Jurnal Kejuruteraan 38(1) 2026: 431-442
https://doi.org/10.17576/jkukm-2026-38(1)-37

Sustainable Fired Clay Bricks: The Impact of Natural Additives on Material Strength and Environmental Performance

Mirza Awais Arif[a], Asif Mansoor[a], Murtaza Hussain[b], Syed Mustafa Haider[a] & Imran Shah[c*]

[a]*Department of Industrial & Manufacturing Engineering,*
National University of Sciences & Technology (NUST), Karachi 07548, Pakistan

[b]*Department of Engineering Sciences,*
National University of Sciences & Technology (NUST), Karachi 07548, Pakistan

[c]*Department of Mechatronics Engineering,*
Air University, Islamabad 44000, Pakistan

[*]*Corresponding author: imranshahswabi@gmail.com*

Received 20 March 2024, Received in revised form 23 September 2025
Accepted 23 October 2025, Available online 30 January 2026

ABSTRACT

In Pakistan, rapid urbanization and construction demand have depleted clay resources and increased environmental degradation. This study explores a novel approach to enhance the sustainability of fired clay bricks by incorporating almond shell powder and walnut shell powder as additive at varying concentrations (A5, A10, A15, W5, W10, and W15). The raw materials were analysed using X-ray diffraction to assess their mineral composition. Experimental results show that increasing additives content leads to a higher loss on ignition, with maximum values of 17.2% for A15 and 12.6% for W15. Water absorption also increases significantly, reaching 25% for A15 and 26% for W15, indicating higher porosity. As additives concentration rises, the bulk density of the bricks decreases, with values of 1186 kg/m³ for A15 and 1360 kg/m³ for W15. While compressive strength decreased with the increase in additives content, the bricks containing lower additives concentrations (A5 and W5) exhibited optimal strengths of 14.85 MPa and 15.2 MPa. Scanning electron microscopy (SEM) revealed a clear correlation between additives concentration and pore formation within the bricks. Energy dispersive spectroscopy (EDS) was utilized to further investigate the elemental composition. Notably, thermal insulation properties improved with higher additives concentrations, suggesting the potential for enhanced energy efficiency in construction applications. Results highlight the potential of almond and walnut shell powders, as a sustainable alternative to traditional clay-based bricks, offering a pathway to reduce the environmental impact of construction materials while mitigating the depletion of clay resources.

Keywords: agricultural waste; eco-friendly; sustainable development; composites; microscopic characteristics.

INTRODUCTION

The escalation in atmospheric pollution levels Presents a significant environmental hazard. Global waste generation currently stands at 1.3 billion tons annually, with a projected increase to 2.2 billion tons by the year 2025 (Al-Fakih et al. 2019), The velocity of waste generation is most rapid in China, various regions of East Asia, as well as certain areas of Eastern Europe and the Middle East (Hoornweg et al. 2012). The yearly growth rate of municipal solid waste in Pakistan is 2.4% due to factors such as population expansion and urban development (Safar et al. 2021; Awoyera et al. 2020). The utilization of waste materials not only serves to mitigate environmental pollution but also demonstrates cost-effectiveness in various construction applications (Subhani et al. 2024). Pakistan is also a major producer of dry fruits, with exports reaching an estimated $48 million in 2015 (Aazim, 2016), which left behind these dry fruit shells. Incorporating this nutshell waste as a powder in conventional clay bricks offers a solution for agricultural waste disposal. (Xie et al.

2022), in their work utilized various agricultural wastes, to be filled in the hollow core of the bricks for properties enhancement. In their work, improved heat insulation of the bricks was the main objective. Typical agricultural wastes, reed stems and leaves, rice husk and straws, and wheat stems, were added to the bricks for the analysis. It was found that filling the agriculture waste in the hollow core of bricks improves the thermal insulation from 2.7 to 3.2%. Walnut shell ash exhibits lower density, reduced initial and total surface water absorption, and enhanced thermal performance. Almond shells consist of approximately 37 wt. % cellulose, 32 wt. % hemicellulose, 27 wt. % lignin, and 4 wt. % other components (Caballero et al. 1997). Researchers, such as (Xu et al. 2014), have utilized river sediments as a key raw material in the manufacturing of insulating bricks, achieving increased thermal conductivity because of the highly porous structure of the bricks. (Mendívil et al. 2017), used wood chips from grapevine shoots with clay, percentage of grapevine shoots affecting thermal insulation and energy requirements during the firing process. (Velasco et al. 2014), utilize spent mushroom compost (SMC) was introduced as an additive for the enhancement of insulation properties in brick production. Various concentrations of SMC were assessed. An optimized mixture of clay incorporating up to 17% SMC exhibited enhanced thermal performance, notably decreasing thermal conductivity. (Santos et al. 2015), have utilized industrial nano-crystalline aluminum sludge. These modified bricks exhibit decreased density compared to their original counterparts, alongside increased water absorption, and a reduction in thermal transmittance. (Mahdi et al. 2022), analyzed geopolymer paver block properties, which were made by the addition of brick kiln ash of rice husk. From their work, it was found that this addition reduces the workability of the mixture. It shows a significant increase in tensile and flexural strength, although the compressive strength of bricks slightly increased. Moreover, the bricks were found to be more resistant to acid attack and frosting. (Cultrone et al. 2020), analyzed bricks physical properties by adding sawdust, and clays having higher concentrations of carbonate-containing silicate as additives in 2.5%, 5%, and 10% wt. form the results it was found that incorporating sawdust did not affect fired bricks mineralogical properties at 800℃ to 1100℃, however by increasing combustion temperature percentage of quartz was reduced, whereas carbonates and silicates disappeared. It was concluded that carbonates were liberated during combustion and silicates were transformed into other compounds. (Vera et al. 2024), performed research for improving the thermal resistance of building materials by varying the mortar's thermal conductivity, brick gird, and brick thickness. The effect on the U-value was analyzed under varying above-mentioned parameters. It was found that smaller rectangular cavities reduced the U-value effectively whereas change in thermal conductivity has negligible effect. (Moujoud et al. 2023), in their work utilized coconut shell powder as an additive in the brick manufacturing material. The concentration of shell powder was in 10, 20, and 30% wt. and was sintered at 900, 1000, and 1100℃. It was found that at higher concentrations of shell powder the values of mechanical strengths, and density are found to be lowered, as this enhances the porosity and water absorption. However, sintering at 1100℃, with a concentration value of 30% shell powder wt. Resulted, lowering of thermal conductivity to 0.37 W/m.K and tensile strength was in an acceptable range of ~9.88 MPa. (Korpayev et al. 2023), utilized stone wool waste for brick manufacturing. Their work aimed to recycle and utilize stone wool for a useful purpose to reduce environmental pollution. Stone wool was added to the material of bricks in percentages of 5, 10, 12.5, and 17.5, and once bricks were sintered under the temperatures of 850, 950, and 1050 ℃, properties such as thermal and mechanical were analyzed. The results showed bulk density was lowered up to 13%, compressive strength was 27 MPa and bending strength was 13.79 MPa. Thermal conductivity was lowered up to 20.75%, whereas the freezing effect in brick was reduced to 3%. (Maafa et al. 2023), utilized the dried powdered pomegranate peel in clay brick manufacturing. Thermal insulation, bulk density, porosity, and compressive strength were the parameters analyzed for this waste addition. Different concentrations (5%, 7.5%, 10%, and 15% /wt.) of peel powder were added to bricks. The sintering temperature was 700, 800, and 900℃ to ensure completely baked bricks. Moreover, in this work, the photolytic catalytic phenomenon was investigated, as bricks are dried in sunlight. Thermal conductivity was reduced to 21%, and density was lowered by 7.6% after sintering at 900℃. A reduction in compressive strength was also found and photodegradation was also observed at 700℃ sintering temperatures. This concludes that agricultural waste addition results in lightweight and highly thermal insulator bricks, with economic cost. (Kim et al. 2023), examined the impact of incorporating biomass fly ash on various properties of mortar, including mechanical strength, resistance to chloride penetration, and durability. The mortar was augmented with biomass fly ash at levels of 10%, 15%, and 20%. The findings revealed with the addition of biomass fly ash, porosity decreases, enhanced mechanical strength, and decreased chloride penetration. These outcomes collectively support the beneficial application of waste materials in construction activities. (Gencel, 2015) introduced pores into bricks by incorporating pumice as an additive, yielding a substantial reduction in thermal conductivity. (Arezki et al. 2016), employed various clay mixtures with different proportions of ground olive stones to manufacture fired clay bricks. This endeavor involved an investigation of shrinkage, density, thermal conductivity, water absorption, pore size distribution, as well as compressive and flexural strength. Notably, adding ground olive stone resulted in the reduction of compressive strength and an increase in porosity. (Abdullah et al. 2017), incorporated rice husk, corncob, and coconut coir as additives in clay bricks, with variations in compressive strength, water absorption, and efflorescence. (Hwang et al. 2015), employed unground rice husk and fly ash in fired clay bricks manufacturing, achieving improved flexural and compressive strength compared to locally available bricks.

Collectively, the studies exemplify the effective application of agricultural by-products in the production of bricks, highlighting their ecological advantages. These by-products not only enhance the fundamental properties of bricks but also decrease manufacturing costs by minimizing the consumption of essential materials and energy resources. Current investigations are concentrated on the evaluation of the physical, thermal, and mechanical properties of bricks, with a specific focus on the incorporation of walnut and almond shells powdered as waste additives. These waste-added bricks are compared to conventional bricks. Weight reduction is particularly advantageous for multistorey structures. The inclusion of additives further aids in diminishing the consumption of clay and sand, effectively addressing concerns related to land erosion.

METHODOLOGY

DATA COLLECTION PREPARATION

Clay was collected from the surrounding area for the manufacturing of bricks, while almond and walnut shells were acquired from a local dry fruit store. X-ray diffraction (XRD) was performed on D8 DISCOVER Bruker (Billerica,MA,USA) with Cu-Kα where λ= 1.54Å at ambient temperature with range of 2θ from 10° to 80° with step size of 0.050 to identify the primary mineral phase present in the clay and almond and walnut shells powder. For SEM/EDS, VEGA3 TESCAN machine were employed to analyse the surface microstructure and morphological characteristics of the Clay and almond and walnut shell powder brick under the accelerated voltage of 20 kV.

PREPARATION OF SAMPLE

Figure 1 represents the brick manufacturing process. Firstly, almond and walnut shells were grounded through a ball milling process and then mixed with clay at ratios such as 5%, 10%, and 15% wt. Which were mixed for 2 minutes to achieve a uniform dry mixture. Subsequently, 20% by weight of water was incorporated into the mixture before the molding process. The wet dough of the mixture was left for 3 hours to fill the water in voids then it was placed in a mold (size 9″x4.5″x3″) for a regular shape and to eliminate trapped air bubbles, the molds filled with the mixture were subjected to compression at three different intervals before being taken out of the mold in a wet plastic green state. All green body specimens were labeled as indicated in Table 1. The wet green body sample was left for 48 hours in the atmosphere for air drying until the samples became hard. The dried bricks were placed in an electric furnace for the baking/sintering process at a controlled temperature. Each brick was sintered separately in the steps of 28 °C to 200 °C, then left at 200 °C for 1 hour, afterward temperature was increased to 400 °C, 600 °C and 900 °C. The intermediate time for each step was kept at 1 hour. After 08 hours the brick was fully sintered and removed from the furnace.

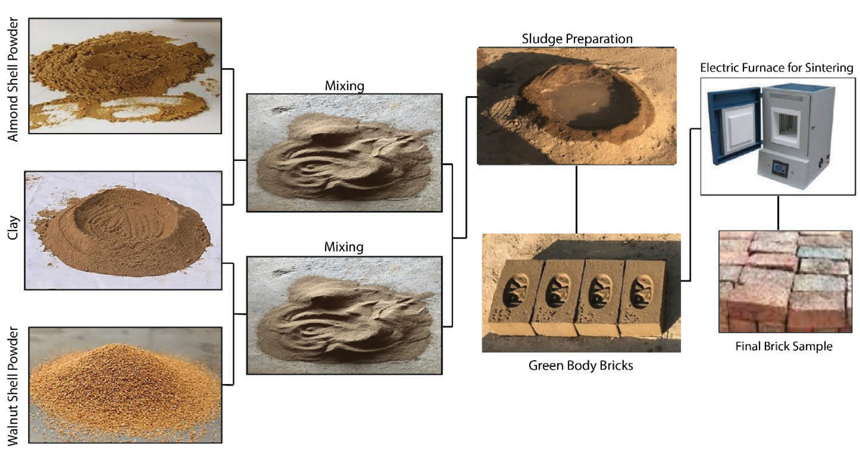


FIGURE 1. Brick preparation schematic

Table 1 shows normal brick (NB) represents without additives, while symbols A5, A10, A15, and W5, W10, and W15 show added concentration of almond shell powder and walnut shell powder as 5%,10%, 15 % by weight as additives in bricks manufacturing.

TABLE 1. Mixture proportion of materials (%).

Brick Series	NB	A5	A10	A15	W5	W10	W15
Clay (C)	100	95	90	85	95	90	85
Almond (A)	-	5	10	15	-	-	-
Walnut (W)	-	-	-	-	5	10	15

CHARACTERIZATION OF SINTERED BRICKS

The particle size was determined by using the sieving method according to ASTM D422. The manufactured bricks were tested according to ASTM C67 and ASTM C20. The heating and cooling thermal cycles assessment was obtained from Heating and cooling cycle Setup (Awais et al. 2024).

According to ASTM C67 methodology, Compressive strength can be represented in equation 1.

$$C = \frac{W}{A} \tag{1}$$

Where C represents compressive strength, W represents maximum load bearing, and A represents the average of the areas.

ASTM standard C326 is a test for the analysis of minerals, The percentage LOI was calculated by using equation 2.

$$\text{Loss on ignition} = \frac{W_b - W_a}{W_b} \times 100 \tag{2}$$

Where W_b and W_a are the weights of the brick before and after heating respectively. Bulk density and water absorption are represented by Equation 3 and Equation 4 respectively.

$$\text{Bulk Density} = \frac{\text{Dry Weight(kg)}}{\text{Volume(m3)}} \tag{3}$$

$$\text{Water absorption} = \frac{W_s - W_d}{W_d} \times 100 \tag{4}$$

Where W_d and W_s represent the dry weight and saturated weight of brick.

SSD Density of different specimens of bricks are calculated from the following equation 5.

$$\text{SSD Density} = \frac{\text{SSD Weight(kg)}}{\text{Volume(m3)}} \tag{5}$$

RESULTS AND DISCUSSION

PROPERTIES OF RAW MATERIALS

Figure 2 depicts the XRD result for the clay sample. The notable presence of corundum (Al_2O_3), silica (SiO_2), and calcite ($CaCO_3$) was confirmed in the composition of the clay. Typically, clay containing approximately 50% to 60% of SiO_2 and 10% to 20% of Al_2O_3 is deemed suitable to produce bricks. Consequently, this clay material can be classified as a low-refractory substance (Kazmi et al. 2018).

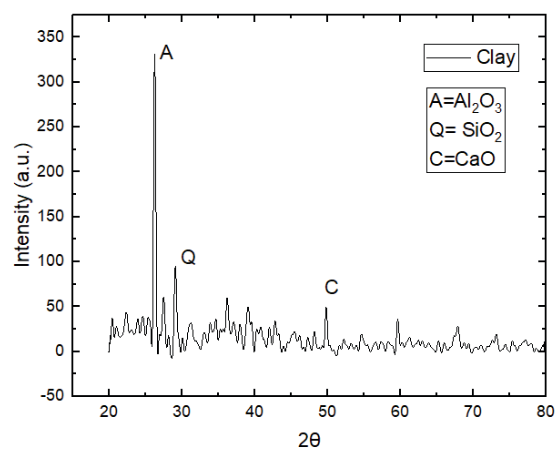


FIGURE 2. XRD patterns of clay

Figure 3 illustrates the XRD patterns for walnut shell powder and almond shell powder. In both cases, a characteristic amorphous phase ranging from 15° to 30° (2θ) was observed, manifesting as a broad hump. This trend predominantly indicates the presence of silica in an amorphous state, as documented in previous studies (Kazmi et al. 2018; Munir et al. 2018). The XRD analysis confirms the amorphous nature of these materials (Li, 2011). An important characteristic of such amorphous materials is their ability to form secondary hydrates after reaction with the $Ca(OH)_2$ in an alkaline cementitious matrix. Thus, it can be deduced that walnut shell powder and almond shell powder shall be equally useful in other composites for constructions such as geopolymer and concrete.

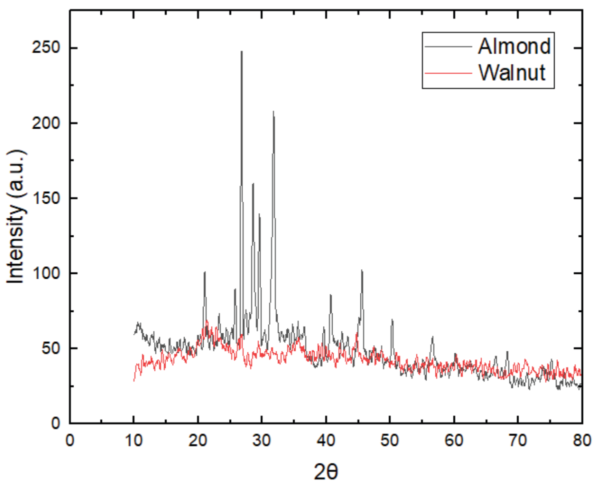


FIGURE 3. XRD of Almond shell powder and Walnut shell powder

SEM/EDX ANALYSIS

Figure 4 illustrates microstructural characteristics of sintered NB, A15, and W15. Introduction of additives led to the development of a substantial quantity of micropores. The conspicuous pores displayed diverse configurations, encompassing circular and oval shapes. SEM micrographs were processed in ImageJ (Fiji) after calibration using the scale bar of each image. Pore structures were identified through Otsu-based thresholding and quantified with the Analyze Particles function. For the normal brick sample, the mean pore diameter was approximately 0.28 µm with a porosity of 1.2%. In the case of the A15 brick, the corresponding values were 0.39 µm and 8.5%, respectively. The W15 brick exhibited a mean pore size of 0.68 µm and a porosity of 4.3%. The microstructure of A15 bricks as shown in fig 4a, reveals the presence of greater porosity percentage along with weaker adhesion between the shell particles and the clay matrix. These features create more open and interconnected voids which facilitate water ingress and result in higher water absorption. In contrast, in fig 4c, W15 bricks display a comparatively compact structure characterized by smaller and less connected pores. The more uniform distribution of particles and the reduced number of open voids contribute to lower water absorption in W15, as the denser matrix hinders capillary penetration. The quantity and dimensions of these pores exhibit a direct correlation with additives percentage. This increase in pore size can be ascribed to the heightened presence of combustible materials resulting from exposure to elevated temperatures. During the sintering process, burning of additives and evolution of gas within the brick body were significant contributors for creating pores characterized by irregularly shaped openings. An EDX test was performed to analyze the constituents of normal brick, A15 and W15. Outcomes are depicted in Figure 5. The principal elements found in clay and almond and walnut shell powder bricks were Silicon (Si), Aluminium (Al), Iron (Fe), Calcium (Ca), and Magnesium (Mg). Figure 5 shows the EDX spectrum and Table 2 shows the element, weight (%), and atomic (%) of normal brick, W15, and A15 respectively.

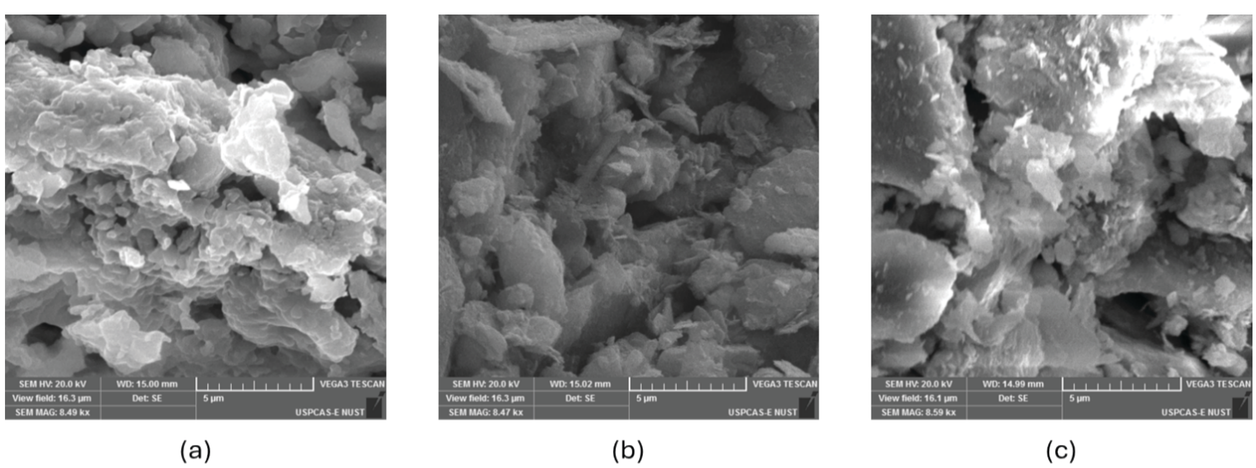
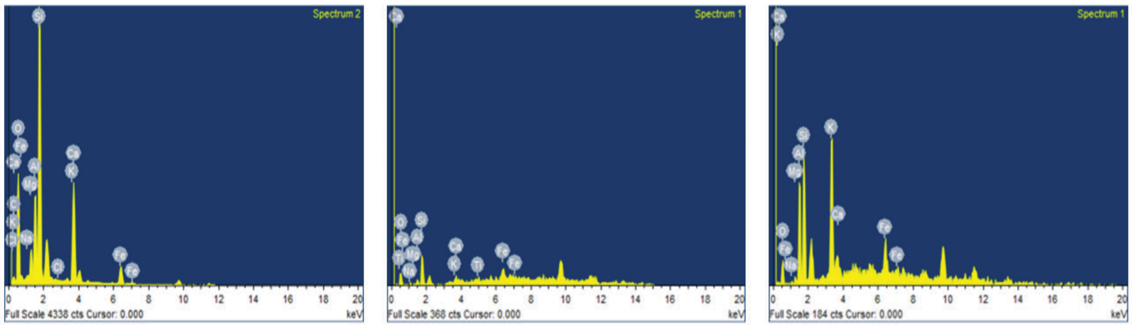


FIGURE 4. SEM images of bricks: (a) normal brick; (b) A15 brick; (c) W15 brick



(a) (b) (c)

FIGURE 5. EDX spectrum of bricks: (a) normal brick; (b) A15 brick; (c) W15 brick

TABLE 2. Elemental composition

Normal brick		A15		W15	
Element	Weight (%)	Element	Weight (%)	Element	Weight (%)
C K	12	O K	82.85	O K	0.99
O K	53.24	Na K	0.5	Na K	1.36
Na K	0.26	Mg K	0.09	Mg K	1.37
Mg K	1.92	Al K	1.09	Al K	16.84
Al K	4.58	Si K	5.88	Si K	22.77
Si K	15.13	K K	0.68	K K	32.86
Cl K	0.07	Ca K	1.71	Ca K	3.56
K K	0.25	Ti K	0.62	Fe K	20.23
Ca K	8.68	Fe K	6.58		
Fe K	3.87				
Totals	100	Totals	100	Totals	100

LOSS ON IGNITION (LOI)

To achieve optimal performance, the weight loss from ignition must not exceed 15% (Weng et al. 2003). When pore-inducing substances are introduced, weight loss upon ignition rises. When an organic or non-organic component is added to the clay mixture, it causes porosity to form in the system throughout the drying and burning phases. This is made possible by processes including carbonate breakdown and dihydroxylation. Because air is lighter than clay and additive substances, the weight decreases as voids occur (Lin, 2006). The introduction of Almond and Walnut shell powder into the brick samples was found to raise weight loss as the additive percentage increased as shown in Figure 6a. Results reveal that by increasing the additive percentage of almond shell powder content to 5,10 and 15%, the LOI of bricks rises to 14.2, 15.5, and 17.2%. Similarly, when increasing the additive percentage of walnut shell powder to 5,10, and 15%, LOI rises to 8.2, 10.8 and 12.6%. The weight loss of the walnut shell powder bricks increased steadily, indicating the existence of a constant amount of organic material and their ability to induce pores. However, almond shell powder bricks result in a larger reduction in weight, indicating that they contain a higher percentage of volatile components.

COMPRESSIVE STRENGTH (CS)

Figure 6b shows compressive decreases with the increase of additive percentage. Results reveal that by increasing the additive percentage of almond shell powder content to 5,10 and 15%, the compressive strength of bricks decreases to 14.8, 14.1, and 12.7 MPa. Similarly, when increasing the additive percentage of walnut shell powder to 5,10, and 15%, the compressive strength decreased to 15.2, 14.3 and 13.1 MPa respectively.

SATURATED SURFACE DRY DENSITY (SSD)

Best range for SSD density is 1520 Kg/m^3 to 1680 Kg/m^3. Figure 6c shows as the additive percentage increases, the SSD density decreases. Result indicates that by increasing almond shell powder in bricks at A5, A10 and A15, the SSD density decreases from 1539 Kg/m^3, 1529 Kg/m^3 to 1519 Kg/m^3 respectively. Similarly, by increasing walnut shell powder content at W5, W10 and W15, SSD density decreased from 1596 Kg/m^3, 1578 Kg/m^3 to 1556 Kg/m^3 respectively.

WATER ABSORPTION (WA)

According to ASTM C62-04, the acceptable rate of water absorption is 22% for moderate weathering (MW) and no limit for negligible weathering. The water absorption capacity of bricks is a pivotal factor contributing to the assessment of their durability. As the WA decreases the brick's bonding increases. Figure 6d shows the WA of sintered bricks increases with the increase of additive percentage. Every specimen has water absorption of less than 22% except for A15 and W15 which is 26% and 25%. When additives were added to brick, it was found that the water absorption rate increased as the additive proportion rose. The results showed that more organic decomposable elements get included as the additives percentage rises. These materials, when fired, generate voids that allow water to enter and allow bricks to retain water as well. The percentage of additives is closely correlated with water absorption. Bricks with the addition of walnut shell powder exhibit less rise than bricks with the addition of almond shell power because of the variance in organic content, specific size, and chemical composition which indicates walnut shell powder is less successful in generating porosity.

BULK DENSITY

According to ASTM C90-22, density values for lightweight, medium weight, and normal weight are 1680 kg/m3, 1680-2000 kg/m3, and 2000 kg/m3 or more. Figure 6e shows that by increasing the percentage of additives, the density of resulting bricks decreases. The density of bricks with the addition of almond shell powder at A5, A10, and A15 decreases from 1253 Kg/m3, 1206 Kg/m3 to 1186 Kg/m3 respectively. In the case of walnut shell powder at W5, W10, and W15, density decreases from 1515 Kg/m3, 1402 Kg/m^3 to 1360 Kg/m^3. Organic components volatilize during the combustion process, creating pores because these air-filled holes are substantially lighter than the solid substance they replace, so the density of the material decreases. Bricks with lower density has several advantages in construction, such as less structural dead load, easier handling, and lower shipping costs.

EFFLORESCENCE

Efflorescence refers to the appearance of whitish salt deposits on the exterior of construction materials, resulting from the migration and crystallization of soluble salts (Anjum et al. 2022). The main contributors to this phenomenon are calcium oxide and other inorganic salts. According to ASTM C67-08, the extent of efflorescence can be graded into five levels: none, slight, moderate, heavy, and severe. It was observed that prepared brick with almond and walnut shell powder exhibits no efflorescence which indicates their suitability in construction applications. Similar kind of findings have been observed in previous findings, where bricks prepared with rice husk ash and sugarcane bagasse ash showed no efflorescence (Kazmi et al. 2016). Another study highlighted that no efflorescence was observed in brick with additives such as waste marble powder and sugarcane bagasse (Abbas et al. 2023). Hence it was concluded these waste materials can be added as replacement of clay as they did not cause any efflorescence.

THERMAL CYCLING

The average of the results from five thermal cycles was used to determine the peak surface temperature of sintered brick $T_{(max-s)}$ and the peak air temperature $T_{(max-a)}$ within the containment box. Table 3 summarizes these results. The $T_{(max-s)}$ values of the almond and walnut shell powder bricks are 41 ± 1.06 °C, 47.4 ± 1.02 °C, 45.1 ± 1.33 °C, 43.5 °C and 41°C, 44.9 °C, 45.7 °C and 46.5 °C respectively, and the corresponding $T_{(max-a)}$ values are 28.3 ± 0.48 °C, 31.2 °C ± 30.9 °C, 29.8 ± 0.24 °C and 28.4 °C, 30.1 °C, 32.2 °C and 32.1 °C. Figure 7 represents the heating and cooling process of bricks. As demonstrated in Figure 7a, c showcases a higher inner surface temperature comparison for A5, A10, A15, W5, W10, and W15 in comparison with 0% additive during a 160-minute heating process.

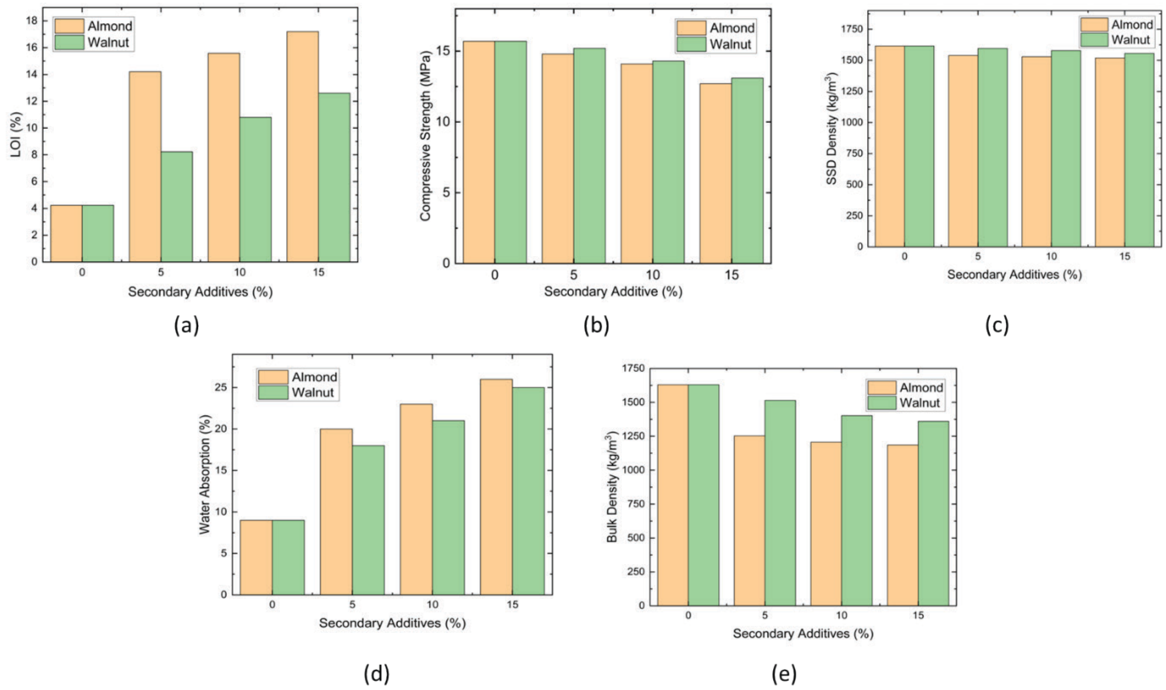


FIGURE 6. Experimental results of bricks: (a) Loss on ignition; (b) Compressive strength; (c) SSD Density; (d) Water absorption; (e) Bulk density

TABLE 3. Maximum surface temperatures ($T_{(max-s)}$) ˚C and Maximum air temperature ($T_{(max-a)}$) ˚C of bricks with the addition of additives.

Bricks with almond shell powder additives	0%	5%	10%	15%
$T_{(max-s)}$	41	47.4	45.1	43.5
$T_{(max-a)}$	28.3	31.2	30.9	29.8
Bricks with walnut shell powder additive	0%	5%	10%	15%
$T_{(max-s)}$	41	44.9	45.7	46.5
$T_{(max-a)}$	28.4	30.1	32.2	32.1

During the 75-minute cooling period, they also show an increase in their inner surface temperature. These findings demonstrate how almond and walnut shell bricks absorb and release energy during the heating and cooling processes. The evolution of the inner air temperature inside the heating box utilizing almond and walnut shell bricks is shown in Figure 7b, d. The trends in the development of the acquired inner air temperature are similar to those shown in Figure 7a, c. This confirms the bricks with additives have good endothermic and exothermic properties, as well as prepared bricks, have better thermal insulation performance. The finding highlights a trade-off between thermal insulation and compressive strength. Incorporating agricultural waste increases porosity, which improves thermal resistance but reduces load-bearing capacity compared to conventional clay bricks as shown in figure 6b. To balance these properties, future work should refine optimization of additive content is essential, and reinforcement with fibers, binders, or surface densification may enhance strength while preserving insulation.

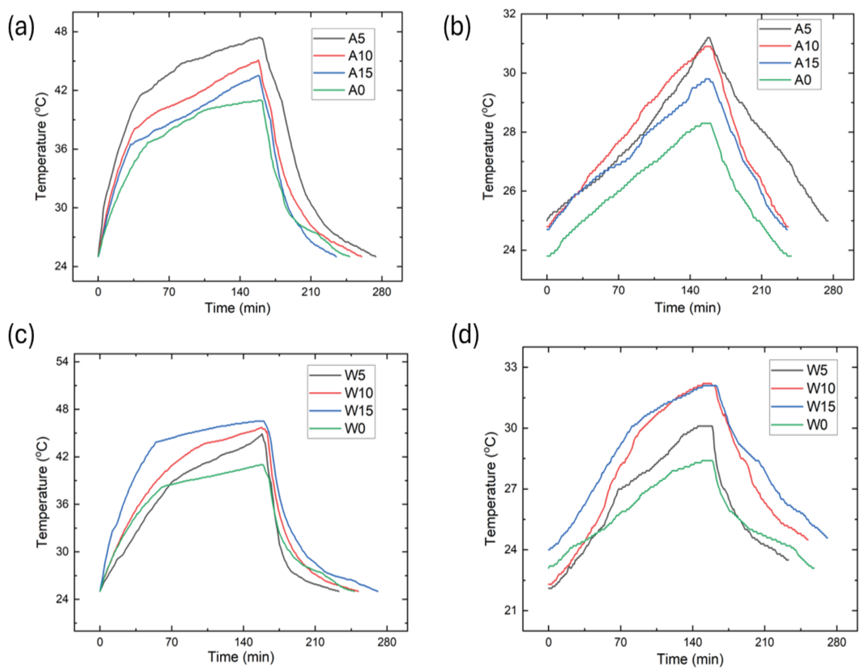


FIGURE 7. Thermal cycling of bricks: (a) Almond bricks surface temp; (b) Almond bricks air temp; (c) Walnut bricks surface temp; (d) Walnut bricks air temp

COMPARISON WITH PREVIOUS WORKS

Table 4. provides a comprehensive overview of the advancements and attributes of fired clay bricks that incorporate a variety of additives, as well as the firing temperatures employed in several contemporary studies. To enhance the understanding of the implications of utilizing different waste materials as additives in the manufacturing of bricks, researchers have systematically altered both the firing temperature and the quantity of waste employed, as illustrated in Table 4. The range of sintering temperatures, which spans from 800°C to 1200°C, aligns with the firing temperatures utilized in the present investigation. It is noteworthy that while lower sintering temperatures can contribute to reduced energy consumption. The composition varied across the studies; however, the overarching objective remained the formulation of

bricks exhibiting optimal physical, mechanical, and thermal characteristics. Across previous research, the observed bulk density values ranged from 1300 kg/m³ to 1800 kg/m³, which is consistent with our finding's of 1515 kg/m³ to 1206 kg/m³. Furthermore, water absorption rates reported in the literature reached as high as 30%, whereas the present study indicates a water absorption rate of less than 26%. Compressive strength and other properties were also compared with the previous research as indicated in table 4.

TABLE 4. Comparative table with previous works.

Waste material and content (wt%)	Production method	Bulk density (kg/m3)	Compressive strength (MPa)	Water absorption (%)	Other properties	Ref.
Rice husk and wood ash (10-30%)	Fired at 900 °C and 1000 °C for 4 hr	1839-1394	Ranged from 53.4 to 13.5	WA increased up to 21.2%	Thermal conductivity up to 0.68 W/mK	Eliche-Quesada et al. (2017)
Spent shea waste (5-20%)	Fire at 900 °C or 1200 °C for 1 hr	1800-1220	Ranged from 11 to 4	WA increased up to 32%	-	Adazabra et al. (2017)a; Adazabra et al. (2017b)

continue...

...cont.

Sugarcane bagasse ash, rice husk ash (5-15%) and line (3-18%)	10 d of sun drying then 36 hr of firing at 800 ºC	1220-1060	Ranged from 5.53 to 7.18	WA ranged between 23.8% and 17.5 %	IRA ranged between 0.55 and 0.805 g/cm2/min	Kazmi et al. (2018); Saleem at al. (2017)
Wheat straw, olive stone flour, and sunflower seed cake (4%,8%, and 17%)	Dried up to 105 C, fired at 920 ºC for 1 hr	1700-1460	-	WA ranged between 17.8% and 30 %	Linear shrinkage decreased from 5.8% to 3.3%	Bories et al. (2015)
Almond shell powder and walnut shell powder (5-15%)	Fired up to 900 ºC	1515-1206	Ranged from 15.7 to 12.7	WA ranged upto 26%	Loss on ignition 8.2 to 17.2	Our Research

Concluding that good properties of bricks can be achieved by using almond and walnut shell powder as additives.

COST AND ENERGY ANALYSIS

Cost and energy analysis were undertaken at laboratory scale in which one brick in sintered at a time in electric furnace. The preparation time and corresponding energy consumption of both conventional and additive-incorporated bricks were recorded during the sintering stage. As shown in Figure 8, bricks containing additives require approximately 5.7% less energy than conventional ones, subsequently resulting in low cost. This reduction is attributed to the early thermal decomposition of organic additives, which release additional heat within the brick matrix, enhancing internal heat transfer and shortening the firing duration. Similar findings have been reported in literature, where the incorporation of Parthenium hysterophorus biomass led to a 15–20% reduction in firing energy (Ahmad et al. 2025) and pomegranate peel waste achieved 17.5–33.1% lower building energy consumption, confirming their energy-saving potential of organic waste additives (Ahmed et al. 2023). The results revealed that the production process can feasibly be scaled up to industrial level for even greater energy and cost efficiency.

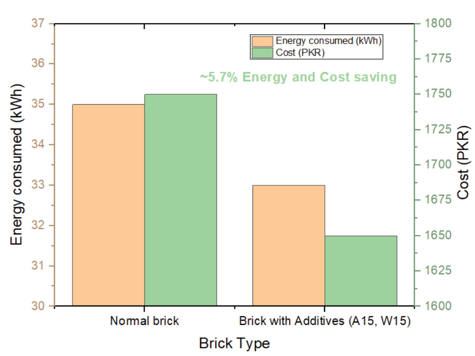


FIGURE 8. Energy and cost analysis

CONCLUSIONS

It is feasible to prepare sintered bricks with the use of almond and walnut shell powder, and good properties can be achieved. Results indicate LOI increases, by increasing the amount of almond shell powder and walnut shell powder concentration in prepared bricks reaching a maximum of up to 17.2% and 12.6% for A15 and W15 specimens. Water absorption increases by increasing additives percentage, the water absorption increases up to a maximum of 25% and 26% for A15 and W15. As the additives concentration increases, the bulk density of resulting bricks decreases from 1253 Kg/m^3 to 1186 Kg/m^3 for almond shell powder bricks and 1515 Kg/m^3 to 1360 Kg/m^3 for walnut shell powder bricks. Compressive strength demonstrates a downward trend with the increase of additives percentage with maximum obtained strength for is 15.2 MPa for A5 and 14.8 MPa for W5. The thermal performance was thoroughly examined through the implementation of a heating and cooling cycle. SEM analysis reveals that pore size increases with increasing of additives content but reduces compressive strength. Moreover, the use of agricultural waste in bricks shows promise for large-scale production, though future studies must evaluate energy demands and cost-effectiveness at industrial scale. The research validated the hypothesis that almond and walnut shell powder blended with clay fulfilled the essential technical standards, positioning them as a viable substitute raw material for brick manufacturing.

ACKNOWLEDGEMENT

We like to thank everyone for their support.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Aazim, M. 2016. Production and Export of Fresh and Dry Fruits. *Dawn News*, 12 December 2016.

Abbas, S., Baig, A., Hameed, R., Kazmi, S.M.S., Munir, M.J. & Shaukat, S. 2023. Manufacturing of clay bricks using hybrid waste marble powder and sugarcane bagasse ash: a sustainable building unit. *Sustainability* 15(20): 14692.

Abdullah, A.C. & Lee, C.C. 2017. Effect of treatments on properties of cement-fiber bricks utilizing rice husk, corncob and coconut coir. *Procedia Engineering* 180: 1266–1273.

Adazabra, A.N., Viruthagiri, G. & Kannan, P. 2017. Influence of spent shea waste addition on the technological properties of fired clay bricks. *Journal of Building Engineering* 11: 166–177.

Adazabra, A.N., Viruthagiri, G. & Shanmugam, N. 2017. Infrared analysis of clay bricks incorporated with spent shea waste from the shea butter industry. *Journal of Environmental Management* 191: 66–74.

Ahmad, M.S., Ahmad, M.N., Muhammad, T., Khan, M.J., Jabbir, F., Alghamdi, S.A., Alhomrani, M., Alamri, A.S. & Shah, S. 2025. Utilizing agricultural waste in brick manufacturing for sustainable consumption and circular economy. *Scientific Reports* 15(1): 22741.

Ahmed, S., El Attar, M.E., Zouli, N., Abutaleb, A., Maafa, I.M., Ahmed, M.M., Yousef, A. & Ragab, A. 2023. Improving the thermal performance and energy efficiency of buildings by incorporating biomass waste into clay bricks. *Materials* 16(7): 2893.

Al-Fakih, A., Mohammed, B.S., Liew, M.S. & Nikbakht, E. 2019. Incorporation of waste materials in the manufacture of masonry bricks: An update review. *Journal of Building Engineering* 21: 37–54.

Anjum, F., Naz, M.Y., Ghaffar, A., Kamran, K., Shukrullah, S. & Ullah, S. 2022. Sustainable insulating porous building materials for energy-saving perspective: Stones to environmentally friendly bricks. *Construction and Building Materials* 318: 125930.

Arezki, S., Chelouah, N. & Tahakourt, A. 2016. The effect of the addition of ground olive stones on the physical and mechanical properties of clay bricks. *Materiales de Construcción* 66(322): e082–e082.

Awais, M., Mansoor, A., Shah, I., Hussain, M. & Asif, M. 2024. Characterization and Development of Ceramics with Inorganic Additives. *Inventions* 9(6): 121.

Awoyera, P.O. & Adesina, A. 2020. Plastic wastes to construction products: Status, limitations and future perspective. *Case Studies in Construction Materials* 12: e00330.

Bories, C., Aouba, L., Vedrenne, E. & Vilarem, G. 2015. Fired clay bricks using agricultural biomass wastes: Study and characterization. *Construction and Building Materials* 91: 158–163.

Caballero, J.A., Conesa, J.A., Font, R. & Marcilla, A. 1997. Pyrolysis kinetics of almond shells and olive stones considering their organic fractions. *Journal of Analytical and Applied Pyrolysis* 42(2): 159–175.

Cultrone, G., Aurrekoetxea, I., Casado, C. & Arizzi, A. 2020. Sawdust recycling in the production of lightweight bricks: How the amount of additive and the firing temperature influence the physical properties of the bricks. *Construction and Building Materials* 235: 117436.

Eliche-Quesada, D., Felipe-Sesé, M.A., López-Pérez, J.A. & Infantes-Molina, A. 2017. Characterization and evaluation of rice husk ash and wood ash in sustainable clay matrix bricks. *Ceramics International* 43(1): 463–475.

Gencel, O. 2015. Characteristics of fired clay bricks with pumice additive. *Energy and Buildings* 102: 217–224.

Hoornweg, D. & Bhada-Tata, P. 2012. *What a waste: A global review of solid waste management.*

Hwang, C.-L. & Huynh, T.-P. 2015. Investigation into the use of unground rice husk ash to produce eco-friendly construction bricks. *Construction and Building Materials* 93: 335–341.

Kazmi, S.M.S., Abbas, S., Saleem, M.A., Munir, M.J. & Khitab, A. 2016. Manufacturing of sustainable clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes. *Construction and Building Materials* 120: 29–41.

Kazmi, S.M.S., Munir, M.J., Patnaikuni, I., Wu, Y.-F. & Fawad, U. 2018. Thermal performance enhancement of eco-friendly bricks incorporating agro-wastes. *Energy and Buildings* 158: 1117–1129.

Kazmi, S.M.S., Munir, M.J., Wu, Y.-F., Hanif, A. & Patnaikuni, I. 2018. Thermal performance evaluation of eco-friendly bricks incorporating waste glass sludge. *Journal of Cleaner Production* 172: 1867–1880.

Kim, K.W., Park, K.T., Ates, F., Kim, H.G. & Woo, B.-H. 2023. Effect of pretreated biomass fly ash on the mechanical properties and durability of cement mortar. *Case Studies in Construction Materials* 18: e01754.

Korpayev, S., Bayramov, M., Durdyev, S., Hamrayev, H., Baymyradova, D. & Nurmuhammedov, A. 2023. Effect of stone wool waste from greenhouse agriculture in brick production. *Journal of Building Engineering* 63: 105340.

Li, Z. 2011. Materials for making concrete. *Advanced Concrete Technology* 23–93.

Lin, K.L. 2006. Feasibility study of using brick made from municipal solid waste incinerator fly ash slag. *Journal of Hazardous Materials* 137(3): 1810–1816.

Maafa, I.M., Abutaleb, A., Zouli, N., Zeyad, A.M., Yousef, A. & Ahmed, M.M. 2023. Effect of agricultural biomass wastes on thermal insulation and self-cleaning of fired bricks. *Journal of Materials Research and Technology* 24: 4060–4073.

Mahdi, S.N., Hossiney, N. & Abdullah, M.M.A.B. 2022. Strength and durability properties of geopolymer paver blocks made with fly ash and brick kiln rice husk ash. *Case Studies in Construction Materials* 16: e00800.

Mendívil, M.A., Muñoz, P., Morales, M.P., Letelier, V. & Juárez, M.C. 2017. Grapevine shoots for improving thermal properties of structural fired clay bricks: New method of agricultural-waste valorization. *Journal of Materials in Civil Engineering* 29(8): 4017074.

Moujoud, Z., Harrati, A., Manni, A., Naim, A., El Bouari, A. & Tanane, O. 2023. Study of fired clay bricks with coconut shell waste as a renewable pore-forming agent: Technological, mechanical, and thermal properties. *Journal of Building Engineering* 68: 106107.

Munir, M.J., Kazmi, S.M.S., Wu, Y.-F., Hanif, A. & Khan, M.U.A. 2018. Thermally efficient fired clay bricks incorporating waste marble sludge: An industrial-scale study. *Journal of Cleaner Production* 174: 1122–1135.

Safar, K.M., Bux, M.R., Faria, U. & Pervez, S. 2021. Integrated model of municipal solid waste management for energy recovery in Pakistan. *Energy* 219: 119632.

Saleem, M.A., Kazmi, S.M.S. & Abbas, S. 2017. Clay bricks prepared with sugarcane bagasse and rice husk ash – A sustainable solution. *MATEC Web of Conferences* 120: 3001.

Santos, P., Martins, C. & Júlio, E. 2015. Enhancement of the thermal performance of perforated clay brick walls through the addition of industrial nano-crystalline aluminium sludge. *Construction and Building Materials* 101: 227–238.

Subhani, H.A., Khushnood, R.A. & Shakeel, S. 2024. Synthesis of recycled bricks containing mixed plastic waste and foundry sand: Physico-mechanical investigation. *Construction and Building Materials* 416: 135197.

Velasco, P.M., Ortiz, M.P.M., Giro, M.A.M., Castelló, M.C.J. & Velasco, L.M. 2014. Development of better insulation bricks by adding mushroom compost wastes. *Energy and Buildings* 80: 17–22.

Vera, S., Figueroa, C., Chubretovic, S., Remesar, J.C. & Vargas, F. 2024. Improvement of the thermal performance of hollow clay bricks for structural masonry walls. *Construction and Building Materials* 415: 135060.

Weng, C.-H., Lin, D.-F. & Chiang, P.-C. 2003. Utilization of sludge as brick materials. *Advances in Environmental Research* 7(3): 679–685.

Xie, X., Zhang, W., Luan, X., Gao, W., Geng, X. & Xue, Y. 2022. Thermal performance enhancement of hollow brick by agricultural wastes. *Case Studies in Construction Materials* 16: e01047.

Xu, Y., Yan, C., Xu, B., Ruan, X. & Wei, Z. 2014. The use of urban river sediments as a primary raw material in the production of highly insulating brick. *Ceramics International* 40(6): 8833–8840.