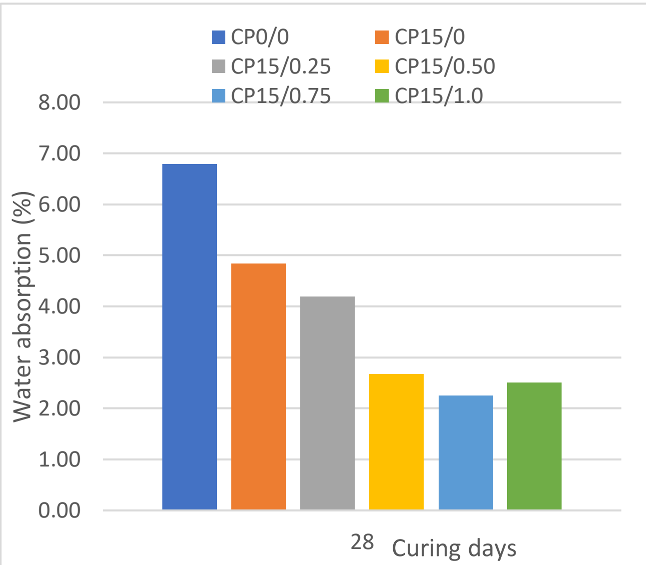

Fig. 5. Average Water Absorption Chart

C. *Mechanical properties*

1 Compressive Strength

Fig. 6 illustrates the result of the compressive strength of the bricks stabilised with MG and CPF. In this study, it is noted that the compressive strength increased with increase in curing age across all mix proportions, and the control with milled glass ($CP_{15/0}$) outperformed the control without MG ($CP_{0/0}$). The compressive strength increased from 1.315 N/mm² in the control sample without MG to 1.834 N/mm² in the control sample with 15% MG (i.e.32.96% increase), demonstrating a positive effect of MG inclusion. This increase in strength could be attributed to the fine MG particles which sealed the pores formed in the soil matrix leading to improved bonding in the earth material. Similar outcomes were found in prior studies. [18] observed similar results when they incorporated 15% waste glass dust into clay bricks. Their study found improvements in mechanical and durability properties. Also, [31] noted that compressive strength increased from 8.5 N/mm² to 28.5 N/mm² as glass content increased to 30%.

The addition of CPF up to 0.75% further improved compressive strength up to 2.135 N/mm² (i.e. 47.54% increase between the optimum and $CP_{0/0,}$ and 15.18% between the optimum and $CP_{15/0}$). However, increasing it to 1% led to a reduction in strength, indicating that excessive fibre content can weaken the structural integrity of the bricks. This improvement in compressive strength may be attributed to the strength of the fibres and the ability of the MG to fill the internal voids within the soil matrix, while the decrease in the compressive strength with 1 % CPF quantity in the specimens could be attributed to the increase in the volume of pores in the soil mixture (resulting in a decrease in glass-fibre-matrix cohesion). Regarding the use of natural fibres in bricks, similar trends were observed by [32] who examined cement-stabilised earth bricks reinforced with pineapple leaf fibres and found that compressive strength increased up to 3% fibre content, after which it declined. Similarly, [33] investigated the impact of palm fibre on earth blocks and found that adding up to 1% palm fibre content improved strength to 1.38 N/mm², while further increases reduced performance due to increased porosity caused by the fibrous material.

The results of the current study show that the inclusion of MG and CPF significantly improved the compressive strength of the earth bricks. This was confirmed with the One-Way ANOVA test result shown in Table III (at a significance level of 5 % (p = 0.012)) which was conducted to determine the existence of significant difference among the test results. The Standard Deviation (Std Dev) of the compressive strength of the bricks at 28 days are presented in Table IV. The analysis showed maximum strength obtained for 0.75% CPF replacement with a low standard deviation (0.00802) and SEM (0.00463), indicating minimal variability in the data. The analysis indicates that as fibre content increases beyond this 0.75% threshold with MG being constant, the strength decreases, and data variability rises, indicating a weaker and less reliable mix. The result revealed that a significant difference exists among the treatment name groupings. The current results meet the acceptable compressive strength of 2.068 N/mm² for soil-stabilised blocks, as outlined in GS 1207:2018 [34]. Based on these benchmarks, the optimum compressive strength value obtained in this study is considered suitable for construction purposes.

TABLE III: ONE-WAY-ANOVA OF COMPRESSIVE STRENGTH

Source of Variation	DF	SS	MS	F	P
Between Subjects	2	0.0778	0.0389		
Between Treatments	5	1.337	0.267	5.306	0.012
Residual	10	0.504	0.0504		
Total	17	1.919	0.113		

TABLE IV: DESCRIPTIVE STATISTICS OF COMPRESSIVE STRENGTH AT 28 DAYS CURING AGE

Treatment Name	N	Missing	Mean	Std Dev	SEM
$CP_{0/0}$	3	0	1.315	0.455	0.263
$CP_{15/0}$	3	0	1.834	0.123	0.0709
$CP_{15/0.25}$	3	0	1.935	0.0801	0.0463
$CP_{15/0.50}$	3	0	2.107	0.0887	0.0512
$CP_{15/0.75}$	3	0	2.135	0.00802	0.00463
$CP_{15/1.0}$	3	0	1.779	0.233	0.134

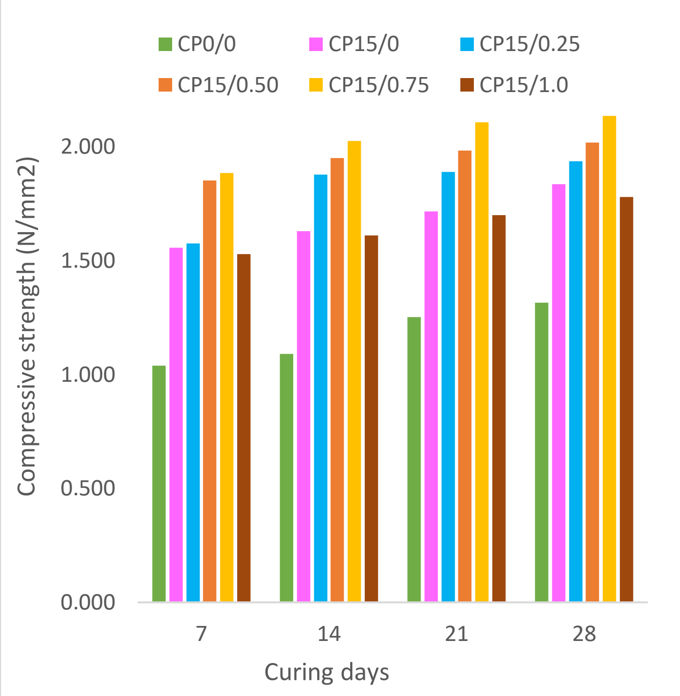

Fig. 6: Average Compressive Strength Chart

2 Split Tensile Test

The results presented in Fig. 7 illustrates the tensile strength of earth bricks produced using MG as a binder and CPF as reinforcement. The tensile strength increased with increase in curing age across all mix proportions, and all the specimens with MG and CPF performed better than the two control groups ($CP_{0/0}$ and $CP_{15/0}$) in tensile strength.

In this current study, tensile strength increased from 0.103 N/mm² for the control sample without MG ($CP_{0/0}$) to 0.137 N/mm² for the control sample with 15% MG showing 28.33% improvement. Further addition of CPF up to 0.75% raised the tensile strength to 0.233 N/mm², representing 77.38% improvement between the optimum and $CP_{0/0}$ and 51.89% between the optimum and $CP_{15/0}$. This upsurge in strength could be due to increased cohesion between the CPF and fine MG particles. However, beyond the 0.75% threshold, the strength declined, which is consistent with the trend reported in earlier research. [14] reported that wood fibre and MG enhanced splitting tensile strength of bricks up to 13.8% at 28 days curing while the optimum values were realised at 15 wt.% MG. Also, [13] examined the use of jute fibre in earth blocks, and the results showed a 30–40% improvement in both compressive and tensile strengths. The tensile strength of bricks increased at the optimum fibre content of 0.5%. This affirms that incorporating agricultural fibres into earth bricks initially boosts the mechanical strength of the bricks, followed by a decline when the fibre content exceeds an optimal level. The current study further revealed that fibre-reinforced specimens consistently exhibited a gradual failure (as the fibres bridged the failure planes) as compared to the control specimens which were sudden, as shown in Fig. 8 (b).

The ANOVA test results provide insights into the tensile strength of earth bricks at 28 days for different CPF and MG treatments. At a significance level of 5%, a one-way ANOVA was conducted to examine potential notable disparities in the split tensile strength of earth bricks made from MG and CPF, as depicted in Table V. The outcomes outlined in Table V indicate that the differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = < 0.001$). The Standard Deviation (Std Dev) of the split tensile strength of the bricks at 28 days are presented in Table VI. The analysis showed maximum strength obtained for 0.75% CPF replacement with a low standard deviation (0.0052) and SEM (0.003), indicating minimal variability in the data. The analysis indicates that as fibre content increases beyond this 0.75% threshold with MG being constant, the strength decreases, and data variability rises, indicating a weaker and less reliable mix. The result revealed that a significant difference exists among the treatment name groupings. This study confirms that MG and CPF, when used in optimal proportions, significantly improve the tensile strength of earth bricks

TABLE V: ONE-WAY-ANOVA TEST RESULTS OF SPLIT TENSILE STRENGTH

One Way RM ANOVA					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Between Subjects	2	0.000291	0.000145		
Between Treatments	5	0.0305	0.00609	20.872	<0.001
Residual	10	0.00292	0.000292		
Total	17	0.0337	0.00198		

TABLE VI: DESCRIPTIVE STATISTICS OF SPLIT TENSILE STRENGTH AT 28 DAYS CURING AGE

Treatment Name	N	Missing	Mean	Std Dev	SEM
$CP_{0/0}$	300.00%	0%	0.103	0.0224	0.0129
$CP_{15/0}$	3.000	0.000	0.137	0.01	0.00577
$CP_{15/0.25}$	3.000	0.000	0.15	0.0147	0.0085
$CP_{15/0.50}$	3.000	0.000	0.169	0.00252	0.00145
$CP_{15/0.75}$	3.000	0.000	0.233	0.0052	0.003
$CP_{15/1.0}$	3.000	0.000	0.126	0.0275	0.0159

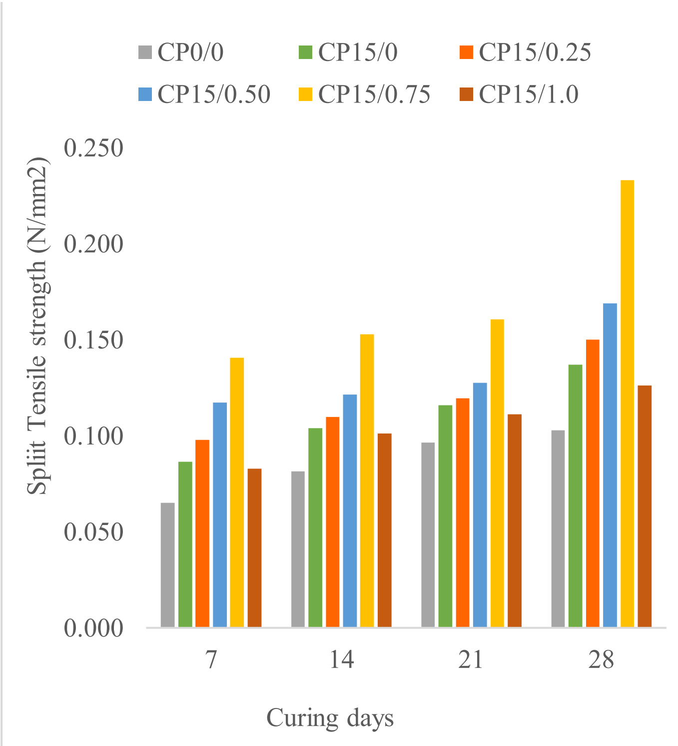

Fig. 7: Average Split Tensile Strength Chart

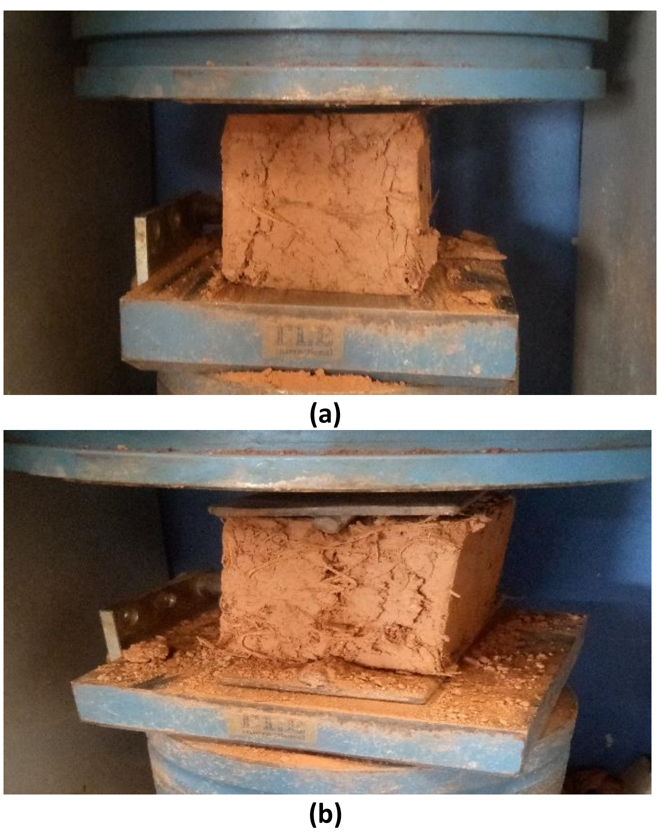

Fig. 8: (a) Compression Strength failure (b) Split Tensile Strength failure

D. *Durability Properties*

1 Erosion Resistance

Fig. 9 presents the average findings from the erosion test. The results reveal a reduction in average pit depth with increasing fibre content, demonstrating that higher fibre content enhances resistance to erosion. The first control brick ($CP_{0/0}$) exhibited the highest pit depth of 8.5 mm, with an erodibility index of 3, indicating high susceptibility to erosion. In contrast, the second control brick ($CP_{15/0}$) showed a significantly lower pit depth of 1.2 mm and an erodibility index of 2, signifying mild erosiveness. This implies that incorporating MG into earth bricks improved the resistance to erosion.

For bricks with 0.50%, 0.75%, and 1% CPF replacements, combined with a constant amount (15%) of MG, the erodibility index remained at 2 (mild erosiveness), but the average pit depth varied at 2.3 mm, 0.75 mm, and 1 mm, respectively. This indicates that increasing fibre content reduced erosion susceptibility, with 0.75% fibre content achieving the lowest pit depth of 0.75 mm, signifying superior erosion resistance.

However, at 0.25% CPF replacement, the bricks were still classified as erosive (index 3), with an average pit depth of 6mm, showing that lower fibre content was insufficient to significantly improve erosion resistance.

The increased erosion resistance of the fibre-reinforced earth bricks could be attributed to the binding effect of the MG and the ability of the CPF to hold the earth particles together, hence, preventing the earth bricks from being severely eroded. The findings of the study are in agreement with prior research conducted by [35], [36], which also demonstrate reduction in erosion of earth bricks. However, this study included CPF and MG, providing additional stabilising effect. [35] reported that erosion decreased with increasing sugarcane bagasse fibre content up to 0.5%. This improvement was attributed to the fibres’ ability to reduce water infiltration by bridging soil particles, thus enhancing cohesion and resistance to erosion. Similarly, [36] observed that incorporating clay pozzolana in stabilised earth blocks reduced erosion, with recorded pitting depths between 1.5 mm and 2.0 mm. This was attributed to the binding effect of pozzolana, which held soil particles together and reduced surface degradation. However, the tested earth bricks in this study fall within the non-erosive to mildly erosive classification as outlined in [26].

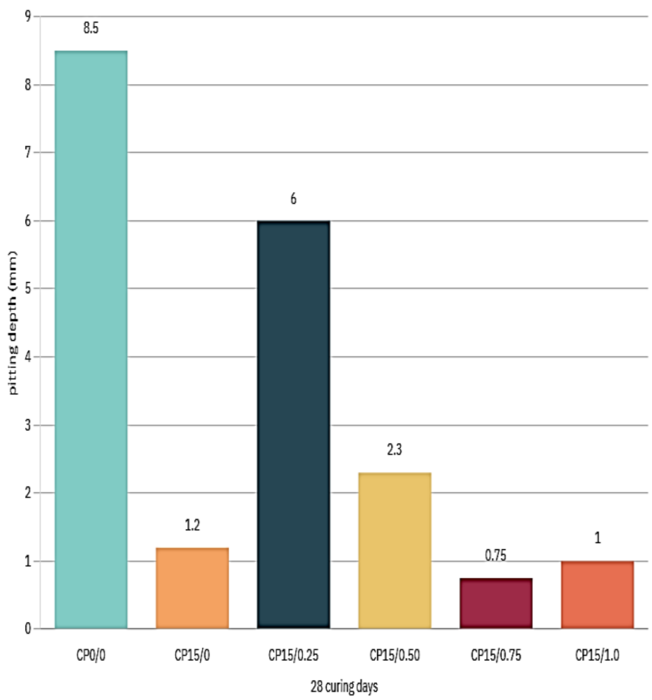

Fig. 9: Erosion Resistance Chart

IV. CONCLUSION

This study investigated the properties of earth bricks stabilised with MG as a binder and CPF as reinforcement. Earth bricks were produced with varying fibre contents 0.25%, 0.50%, 0.75%, and 1% by wt. over curing periods of 7, 14, 21, and 28 days. The following conclusions were drawn from the study:

- The inclusion of MG in earth bricks improves density, but the average density of the bricks was observed to slightly decrease with increasing percentages of CPF content.
- The incorporation of MG resulted in a significant reduction in water absorption but CPF addition led to further improvement in water resistance with the optimal performance in water resistance achieved at the mix ratio of 15% MG and 0.75% CPF content.
- The compressive strength, split tensile strength, and erosion resistance of the earth bricks showed marked improvements with the addition of MG and CPF. The optimum was recorded at 15% MG and 0.75% CPF contents.
- MG and CPF may be used together at optimal limits to improve the physical, mechanical, and durability properties of earth bricks for eco-friendly, sustainable, and affordable housing in Ghana.

This study concludes that the combination of MG and CPF positively influenced the properties of earth bricks. The findings of the study strongly encourage the use of MG and CPF as sustainable and eco-friendly stabilisers for producing earth bricks. 15 wt.% MG and 0.75% CPF inclusion in earth bricks is recommended for use by construction practitioners.

The conclusions drawn from the study are based on specific soil from a single location and do not account for degradation by organisms like termites. Future studies may validate these results across varied soil types and include biodegradation testing, and microstructural characteristics of these bricks. Addressing these factors will be vital for knowledge transfer and practical implementation.

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