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Using Arundo donax as Agricultural and Industrial Waste as Expanded Polystyrene in the Production of Cement Bricks

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Abstract: In this study, natural coarse aggregates were to some extent substituted with industrial waste materials and agricultural waste materials to come up with sustainable compositions of cement bricks. Seven experimental mixes were prepared, which were divided into two groups and a control mix. The former group was a partial replacement of traditional coarse aggregate (CA) with Expanded Polystyrene coarse aggregate (EXCA), where the substitution levels were 5%,7.5% and 10% percent and the other group was the substitution of Arundo donax coarse aggregate (ARCA) by the same ratio. Systematic testing was conducted on compressive strength, sorptivity, unit weight, and thermal conductivity properties of the bricks. The results revealed that the gradual decrease in compressive strength with increasing percentages of EX and AR aggregates occurred at the expense of the control mix. Replacing 10% of natural coarse aggregates with EX and AR reduced compressive strength by 46.7% and 44.0%, respectively. The 10% EXCA mix had the lowest density of 2000 kg/m³ (the control had 2189 kg/m³) and the best thermal conductivity reduction of 17.64% from 1.38 W/m.K to 1.13 W/m.K, indicating a better insulation result. Equally, the blend with 5% percent of ADCA had a density of 2100 kg/m³ and a thermal conductivity that was 11.47% lower than the conduction of 1.38 W/m.K. These findings indicate the promise of EX and AR waste as using sustainable alternative to the traditional aggregates in the manufacture of lightweight and energy-efficient cement bricks to be used in modern constructions.

Keywords: Cement Bricks; Expanded Polystyrene; Arundo Donax; Thermal Performance; Recycled Industrial and Agricultural Waste.

1. Introduction

Concrete is the most widely used construction material globally due to its strength, durability, and versatility. However, its high density, typically ranging between 2200 and 2400 kg/m³, creates considerable challenges in modern applications such as precast and prefabricated systems, where excessive dead loads demand heavy lifting equipment, higher transportation costs, and increased embodied energy and carbon emissions [1–6]. To overcome these limitations, lightweight concrete (LWC) has been developed as a sustainable alternative capable of reducing structural weight while maintaining sufficient mechanical integrity. The incorporation of lightweight aggregates (LWA) in concrete mixtures not only lowers density but also enhances thermal insulation and energy efficiency, which contributes significantly to sustainable construction and life-cycle cost reduction [7,8].

In this regard, lightweight concrete offers multiple advantages, including decreased dead loads, reduced foundation size, and lower transportation energy, making it particularly beneficial for high-rise, modular, and energy-efficient buildings [9,10]. Furthermore, modern construction increasingly demands materials that provide both high structural performance and improved thermal and acoustic insulation. Hence, LWC serves as a promising material balancing strength, functionality, and sustainability [11,12]. Lightweight concrete can be produced either by introducing air voids through gas-forming agents or by replacing traditional natural aggregates with porous lightweight alternatives. Among these, expanded polystyrene aggregates (EPS) have received wide attention because of their extremely low density, ease of handling, and excellent thermal insulation capacity [13–15]. EPS is a cellular plastic material composed of approximately 98 % air, with a particle density ranging from 10 to 50 kg/m^3. Its closed-cell structure contributes to reduced water absorption, high durability, and superior insulation performance, making it a valuable component in sustainable concrete [16–18]. Nevertheless, the main drawback of EPS in concrete is its weak interfacial bonding, which leads to lower compressive strength. Therefore, combining EPS with other reinforcing natural materials could potentially compensate for these mechanical losses while maintaining desirable thermal performance. Parallel to synthetic additives, there has been increasing attention to natural and agricultural waste materials as environmentally friendly alternatives for aggregate substitution and reinforcement. In this context, Arundo donax (giant reed), a fast-growing perennial grass abundant in Mediterranean regions, presents a promising resource [19,20]. Due to its rapid propagation and fibrous structure, Arundo donax can be processed into lightweight aggregates (ADCA), offering mechanical reinforcement and improved bonding with cementitious matrices. Moreover, integrating such agro-based waste promotes circular economic practices, mitigates disposal issues, and enhances the sustainability of building materials [21,22].

Despite the expanding literature on lightweight and sustainable concrete, the hybrid use of synthetic and bio-based aggregates, particularly EPS combined with ARCA, remains underexplored, especially in cement brick production. Previous studies have primarily addressed the individual effects of EPS or natural fibers but have rarely investigated their synergistic influence on both mechanical and thermal properties. Furthermore, few investigations have extended beyond laboratory testing to assess the real-scale thermal performance, cooling load reduction, and energy-saving potential of such lightweight cementitious systems under actual climatic conditions. Accordingly, this research aims to develop eco-efficient lightweight cement bricks incorporating EPS aggregates, Arundo donax coarse aggregates, and fibers, to simultaneously achieve low density, adequate mechanical strength, and enhanced thermal insulation. The experimental program includes mechanical (compressive strength), physical (density and sorptivity), and thermal performance assessments.

2. Experemental Work(Materials and Methods)

2.1. Cement

The binding materials used for this research are ordinary Portland cement of grade 42.5 as per the ASTM C-150 standard [23] . The cement was of a uniform grey color and free from any hard lumps.

2.2. Aggregate

- Traditional coarse aggregate (CA)

The coarse aggregate that was used in this study was natural coarse aggregate found in the Ataka region of Suez, Egypt. The coarse aggregate was then brought through a set of standard tests to determine its physical properties and determine compliance with the specifications found in ASTM C33/C33M-18 [24] , before it was incorporated into the cement brick mixtures. The test results proved that the natural course complied with the requirements to be used as coarse aggregate in cement-based materials.

- Traditional fine aggregate (FA)

Fine aggregate that was used in this study was natural sand found in the Ataka region of Suez, Egypt. The sand was then brought through a set of standard tests to determine its physical properties and determine compliance with the specifications found in

ASTM C33/C33M-18 [24], before it was incorporated into the cement brick mixtures. The test results proved that the natural sand complied with the requirements to be used as fine aggregate in cement-based materials.

- Arundo donax Coarse Aggregate (ARCA):

ARCA were prepared through a systematic process involving collection, thorough purification, and solar drying for a duration of seven days. Following drying, the material was mechanically cut into uniform strips approximately 2.5–3.5 mm in diameter and 2.5 ± 6.5 mm in length. Physical Properties of Aggregates as shown in **Table 1,** according to ACI 213R-03 [25]. To enhance interfacial bonding, the aggregates underwent an alkali pretreatment process involving immersion in a 5% sodium hydroxide ($NaOH$) solution with a molarity of 1M at room temperature for four hours. This treatment effectively removed surface impurities such as lignin and hemicellulose, thereby improving surface roughness and the bonding potential of the aggregates. After the chemical treatment, the aggregates were thoroughly rinsed several times with distilled water until a neutral pH was achieved to ensure the complete removal of residual alkali. Finally, the treated aggregates were sun-dried for 72 hours to eliminate any remaining moisture content before use in the mixtures.

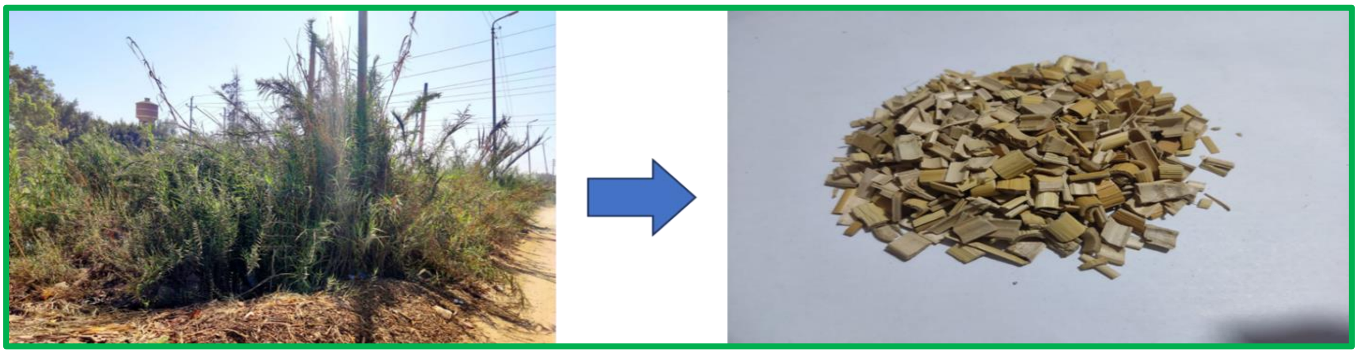

Fig. 1: Arundo donax Coarse Aggregate

- Expanded Polystyrene Coarse Aggregate (EXCA)

The EX-garbage was sourced from discarded packaging materials of household and electrical appliances, as well as from improperly disposed of building renovation debris. The collected material was carefully cleaned. To achieve optimal particle dispersion, the waste was ground in multiple small-volume stages, as illustrated in **Fig. 2**. After grinding, it was observed that the majority of the processed EX waste particles fell within the size range of coarse aggregates (4.75–10 mm), the physical Properties of Aggregates as shown in **Table 1** according to ACI 213R-03 [25]**.** Consequently, the material was utilized as expanded coarse aggregate (EXCA) rather than as a fine aggregate replacement. This decision was further justified by the fact that coarse aggregates represent the largest volumetric fraction in concrete mixtures, making their substitution more effective in reducing density and enhancing thermal performance.

Fig. 2: Expanded Polystyrene Coarse Aggregate

Table 1: Physical Properties of Aggregates

Property	Natural aggregate		Waste Aggregate	
	NCA	NFA	ARCA	EXCA
Bulk density (Kg/m^3)	1830 ±4	1665 ±3	931 ±2	782 ±2
Specific gravity	2.65 ±.1	2.66 ±.1	1.11±.05	1.02 ±.05
Water absorption (%)	0.90 ±.02	3.96 ± .02	20 ± 1	18 ±.1
Fine Dust Content and Clay (% By Volume)	0.74 ±.02	0.86 ±.03	0.73 ±.02	0.55 ±.01

2.3. Methodology and Mix Design

The mixing procedure was done in a logical and controlled way to maintain consistency and reproducibility of all batches. First, CA was mixed with FA dry during a period of about two minutes so that the particles would be equally distributed. Cement was added to the mixture, and the materials were stirred to allow further dispersion of the binder for another minute. Water was then added gradually with constant mixing for three to four minutes, and a well-integrated and homogeneous mixture was formed. The cement content in each mix was held steady at 375 kg/m3, and the CA and FA ratio (50 % CA: 50 % FA), so that a consistent blend would be used to obtain consistent results across the entire test specimen, as shown in **Table 2.**

Bricks of cement in 250 x120x60 mm size were prepared to be tested. The experiment program was split into two groups according to the type of waste aggregate. In the former, CA was partially substituted with industrial waste EXCA at the replacement levels of 5%, 7.5% and 10%. In the second group, CA was partially changed with agricultural waste ARCA. The replacement rates were 5%, 7.5, and 10%. The selection of these specific replacement levels was based on both previous literature and preliminary laboratory trials, which indicated that these ranges effectively balance mechanical integrity and thermal efficiency while maximizing waste utilization and minimizing environmental impact. The proposed experimental design would holistically assess the effects of different ratios of industrial and agricultural waste materials on the mechanical strength and thermal conductivity of cement bricks. It would be used in developing the idea of sustainable and lightweight construction materials.

Table. 2: Mix Proportions of Cement Brick Specimens / m^3

Mixture	Cement (kg)	Water /cement %	FA (%)	CA (%)	EXCA %/ TCA	ARCA %/ TCA
Control	375	35	100	100	0	0
EXCA05	375	35	100	95	5	0
EXCA07.5	375	35	100	92.5	7.5	0
EXCA10	375	35	100	90	10	0
ARCA05	375	35	100	95	0	5
ARCA07.5	375	35	100	92.5	0	7.5
ARCA10	375	35	100	90	0	10

2.3.1. Custom-Made Metal Mold

Fig. 3, The follow-up production procedure of cement bricks was done using a fabricated steel molding, whose inner dimensions were 250 ×120 × 60mm. The molding was performed in line with the requirements set in ASTM C67/C67M-23a [26], which provided consistency and adherence to standard tests.

Fig. 3: Metal Mold for Cement Brick Fabrication

2.3.2 Preparation processes

The mixing procedure was done in a logical and controlled way to maintain consistency and reproducibility of all batches. First, CA was mixed with FA dry during a period of about two minutes so that the particles would be equally distributed. Cement was added to the mixture, and the materials were stirred to allow further dispersion of the binder for another minute. Water was then added gradually with constant mixing for three to four minutes, and a well-integrated and homogeneous mixture was formed. Equally, the mixtures using ARCA, EXCA, CA, and FA were first mixed and allowed to dry mix two minutes. The addition of cement was then followed by one minute of mixing, and then constant stirring for three to four minutes, with the water being added gradually. This methodical process guaranteed the uniformity of all mixtures irrespective of the type of aggregate by way of consistent workability, even dispersion, and cohesion that guaranteed dependable performance analysis.

After the mixing process, the fresh mixtures were cast into molds in three successive layers, each compacted thoroughly to remove entrapped air. The specimens were then left to cure until the testing, with three samples prepared and tested for each property to ensure repeatability and reliability of the results.

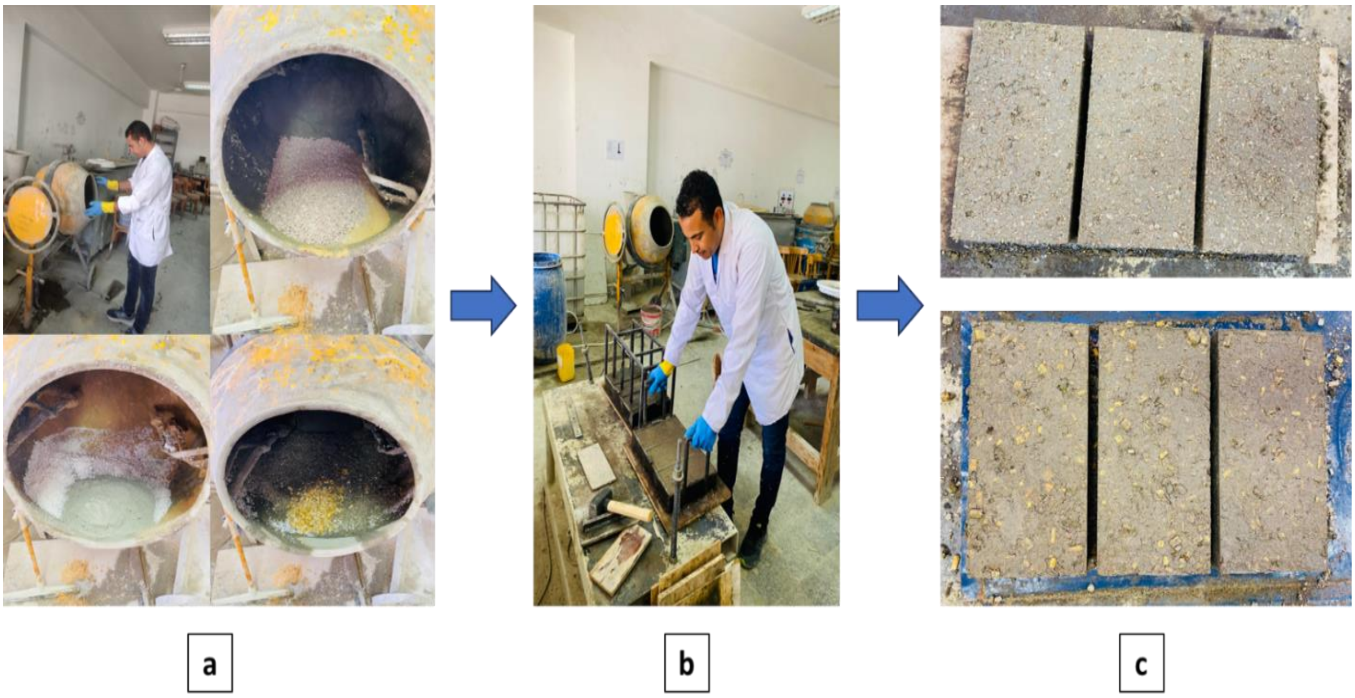

Fig. 4: Procedure of Cement Bricks, comprising (a) Mixing, (b) Molding, and (c) Curing Phases.

2.4. Mechanical properties

A 2000 KN compression testing machine was used for tests lasting 7 and 28 days, which conformed to the ASTM C67/C67M-23a [26]. As shown in **Fig. 5,** every brick specimen measured 250mm x 120mm, and the packing was placed perpendicularly on the bedcovers' wall.

Fig.5. Compressive test of cement bricks**.**

2.5. Physical properties:

2.5.1. Density test

The cement brick specimens were measured in 28 days, which conformed to the ASTM C67/C67M-23a [26] standard. All the mixtures were repeated three times to confirm the consistency of results and reduce the error of the experiment.

2.5.2. Sorptivity test

Tests on brick specimens were conducted for sorptivity according to ASTM C1585- [27]. Before the testing, the samples were dried in the oven at 100 5 C for 24 hours until the samples reached the same mass. The four sides of every brick were then closed with insulating material to allow the unidirectional entry of water as illustrated in Fig. 9. In the test, the lower surface of each specimen was wetted with water to a depth of 3-5mm and the mass readings of the specimen were taken at specific time intervals over a span of 6 hours. The mixture was tested thrice to ascertain reproducibility. By proceeding in this way, the sorptivity coefficient was calculated, which involves plotting cumulative water absorption per unit area versus the square root of time in accordance with the procedure of [28].

3.6. Thermal Properties:

The thermal conductivity of the specimens was calculated as per ASTM C177 standard [29]. The experiment was designed with the involvement of an electric heating component that would maintain the temperature at the lower surface of a 5 mm-thick copper plate, as shown in Fig. 10. This design was intended to enhance the easy transfer of heat vertically using the tested specimens. The specimens were tested through one cycle of 24 hours. The thermal stress analysis was used to calculate the proper heating capacity so that the surface temperature would not be higher than 70 °C in the first 6 hours of the company. Test interval continued up to 6 hours or until thermal equilibrium was reached, the goal of which was considered to be a change in temperature of less than 1 °C per 10 minutes. The values of thermal conductivity were calculated in steady-state operation after the temperature gradient across the surfaces of the specimen had reached a stable value (ΔT) from q1. The experiments were all carried out in a regulated environmental chamber at 24 +2 °C and 50 +5 percent relative humidity so that the testing conditions and the effect of moisture could be minimized [30,31]. All measurements were done three times to confirm the reliability and consistency of the measurement.

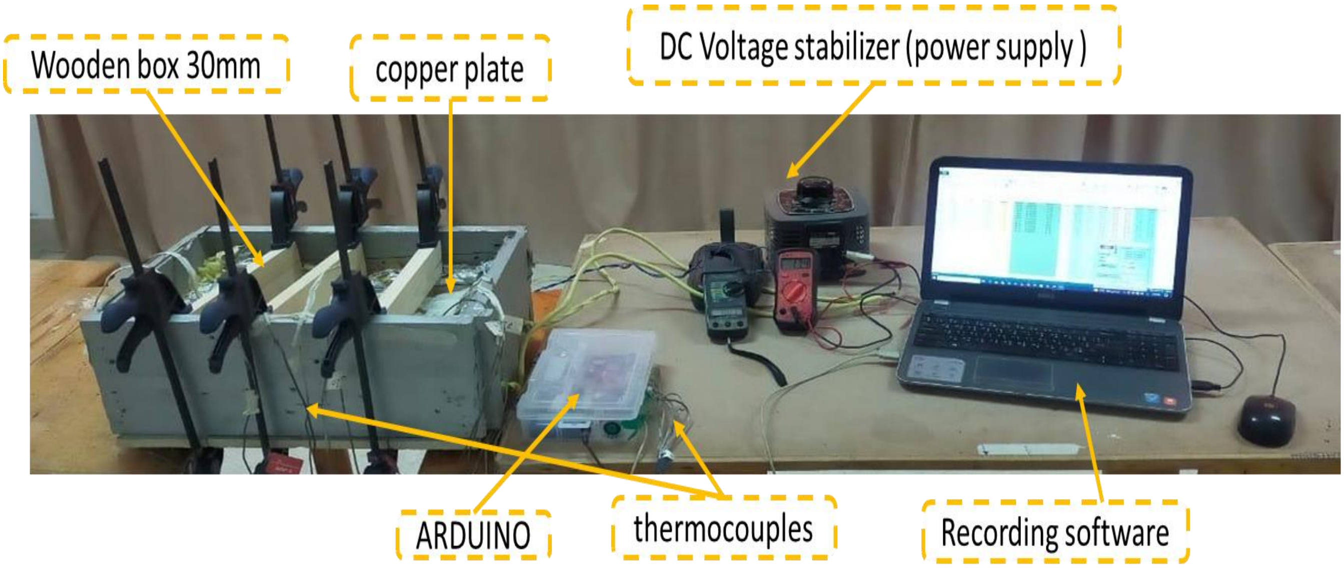

Fig. 6: The thermal conductivity measurement device.

The thermal conductivity of the copper plate (K_c) was first determined and subsequently employed to calculate the corresponding heat transfer rates and thermal conductivities (K_s) of the tested specimens. The heat transfer through the copper plate was evaluated using q.1:

$$Qc=Kc\times Ac\frac{\Delta Xc}{\Delta Tc} \quad \textbf{(q1)}$$

Where, $A_c$represents the surface area of the copper plate (m²), $\Delta X_c$is its thickness (m), Q_cDenotes the heat transfer rate through the plate.

3. Results & Discussion

The results of the experiment related to the mechanical, physical, and thermal performance of the developed cement brick mixtures are presented and analyzed in this section. Mechanical and Physical behavior properties are tested to determine how the replacement of aggregates affects the density, porosity, and moisture absorption properties. In addition, thermal conductivity and surface temperature changes are explored to understand the thermal performance of the modified cement bricks in terms of the heat transfer resistance and insulation efficiency. All reported results represent the average values of three specimens tested for each property to ensure the reliability and consistency of the experimental outcomes.

3.1. Compressive Strength

The compressive strength of the cement bricks was investigated by replacing CA with varying proportions of EX and AR aggregates. The control mixture achieved the highest compressive strength of 25 MPa, as presented in **Fig. 7**. The incorporation of EX and AR aggregates, however, led to a notable reduction in compressive strength compared with the control. The decrease became more pronounced as the replacement ratio of EXCA increased, with cuts of 26.67%, 40%, and 46.67% for the 5%, 7.5%, and 10% substitution levels, respectively. This decline is primarily attributed to the extremely low density and high porosity of EX particles, which contain approximately 95% air voids, resulting in a weaker load-bearing skeleton within the composite. Comparable findings were reported [32–34], also observed that the inclusion of expanded or recycled plastic-based aggregates reduces the mechanical strength due to weak interfacial bonding and the deformability of polymeric particles under compression.

However, such reduction is often balanced by significant density reduction and thermal insulation gains, suggesting a trade-off relationship between structural and thermal properties. Similarly, the replacement of CA with ARCA produced a consistent strength reduction trend by 23.33%, 37.33%, and 44% for replacement ratios of 5%, 7.5%, and 10%, respectively. The reduction is associated with the porous, irregular surface texture and lower intrinsic stiffness of AR particles, which decreases matrix cohesion and interfacial bonding efficiency. Comparable reductions were observed in studies utilizing other lignocellulosic residues such as date seeds, palm fronds, and bamboo fibers [12,18,34–37], where similar decreases in compressive strength were accompanied by improved thermal resistance and reduced unit weight. Therefore, the observed mechanical behavior aligns well with the general performance pattern reported in sustainable lightweight brick and concrete systems.

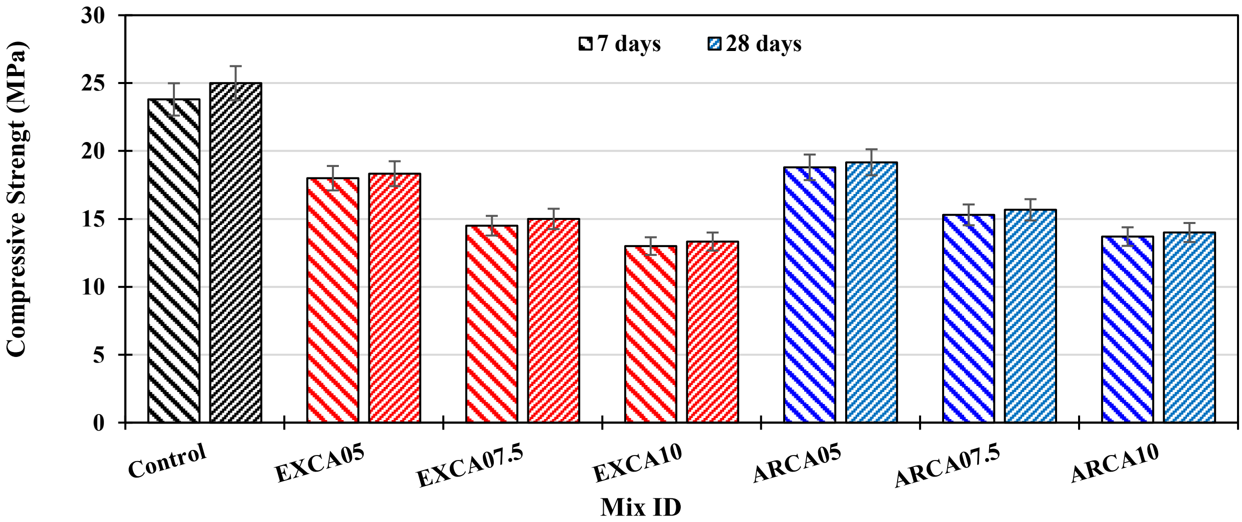

Fig.7: Compressive strength results of cement brick at 7 and 28 days.

3.2. Physical properties

- Unit weight

As demonstrated in Fig. 8, the unit weight analysis at 28 days gives the correct impression of the effect of substituting natural coarse aggregates with EX and AR aggregates on the density properties of cement bricks. The maximum unit weight of 2189 kg/m^3 had been registered in the control mixture. The proportion of EX and AR aggregates had a gradual decrease in the unit weight, mainly because their densities were low in nature. On replacement of CA with EXCA, unit weight reduced by 4.31%, 6.09% and 8.63% at the replacement levels of 5%, 7.5% and 10% percent respectively. This is a significant drop due to a very small specific gravity of the EX-beads, which results in an apparent reduction in the overall density with increasing replacement ratios. These results correspond closely with results obtained by [35,36]. The same declining trend was observed in the mixtures in which CA was replaced with ARCA. The respective weight per unit of the replacements was reduced by 4.06%, 5.58%, and 7.87% percent when replacement ratios of 5%, 7.5%, and 10% percent were used. Whereas the reduction in density can slightly reduce compressive strength and load-bearing capacity of the bricks, it greatly improves thermal insulation properties of the bricks. It thus makes them very suitable for lightweight and energy-saving construction works.

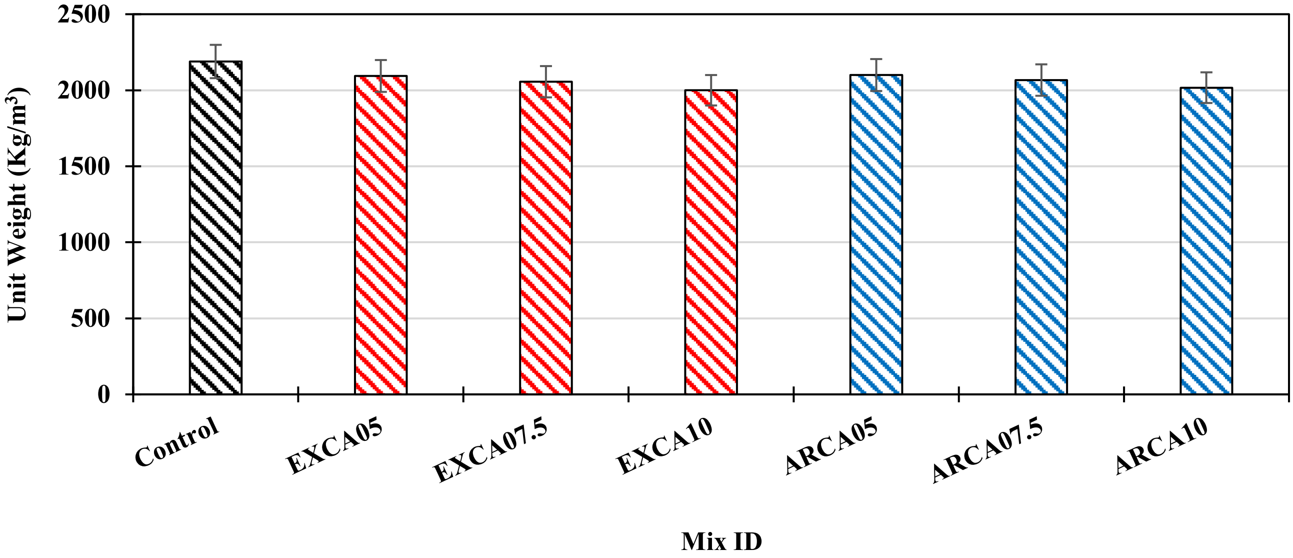

Fig. 8: Unit weight results of cement bricks at 28 days

- Sorptivity test

The unidirectional capillary water absorption over time as a purpose of the rectangular source of time (0.5 seconds) of the sorptivity performance of bricks made of cement with EXCA and ARCA as partial substitutes of natural coarse aggregates (CA) was investigated as shown in Fig. 9. The highest initial sorptivity rate of the control mixture was 7.96 mm/min 1/ 2 L after one hour. Still, it declined a little to 6.82 mm/min 1/ 2 L after six hours. When EXCA aggregates were introduced, there was a significant decrease in the sorptivity at all levels of replacement. With 5%, 7.5% and 10% percent EXCA substitution, one-hour sorptivity dropped by 21.13%, 27.25%, and 35.55% percent and six-hour drop of 28.12%, 35.80% and 40.30% respectively. Such a prominent decrease is indicative of the capacity of EX aggregates to mechanically discontinue capillary networks and limit water migration in the matrix, which is caused by their lightweight, closed-cell morphology and intrinsically low water absorption capacity. The same but less homogenous tendency was noted with bricks with ARCA. The sorptivity after one hour declined by 22.21%, 15.54%, and 11.79% at the replacement level of 5%, 7.5% and 10%, respectively, and after one hour, 18.77%, 11.36% and 9.55% were achieved, respectively. These results are indicators that intermediate use of AR aggregates does improve resistance to moisture ingress, but intensive use is more likely to raise sorptivity. The mechanism behind this reversal is most probably the formation of microvoids and interconnected channels in the matrix because of the porous character of AR aggregates, making it easy to penetrate by water and decreasing the efficiency of the capillary blockage in general.

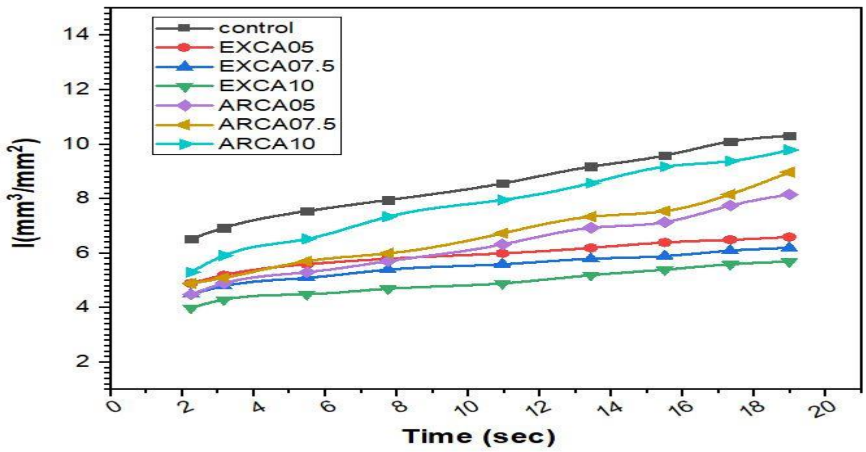

Fig. 9. Sorptivity results of cement bricks.

3.3. Assessment of Thermal Conductivity in Cement Bricks

This study further assessed the thermal performance of solid cement bricks incorporating EXCA and ARCA aggregates, focusing on the variation in thermal conductivity (K) with partial substitution of natural coarse aggregates, as illustrated in Fig. 10. The control mixture exhibited a K-value of 1.38 W/m·K, which served as the reference benchmark for comparison. Progressive replacement of natural aggregates with EXCA resulted in a pronounced reduction in thermal conductivity by 12.32%, 15.06%, and 17.64% at 5%, 7.5%, and 10% replacement levels, respectively. This decline demonstrates the effectiveness of incorporating lightweight, porous materials in reducing heat transfer through the composite matrix. Such reductions are in close agreement with the findings [34,37], which reported similar thermal behavior in lightweight concrete systems containing expanded polystyrene, plastic, and agricultural fillers. These studies attributed the thermal improvement to the alteration of the heat conduction pathway within the composite, where the continuous solid phase is interrupted by air-filled pores, extending the conduction route and increasing thermal resistance. In this mechanism, heat transfer occurs initially through the solid cementitious matrix and subsequently through the entrapped air phase, predominantly by conduction rather than convection, which significantly impedes overall heat flow.

A comparable decreasing trend in K-values was observed for the ARCA-modified mixtures, which showed reductions of 11.47%, 14.53%, and 17.13% at 5%, 7.5%, and 10% substitution levels, respectively, relative to the control. This consistent decrease can be attributed to the low density, cellular structure, and high porosity of AR aggregates, which disrupt the continuity of the thermal conduction network within the brick. These results align with the observations [38,39], found that incorporating natural fibers and agricultural residues into cementitious materials effectively enhances insulation performance due to their internal voids and low intrinsic thermal conductivity.

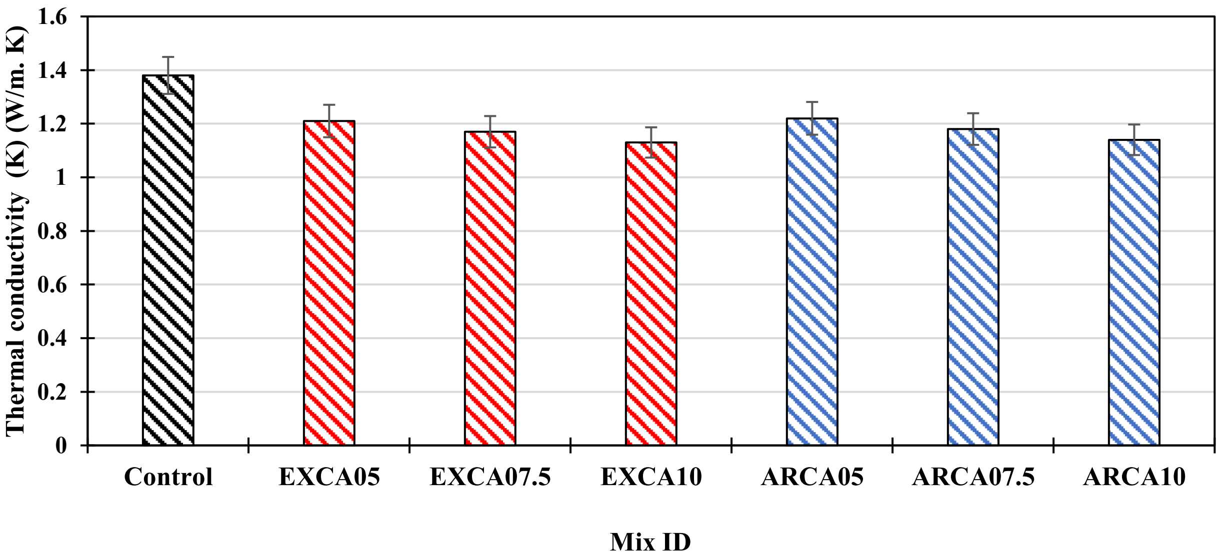

Fig. 10 The Thermal Conductivity in Cement Brick.

Moreover, the relationship between unit weight and thermal conductivity was further analyzed to establish the interdependence between density reduction and insulation enhancement, as depicted in **Fig. 11**. A clear positive correlation was observed, where mixtures with lower unit weight exhibited proportionally lower thermal conductivity values. This correlation indicates that as the inclusion of lightweight aggregates (EXCA and ARCA) increases, the overall density of the cement bricks decreases, leading to a decline in solid-phase heat conduction pathways. The trapped air voids within these aggregates act as thermal barriers that hinder heat transfer across the matrix, thus improving insulation efficiency. This finding is consistent with previous studies [40–42] reported a strong dependence of thermal conductivity on the bulk density of cementitious composites containing lightweight or natural fibrous inclusions. Accordingly, this interrelationship reinforces the dual benefit of density reduction, simultaneously achieving material lightness and enhanced thermal resistance, both of which are critical parameters in developing sustainable and energy-efficient building materials.

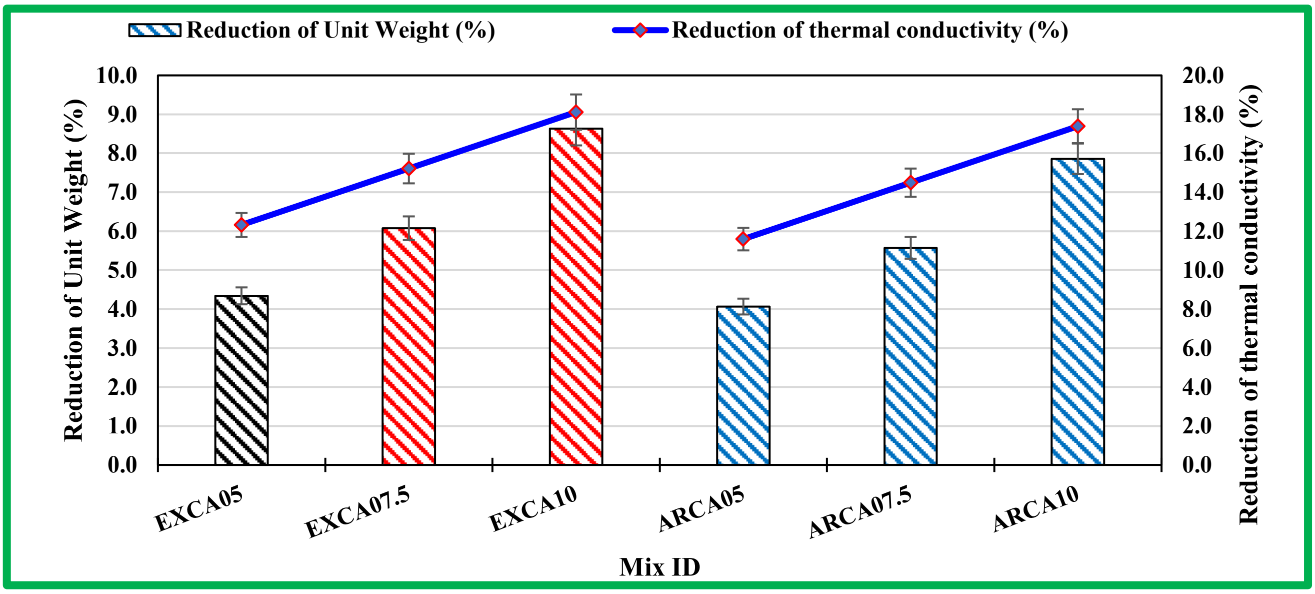

Fig. 11: The relationship between the percentage decrease in conductivity and the unit weight of samples.

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4. Conclusions

- This study demonstrated the feasibility of utilizing packaging waste EX and AR as sustainable substitutes for coarse aggregate in cement bricks.
- Replacing 10% of natural coarse aggregates with EX and AR reduced compressive strength by 46.7% and 44.0%, respectively, while maintaining acceptable levels for lightweight structural applications.
- Brick density decreased by 6.09% compared with the control mix, producing lighter units with potential handling and cost advantages.
- Incorporating 10% EX reduced water absorption by 27.25% after 1 h and 35.8% after 6 h relative to the control, indicating enhanced moisture resistance.
- Thermal conductivity decreased by 17.64%, accompanied by a 2.5 °C reduction in surface temperature and confirming improved thermal insulation under hot climatic conditions.

Finally, this study lies in integrating two environmentally friendly waste materials, EX and AR, to produce lightweight, thermally efficient cement bricks, offering a dual benefit of waste valorization and energy-efficient building solutions.

Future studies should focus on comprehensive durability assessments of the developed eco-friendly cement bricks under long-term environmental exposure, including wet–dry, freeze–thaw, and thermal cycling conditions. Microstructural analyses using techniques such as SEM and XRD are recommended to understand better the interfacial bonding mechanisms between the cement matrix and waste-based aggregates.

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References

[1] M. Fang, R. Zhou, W. Ke, B. Tian, Y. Zhang, J. Liu, Precast system and assembly connection of cement concrete slabs for road pavement: A review, Journal of Traffic and Transportation Engineering (English Edition) 9 (2022). https://doi.org/10.1016/j.jtte.2021.10.003.

[2] A.M. Heniegal, I.S. Agwa, A. Saleem, M.M. Elsied, N.B. Farhat, A new composite sustainable brick for hot-buildings using phase change materials and recycled plastics for improving energy saving and thermal comfort: Experimental and simulation study, Journal of Building Engineering 114 (2025) 114318. https://doi.org/10.1016/j.jobe.2025.114318.

[3] A.M. Heniegal, O. Mohamed, O. Ibrahim, N. Bassim Frahat, M. Amin, Preparation of microencapsulated PCMs for energy-saving and thermal comfort of buildings, n.d.

[4] M. Amin, Y. Elsakhawy, K. Abu El-Hassan, N. Bassim Frahat, Optimizing ceramic waste powder ratios for cost and CO2 emission reduction in high-strength concrete to enhance efficiency and sustainability, Sustainable Structures 2025 (2025) 81. https://doi.org/10.54113/j.sust.2025.000081.

[5] A.M. Heniegal, O.M.O. Ibrahim, N.B. Frahat, M. Amin, Preparation of microencapsulated PCMs for energy saving and thermal comfort of buildings, Journal of University of Shanghai for Science and Technology 23 (2021). https://doi.org/10.51201/jusst/21/09544.

[6] R.F.A. Abd El Aal, A.M.S. Hassan, A.A. elmoneim Fahmi, S.M.A. Ali, M. Abdelhady, Optimizing Courtyard Geometry for Enhanced Indoor Ventilation in Contemporary Residential Buildings, Industrial Technology Journal 0 (2025) 0–0. https://doi.org/10.21608/itj.2025.366033.1022.

[7] M.R. Ali, M. Maslehuddin, M. Shameem, M.S. Barry, Thermal-resistant lightweight concrete with polyethylene beads as coarse aggregates, Constr Build Mater 164 (2018). https://doi.org/10.1016/j.conbuildmat.2018.01.012.

[8] A.M. Seddik Hassan, A. Abdeen, A.S. Mohamed, B. Elboshy, Thermal performance analysis of clay brick mixed with sludge and agriculture waste, Constr Build Mater 344 (2022) 128267. https://doi.org/10.1016/J.CONBUILDMAT.2022.128267.

[9] J. Strzałkowski, P. Sikora, S.Y. Chung, M. Abd Elrahman, Thermal performance of building envelopes with structural layers of the same density: Lightweight aggregate concrete versus foamed concrete, Build Environ 196 (2021). https://doi.org/10.1016/j.buildenv.2021.107799.

[10] N.B. Frahat, A.S. Malek, A. Ali, O.M.O. Ibrahim, New strategy for closing the plastic loop: Lightweight concrete by the waste of recycled synthetic fibers, Constr Build Mater 423 (2024) 135896. https://doi.org/10.1016/J.CONBUILDMAT.2024.135896.

[11] A.H. Medher, A.I. Al-Hadithi, N. Hilal, The Possibility of Producing Self-Compacting Lightweight Concrete by Using Expanded Polystyrene Beads as Coarse Aggregate, Arab J Sci Eng 46 (2021). https://doi.org/10.1007/s13369-020-04886-9.

[12] A.M.S. Hassan, H. Shoukry, P. Perumal, M.M. Abd El-razik, R.M.H. Aly, A.M.Y. Alzahrani, Evaluation of the thermo-physical, mechanical, and fire resistance performances of limestone calcined clay cement (LC3)-based

lightweight rendering mortars, Journal of Building Engineering 71 (2023) 106495. https://doi.org/10.1016/J.JOBE.2023.106495.

[13] Correction to "Application of expanded polystyrene (EPS) in buildings and constructions: A review"(J Appl Polym Sci, (2019), 136, 47, (529), 10.1002/app.47529), J Appl Polym Sci 141 (2024). https://doi.org/10.1002/app.54965.

[14] G.O. Bamigboye, K. Tarverdi, A. Umoren, D.E. Bassey, U. Okorie, J. Adediran, Evaluation of eco-friendly concrete having waste PET as fine aggregates, Cleaner Materials 2 (2021). https://doi.org/10.1016/j.clema.2021.100026.

[15] A.M. Seddik Hassan, R.M.H. Aly, A.M.Y. Alzahrani, M.M. Abd El-razik, H. Shoukry, Improving fire resistance and energy performance of fast buildings made of hollow polypropylene blocks, Journal of Building Engineering 46 (2022) 103830. https://doi.org/10.1016/J.JOBE.2021.103830.

[16] A.M. Zeyad, M. Shubaili, N.B. Frahat, A.H. Khan, I.S. Agwa, Evaluation of sustainable lightweight concrete incorporating popcorn and pumice aggregates with sugarcane leaf ash, Sustain Chem Pharm 45 (2025) 101975. https://doi.org/10.1016/J.SCP.2025.101975.

[17] N.B. Frahat, A.S. Awed, S.M. Kassem, M.I.A. Abdel Maksoud, O. Mohamed Omar Ibrahim, Innovative shielding solutions by geopolymer paste and fly ash as effective substitution of cement materials for sustainable protection, Journal of Building Engineering (2024) 108977. https://doi.org/10.1016/J.JOBE.2024.108977.

[18] S.A. Mostafa, I.S. Agwa, B. Elboshy, A.M. Zeyad, A.M. Seddik Hassan, The effect of lightweight geopolymer concrete containing air agent on building envelope performance and internal thermal comfort, Case Studies in Construction Materials 20 (2024) e03365. https://doi.org/10.1016/J.CSCM.2024.E03365.

[19] V. Fiore, T. Scalici, A. Valenza, Characterization of a new natural fiber from Arundo donax L. as potential reinforcement of polymer composites, Carbohydr Polym 106 (2014). https://doi.org/10.1016/j.carbpol.2014.02.016.

[20] N.B. Frahat, O.M.O. Ibrahim, I.S. Agwa, M.M. Attia, A.M. Zeyad, S.G. Desouky, Effect of eggshell powder as fly ash replacement and nutrient source for bacteria on the properties and self-healing of geopolymer concrete, Innovative Infrastructure Solutions 10 (2025) 410. https://doi.org/10.1007/s41062-025-02197-2.

[21] A.H. Abo Alela, B. Elboshy, A.M. Seddik Hassan, A.S. Mohamed, E.N. Shaqour, Effect of the Addition of Sawdust on Clay Brick Construction Properties and Thermal Insulation: Experimental and Simulation Approaches, Journal of Architectural Engineering 30 (2024). https://doi.org/10.1061/jaeied.aeeng-1676.

[22] E.N. Shaqour, et al., Life Cycle Impact Assessment of Solid Concrete Blocks Incorporating Recycled Fine and Coarse Crushed Ceramic Aggregates, Journal of Architectural Engineering 31 (2025) 05024010.

[23] Standard Specification for Portland Cement 1, n.d. https://standards.iteh.ai/catalog/standards/sist/d04e0644-47ea-401a-a4c4-dc6e8962ed23/astm-c150-00.

[24] ASTM C33/C33M-18, Standard Specification for Concrete Aggregates 1, (n.d.). https://doi.org/10.1520/C0033_C0033M-1.

[25] ACI Committee 213, Guide for Structural Lightweight-Aggregate Concrete - (ACI 213R-03), ACI Manual of Concrete Practice (2013).

[26] ASTM C67/C67M-23a, Test Methods for Sampling and Testing Brick and Structural Clay Tile, (2023). https://doi.org/10.1520/C0067_C0067M-23A.

[27] ASTM-C1585-13, Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, (2013). https://doi.org/10.1520/C1585-13.

[28] A.M. Heniegal, O.M. Omar Ibrahim, N.B. Frahat, M. Amin, New techniques for the energy saving of sustainable buildings by using phase change materials, Journal of Building Engineering 41 (2021). https://doi.org/10.1016/j.jobe.2021.102418.

[29] ASTM, ASTM C 177 - Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus, Annual Book of ASTM Standards (2010).

[30] A.M. Heniegal, O.M.O. Ibrahim, N.B. Frahat, M. Amin, Thermal and Mechanical Properties of Mortar Incorporated with Phase Change Materials (PCMs), Key Eng Mater 921 (2022) 259–269. https://doi.org/10.4028/p-f0qyby.

[31] N.B. Frahat, M. Amin, A.M. Heniegal, K.S. El-Alfy, H.H. Hassan, Effect of Phase Change Materials on Optimization of Thermal Properties of Concrete, Key Eng Mater 1020 (2025) 91–100. https://doi.org/10.4028/p-afxey8.

[32] A.J. ADEALA, O.B. SOYEM, Structural Use of Expanded Polystyrene Concrete, Int J Innov Sci Res Technol 5 (2020). https://doi.org/10.38124/ijisrt20jun849.

[33] Y.A.Y. Ali, E.H.A. Fahmy, M.N. AbouZeid, Y.B.I. Shaheen, M.N.A. Mooty, Use of expanded polystyrene in developing solid brick masonry units, Constr Build Mater 242 (2020). https://doi.org/10.1016/j.conbuildmat.2020.118109.

[34] M.I. Abdelhady, M.A. Elsayed, A.A. Elmoneim Fahmi, N.B. Frahat, Energy-saving potential in buildings by cement bricks made with date seed aggregates and Arundo donax fiber with thermal and mechanical assessment, Energy Build 345 (2025). https://doi.org/10.1016/j.enbuild.2025.116140.

[35] Y. Xu, L. Jiang, J. Xu, Y. Li, Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick, Constr Build Mater 27 (2012). https://doi.org/10.1016/j.conbuildmat.2011.08.030.

[36] A.M. Heniegal, N.B. Frahat, M.M. Elsied, I.S. Agwa, Innovative technique for sustainable lightweight cement bricks incorporating popcorn coarse aggregate and PCM: Optimization of thermal, mechanical, and physical properties, Constr Build Mater 493 (2025). https://doi.org/10.1016/j.conbuildmat.2025.143262.

[37] S.S. Abdulhussein, I. Johari, N.M. Fawzi, Mechanical properties of sustainable structural aerated-polystyrene concrete, World Journal of Engineering (2024). https://doi.org/10.1108/WJE-01-2024-0047.

[38] W. Wang, W. Wei, S. Gao, G. Chen, J. Yuan, Y. Li, Agricultural and Aquaculture Wastes as Concrete Components: A Review, Front Mater 8 (2021). https://doi.org/10.3389/fmats.2021.762568.

[39] X. Xie, W. Zhang, X. Luan, W. Gao, X. Geng, Y. Xue, Thermal performance enhancement of hollow brick by agricultural wastes, Case Studies in Construction Materials 16 (2022). https://doi.org/10.1016/j.cscm.2022.e01047.

[40] D. Saradhi Babu, K. Ganesh Babu, W.T. Huan, Mechanical properties of lightweight expanded polystyrene concrete containing fly ash, Indian Concrete Journal 80 (2006).

[41] F. Collet, S. Pretot, Thermal conductivity of hemp concretes: Variation with formulation, density and water content, Constr Build Mater 65 (2014). https://doi.org/10.1016/j.conbuildmat.2014.05.039.

[42] Y. Aocharoen, P. Chotickai, Compressive mechanical and durability properties of concrete with polyethylene terephthalate and high-density polyethylene aggregates, Clean Eng Technol 12 (2023). https://doi.org/10.1016/j.clet.2023.100600.