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Original Research Article

Influence of Palm Fruit Fibres and Cow Dung on Locally Produced Earth Bricks in Ghana for Sustainable Construction

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Highlights:

- Adding cow dung (CD) and palm fruit fibres (PFF) increased brick performance, with about 24% improvement in compressive strength and up to 23% improvement in split tensile strength compared to control samples.
- While untreated bricks lost about 65% abrasion resistance, stabilised bricks showed only around a 5% reduction, indicating significantly better durability.
- Using agricultural waste (CD and PFF) promotes eco-friendly construction, reduces environmental pollution, lowers material costs, and supports sustainable waste management.

Abstract: This study examined the effects of using agricultural waste, specifically palm fruit fibres (PFF) and cow dung (CD), in the production of compressed earth bricks for sustainable construction applications. Various proportions of cow dung (ranging from 2% to 10%) and palm fruit fibres (from 0.1% to 0.5%) were used to stabilise the earth bricks. After a 28-day curing period, the mechanical and durability properties of the bricks were analysed. The results indicated that both the compressive strength and split tensile strength of the samples increased with higher percentages of CD and PFF in the mixture. The incorporation of PFF and CD led to an approximate 24.05% increase in compressive strength and a 1.59% to 23.02% increase in split tensile strength. Notably, while the control sample exhibited a 65% reduction in abrasion resistance, the stabilised specimens showed only about a 5% decrease. The study concludes that CD and PFF enhance the mechanical properties and abrasion resistance of earth bricks. The optimal composition for performance was found to be a mixture containing 10% CD and 0.5% PFF. This improvement is likely attributed to the additional properties of CD and the reinforcing effect of PFF, which together enhance the structural integrity of the stabilised specimens. The study highlights the potential of using agricultural waste (CD and PFF) as eco-friendly materials in brick production. This could reduce reliance on conventional materials, lower production costs, and contribute to sustainable building practices. Using agricultural and organic waste like CD and PFF promotes recycling and waste management. This approach reduces environmental pollution and supports sustainability in construction practices.

Keywords: Abrasion resistance, agricultural waste, cow dung, compressed earth bricks, palm fruit fibres

1. Introduction

The construction industry in Ghana is predominantly dependent on traditional building materials such as cement, sandcrete blocks, and concrete [1]. While these materials have been widely used over the years, they pose considerable environmental and economic challenges, including exorbitant production costs, substantial carbon emissions, and the depletion of natural resources [2]. In light of these pressing issues, there has been growing interest in sustainable alternatives, particularly earth bricks reinforced with organic materials [3]. These innovative solutions have the potential to enhance both the strength and durability of construction while promoting eco-friendly practices [4]. One particularly promising avenue for improvement lies in the incorporation of agricultural waste into the production of locally manufactured earth bricks. By utilising palm fruit fibres, a readily available by-product of the palm oil industry, their natural properties can be exploited to bolster the mechanical strength of these composite materials. Research has demonstrated that palm fruit fibres can significantly enhance tensile strength and crack resistance, making them a valuable addition to construction materials in Ghana [5]. Similarly, cow dung, which is abundantly produced in rural communities, contains organic compounds that not only act as effective binding agents but also improve the overall structural integrity of earth bricks, as evidenced

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by various studies in the field of bio-based construction [6]. Despite the clear potential for these materials to revolutionise building practices, there remains a notable gap in research regarding the synergistic effects of combining palm fruit fibres and cow dung on the performance characteristics of locally produced earth bricks in Ghana. Gaining a comprehensive understanding of these properties is vital for ensuring that such eco-friendly bricks can meet established construction standards and ultimately be embraced as a viable alternative in sustainable building practices.

2. Materials and Methods

2.1. Materials

The study utilised various materials, including earth, cow dung (CD), and palm fruit fibres (PFF). The earth, shown in Figure 1(a), was sourced from Hemang Buoho in the Ashanti Region of Ghana, specifically from a depth of 150 mm below ground level. The cow dung, shown in Figure 1(b), was gathered from the Kumasi abattoir in a wet state and then left to sun-dry for a few weeks until uniformly dried. Subsequently, the sun-dried CD was manually pulverised into finer particles before being used. The palm fruit fibres, shown in Figure 1(c), were sourced in their wet state from the Offinso Oil Processing Mill in the Ashanti Region of Ghana and were submerged in hot water to remove the oil content. The PFF were then sun-dried before being used. The water used for mixing the materials adhered to the standards outlined in BS EN 1008 (2002) [7].

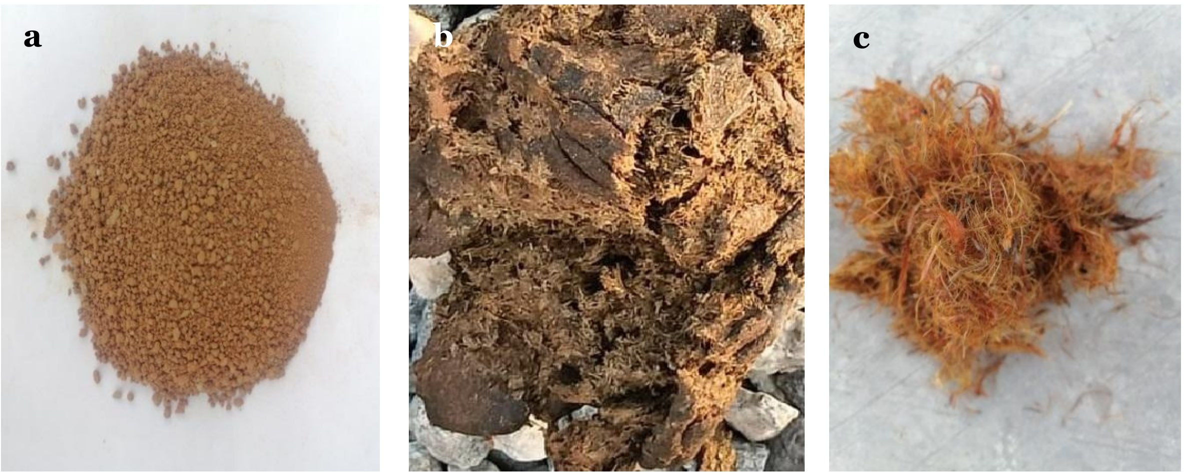


Figure 1. Preparation of The Materials

2.2. Methods/procedures

The experiment involved analysing the size distribution of particles in the earth following the BS EN 1377-1:1990 standard [8]. The study also determined the physical and mechanical properties of the PFF, following the research conducted by Danso et al. (2015) [9], as shown in Figure 2(a). The chemical and oxide composition of CD was also determined. The specimens were mechanically moulded using a compressed hydraulic brick moulding machine with a mould size of 100 mm × 100 mm × 100 mm. To facilitate the easy removal of the mould and achieve a smooth finish on the earth bricks, the mould was oiled. The mixture was then placed in the mould in three layers and compacted 25 times using a wooden rammer to fill the voids, as shown in Figure 2(b). A metal float was subsequently used to level the surface of the mould in order to remove the excess material. The top cover of the mould was firmly tightened, and a pressure of 140 bars was applied using the hydraulic jack of the moulding machine to uniformly compress the mixture and obtain the desired compressed earth bricks. The specimens were then cured using the air-drying method for 28 days, as shown in Figure 2(c). After 28 days of curing, the compressive strength of the specimens was tested following the guidelines outlined in BS EN 772-1:2011 [10]. The split tensile strength of the specimens was also tested following BS EN 12390-6:2009 [11]. Finally, the durability (abrasion resistance) of the specimens was tested following Zievie et al. [12].

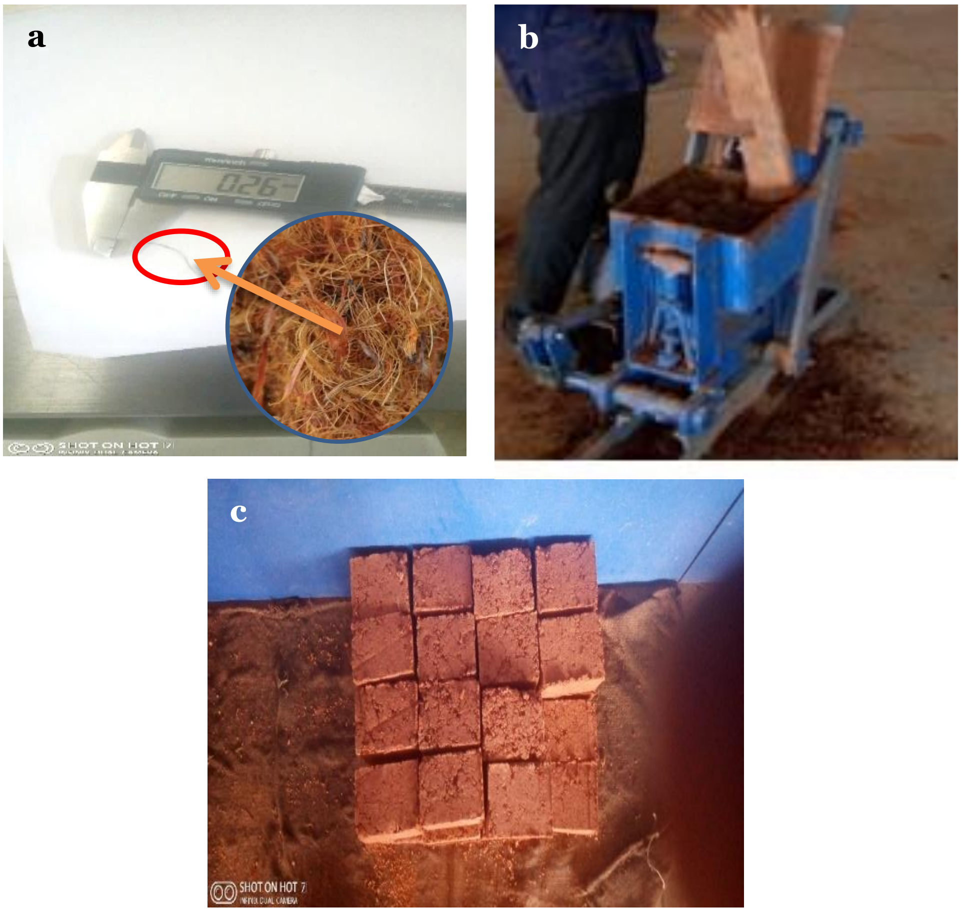


Figure 2. (a) Measuring the Diameter of The Fibres, (B) Moulding of The Specimens, (C) Curing of The Specimens

3. Results and Discussions

3.1. Results of Particle Size Distribution of The Earth

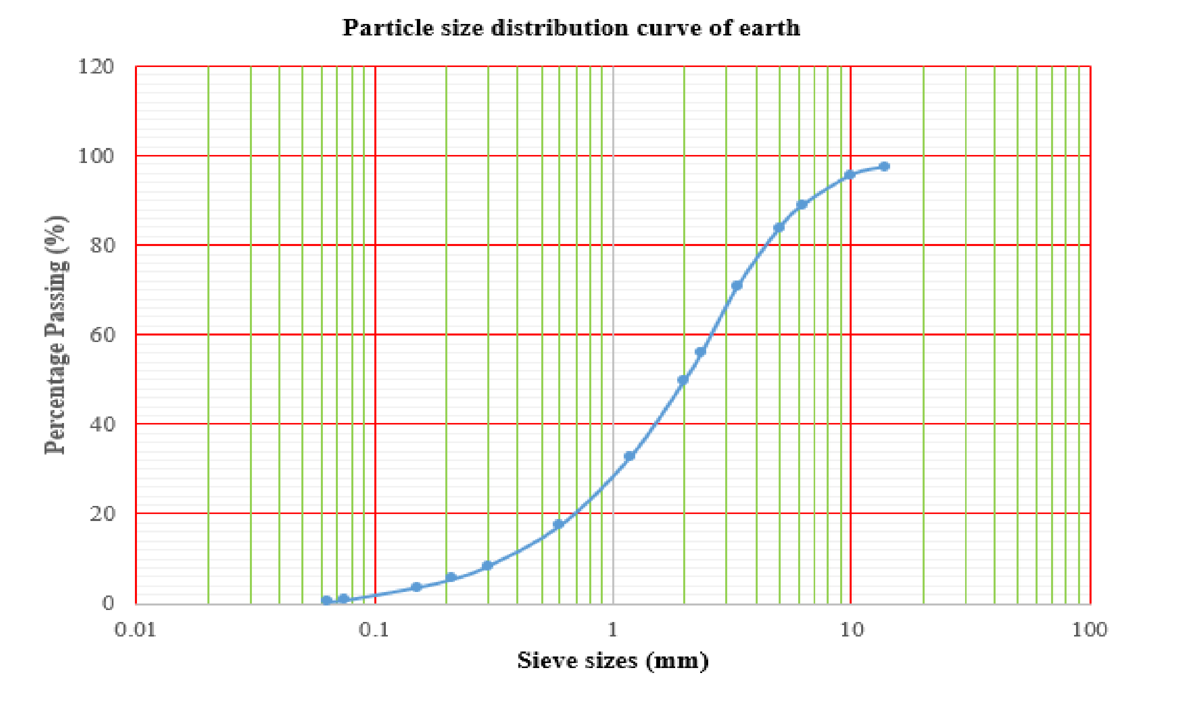
Figure 3 presents the particle size distribution of the soil analysed in this study. The graph shows sieve sizes (mm) on the x-axis, ranging from fine to coarse particles, and the cumulative percentage of material passing through the sieves on the y-axis. The curve starts near 0% for fine particles (0.01 mm) and rises sharply towards larger sizes, indicating that more material passes through as particle size increases, ultimately reaching nearly 100% at the largest sieve sizes. The following observations were made:

- Clay (0%): No clay-sized particles (<0.002 mm), indicating a coarse-grained material.
- Silt (0%): No silt-sized particles (0.002–0.06 mm), reinforcing the predominance of larger particles.
- Sand (49.9%): Nearly half of the sample consists of sand-sized particles (0.06–2 mm), suggesting sandy soil properties.
- Gravel (50.1%): The remaining half comprises gravel-sized particles (>2 mm), indicating good drainage and load-bearing capacity.

The distribution curve indicates that the soil is predominantly coarse-grained, with an equal mix of sand and gravel, minimal plasticity, and well-graded characteristics. Such analysis is crucial for geotechnical engineering applications, including foundation design and road construction.

3.2. Results of Chemical and Oxide Composition of The Cow Dung (CD)

The analysis in Table 1 details the chemical and oxide composition of cow dung (CD), revealing that water (H_2O) constitutes 75.20% of its total makeup, indicating that it must be dried before use in construction. Once dried, CD can function as an organic binder or filler in lightweight composite materials. Silicon dioxide (SiO_2) follows at 6.20%, suggesting the presence of fibrous plant materials that enhance strength and thermal resistance, making it suitable for applications in earth blocks and concrete.



Below 0.002 mm	Fine 0.002-0.006 mm	Medium 0.006-0.02 mm	Coarse 0.02-0.06 mm	Fine 0.06-0.2 mm	Medium 0.2-0.6 mm	Coarse 0.6-2 mm	Fine 2-6 mm	Medium 6-20 mm	Coarse 20-60 mm
Clay = 0%	**Silt = 0%**			**Sand = 49.9%**			**Gravel = 50.1%**		

Figure 3. Results of Particle Size Distribution of The Earth

Table 1. Results of Chemical and Oxide Composition of the Cow Dung (CD).

No.	Chemical/Oxide Formula	Composition Weight (%)
1	Na_2O	0.25
2	Fe_2O_3	0.52
3	CaO	0.30
4	SiO_2	6.20
5	Al_2O_3	1.21
6	MgO	0.20
7	H_2O	75.20
8	P	0.51
9	N	1.10
10	K	0.30
11	Cu, Zn, Mn	< 0.1

Additionally, aluminium oxide (Al_2O_3) at 1.21%, along with other oxides such as calcium oxide (CaO) and magnesium oxide (MgO) (at 0.30% and 0.20%, respectively), may improve binding properties and Potential Hydrogen (pH) balance in agricultural contexts. The nutrient content includes nitrogen (1.10%), phosphorus (0.51%), and potassium (0.30%), enhancing soil fertility, while trace metals such as iron oxide (Fe_2O_3) (0.52%) contribute to the strength and appearance of construction materials. Despite its potential environmental impact, processed cow dung could also be used to create lightweight insulating panels and bio-concrete, contributing to sustainability efforts in construction. Overall, CD presents a dual benefit as a building material and an organic fertiliser while indicating a low risk of contamination for agricultural use.

3.3. Results of The Properties of the Palm Fruit Fibre

Table 2 presents an analysis of PFF, highlighting its potential in the construction industry. The analysis reveals that the average length and diameter of PFF are 5.51 mm and 0.21 mm, respectively. While its short length may limit its use in structural applications requiring long fibres, PFF is well-suited for reinforcing composites, enhancing uniformity, and reducing material segregation. Its fine diameter may improve bonding within matrices, leading to better stress transfer.

Table 2. Results of Properties of The Palm Fruit Fibre

No.	Properties	Characteristics
1	Length	5.51 (mm)
2	Diameter	0.21 (mm)
3	Specific weight	0.38 (g/cm^3)
4	Water Absorption	210.00 (%)
5	Tensile Strength	105 (Mpa)
6	Young's Modulus	2.90 (Mpa)
7	Elongation at Break	6.0 (%)

PFF has a specific weight of 0.38 g/cm^3, making it significantly lighter than steel (7.85 g/cm^3) and ideal for applications such as prefabricated panels. Its high-water absorption capacity of 210% indicates strong hydrophilicity, which may raise concerns about swelling and dimensional stability. Treatments may be necessary to mitigate these issues. The tensile strength of PFF is 105 MPa, making it suitable for secondary reinforcement in lightweight, non-structural elements but insufficient for primary support. With a Young's modulus of 2.90 MPa, PFF exhibits flexibility, which is beneficial for energy dissipation under dynamic loads. Its elongation at break is 6.0%, indicating ductility, which is valuable for impact-resistant applications.

Overall, PFF shows promise for structural reinforcement, enhancing toughness in composite applications. However, its hydrophilic nature and moderate tensile properties limit its suitability for critical structural roles. Chemical treatments could expand its applications, aligning with sustainable construction practices.

3.4. Results of Compressive Strength of The Specimens

The split tensile strength test results after 28 days of curing are illustrated in Figure 4. The study demonstrated that an increase in cow dung (CD) and palm fruit fibre (PFF) content led to an increase in split tensile strength, ranging from 1.59% to 23.02%, indicating that these materials reinforce the specimen effectively. The highest tensile strength was observed at 10% CD and 0.5% PFF content, while the lowest tensile strength occurred at 0% CD and 0% PFF content (the control). The results show a clear positive trend, where increasing CD and PFF content enhances the tensile performance of the specimens.

The improved tensile strength is attributed to the reinforcement effect of PFF, which prevents premature splitting. This suggests that fibre-reinforced composites can enhance durability and structural integrity under tensile loads.

This outcome was anticipated, as compressive and tensile strengths are key factors influencing mechanical properties [9]. Additionally, the control specimens (0% CD and 0% PFF) fractured completely under applied loads, as shown in Figure 5 (a). While those with CD and PFF maintained some integrity, preventing complete separation, as depicted in Figure 5 (b). This implies that fibre addition increases ductility, making the material more resilient to stress. The elongation at break for PFF was observed to be 6.0%, which is relatively moderate among natural fibres. This characteristic indicates that PFF exhibits ductile behaviour, allowing the structure to endure some deformation before failure under tensile loading. This property is particularly valuable for applications that can tolerate a certain degree of deformation. These results suggest that using CD and PFF in construction materials can lead to more sustainable, durable, and resilient composites.

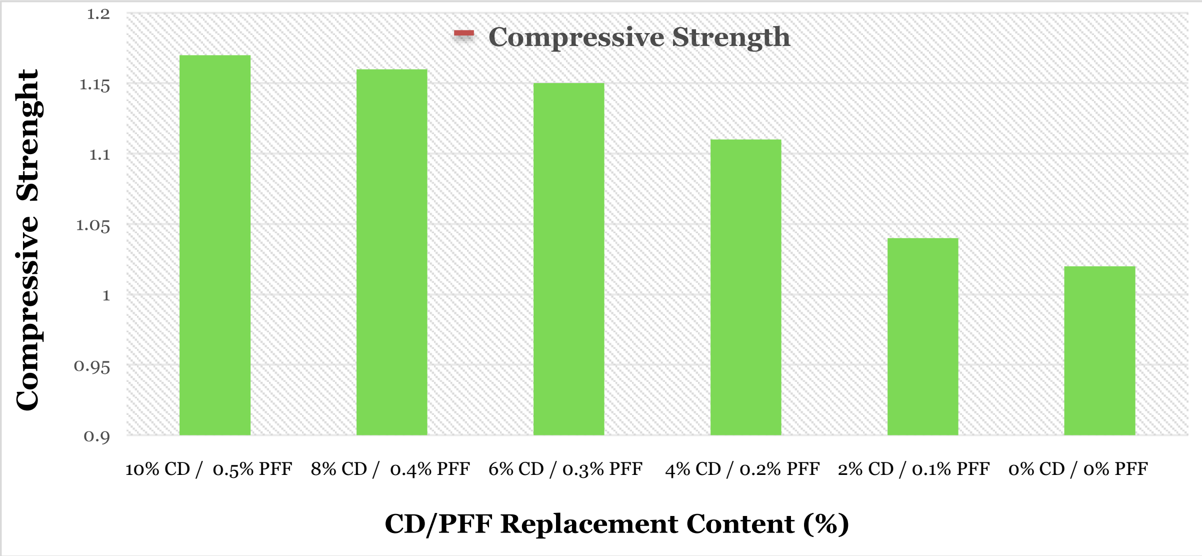


Figure 4. Results of Split Tensile Strength Test of The Specimens

The findings suggest that incorporating natural fibres and organic materials like CD and PFF can improve the mechanical performance of construction materials. This has potential applications in sustainable building materials, particularly in regions where cost-effective and eco-friendly alternatives are needed. The study findings align with previous research, reinforcing the understanding that compressive and tensile strength enhancements are achievable with fibre reinforcement [9].

Figure 5. Failure Mode of The Specimens Under a Tensile Loading. (a) Control Specimen; (b) Reinforced Specimen

3.5. Results of Abrasion Resistance Test of The Specimens

The results from the abrasion test are shown in Figure 6. The investigation demonstrated that with an increase in both cow dung (CD) and palm fruit fibre (PFF) content in the mixtures, there was approximately a 65 per cent corresponding decrease in the abrasion resistance of the control specimens and about a 5 per cent decrease in the abrasion resistance of the stabilised specimens. This demonstrates the limited durability of traditional specimens without the incorporation of stabilising materials like CD and PFF.

The specimens with 10% CD and 0.5% PFF replacement content exhibited the highest abrasion resistance. This suggests that combining organic materials such as cow dung and palm fruit fibre effectively enhances the durability of materials subjected to abrasive forces. The enhanced resistance can likely be attributed to the synergistic properties of CD and PFF, as they improve the mechanical interlocking and stability of the mixture.

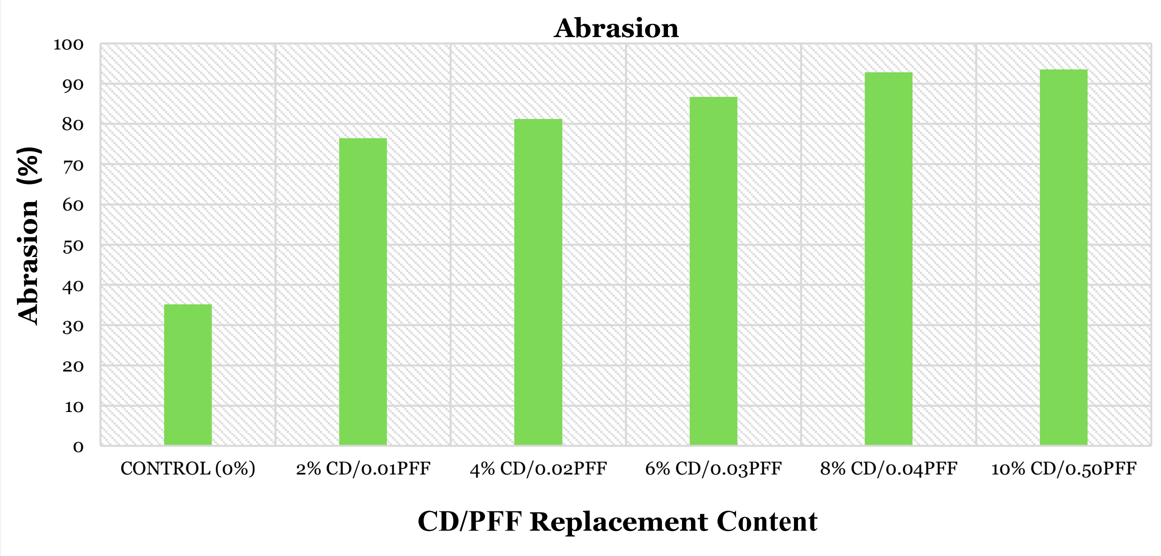


Figure 6. Abrasion Resistance Test Results of The Specimens

The results of this study could have significant implications for construction and material science industries, particularly in sustainable construction. Incorporating waste materials like cow dung and palm fruit fibre into construction materials could result in cost-effective, eco-friendly, and durable products. Potential applications include pavements, flooring, or other surfaces exposed to wear and tear. The findings align with prior research [13, 14], which observed improvements in abrasion resistance with increased organic content. This reinforces the validity of using natural fibres and waste materials for performance enhancement.

4. 4. Correlation Between Construct

Table 3 summarises the correlation between CD and PFF content, compressive strength, tensile strength, and abrasion resistance. The variables include the Pearson correlation coefficient (r), significance values (p), and sample size (N). The analysis reveals a strong positive correlation between CD and PFF content and compressive strength ($r = 0.903$, $p = 0.006$). Conversely, there are strong positive correlations with tensile strength ($r = 0.971$, $p = 0.013$) and abrasion resistance ($r = 0.981$, $p = 0.003$). The study revealed that the correlations among these variables are very strong, as indicated by coefficients close to ±1. All p-values are below 0.05, which suggests that the correlations are statistically significant. Key insights from this analysis indicate that an increase in CD and PFF content in the mixes positively affects the compressive strength while simultaneously improving the tensile strength and abrasion resistance of the construct. Additionally, compressive strength, tensile strength, and abrasion resistance are positively related, implying that enhancing one property tends to improve the others.

An increase in CD & PFF content leads to an improvement in all three mechanical properties, meaning that optimizing the content of CD & PFF can enhance structural performance. This insight is valuable for material engineers and construction applications where strength and durability are critical factors. The findings suggest that CD & PFF-enhanced materials could be used in construction applications where both strength and durability are required, such as road pavements, structural concrete, and wear-resistant surfaces.

Since abrasion resistance is positively correlated with other strengths, the material may perform well in high-wear environments. The findings suggest that CD & PFF-enhanced materials could be used in construction applications where both strength and durability are required, such as road pavements, structural concrete, and wear-resistant surfaces. Since abrasion resistance is positively correlated with other strengths, the material may perform well in high-wear environments.

Table 3. Correlation Between Construct.

		CD&PFF Content	Compressive (N/mm^2)	Tensile (MPa)	Abrasion (%)
CD&PFF Content	Pearson Correlation	1	0.903	0.971	0.981
	Sig. (2-tailed)		0.006**	0.013*	0.003**
	N		5	5	5
Compressive (N/mm^2)	Pearson Correlation		1	0.994	0.969
	Sig. (2-tailed)			0.001**	0.007**
	N			5	5
Tensile (MPa)	Pearson Correlation			1	0.959
	Sig. (2-tailed)				0.010*
	N				5
Abrasion resistance	Pearson Correlation				1
	Sig. (2-tailed)				
	N				

*Statistically significant at $p < 0.05$ and **$p < 0.01$.

5. Conclusion

The study revealed that incorporating PFF and CD into earth bricks resulted in an approximate 24.05% and 23.02% increase in compressive strength and split tensile strength, respectively.

1) An increase in both CD and PFF content in the mix resulted in approximately a 65% corresponding decrease in the abrasion resistance of the control specimens and about a 5% decrease in the abrasion resistance of the stabilised specimens. This indicates that the abrasion resistance of the stabilised earth bricks was improved compared with the control specimens.
2) The study shows that adding CD and PFF to the mixes improved the compressive strength, tensile strength, and abrasion resistance of earth bricks. The ideal mix was determined to be 10% CD and 0.5% PFF content, which showed the best performance across all evaluated parameters. This enhancement is likely due to the advantageous properties of CD and the strengthening effects of PFF, which improve the structural integrity of the bricks.
3) The study shows that adding CD and PFF greatly improves the strength and durability of the construction material. The clear connection between these improvements suggests that increasing the amount of CD and PFF is an effective way to enhance overall material performance. The study highlights the potential of using agricultural waste (CD and PFF) as eco-friendly materials in brick production. This could reduce reliance on conventional materials, lower production costs, and contribute to sustainable building practices. The study suggests that incorporating CD and PFF in controlled proportions can enhance the structural properties of earth bricks, making them a viable alternative for sustainable construction.

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Author Contributions:

Adamu Wahab, Alexander Owusu Ansah, and Asu-Poku Justin equally contributed in conceptualization, methodology, investigation, formal analysis, visualization, writing—original draft, and writing—review and editing. All authors read and approved the final manuscript.

Conflicts 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

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