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Production of Rice Husk Ash-Enhanced Lightweight Bricks as a Strategy for Waste Management

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ABSTRACT
Tanzania produces 2.33 million tons of rice annually, generating large quantities of rice husks, of which 20-25% are improperly managed, thus contributing to environmental degradation. This study investigated the use of rice husks ash as partial substitute for clay in the lightweight brick production, aiming to convert agricultural waste into value added construction materials. Bricks were fabricated using rice husk ash to clay ratios of 20:80 (LWB-A), 25:75 (LWB-B), 50:50 (LWB-C), and 80:20 (LWB-D) and then fired at different temperature (800°C, 900°C, and 1000°C). The bricks were evaluated for compressive strength, water absorption and density. Results indicated that rice husk ash contribute to reduced bulk density (down to 0.226 g/cm³), while maintaining structural performance when appropriately blended with clay. The optimal formulation (LWB-B), and fired at 1000°C achieved a compressive strength of 7.95N/mm², water absorption of 15% and density of 1606kg/m³, meeting standard requirement for lightweight construction bricks. These findings demonstrate the technical viability of rice husk ash as a sustainable additive in bricks manufacturing. Further research is recommended to optimize material behavior and assess environmental and economic implications for large-scale application.

Key Words: Compressive Strength, Water Absorption, Clay Substitution, Sustainable Materials

INTRODUCTION

Globally, rice is considered as one of the food crops feeding more than half of the world's population (Seleiman et al., 2022). Its production has reached more than 750 million tons of grain per year and is expected to reach 567 million tons by 2030 (Kordi et al., 2024; Mohidem et al., 2022) and increase by 28% by 2050 due to increased global population demands (Harun et al., 2022). The production is dominated by China and India, which produce almost 50% of global rice production (Abeysekara and Rathnayake, 2024). Rice is also a staple food crop in Africa, with its production steadily increasing from 21 million metric tonnes in the 2017/2018 trade year to 26 million metric tonnes in the 2023/2024 trade year (Saifaddin, 2024). Production of rice husks as a residue occurs alongside the processing of paddy. Currently, about 150 million tons of husks are generated globally after processing of the paddies (Kordi et al., 2024), which is equivalent to 20% of the rice grains. Experience shows that 90% are burned in open air or disposed of into rivers and oceans (Quispe et al., 2017).

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In Tanzania, domestic rice production currently stands at 2,332,000 tonnes annually (URT, 2024). This indicates a significant amount of rice husks since 20-25% of husks are produced from each kilogram of rice processed. The increased demand for rice accounts for greater generation of rice husks during the processing of the paddy rice, which, like other agricultural residues, is underutilised and regarded as waste. Larger piles of rice husks have been observed in areas where they cultivate paddy in Tanzania (Leonard et al., 2024; Yustas et al., 2022), implying that they are underused and therefore contribute to environmental pollution. Rice husks, when burned or decomposed anaerobically in open space, produce carbon dioxide and methane, respectively (Sun et al., 2016).

Rice husks have great potential for a wide range of applications, including energy production through briquetting and biogas production, adsorbents for the removal of heavy metals, fertilisers for improving crop productivity, production of lightweight bricks and cementitious materials (Li et al., 2021; Shahrokhi-Shahraki et al., 2021; Menya et al., 2018; Jongpradist et al., 2018). However, rice husks produce a low quantity of biogas compared to other substrates due to high lignin and silicon content (Arell et al., 2023). In addition, when used in the production of briquettes without being blended with other biomass, they produce biobriquettes with low calorific value due to high ash content. Rice husks have a maximum of 24 wt % ash content on a dry basis (Pachchigar et al., 2024), which is not suitable for briquettes and affects the quality of briquettes produced. However, Rice Husk Ash (RHA) content can be useful as a partial replacement of cement in brickmaking. Rice husk ash has a 85–94% silica content expressed as SiO_2 (Beidaghy et al., 2019), depending on the cultivation method and type of seeds used. In addition, it has pozzolanic properties that can serve as an alternative binding material to increase the compressive strength and durability of the bricks. The remaining percent of RHA content is composed of iron (Fe), manganese (Mn), calcium (Ca), sodium (Na), and magnesium (Mg) (Pachchigar et al., 2024; Bakar et al., 2016).

For the construction industry, the development and use of industrial and agricultural wastes, such as fly ash, blast furnace slag, metakaolin, RHA, and bagasse ash (BA), are rapidly receiving attention, as reviewed in a number of literature materials. The use of ashes in the grinding process in cement concrete generally improves its properties. Concretes containing fly ash or RHA is of excellent quality with reduced porosity and improved resistance to sulphate attack and chloride penetration (Yang, 2016). It also has high strength (Jongpradist et al., 2018).

The RHA used in plain cement concrete exhibits some pozzolanic characteristics, which often lead to economic and cost savings, while also imparting effectiveness in improving the strength. Chemical composition of RHA produced by utilising the fluidised bed type furnace is reported to be SiO_2 (80-95%), K_2O (1-2%) and unburnt carbon (3-18%) (Muralli et al., 2025; Jonathan et al, 2020). The presence of silica in large amounts signifies the binding property of the RHA (Mohan et al., 2012). With all the benefits of rice husks in construction, Tanzania still generates a large quantity of rice husks and disposes it of haphazardly. This perhaps due to limited knowledge on the immediate valuable use of the same, and limited infrastructure and technology for large-scale conversion and utilization (Omari, 2022; John, 2021; Mdoe 2014). This study aimed to evaluate the feasibility of utilising accumulated rice husks in brick manufacturing by investigating the effect of varying RHA and clay soil mixing ratios on the physical and mechanical properties of the resulting brick. The research seek to promote the sustainable management of rice husk waste in Tanzania by mitigating the environmental impacts associated with its improper disposal.

METHODOLOGY

Raw materials

The study utilised rice husks sourced from milling operations in Tandale and clay soil obtained from Pugu-Kigogo area in Dar es Salaam City. The clay served as important alumino-silicate material in the fabrication of brick, while RHA derived though controlled combustion of rise husks functioned as a pozzolanic additive and partial binder within the mix design. Potable water, meeting standard laboratory testing requirements, was used for specimen preparation and curing. All material processing, mixing, moulding, and testing procedures were conducted at the Building Materials Laboratory of the University of Dar es Salaam. Plate 1 shows materials used in this study. Clean water was used for mixing and testing lightweight bricks sourced from the University of Dar es Salaam's building materials laboratory.

Plate 1: Materials used in the study namely, Clay Soil and Rice husks

Preparation of materials

Rice husk ash (RHA): Rice husks were dried directly in the sun for one (1) day and carbonised to obtain char using a locally made carbonizer consisting of a furnace and chimney stack to facilitate easy dispersion of smoke. The carbonised samples (char) were left to cool overnight and thereafter put in crucibles, then placed in a muffle furnace. The ignition process was performed at 600°C for two (2) hours to obtain the ash (RHA), as shown on Plate 2.

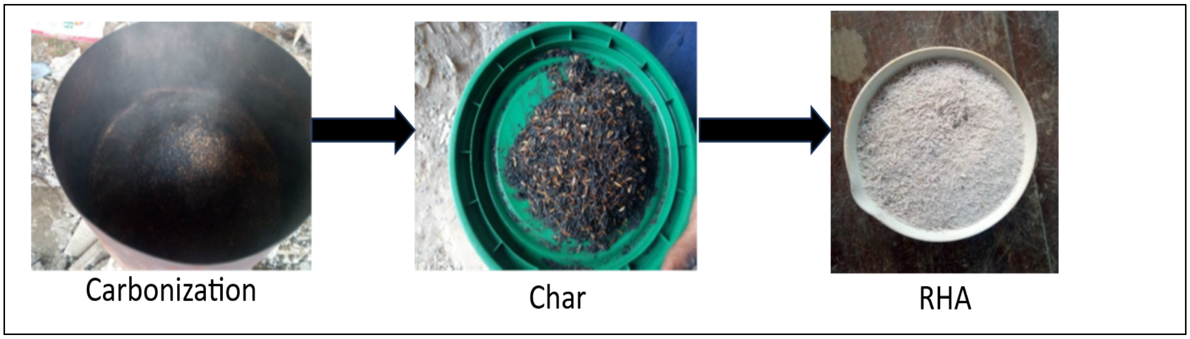


Plate 2: Rice husk ash preparation process

Processing of clay soil: The clay soil was firstly poured and spread out on woven sacks and then left to sun-dried for one (1) day to reduce the moisture the clay particles to stick together. After drying, the soil was crushed into smaller pieces using a hammer and sieved through 1.18mm diameter mesh to obtain fine particles suitable for characterising the clay samples and subsequently brick production.

Characterisation of materials

Determination of RHA Bulk density

The ratio of dry mass of RHA to the volume of water used was measured to determine the volume of RHA in the produced brick. A 25ml measuring cylinder was firstly weighed and recorded as M1. Then A sample of RHA was added to the graduated cylinder until it was half full. The weight of the cylinder and sample was recorded as M2. To obtain the mass (Ms) of the RHA, it involved subtracting M1 from M2. The bulk density was calculated using equation (1).

$$Bulky\ density = \frac{Mass\ of\ dry\ material\ (MS)}{Volume\ of\ materials}$$
…………………..…………………(1)

Specific gravity

The specific gravity of RHA is essential for assessing the effectiveness of motor mixing and bonding particularly in relation to moisture content. The small pycnometer method, as specified in BS 1377 (1990), was employed for this purpose. Firstly, RHA Samples were placed on a plate and oven-dried at 105°C for 24 hours. To eliminate moisture. At the same time distilled water was boiled and then left to cool for use in the test. The empty pycnometer bottle was weighed using an analytical balance and the weight was recorded as **W1**. Approximately 3 grams of the dried RHA sample were added to the pycnometer, which was then weighed again. This weight was recorded as **W2**, and the sample was subsequently removed. Next a small amount of distilled water was added to the pycnometer along with the sample, and the mixture was boiled for 10 minutes to remove any trapped air. After boiling, the bottle was filled with distilled water up to the calibration mark and left to cool for one (1) hour. The outer surface of the pycnometer was dried with a cloth, and it was then weighed and recorded as **W3**.

Finally, the pycnometer was emptied, thoroughly cleaned, filled with air-free distilled water, and weighed again. This final weight was recorded as **W4**. The Specific gravity of RHA was then computed using equation (2).

$$Specific\ gravity = \frac{W2-W1}{(W2-W1)-(W3-W4)}$$
…………………………………… (2)

Where: W1= Weight of dry pycnometer, W2= Weight of dry pycnometer + Sample, W3= W2 + distilled water and W4= Weight of pycnometer + distilled water

Porosity

Porosity of clay soil was measured to assess the amount of empty space or voids in the material which have an influence on the bond between bricks and the mortar. Twenty (20) mls of the sample soil was measured and placed into a graduated cylinder, then recorded as Vs. Then, a volume of 25mls of distilled water was measured into a cylinder. The water was then added to saturate the soil in the beaker to its exact top. The volume of water used to saturate the soil was subtracted from the initial volume in the cylinder, then recorded as pore volume (Vp). The total volume was obtained by adding Vs and Vp, and the % porosity was calculated using equation (3).

$$\% \, Porosity = \frac{Pore\ volume\ (Vp)}{Total\ Volume\ (Vs+Vp)} \times 100\% \qquad \ldots\ldots(3)$$

Organic matter content

Organic matter content of soil was determined since it contributes to weight loss when firing bricks. It was determined using the oxidation (Loss on Ignition) method. The air-dried clay sample was oven-dried for 24 hours at 105°C, then dried crucibles were heated in a muffle furnace at 550°C for two (2) hours, then cooled in a desiccator. To the cooled crucibles, 10g of clay soil was added and the sample was ignited at 550°C in a muffle furnace for 16 hours then removed and cooled. The organic matter content was then calculated using equation (4).

$$Organic\ content\ (\%) = \frac{Mass\ of\ organic\ matter\ (C-D)}{Mass\ of\ dry\ soil\ (C-A)} \times 100\% \qquad \ldots\ldots(4)$$

Where: A= mass of air-dried soil sample (g), C= mass of soil sample after 105°C (g) and D= mass of soil sample after 550°C (g)

Production of lightweight bricks

The production of lightweight bricks was carried out by initially hand-mixing RHA with clay soil until a homogeneous blend was achieved. This was followed by the gradual addition of water in a mechanical mixer to attain the desired plasticity and workability suitable for molding. Materials were mixed in accordance with the predetermined ratios outlined in Table 1. Each mixture was placed into a custom-fabricated wooden mold and compacted to eliminate air voids that might result from insufficient compression. The molded bricks, conforming to BS 3921:1985 standard dimensions of 225×112.5×75mm, were then demolded and sun-dried for a period of two (2) days. Following the drying phase, the bricks were fired in a Thermolyne (Type F6000) muffle furnace at target temperatures of 800°C, 900°C, and 1000°C. Each sample was maintained at its respective firing temperature for two (2) hours, after which it was allowed to cool naturally.

Table 1: Mixing ratios of RHA and clay

Sample ID	Mixing ratios		Number of samples at a specific temperature (°C)			No. of samples for each LWB ratio
	RHA	Clay Soil	800 (°C) After sun drying	900 (°C) After sun drying	1000 (°C) After sun drying	
LWB-A	20	80	1	1	1	3
LWB-B	25	75	1	1	1	3
LWB-C	50	50	1	1	1	3
LWB-D	80	20	1	1	1	3

Plate 3 illustrates step-by-step procedure for producing lightweight bricks, including mixing of RHA and clay soil, molding, compaction, sun drying, and firing at controlled temperatures to achieve the desired brick quality and strength.

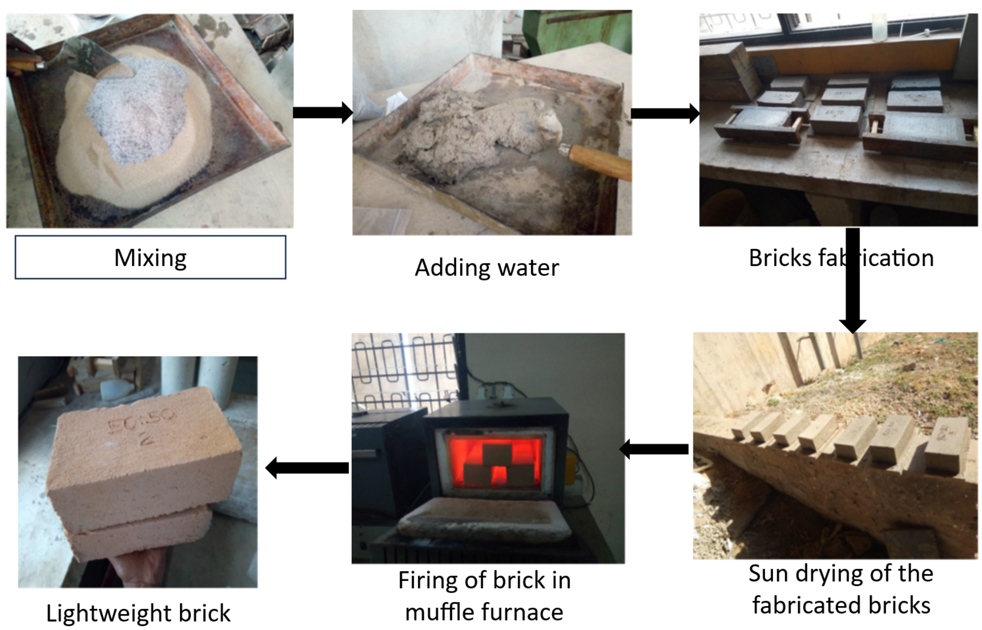


Plate 3: Production of lightweight bricks processes

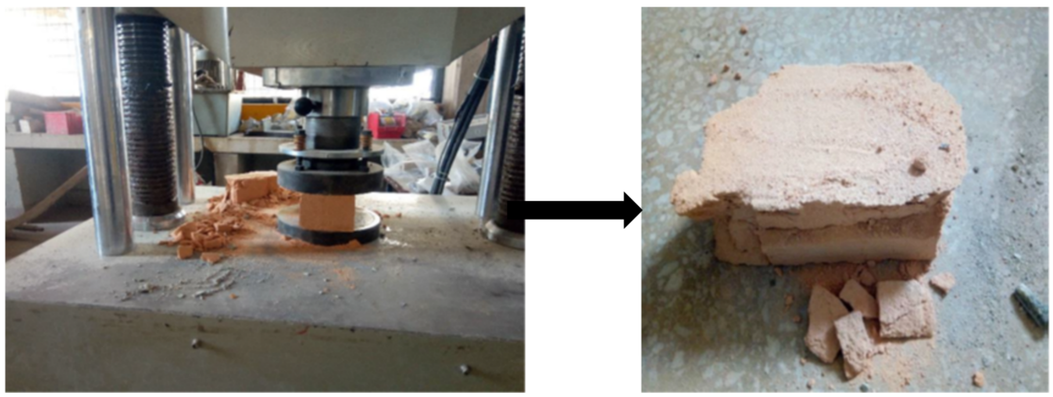
Testing of the lightweight bricks
In order to determine the usability and quality of the lightweight bricks produced, three (3) tests were conducted as indicated below.

Compressive strength test (Crushing test)
This test was conducted using a universal testing machine with a maximum force of 200 tonnes to determine the maximum load a lightweight brick can withstand before failure. After firing, bricks were allowed to cool for 24 hours, then soaked in potable water for 24 hours, followed by drying with a clean cloth. Their dimensions were measured. After measurement, they were left to dry for an additional two (2) days, and then each was placed on the centre of the lower platen of the universal test machine and subjected to compressive force (Plate 1). The maximum load (N) at which the brick failed or fractured was recorded, ensuring the brick's durability. The compressive strength was then computed by using the formula indicated in equation 5 and 6.

$$Compression\ Compression\ strength\left(\frac{N}{mm^2}\right) = \frac{Maximum\ load\ at\ which\ the\ speciment\ starts\ breaking(N)}{Contact\ area\ (mm2)} \quad (5)$$

$$S\left(\frac{N}{mm^2}\right) = \frac{Fmax}{l\ \times b} \quad (6)$$

Where: Fmax= maximum load, in newtons, indicated during the test, l = the length of the test piece (mm) and b = the mean of the four measurements of the breadth of the test piece (mm)



A Brick sample on a universal test

A crushed brick sample

Plate 1: Compressive strength test of the bricks

Water absorption test

The fired lightweight bricks were first weighed to determine their initial dry weight which was recorded as W1. The bricks were then submerged in a container with 15 litres of clean water, and then left to soak for 24 hours. After soaking, the bricks were removed wiped with a piece of cloth to eliminate surface and reweighed to obtain saturated weight which was recorded as W2. The aim of this procedure was to measure the percentage of water absorbed into brick's pore structure. The water absorption was calculated using equation 7. Plate 5 shows the bricks submerged in water.

$$Water\ absorption\ (WA) = \frac{W2 - W\ \times 100\%}{W1} \quad (7)$$

Where: W1= weight of the brick before saturation (g) and W2= weight of the brick after 24 hours saturation (g)

Plate 2: Submerged bricks in water to determine water absorption

Density Test
The density was measured to determine the volume that will be occupied in a brick by taking the weight of the cooled brick from the furnace and dividing it by the measured volume of the sample bricks. The density was calculated using equation 8.

$$\rho b = \frac{M}{l \times w \times h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Where: ρb = Density of the brick (kg/m^3), M = Mass of the brick (kg), l x w x h = Volume of the brick (m3); l=length, w= breadth and h=height of the brick (m)

Data analysis
Data were analysed using GraphPad InStat, version 3.1, and Microsoft Excel. The GraphPad InStat version 3.1 software was used for statistical analysis, including correlation and regression analysis, to compare and assess the influence of the independent variables on the dependent variable, while Microsoft Excel was used for drawing graphs.

RESULTS AND DISCUSSION

Characteristics of the materials
Rice Husk Ash: The bulk density of RHA in this study was 0.226 g/cm^3 which is significantly lower than that of conventional fly ash bricks typically around 1.4 g/cm^3 (1400 kg/m^3) as reported by Singh et al., (2024). A lower bulk density suggests that brick incorporating RHA will be lighter in weight. The specific gravity of the RHA was measured at 2.17, which closely aligns with the value of 2.18 reported Hwang and Huynh (2015) in a study on the investigation of eco-friendly construction bricks made from fly ash and residual RHA. These findings support the potential of RHA as viable material for lightweight brick production.

Clay soil: The porosity of clay soil in this study was 18.69%, which is slightly lower than the accepted range of 20-30% reported by Oyelaran (2014). The presence of pores in clay affects the strength by reducing the cross-sectional area that is exposed to an applied load. Therefore, lower porosity is generally associated with the improved strength characteristics. The organic matter content of clay was evaluated to assess its suitability for the production of lightweight brick. Elevated organic content which exceeding 6%, can negatively impact brick strength due to combustion during firing, which leaves behind voids. The organic content found under this study was 4.67%, which is within the acceptable limits specified ASTM C618, (2019), stating that organic matter in raw materials for brick production should not exceed 6%.

Volume of Water Used in Preparation of Lightweight Bricks

The findings revealed that the volume of water required during moulding process is directly proportional to the percentage of RHA incorporated in the brick mix (Table 2). This relationship was supported by statistically significant correlation between the proportions of RHA and clay soil and the volume of water used (P value =0.0387, R^2=0.924), as illustrated in
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Error! Reference source not found. and **Error! Reference source not found.**). A positive correlation was observed, indicating that as the RHA contents increases, so does the volume of water required, for proper moulding. For example, the lightweight brick A, which contained 20% RHA, required 730 ml of water, whereas the mix 80% RHA, required the highest volume (1250 ml).

This trend is attributed to the high surface area and porous nature of RHA which increase water absorption within the clay matrix. The addition of RHA introduces more pores, facilitating greater water retention, as noted by Janbuala and Wasanapiarnpong (2015) and Ani and Nahid (2023). Consequently, higher RHA content in the mix necessitates more water to achieve the desired workability and consistency in moulding

Table 2: Volume of water used in preparation of light weight bricks

Sample ID	Mixing ratios		Volume of water used in the mix (mls)	Average weight of the LWB after compaction (g)
	RHA	Clay Soil		
LWB-A	20	80	730	3030
LWB-B	25	75	750	3018
LWB-C	50	50	850	2685
LWB-D	80	20	1250	1910

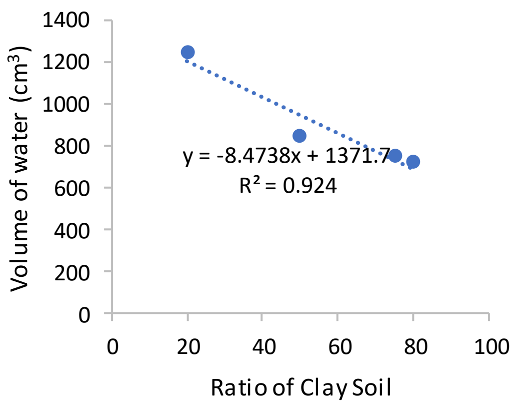

Figure 1: Correlation between water used and clay soil ratio

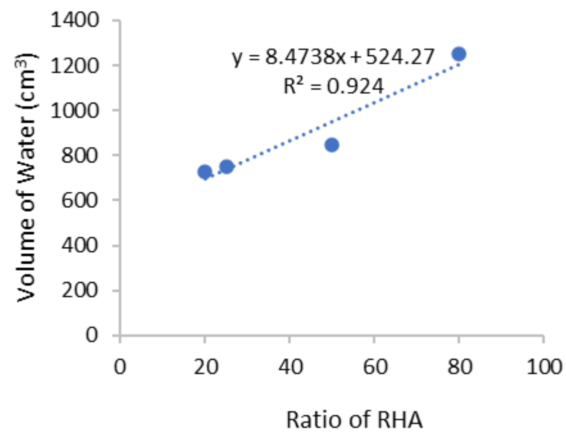

Figure 2: Correlation between water used and RHA

Effect of Mixed ration and firing Temperatures on Weight Reduction

Firing is a critical step in the production of bricks made from clay soil and RHA, as it facilitates the removal of organic and inorganic matter, reduced moisture, and porosity, and significantly enhance the mechanical strength of the final product (Kumar and Maithel 2016; Akinshipe and Kornelius 2017; Srisuwan et al. 2020). The study investigated the impact of different RHA to clay mixing ratios and firing temperatures on brick weight reduction. The highest weight loss was recorded in the 50:50 RHA-clay mix, which experience a weight reduction of 8.4%. In comparison the mix containing 80% RHA and 20% clay exhibited a lower weight reduction of 5.3%, as shown in **Error! Reference source not found.**The results also revealed a trend in the effect of firing temperature. Generally. Weight reduction decreased when the firing temperature increased from 800°C to 900°C, but then increased again to 1000°C. An exception was observed in the 50:50 RHA clay mix, which showed consistent increase in the with loss across the entire temperature range from 6.7% at 800°C to 8.4% at 1000°C. These findings highlight that both the mixing ratio and the firing temperature are key factors influencing the thermal behavior and mass loss characteristics of clay RHA bricks during production.

The weight loss for bricks fired at 800°C to 900°C happened because of the loss of water, burning of organic materials, and breakdown of carbonates and other gases. However, the impact of using 1000°C exceeded that of other temperatures. The weight loss increased at 1000°C was due to the decreasing volume caused by the increasing bulk density and reduced porosity of the bricks, not the brick mass. The sintering process that happened during the firing process at high temperature reduced pore spaces, increased fusion of particles, and increased densification of the bricks (Srisuwan et al. 2020, Pitak et al. 2022). Firing at low temperatures increases porosity less than 900°C, and firing at higher temperatures decreases porosity due to an increase in contact between particles. The same trend was observed by Pitak et al. 2022 when firing bricks made up of clay soil and bottom ash, where weight increased from 6.25% to 7.14% when firing at 900°C and 1000°C, respectively. Additionally, the firing results reported by Srisuwan et al. (2020) also support the findings of the present study, showing an increase in weight from 4.72% to 5.94% when briquettes made of clay soil and wood ash were fired at 900°C and 1000°C, respectively.

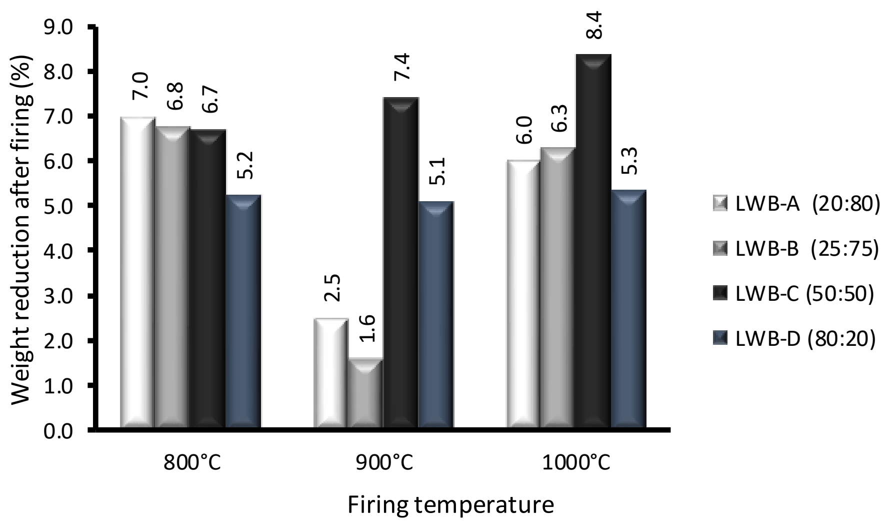

Figure 3: Effect of firing temperature on weight loss

When assessing weight reduction in relation to mixing ratios, a clear trend emerges: increasing RHA content has positive effect on weight reduction, while higher clay proportions (80% and 75%) and lowe RHA content (20% and 25%) exhibited a notable decrease in weight loss dropping from 7.0% and 6.8% down to as low as 2.5% and 1.6%, respectively. However, when these mixes were subjected to higher firing temperature of 1000°C, the weight loss increased significantly reaching 6.0% and 6.3% as shown in **Error! Reference source not found.** and **Error! Reference source not found.**). This pattern is primarily attributed to the combustion of organic content, which leads to the releases of carbon dioxide and water; as well as the thermal decomposition of carbonaceous materials and evaporation of moisture during firing (Labaied et al., 2022; Akinshipe and Kornelius, 2017). The clay used contained 4.61% organic content, which was largely eliminated during the firing, contributing to the observed weight reduction (Kumar and Maithel, 2016).

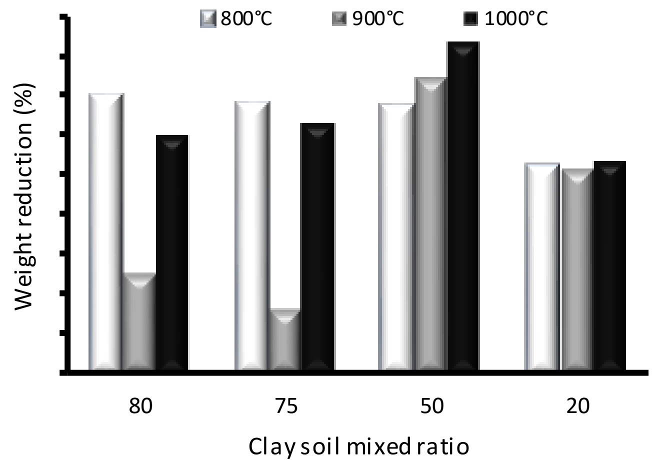

Figure 4: Weight reduction per clay soil mixed ratios

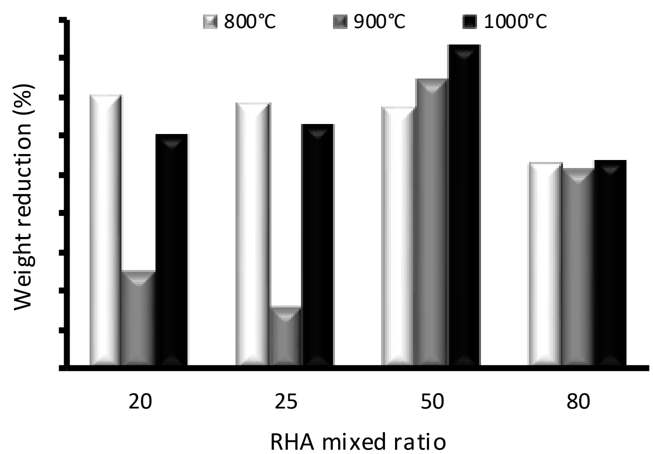

Figure 5: Weight reduction per RHA mixed ratios

When considering ratios of RHA, the trend is the opposite of that in clay soil for all ratios except the 50% ratio. RHA is less dense than clay soil; when used in high proportion compared to clay, it creates less dense brick and more weight loss when fired. As seen in Figure 5, the weight loss increased from 2.5% to 6.0% at 0% RHA and from 7.4% to 8.4% at 50% RHA when the temperature increased from 900°C to 1000°C, respectively. However, at a high ash content of 80%, the loss was very limited, about 0.2%. This might be due to the limited amount of organic matter, which is more in clay compared to ash. Ash content is composed of carbonates and organic carbon, which also decompose and combust, respectively, at high temperatures and contribute to weight loss (Andreola et al., 2018; Zibret et al., 2024). RHA consists of 10–18% of carbon and 0.5–1.3% of carbonates (Babaso and Sharanagouda, 2017; Hassan and Maharaz, 2015). In addition, the burning of ash components creates additional pores in the brick structure, which also increases the overall weight loss during firing (Bose et al., 2024).

This is also justified by Hassan and Maharaz (2015) who found that the porosity of the brick decreases with RHA addition up to 40 wt% and increased until 80 wt% due to amorphousness and high SiO2 content, and volume of brick shrinks more when the ratio of RHA increased (from >5% to >16% when the ration of RHA is 20% to 80%, respectively). Generally, as seen in (**Error! Reference source not found.** and **Error! Reference source not found.**) when the mixing ratios between clay soil and RHA were between 80-50% and 20-50%, respectively the decrease in weight was mainly due to loss of water, combustion of organic matter and decomposition of carbonates while the rest mixing ratios was attributed by increased porosity of RHA since the weight of clay was very low about 20% only (Eliche-Quesada et al., 2016, Zibret et al., 2024). The three factors contributed to weight loss for all the bricks fired at different temperatures in this study, which comply with that of good-quality clay bricks, which have shrinkage below 8% after firing, as detailed by Srisuwan et al., 2020.

Compressive Strength

The compressive strength test is one of the important parameters for bricks, which determines load-bearing capacity and structural integrity in the construction industry. In addition, the strength of the brick determines its uses according to Tanzanian standards TZS 1474:2012 (E). Results indicate that the compressive strength gradually increased from 20% to 25% of RHA but decreased when the amount of RHA exceeded 25%. The strongest brick had a compressive strength of 7.95 N/mm² when made with 25% RHA and 75% clay soil and fired at 1000°C, while the weakest had a strength of 1.37 N/mm² when made with 80% RHA and 20% clay soil and fired at 800°C (**Error! Reference source not found.**). The bricks made with more soil (75-80%) and less ash (20-25%) met the required strength, while the rest did not meet the required compressive strengths for burnt building bricks as specified by TZS 1474: 2012 (E), which range from 3.5 N/mm² to 21 N/mm². This finding implies that the compression strength of clay brick increases with an increasing firing temperature and decreases with increasing ash content (Dinesh et al., 2023; De Silva et al., 2018). This conclusion was also proven statistically through the correlation analysis, which revealed P value=0.0001, r=-0.8892, and r^2=0.7907 implying a strong inverse relationship between the RHA content and the brick compression strength. Higher ash content leads to greater porosity, which reduces brick strength, while firing temperatures above 900°C decrease porosity and create a strong, cohesive structure that enhances strength (Saenz et al. 2019; Dogan-Saglamtimur et al., 2021). It was thus noted that the optimum ratio is 25:75 (RHA:C). These results do not align with those reported by Janbuala et al. (2015), who established a compressive strength of 5.97 MPa for clay bricks made with 10% RHA and clay soil, and Dinesh et al. (2023), who found a compressive strength of 4.70 N/mm² for clay bricks made with 5% RHA. The difference might be due to the ratio of RHA used and also the nature of the clay soil used.

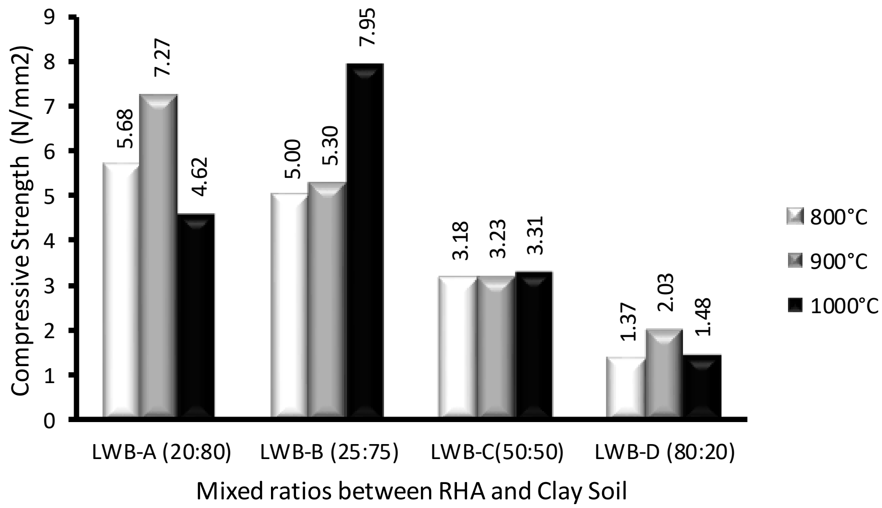

Figure 6: Compression strength of the lightweight bricks produced

Based on the maximum compression strength obtained, the brick made with 25:75 can be used for load-bearing and non-load-bearing walls (partition walls) in residential and light commercial construction, but it is generally considered suitable for moderate structural applications rather than heavy-duty or severe weather exposure or engineering bricks, which require much higher strength (≥50 N/mm²). This rating is according to British Standard BS 3921 and Tanzanian standards TZS 1474:2012 (E).

Water Absorption Test

Water absorption test was carried out on the fabricated bricks to determine water-holding capacity, which is a key factor influencing durability and long-term performance (Phonphuak et al., 2016). The highest water absorption was 48.6%, recorded for the brick made using RHA and clay soil at a ratio of 80:20 fired at 800°C, while the lowest was 12.4%, obtained for briquette made with 20% RHA fired at 1000°C. The trend shows that water absorption increased with increased ash content and decreased with increased clay brick firing temperature (**Error! Reference source not found.**). The regression analysis indicated a correlation coefficient (r) of 0.9586, an r^2 of 0.9190 and P value=0.0001, which implies a very strong positive linear correlation between the increasing ratio of RHA and the water absorption of clay brick. The increased ash content increases porosity in the brick structure that allows water to penetrate and absorbed within the brick.

A similar trend has been reported by Ani et al., (2023) who established water absorption values ranging from 17.8% and 21.33%, for bricks containing 5% and 20% RHA, respectively. These results support the findings that increasing the proportion of RHA in the mix leads to higher water absorption. This correlation is further supported by Janbuala and Wasanapiarnpong (2016), who noted that bricks containing 30% RHA exhibited water absorption exceeding 23.8%.

The bricks with high water absorption capacity (48.6%, 45.6%, and 40.6%) were found to correspond with lower compression strength (1.37 N/mm², 2.03

N/mm², and 1.48 N/mm²), respectively. The p-value of 0.0009 obtained in correlation analysis between water absorption and brick compression strength implies that there is a very strong relationship between the two variables.

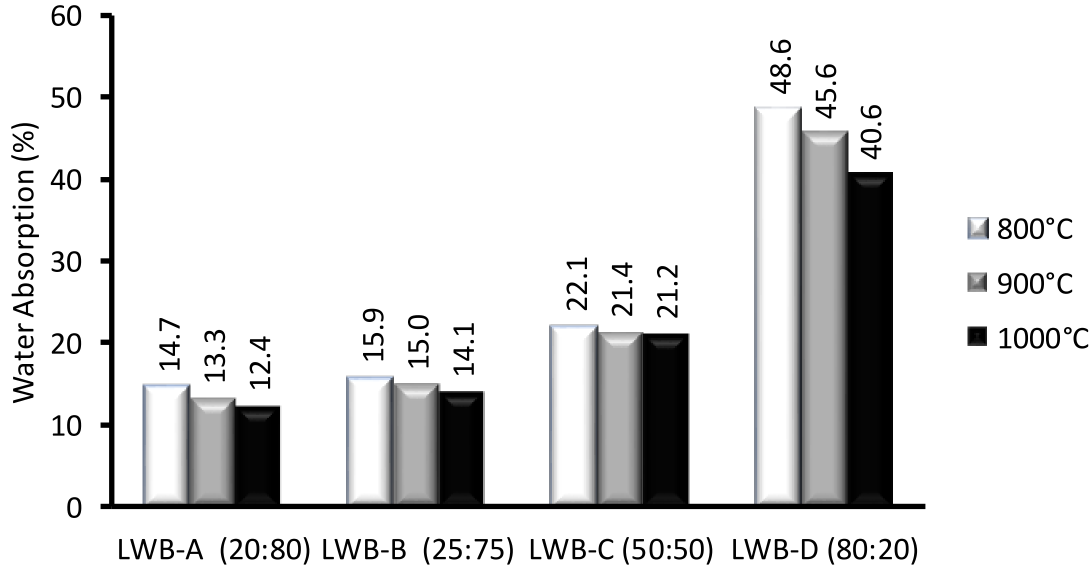

Figure 7: The percentage (%) water absorption for different mixing ratios

Density

The density of the brick provides insights into its mechanical and thermal performance, particularly regarding overall dead load and the enhancement of thermal behaviour in structures. The regression analysis showed a P-value of 0.0001 and r = -0.9821, which means there is a strong negative relationship between the amount of RHA and the density of the brick. This conclusion implies that the values of density in bricks decrease with increasing proportions of RHA. The highest value of density was found to be 1,606 kg/m³ at a ratio of 25% RHA and 75% clay soil, while the lowest value was found to be 964.4 kg/m^3 in the ratio with 80% of RHA and 20% of clay soil (**Error! Reference source not found.**). This analysis revealed that there is an inverse relationship between the quantity of RHA and the density of the bricks. A similar pattern was seen in a study by (Phonphuak et al., 2019) on fired clay bricks, where the lower density was linked to more pores created by adding more rice husks. The durable values of densities obtained in the study ranged between 1370 kg/m³ and 1890 kg/m³, which correlate to values in this study. The density obtained by this study at 25% RHA is higher than that reported by Janbuala & Wasanapiarnpong (2015), when a 10% addition of RHA was used, which obtained a density of 1.18g/cm³ (1180 kg/m³). This finding signifies that the higher the ratio of RHA, the lower the density of brick obtained.

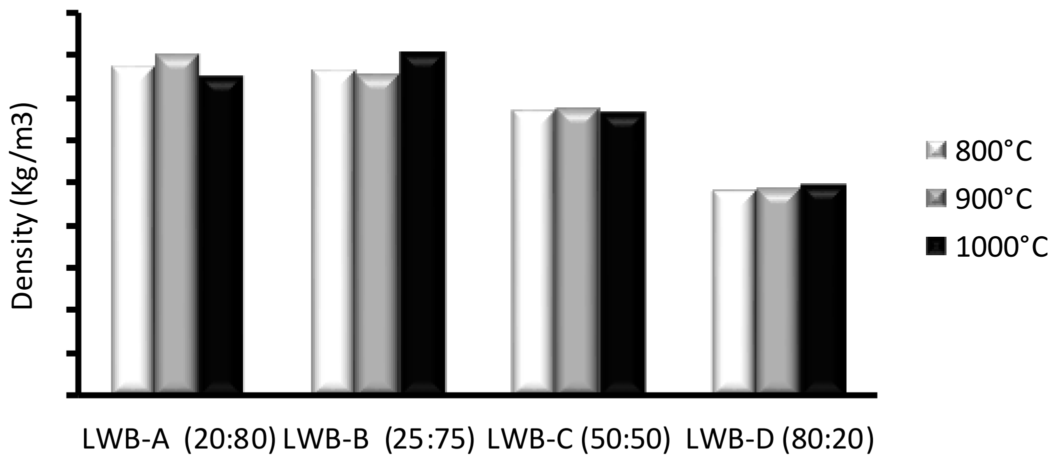

Figure 8: Density of bricks made using different mixed ratios of RHA and clay soil

CONCLUSION AND RECOMMENDATION

Conclusion

Findings of the study demonstrate that fired brick made of RHA and clay soil presents a viable and sustainable solution for managing the growing volume of rice husk waste. RHA was found to be a suitable material for lightweight brick production due to its low bulk density (0.226 g/cm3). Lightweight bricks that contained 25% rice husk ash and 75% clay soil fired at 1000°C achieved the highest compressive strength of 7.95 N/mm² compared to other bricks with similar mixing ratios and those with greater amounts of rice husk ash. The percentage of water absorption for this mixed ratio was relatively low at 15%, which indicates that it exhibits the best properties for brick application. The study also confirms that the density of bricks decreased with a higher amount of rice husk ash. Based on the compressive strength obtained, the bricks produced using a 25:75 ratio of RHA and clay soil can be used for the construction of internal or partitioning walls of building and reduce the cost of using cement blocks.

Recommendations

This study recommends other studies to characterize the physical and chemical composition of ash before the fabrication of brick, assess alternative ways of producing ash rather than using a muffle furnace, which adds to production cost due to energy costs. A comprehensive assessment should be conducted to evaluate the environmental and economic costs of using rice husks in brick making, as well as the existing market demand for the product.

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