

Article

## The role of palm fiber ash in improving clay bricks

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### Abstract

This research examines the effect of adding ash from the combustion of palm fibers to clay bricks to improve their physical and mechanical properties and durability. This research is part of the development of environmentally friendly building materials through the recycling of agricultural waste and the reduction of dependence on natural resources. The methodology involved incorporating different ash ratios (5% to 15%) into a clay and sand mixture, then measuring the bulk density, water absorption rate, and compressive strength according to ASTM standards. The results were analysed using experimental models and compared to reference samples. The results showed that the addition of ash resulted in a 3.7% decrease in density and an improvement in moisture resistance, with a 9.3% decrease in water absorption rate. Compressive strength also increased to 43.75%. The study confirms the feasibility of using ash as an effective additive to improve the performance of clay bricks, while reducing environmental impact and promoting the circular economy.

### 1. Introduction

Clay bricks are one of the oldest and most widely used building materials, thanks to the availability of raw materials and their ease of manufacture [1]. Faced with the growing need for sustainable and high-performance building solutions, attention has focused on improving the properties of traditional clay bricks without increasing costs [2]. The use of ash has proven to be an innovative additive that balances lightness, durability, and water resistance [3]. Clay bricks are environmentally friendly [4], as they utilise renewable natural materials and generate low carbon dioxide emissions during production [5]. They also provide good thermal and sound insulation, thus improving occupant comfort. However, their high weight and water absorption capacity remain significant challenges that compromise their long-term sustainability [6]. Conventional clay bricks suffer from high density, which increases structural loads on foundations and increases transportation and installation costs. Their high water absorption rate also leads to deterioration of the visible surface and moisture infiltration into the walls [7]. This hurts insulation effectiveness and the lifespan of the building. Furthermore, the hardness of a brick can indicate its load-bearing capacity, but its low hardness prevents its use in more demanding construction systems.

Fly ash is extracted from the combustion of organic waste and contains pozzolanic compounds such as silicates and aluminates. Its fine particles are characterised by their ability to fill the microscopic spaces between clay particles [8]. This filling reduces porosity and helps improve the internal cohesion of the material after reacting with the hydroxide released by the clay. In a study by Kumar et al., the effect of adding silica ash (SCA) and fly ash (FAS) to the brick substrate on the structural properties and durability of clay bricks (CBs) produced in an industrial kiln was investigated. FAS and FAS were incorporated in a ratio of 2 to 10%.

The results showed that incorporating 4% SCA increased compressive strength by 27.55%, while incorporating 4% FAS increased strength by 17.36%. Both additives also reduced brick weight and water absorption [9]. Another study investigated the feasibility of reusing fly ash (FAS) in the manufacture of clay bricks. This ash was mixed with low-calcium clay in a ratio of 10:40 %. The results showed that adding FAS affected the physical and mechanical properties of the bricks, reducing their density and shrinkage. The microstructure has also developed, and the pores have increased from fine to medium. The use of VCs of 10 to 30% is recommended, depending on the target temperature and environment. This allows the production of clay bricks of acceptable quality while reducing the consumption of natural resources by up to 30% [10]. Replacing part of the raw clay mass with lighter ash significantly reduces the bulk density of the bricks [11]. Blocking microscopic voids with ash particles prevents water from penetrating through the internal structure of the bricks. The pozzolanic reaction between the ash compounds and calcium hydroxide produces cementitious crystalline structures that seal small water channels. The air pores created by burning palm fibres also trap water in isolated pockets, preventing continuous moisture distribution. This is what Bih and his colleagues concluded in their research [12]. The presence of ash helps reduce thermal differences during combustion by lowering the temperature required for pellet adhesion. This reduces material shrinkage during drying and limits crack formation [13]. This research aims to study the effect of adding 5 to 15% palm fiber ash to a clay and sand-based clay brick mix to improve its physical and mechanical properties. This addition is part of the development of more sustainable building materials, valorizing agricultural waste and improving the performance of traditional bricks. The research focuses on analyzing variations in the bricks' bulk density and water absorption rate, which are essential factors in determining their resistance to moisture and corrosion. Additionally, the compressive strength of the resulting bricks is evaluated to assess the extent to which their stiffness and capacity to withstand structural loads are improved. Through this study, the researchers aim to demonstrate the feasibility of using palm fibre ash as an effective additive to enhance the quality of clay bricks, while reducing environmental impact and optimizing the use of local renewable resources.

## **2. Materials and Methods**

### **2.1 Materials**

#### **2.1.1 Clay**

The chemical composition of the clay presented in the table exhibits distinct mineral and geotechnical properties that make it an ideal material for numerous technical and industrial applications. Its high silicon dioxide ( $\text{SiO}_2$ ) content of 63% indicates that the clay is rich in silicate minerals, such as quartz and kaolinite, which gives it good hardness and heat resistance, making it ideal for the manufacture of bricks and ceramics. The presence of 16% aluminum oxide ( $\text{Al}_2\text{O}_3$ ) enhances the clay's resistance to high temperatures and contributes to improved plasticity and cohesion, essential properties for forming and drying processes.

The 7% iron oxide ( $\text{Fe}_2\text{O}_3$ ) is responsible for the red or brown color of the clay after firing and is involved in the chemical reactions that occur during the heat treatment process. The presence of 2.4% magnesium oxide ( $\text{MgO}$ ) helps improve the clay's physical properties, such as elasticity and hardness, and enhances its resistance to mechanical stress. On the other hand, the presence of 3.6% calcium carbonate ( $\text{CaCO}_3$ ) increases the clay's overall alkalinity and contributes to post-firing hardening, but can lead to efflorescence if not adequately treated.

Secondary compounds such as sulfates ( $\text{SO}_4^{2-}$ ) at 0.41% and chlorides ( $\text{Cl}^-$ ) at 0.14%, although present in small amounts, can adversely affect the clay's stability in construction environments, particularly when interacting with cement or other minerals. Other compounds,

which make up 7.46% of the composition, may include elements such as sodium, titanium, and potassium, which influence the clay's chemical reactivity and give it additional properties such as corrosion resistance or improved cohesion. When this chemical composition is compared to its geotechnical properties, the clay exhibits high plasticity (WL = 81%, WP = 34%), making it easy to work with. However, it can be prone to shrinkage and cracking during drying. The density (2.6 g/cm<sup>3</sup>) is within normal limits, indicating a good mineral balance. All these properties make this type of clay suitable for construction applications, particularly for the manufacture of refractory bricks and ceramics, provided the alkali content is controlled to avoid any long-term problems. The properties of the clay used are shown in Table 1[14].

### *2.1.2 Sand*

The chemical composition of the sand presented in the table reflects its highly pure mineral properties, making it suitable for a wide range of industrial applications, particularly in the construction and glass industries. The very high percentage of silicon dioxide (SiO<sub>2</sub>), at 93.66%, indicates that this sand is primarily composed of quartz, the most abundant mineral in natural sand. This high percentage gives the sand excellent properties in terms of hardness, heat resistance, and transparency, making it ideal for the manufacture of glass, ceramics, and high-performance concrete. The presence of aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) at 1.52% enhances the sand's heat resistance, indicating the presence of trace amounts of clay or feldspar minerals, which do not negatively impact its purity. Iron oxide (Fe<sub>2</sub>O<sub>3</sub>), at 0.59%, is responsible for the slight discoloration that may appear in the sand and can affect its use in industries requiring a pure color, such as clear glass, while remaining within acceptable limits. Calcium oxide (CaO) at 1.14% may be due to the presence of calcium carbonate or calcite impurities, useful in some construction applications but requiring careful adjustment in the glass industry to avoid any reaction with silica.

Potassium oxide (K<sub>2</sub>O) and sodium oxide (Na<sub>2</sub>O) at 0.43% and 0.13%, respectively, are alkaline elements commonly used as fluxes in the glass industry, where they lower the melting temperature and improve flow properties. However, their low presence indicates the purity of the sand and the absence of additional processing to remove these oxides. The complete absence of magnesium oxide (MgO) (0.00%) reflects additional purity, as this compound can affect melting properties in some industries. The sulfate (SO<sub>3</sub>) concentration at 0.05% is very low, but it may be due to gypsum or organic impurities and requires monitoring for applications requiring long-term chemical stability.

In general, this chemical composition indicates that the sand has a high degree of mineral purity, making it suitable for precision industries such as glass, electronics, and specialty concretes. Its geotechnical properties, such as its density (2.5 g/cm<sup>3</sup>) and particle size (2.79), also justify its use in high-performance concrete mixes. The properties of the sand used are shown in Table 2[14].

### *2.1.3 Palm fiber ash*

The type of ash used is palm fiber ash after burning it in the open air. Chemical analysis of the ash, according to the indicated proportions, reveals various mineral components that determine its physical and chemical properties and, consequently, its applications. The most significant proportion is silicon dioxide (SiO<sub>2</sub>), at 45.50%, indicating that the ash is rich in silica. This relatively inert material lends it hardness and chemical resistance, making it suitable for use in cement production or as a filler in concrete mixes.

This is followed by a relatively high percentage of potassium oxide (K<sub>2</sub>O), at 23.30%. This relatively high value indicates the presence of potassium compounds that can influence the melting point and increase the alkaline activity of the ash. This can be useful in specific chemical reactions or to improve soil fertility when the ash is used as a source of potassium in agriculture. Calcium oxide (CaO), at 12.80%, gives the ash significant alkaline properties, contributes to its interaction with water or acids, and improves its cohesion when mixed with silicate materials. Aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) at 5.40% provides heat-resistant properties and participates in the formation of mineral phases with silica and calcium. The presence of phosphorus oxide (P<sub>2</sub>O<sub>5</sub>) at 5.38% indicates the ash's potential as a source of phosphorus in fertilizers, while magnesium oxide (MgO) at 3.20% contributes to better resistance to thermal corrosion. Iron oxide (Fe<sub>2</sub>O<sub>3</sub>) at 3.26% affects color and magnetic properties and can participate in oxidation reactions. The remaining 1.16% represents other trace elements or oxides, which may include impurities or rare elements. this composition makes ash a versatile material, suitable for use in construction, the glass and ceramics industry, soil improvement, and even as a raw material in the chemical industry. However, the effect of strongly alkaline oxides must be taken into account in specific applications. The chemical composition of the used ash is shown in Table 3.

**Table 1.** Clay properties.

Geotechnicals properties		Chemical composition	
Sand (> 0,02mm)	9%	SO <sub>4</sub> <sup>-2</sup>	0.41%
Silt(0,02-0,002mm)	54%	CaCO <sub>3</sub>	3.6%
Clay (<0,002mm)	37%	Cl-	0.14%
Liquid limit WL	81%	SiO <sub>2</sub>	63%
Plastic limit WP	34%	Al <sub>2</sub> O <sub>3</sub>	16%
plastic index IP	47%	Fe <sub>2</sub> O <sub>3</sub>	7%
VB	8	MgO	2.4%
Specific density γ <sub>s</sub>	2.6 g/cm <sup>3</sup>	Other	7.46%

**Table 2** .Sand properties.

Geotechnicals properties		Chemical composition	
Sand equivalent	36.49%	SiO <sub>2</sub>	93.66%
Specific density	2.5g/cm <sup>3</sup>	Al <sub>2</sub> O <sub>3</sub>	1.52%
Apparent density	1.46 g/cm <sup>3</sup>	Fe <sub>2</sub> O <sub>3</sub>	0.59%
Finesse Model	2.79	CaO	1.14%
		K <sub>2</sub> O	0.43%
		Na <sub>2</sub> O	0.13%
		MgO	00%
		SO <sub>3</sub>	0.05%

**Table 3.** Chemical composition of palm fiber ash[15] .

Composition	SiO <sub>2</sub>	MgO	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	CaO	Al <sub>2</sub> O <sub>3</sub>	Others
Percentage (%)	45.50%	3.20%	5.38%	23.30%	3.26%	12.80%	5.40%	1.16%

## 2.2 Methods

### 2.2.1 Sample preparation

First, the clay and sand are sieved using a 2 mm sieve to ensure that all particles in the mix are smaller than this size. This step is crucial for achieving homogeneity in the final mix and preventing the formation of lumps or coarse impurities that could compromise the quality of the bricks. After sieving, the ideal proportions of the solid components are determined based on the results of previous studies, such as those by Mbomba et al. (2000), who recommended a mixture of 70% clay and 30% sand. This ratio balances the plasticity of the clay with the rigidity and shrinkage reduction of the sand, producing a soil suitable for shaping and drying without the formation of significant cracks. After adding the lime, ash is added in proportions of 5%, 10%, and 15%. Water is added to the mix in small amounts while continuing to mix, ensuring even moisture distribution. The amount of water added should be less than 30% of the total volume of the components to avoid excessive plasticity, shrinkage, and cracking during drying. Controlling the amount of water is essential to facilitate shaping and maintain the sample's dimensions after drying.

Once the desired consistency is reached, the mix is placed in 20 x 10 x 5 cm metal molds. The mold is filled, and the mixture is lightly tamped to remove air. The metal molds ensure shape stability and allow for uniform brick surfaces. After shaping, the samples are left in the molds or carefully removed and placed in a dry, well-ventilated area to dry naturally for 28 days. During this period, moisture gradually dissipates, allowing the sample to harden and regain its initial mechanical strength. It is important that drying is slow and gradual to avoid cracks caused by rapid water loss. The wet mass of the samples is 2000 g. Table 4 shows how to prepare samples.

**Table 4** .Sample preparation.

Clay (%)	Sand (%)	Ash (%)	Water (%)	Samples
49	21	0	30	CSA0
45	20	5		CSA5
42	18	10		CSA10
38	17	15		CSA15

## 2.2.2 Measurement of variables

### 2.2.2.1 Measurement of change in density

To measure the bulk density of ash-enriched clay bricks, precise steps are followed in accordance with the American Standard ASTM C67, Standard Test for Physical Properties of Clay Bricks. The process begins by drying the brick sample in an oven at  $110 \pm 5$  °C until it reaches a constant weight. The dry weight of the sample (W) is then recorded. The dimensions of the brick are then accurately measured using appropriate measuring instruments (length, width, height), and the volume (V) is calculated in cubic centimetres. Equation 1 is used to measure the density.

$$\rho = \frac{W}{V} \quad (1)$$

The measurement results are shown in Figure 1.

### 2.2.2.2 Measuring the change in water absorption rate

An experiment is conducted to determine the water absorption rate of ash-enriched clay bricks to assess their quality and moisture resistance. The experiment begins by selecting representative brick samples and then drying them in an oven at 105°C for 4 hours or until a constant weight is achieved. The dry weight of each sample is accurately recorded (m1). The samples are then immersed in clean water for 4 hours to ensure complete saturation. At the end of the immersion, the samples are removed and the wet weight (m2) is recorded. The absorption rate is calculated using the following equation:

$$\text{Absorption Rate (\%)} = \frac{m_2 - m_1}{m_2} \quad (2)$$

The process is repeated on several samples to ensure the accuracy of the results, and the calculated values are compared to the permissible limits according to ASTM C67, the primary reference for clay brick testing. The experimental results are presented in Figure 2.

### 2.2.2.3 Measuring the change in compressive force

The compressive strength test of clay bricks is performed using a 3,000 kN hydraulic press, in accordance with ASTM C67, the standard for testing structural clay bricks and tiles. The process begins by selecting brick samples of regular dimensions. The sample is placed between two press plates in the machine, ensuring that the top and bottom surfaces are flat to achieve balanced load distribution. The load is applied gradually at a constant speed, as specified by the standard, and compression is continued until the sample collapses or shows signs of mechanical failure, such as cracks or separation. The maximum force the specimen can withstand before collapse is recorded, and the compressive strength is calculated using the following mathematical equation:

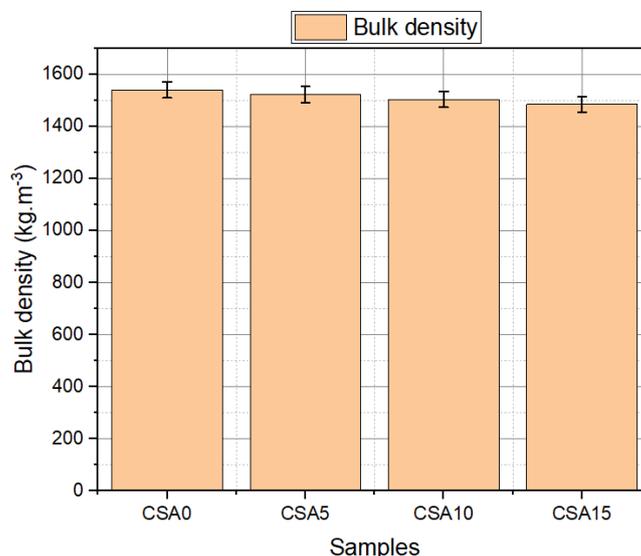
$$\sigma = \frac{F}{A} \quad (3)$$

This test evaluates the brick's ability to support structural loads and determines its suitability for the construction of load-bearing or non-load-bearing walls. The experimental results are shown in Figure 3.

## 3. Results and Discussion

### 3.1. Bulk Density

Figure 1 illustrates the change in the bulk density of clay bricks after the addition of ash. Analysis of the figure shows that the density decreases with increasing ash content. Compared to the reference sample without ash, the decrease varies between 1.18% and 3.7%. This decrease is explained by the fact that replacing part of the clay with ash helps reduce the density of the raw material, as ash is generally less dense than clay minerals. Ash also contains compounds with lower densities than the silica and aluminium present in clay.



**Fig 1.** Change in bulk density.

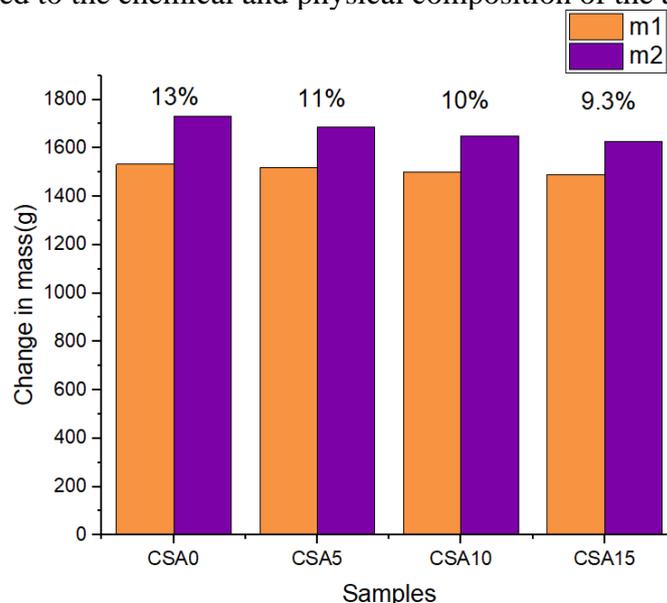
When ash is burned at high temperatures, the carbon and organic matter it contains decomposes, releasing gases that create tiny voids in the brick structure. The ash acts as a melting conductor, forming clay glass around the pores, increasing the volume of the voids and contributing to a decrease in density. In addition to reducing the proportion of heavy materials in the clay, they reduce the dense mineral content, thus decreasing the overall mass of the brick without changing its dimensions. These results are consistent with research on the

preparation and properties of clay bricks with added wood ash. The researchers added wood ash (4–16%) to the clay bricks, which resulted in a decrease in their bulk density depending on the ash content and firing temperature. The research concluded that the wood ash content reduces density [16]. In another study, adding fly ash to clay materials to improve the quality of hard bricks significantly reduced their density. This phenomenon was attributed to the lightness of the fly ash particles. It also improves the durability of the bricks by reducing salt corrosion and improving thermal insulation due to their increased porosity [17].

In another study, the mechanical properties of bricks made from sewage sludge and rice husk ash were investigated. The addition of rice husk ash (RHA) resulted in a significant reduction in brick density, particularly at high firing temperatures (above 500°C), where the density reduction exceeded 50%. The presence of rice husk ash produces lightweight bricks with enhanced thermal and mechanical properties, making them suitable for use as sustainable building materials [18]. These studies are consistent with the results of this study, and the difference in density reduction can be explained by the experimental conditions and the additives used in the bricks.

### 3.2. Water absorption rate

Analysis of Figure 2, which shows the change in the water absorption rate of clay bricks after the addition of ash, reveals a decrease in the water absorption rate. Comparing the wet mass to the dry mass, the water absorption rate drops from 13% to 9.3%. This is explained by several factors related to the chemical and physical composition of the ash.



**Fig 2.** Change in water absorption rate.

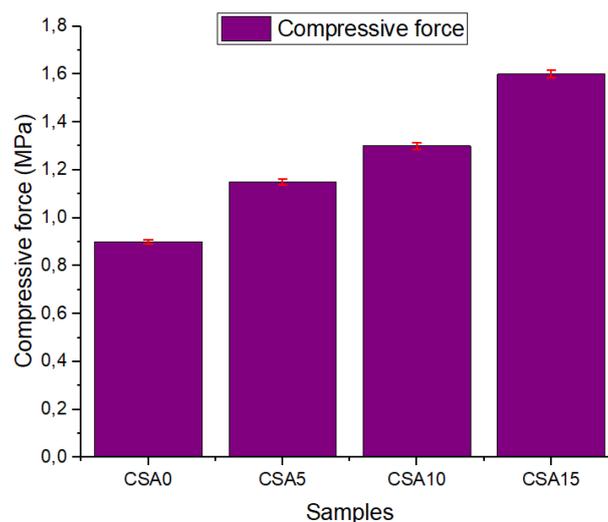
Ash contains fine particles that fill the spaces between the clay particles, reducing the size of the open pores that allow water absorption. In addition, ash contains pozzolanic substances that interact with the clay compounds to form denser compounds, thus improving the structure of the bricks and reducing water absorption. Previous research has concluded that ash improves the cohesion of brick components, reduces water absorption, and reduces their ability to interact with water. These results are consistent with research on the preparation and properties of clay bricks fired with wood ash. Researchers observed that the addition of wood ash to clay bricks affects both porosity and water absorption. The high wood ash content increases porosity and absorption, reducing water absorption to 10.8–14.5%, and compressive strength reaches 19.4 MPa [16]. In another study on the production of durable clay bricks from residual fly ash, the incorporation of fly ash (up to approximately 20%) into clay resulted in bricks that were approximately 10% lighter and exhibited lower water absorption than conventional clay bricks. This reduced water absorption is attributed to the denser

microstructure resulting from the addition of fly ash, which improves durability and mechanical properties [19]. Another study, investigating the potential application of fly ash bricks with quarry dust in construction, showed that fly ash brick samples exhibited significantly reduced water absorption compared to conventional clay bricks, from approximately 18% for clay bricks to only 7.96% for fly ash bricks after 28 days of curing. This reduction improves durability and resistance to salt impact, with the study recommending a target water absorption of approximately 10% to achieve an ideal balance between porosity and maintenance requirements [20].

### 3.3. Compressive force

Figure 3 illustrates the evolution of the Compressive force of clay bricks with the addition of different proportions of ash. An increase in compressive strength is observed with the addition of ash. The compressive strength increases from 0.9 MPa to 1.6 MPa, an estimated increase of between 18.18% and 43.75%. The addition of ash to clay bricks triggers a series of physical and chemical transformations, leading to a significant improvement in their mechanical properties, including increased hardness. This is due to the pozzolanic reaction between the silicate and alumina compounds present in the ash, particularly fly ash, and the hydroxides produced by the clay. This leads to the formation of cementitious compounds such as calcium silicate gel (C-S-H), which improves the internal cohesion of the bricks.

These results are consistent with research on the physical properties and compressive strength of fired clay bricks containing wastepaper. The incorporation of wastepaper ash increased porosity and reduced density, but compressive strength remained sufficient for structural applications and improved thermal insulation [21].



**Fig 3.** Change in Compressive force.

In another study, researchers proposed replacing clay with PPI waste, including ash and fibres, to improve the performance of wood fibre bricks and promote a circular economy. The study examined the incorporation of ash (20%) and fibres (5%) in brick manufacturing, resulting in a material that meets acceptable standards, with a 20% lower thermal conductivity and more than 15% lower density, without affecting thermal capacity [22].

Ash is characterised by its fine particles, which fill small voids in the mix, thus reducing porosity and increasing its hardness. Furthermore, it helps improve particle distribution within the mix, reducing structural defects and increasing structural strength. This reduces cracks and maintains the brick's cohesion. These results are consistent with research on the performance of bricks made from fly ash and bottom ash, whose compressive strength ranged from 7.13 to 17.36 MPa, increasing with ash content. The bricks also showed reduced water absorption and improved mechanical performance [23].

#### **4 .The importance of research results**

This research is essential to address the traditional challenges associated with clay bricks, such as their high density and excessive water absorption rate, which lead to deterioration of building surfaces and increased structural failure. It relies on the use of a local renewable resource, palm fibre ash, to replace part of the clay mass. This achieves two main objectives: reducing the overall weight of the bricks and their porosity, thus limiting moisture infiltration, without compromising basic structural requirements.

This approach aligns with modern principles of sustainable construction, which encourage the reuse of agricultural and industrial waste to optimise resource use and reduce environmental emissions. By examining the effect of ash additions of 5% to 15%, the research provides scientific evidence of the feasibility of converting agricultural waste into an effective pozzolanic material. This material improves the internal cohesion of clay after reacting with hydrated hydroxides, forming microcement bridges that will enhance load-bearing properties and compressive strength. The study's contribution is highlighted by the provision of precise quantitative data on the evolution of the bricks' bulk density. A decrease from 1.18% to 3.7% was observed with increasing ash content, demonstrating the effectiveness of the replacement material in reducing weight without compromising sample dimensions. The research also showed a significant decrease in water absorption, from 13% to 9.3%, thanks to the filling of microvoids with fine ash particles and the formation of more compressible composites. Mechanically, compressive strength increased from 18.18% to 43.75%, confirming the new material's ability to withstand intense structural loads. The significance of this research also lies in providing a practical framework applicable to industrial applications in palm fibre-producing regions, where appropriate addition ratios can be adapted to target temperature and environmental conditions. This paves the way for a circular economy for agricultural waste and strengthens the independence of local communities by providing them with low-cost building materials with limited environmental impact. This research represents a strategic step towards the development of lightweight, high-strength clay bricks, reconciling construction requirements with ecological sustainability considerations. The application of the study results will catalyse the local and international construction sector, supporting innovation in the use of renewable resources and improving building performance in the face of climate change and long-term maintenance challenges.

#### **5.Conclusion**

The results of this study showed that incorporating 5 to 15% ash into clay bricks significantly reduced the bricks' bulk density, ranging from 1.18% to 3.7%. This had a positive impact on structural loads, transportation, and installation costs. This reduction is attributed to the replacement of some of the clay with lighter materials, as well as the formation of micro-voids in the brick structure resulting from the combustion of the organic matter contained in the ash. This creates a lighter structure without affecting the geometric dimensions of the bricks. The water absorption rate was significantly reduced with the addition of ash, from 13% to 9.3%. This reduces open porosity and limits moisture infiltration. The pozzolanic interaction between ash and clay compounds produces transparent cementitious structures that seal micro-water channels, improving the bricks' resistance to moisture and corrosion. The study recorded a significant increase in the compressive strength of bricks with the addition of ash, ranging from 18.18% to 43.75%.

This improvement in hardness is attributed to the internal cohesion resulting from chemical reactions between ash compounds and clay hydroxides. The research confirms that the use of ash not only improves the physical and mechanical properties of bricks but also helps reduce environmental impact by recycling agricultural waste and conserving natural resources. This trend is in line with modern principles of sustainable construction and

promotes the circular economy. In view of these results, the addition of ash to clay bricks represents a promising step towards producing building materials with improved performance and greater environmental friendliness, opening new perspectives for wide applications in the modern construction sector.

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### **Ethical Statement**

This research does not contain any studies with human or animal subjects performed by any of the authors

### **Data Availability Statement**

Not Applicable

### **Conflicts of Interest**

The authors declare no conflicts of interest

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