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Coconut husk ash as a sustainable binder for compressed bricks: A green technology solution for environmental sustainability

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Abstract. The rising cost of cement and concerns about waste management in Malaysia have encouraged the search for alternative construction materials. This study investigates the use of coconut husk ash (CHA) as a partial replacement for cement in compressed bricks. The objective was to compare the physical and mechanical properties of CHA bricks with conventional bricks, focusing on density, water absorption, and compressive strength. Bricks were prepared using a cement to sand ratio of 1:6, with 5%, 10%, and 15% CHA by volume. Standard laboratory procedures were applied to ensure consistent results. The results revealed a positive correlation between the compressive strength and CHA content, with higher CHA percentages enhancing strength. The density of CHA bricks increased with greater CHA content, indicating improved compactness and structural integrity. For instance, the 15% CHA brick exhibited the lowest water absorption value of 15.4% compared to 16.4% for the conventional brick. These findings demonstrate the potential of CHA as a sustainable alternative material for low-cost housing, offering improved physical and mechanical properties compared to conventional bricks.

1. Introduction

The construction sector continues to face two major challenges i.e. rising costs of raw materials and environmental impacts from conventional practices. Cement, a key ingredient in most construction projects, requires high energy input and contributes significantly to carbon emissions during production. The release of carbon dioxide and other pollutants during cement

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manufacturing adversely affects air quality and climate change [1]. In Malaysia, the unit price of cement has shown an upward trend, while demand for affordable housing also increases. These conditions create a strong need for more sustainable alternatives. Agricultural by-products, such as coconut husks, are often discarded or openly burned, which adds to local pollution problems. Converting this waste into coconut husk ash (CHA) provides a way to reduce disposal issues while creating value for the construction industry. Malaysia produces large amounts of coconut waste from small farms and roadside stalls, yet little of it is recycled. By reusing CHA in compressed bricks, both environmental and economic benefits may be achieved, particularly for low-cost housing projects.

The study of using CHA can also reduce waste in agriculture. In Malaysia, there is a need to be more aware of recycling organic material. In Malaysia, farmers burn agriculture waste without proper utilisation worsens environmental pollution. It can be reduced by recycling coconut waste and using it in bricks, reducing agricultural waste, and reusing natural materials. From April 2024 to April 2025, the cement unit price index increased by up to 3.5%, with the highest rise recorded in Johor and Tawau, followed by Pahang (3.3%). Meanwhile, the average price of ordinary Portland cement (OPC) rose marginally by 0.2%, reaching RM23.70 per 50 kg bag in April 2025 compared to RM23.60 in March. These findings indicate a moderate upward trend in cement prices, reflecting supply constraints and demand pressures within the construction sector [2]. Although coconut husk currently has no market value as agricultural waste, it is easily found in coconut stalls and farm areas, as depicted in figures 1 (a) and (b), respectively. It is targeted for use in the low-cost housing industry. In comparison, producing OPC involves high costs, whereas coconut husk is readily available at no monetary expense since coconut husks are commonly discarded as waste.

(a) (b)

Figure 1. Current issues related with coconut husk; (a) coconut husk that was thrown away from the stall at Nibong Tebal and (b) agriculture waste such as coconut husk being burned at Jalan Kampung Kuala Bagan Tiang.

The significance of this project lies in its potential contribution to low-cost housing initiatives. The affordability and sustainability challenges in the housing sector can be addressed by exploring the use of CHA as a partial replacement for OPC in construction materials. Incorporating CHA can reduce the overall cost of construction materials. OPC production involves significant expenses, while coconut husk is abundant and often considered waste [3]. By utilizing this readily available resource, the material costs associated with low-cost housing projects can potentially be lowered, making them more affordable and accessible to a broader population. This research aims to study the utilisation of CHA in the production of compressed bricks. The purpose is to study the physical and mechanical properties of CHA in compressed bricks and to compare the result with conventional brick.

2. Materials and methods

2.1 Materials

2.1.1 Cement and sand
The cement used in this study was selected according to rigorous engineering standards, including BS EN 197-1:2011 [4], to ensure it met the necessary requirements for compressive strength, fineness, and chemical composition. This ensures consistency and reliability during the experiments. The sand was selected based on the specifications outlined in BS EN 771-3:2011 [5], which provides guidelines for aggregates used in masonry units, including bricks. The sand was sieved using a No. 4 sieve (4.75 mm) as per BS EN 933-1:2012 [6] standards to ensure the removal of coarse aggregates and compliance with the required grading distribution.

2.1.2 Coconut husk ash (CHA)
Coconut husks were collected and prepared through a systematic process to ensure quality and consistency. The material shown in the figure 2 (a) is coconut husk powder that has been dried and ground but not yet subjected to the ashing process. The husks were dried under sunlight until moisture reduced to ∼10 – 12%, after which they were ground into powder. At this stage, the material retains its natural brown colour as it still contains lignocellulosic components. The powder serves as a precursor material, which will later be burned in a controlled furnace at high temperatures (approximately 600 – 800°C) to produce CHA. The dried husks were burned in a furnace at 600°C for 3 hours as shown in figure 2 (b). This temperature was selected based on studies showing optimal silicon dioxide (SiO_2) production, which contributes to the strength and durability of bricks [7]. The resulting ash was sieved using a No. 200 sieve (75 μm) to achieve a fine texture comparable to cement [5]. The sieved CHA is shown in figure 2 (c), ensuring uniform particle distribution for effective blending with cement.

(a) (b) (c)

Figure 2. CHA preparation process; (a) coconut husk under sunlight, (b) dried husk after burning for 3 hours at 600°C, and (c) CHA after sieving.

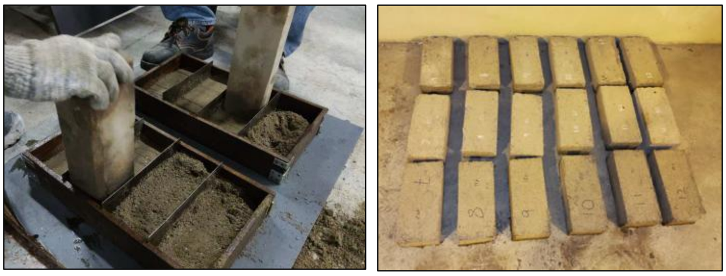
2.2 Methods

2.2.1 Mix design
The experiment was designed to compare conventional compressed bricks with those incorporating different percentages of CHA (0%, 5%, 10%, and 15%). A total of 48 samples were prepared, ensuring adequate representation of each variation for testing physical properties (density and water absorption) and mechanical properties (compressive strength) at 7 and 28 days. The mix design followed a cement-to-sand ratio of 1:6 and a water-to-cement ratio of 1:0.5, as per *Jabatan Kerja Raya* (JKR) standards [8]. CHA replaced cement at 0%, 5%, 10%, and 15% by

volume. The final bricks adhered to BS EN 771-1:2011 [5] dimensions (215 mm x 103 mm x 65 mm), ensuring compatibility with standard construction practices.

2.2.2 Sample production

The materials were mechanically mixed using a rotary drum mixer for 5 minutes to ensure a uniform and homogeneous blend. The mixture was poured into moulds and pressed to form bricks of consistent size and shape as shown in figure 3 (a). Bricks were demoulded and cured for 7 days at 27 ± 2°C and 80 – 85% relative humidity (RH) under controlled environmental conditions as shown in figure 3 (b). For 28-day testing, the bricks were stored under similar controlled conditions to facilitate further hydration and hardening.



(a) (b)

Figure 3. Sample production; (a) mixture was moulded and pressed to form brick and (b) bricks left for curing.

2.2.3 Testing

2.2.3.1 Water absorption and density test

The water absorption test was conducted following ASTM C140:08 [9] and IS 3495 (Part 2):1992 standards [10]. According to the standard requirements, the water absorption should not exceed 20% by weight for bricks classified as Class 12.5 [10]. Bricks were immersed in water at 15.6 to 26.7°C for 24 hours. The immersion water was maintained within this temperature range under laboratory control, with regular thermometer checks to ensure consistency. Water absorption was determined from the difference between the saturated and dry weights, normalized by the dry weight. The density test was conducted per IS 2185 (Part 1):2005 [11]. The density test was carried out at 7 and 28 days of curing. At this stage, the dry weight of each brick was recorded, followed by the measurement of its dimensions using a vernier calliper and ruler to calculate the volume. The density was then obtained by dividing the dry mass by the calculated volume. The load-bearing units shall have a minimum brick density of 1 500 kg/m^3 for Grade A standard [11].

2.2.3.2 Colour comparison of different percentage of brick

A colour comparison test was carried out to observe the effect of CHA on brick appearance. Bricks with 0%, 5%, 10%, and 15% CHA were placed side by side under uniform lighting and photographed daily for 28 days. Changes in colour tone and intensity, particularly the darkening from ash content and moisture during curing, were visually inspected to assess the aesthetic impact.

2.2.3.3 Compressive strength test

The compressive strength of the bricks was evaluated by following BS 5628 standards [12]. The compressive strength test was conducted on samples after 7 and 28 days of curing. The test involved applying maximum compressive force to each sample to determine its load-bearing capacity. A minimum compressive strength of 5 MPa was required per the standard. The deformation of the bricks during testing was also recorded to assess their structural performance.

3. Results and discussion

3.1 Water absorption test

The results of the water absorption tests conducted on both 7-days and 28-days CHA bricks revealed notable improvements in their water resistance properties compared to the conventional bricks, as shown in figure 4. At 7 days, the results indicate a decreasing trend in water absorption with increasing CHA content. The conventional brick exhibited the highest water absorption value of 16.4%, while the bricks with 5% CHA showed a slightly lower percentage of 15.8%. Further reduction was observed for the bricks with 10% CHA (15.7%), and the lowest value was recorded for the bricks with 15% CHA (15.4%).

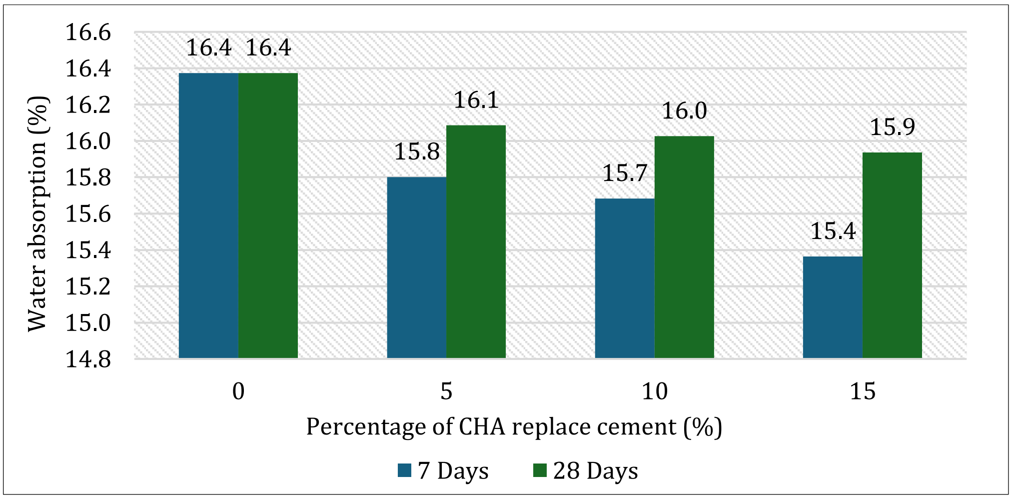


Figure 4. Comparison of water absorption test for compressed bricks.

At 28 days, the conventional brick again showed the highest water absorption value of 16.4%, while the CHA bricks with 5%, 10%, and 15% replacement recorded slightly lower percentages of 16.1%, 16.0%, and 15.9%, respectively. These results demonstrate that incorporating CHA into the brick composition consistently reduces water absorption compared to the control. Interestingly, a slight increase in water absorption was noted for CHA bricks after 28 days compared to their 7-day results. This difference cannot be attributed solely to curing duration, as the testing conditions were identical for both ages. Instead, the increase is likely related to microstructural and chemical changes occurring during extended curing, such as the continued hydration of cementitious compounds and the hygroscopic nature of calcium chloride present in the mix, which may promote additional moisture uptake [14]. Nevertheless, the magnitude of the increase was relatively small, indicating that CHA incorporation still enhances the overall water resistance of the bricks.

Lower water absorption remains a desirable property for construction bricks, as it signifies resistance to moisture penetration and contributes to the durability and longevity of structures by reducing the risk of efflorescence, cracking, and degradation [13]. Nonetheless, it is worth mentioning that even with the slight increase in water absorption after 28 days of curing, the overall values for the CHA bricks remain within the acceptable limit of 20%, as specified in IS 3495

(Part 2):1992 [10]. These results indicate that incorporating 5%, 10%, and 15% CHA as a partial replacement for cement in compressed bricks can still provide good water resistance properties. The presence of CHA, with its pozzolanic properties and high silica content, enhances the density and compactness of the bricks, resulting in reduced pore connectivity and decreased water absorption [7]. This improvement can be attributed to the filler effect of CHA, which fills voids and minimizes water penetration pathways. In conclusion, while the water absorption percentages for the CHA bricks with 5%, 10%, and 15% replacement show a marginal increase after the 28-day curing period compared to the 7-day period, the difference is not significant. Therefore, incorporating CHA in compressed brick manufacturing can effectively enhance water resistance, durability, and overall performance, regardless of the specific curing period within this timeframe.

3.2 Density test

The density test is a fundamental evaluation performed on the compressed bricks with varying percentages of CHA replacement. Density is a crucial parameter as it influences the overall strength, durability, and thermal properties of bricks. The results for both 7-day and 28-day curing are presented in figure 5. At 7 days of curing, the conventional brick without CHA replacement exhibited a density of 1 936 kg/m^3, while the bricks with 5%, 10%, and 15% CHA replacement showed densities of 1 947 kg/m^3, 1 969 kg/m^3, and 1 982 kg/m^3, respectively. At 28 days of curing, the corresponding densities were slightly lower, with values of 1 936 kg/m^3 for the control, and 1 940 kg/m^3, 1 957 kg/m^3, and 1 971 kg/m^3 for 5%, 10%, and 15% CHA replacement, respectively. All values exceeded the minimum density requirement of 1 500 kg/m^3 as specified in IS 2185 (Part 1):2005 [11], confirming the suitability of these bricks for construction applications.

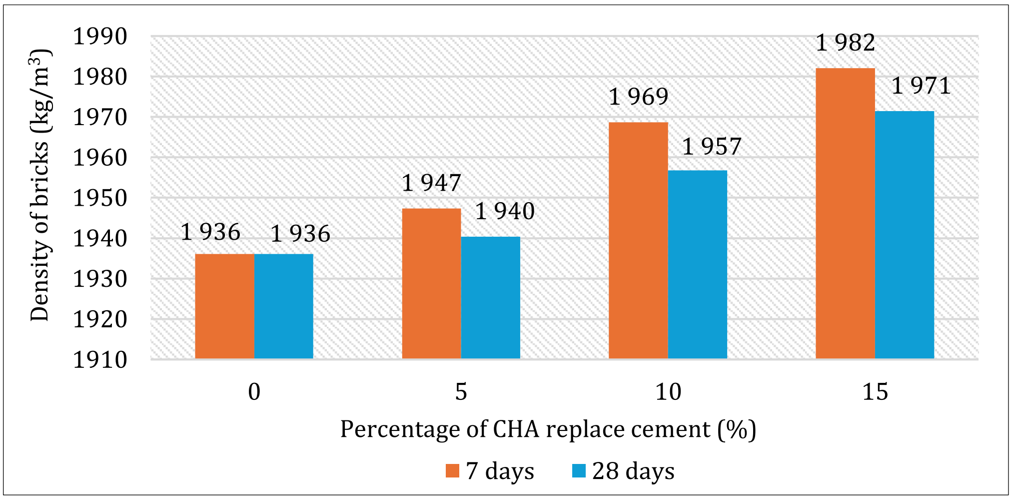


Figure 5. Comparison of density test for compressed bricks.

Interestingly, the results indicate that the density of CHA bricks was marginally higher at 7 days than at 28 days. This observation suggests that early-age compaction and microstructural packing due to CHA's filler effect may initially contribute to higher density. However, as hydration continues, slight microstructural changes or the development of voids within the matrix could account for the marginal reduction observed at 28 days. Despite this reduction, the differences were relatively small, and the overall trend still highlights the role of CHA in enhancing density compared to the control brick. The presence of silica-rich particles in CHA contributes to a denser matrix by reducing porosity and improving particle packing, which in turn enhances the durability and performance of the bricks [15]. Previous studies also reported that converting coconut husk into ash improves its bonding potential compared to raw fibre, leading to better integration within the cementitious matrix [16]. Overall, the study indicates that replacing part of the cement with CHA leads to higher brick density compared to the control samples. Although the density measured at 7 days was slightly greater than at 28 days, all values remained above the required minimum, confirming that CHA bricks can maintain adequate structural strength and are suitable for construction applications.

3.3 Relationship between density and water absorption in compressed bricks incorporating CHA at 28 days

Understanding how density relates to water absorption is important when assessing the physical behaviour of compressed bricks, as illustrated in Figure 6. The analysis shows that a clear relationship exists between these two parameters, providing useful insight into the durability and structural performance of the bricks. The results reveal that as the proportion of CHA in the mix increases, brick density also rises. This outcome is linked to the role of CHA in contributing additional mass and improving the compactness of the brick matrix, which in turn supports better performance. The increase in density suggests a more solid and less porous structure, which typically correlates with lower water absorption capacity.

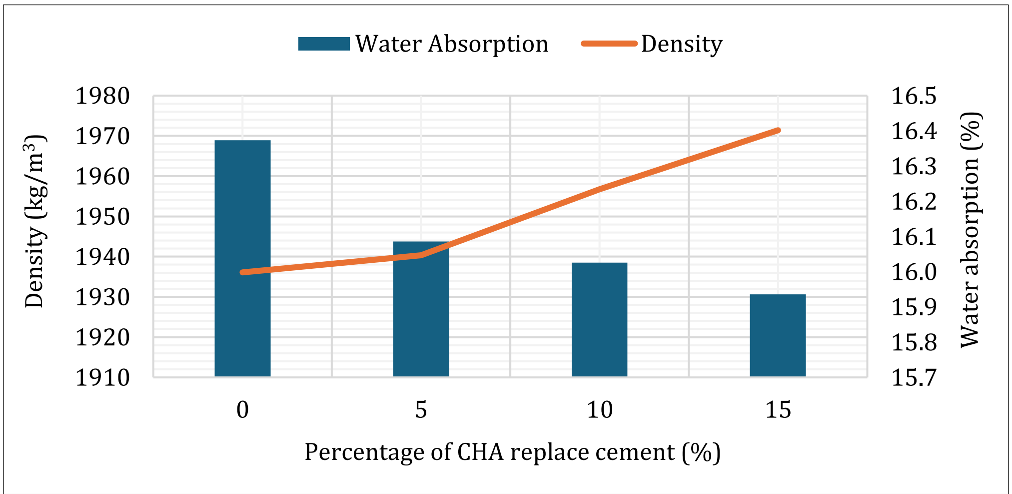
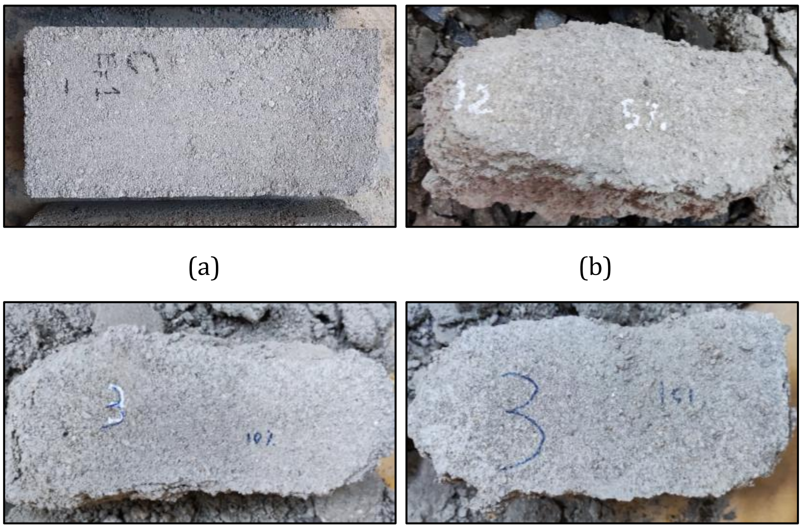


Figure 6. Relationship between density and water absorption in compressed bricks incorporating CHA at 28 days.

3.4 Colour comparison of bricks at different percentages

Cement sand bricks typically exhibit a uniform colouration that may vary depending on raw material composition, manufacturing process, and curing conditions. On the first day, the colour of the bricks appeared darker due to the presence of moisture. After curing, the final appearance is more stable, and the variation in colour is primarily influenced by the incorporation of CHA, as illustrated in figures 7 (a) to (d). At 28 days, differences in colour intensity became evident with increasing CHA content. Bricks with higher percentages of CHA tended to exhibit a slightly darker hue with visible black ash particles, reflecting the influence of ash incorporation. This darker appearance is associated with the presence of silica-rich particles from CHA, which alter the surface texture and colour of the matrix. The colour variation did not significantly affect the overall performance of the bricks but added a distinct aesthetic characteristic that highlights the utilisation of CHA as a partial cement replacement. In addition, some irregular or non-rectangular shapes observed in the 5%, 10%, and 15% CHA samples were attributed to fracture patterns developed during the compression test. While the edges and corners of the bricks showed brittleness and fragmentation, the central portions retained greater integrity. This behaviour reflects non-uniform stress distribution under loading, leading to localized damage and irregular specimen geometry.



(a) (b)

(c) (d)

Figure 7. Variation in colour intensity of compressed bricks according to CHA content (0 – 15%) after 28 days of curing; (a) 0% CHA, (b) 5% CHA, (c) 10% CHA, and (d) 15% CHA.

3.5 Compression strength test

The compression strength test is crucial to assessing compressed bricks' mechanical properties and structural integrity. By subjecting the bricks to compressive forces until failure, the compression strength test provides valuable insights into the overall strength and quality of the bricks. The compressive strength of compressed bricks with varying percentages of CHA as a partial replacement for cement that was evaluated at 7 days, and 28 days of curing is shown in figure 8. The results obtained at each time point provide insights into the bricks' early and long-term strength development.

After 7 days of curing, all tested CHA percentages, including 5%, 10%, and 15%, exhibited compressive strengths exceeding the minimum requirement of BS 5628 which is 5 MPa [12]. The compressive strength of conventional bricks falls below the minimum requirement specified by BS 5628, indicating that it may not possess adequate strength for short-term applications. The highest compressive strength was observed in the 15% CHA replacement batch, valued at 8.620 MPa. The result of the 15% CHA brick indicates that incorporating CHA in the production process can significantly enhance the compressed bricks' strength, surpassing the standard's stipulated threshold. At 28 days of curing, the compressive strength of the conventional brick was 5.250 MPa. However, the CHA-based bricks showed increased compressive strength at 6.211 MPa for 5% CHA, 6.325 MPa for 10% CHA, and 6.478 MPa for 15% CHA. These findings indicate that even with prolonged curing, the compressed bricks retained their strength and fulfilled the minimum compressive strength criteria set by the standard.

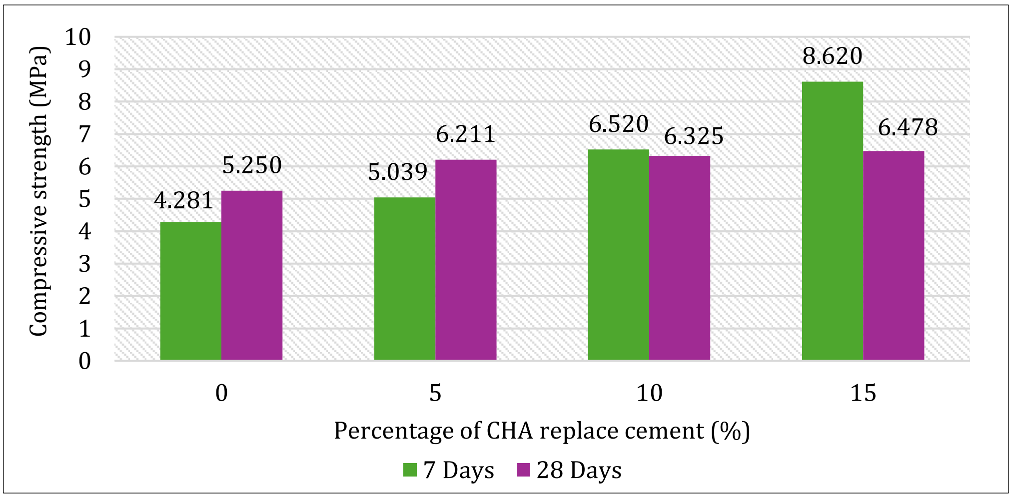


Figure 8. Comparison of the compressive strength of compressed bricks after 7 and 28 days.

The comparison of 7-day and 28-day compressive strength results reveals interesting trends concerning the CHA content. For the CHA bricks with 10% and 15% CHA content, the compressive strength at 7 days exceeds that at 28 days, suggesting that these mixtures demonstrate early strength gain and achieve higher strength levels within a shorter curing period. On the other hand, for the CHA bricks with 0% (conventional bricks) and 5% CHA content, the compressive strength at 7 days is lower than that at 28 days, which can be attributed to the continued hydration of Ordinary Portland Cement (OPC) in low CHA mixes that promotes further strength gain over time. However, the strength values for the 5%, 10%, and 15% CHA mixtures remain relatively consistent between the two curing ages, indicating that higher CHA replacement contributes to a more stable strength development pattern.

This unexpected outcome suggests that calcium chloride might harm the compressive strength development during the 28-day curing period. One possible explanation for this phenomenon is that calcium chloride has a high affinity for moisture absorption. During the curing process, calcium chloride might have accelerated moisture evaporation from the brick, reducing hydration and weaker cementitious bonds [14]. The result indicates that these mixtures require a longer curing time to reach their optimal strength. The results suggest that incorporating CHA can play an important role in the early strength development of compressed bricks. This also shows the need to assess both short-term and long-term strength behaviour when evaluating the impact of CHA content. The trend indicates that strength gains may peak at a certain percentage of CHA, meaning that while CHA contributes to early-age performance, there could be an optimal replacement level for long-term compressive strength.

In addition, both OPC and CHA demonstrate pozzolanic activity, reacting with calcium hydroxide to generate cementitious compounds. This reaction produces extra calcium silicate hydrates, which enhance the strength, durability, and overall performance of brick materials [17]. The variations observed between the 7-day and 28-day compressive strength can be linked to ongoing hydration and curing. As hydration progresses, more cementitious gel forms, contributing to strength improvement in the early stages [18]. Nevertheless, other factors such as the influence of CHA on hydration rate and long-term durability may also explain the differences noted. The observed improvements in compressive strength of CHA bricks can be closely associated with the corresponding trends in water absorption and density. As the CHA content increased, the bricks exhibited lower water absorption and higher density, indicating reduced porosity and better

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compaction of the internal matrix. A denser microstructure minimizes voids and enhances the continuity of the cementitious phase, which in turn facilitates more efficient stress distribution under compressive loads. Additionally, lower water absorption suggests fewer capillary pores, which not only improves durability but also contributes to the mechanical integrity of the bricks. The synergistic effect of reduced porosity and increased particle packing due to the fine CHA particles promotes stronger interfacial bonding, thereby enhancing the overall compressive strength. These interlinked physical and mechanical improvements affirm that CHA contributes significantly to the performance enhancement of compressed bricks when used as a partial cement substitute. In summary, the results of this study demonstrate the potential of CHA as a cement replacement in compressed brick production, showcasing its ability to contribute to the compressive strength development of the bricks. These findings contribute to the body of knowledge in civil engineering and encourage further exploration and utilisation of CHA as a sustainable construction material.

4. Conclusion

This study shows that incorporating coconut husk ash in compressed brick production can enhance water resistance, increase density, and improve compressive strength compared to conventional bricks. The 5% CHA mixture, for instance, demonstrated a 17% strength increase, while higher CHA levels continued to perform above the control samples. Although the 10% and 15% mixes recorded slightly lower strengths at 28 days compared to 7 days, their values remained higher than the conventional brick. The results indicate that CHA is a feasible option for developing affordable and eco-friendly building materials. Its use also supports the recycling of agricultural waste, aligning with Malaysia’s sustainability goals. However, the present work was limited to laboratory-scale testing under controlled curing conditions. Further pilot studies in real construction environments are recommended before large-scale adoption. This study's contributions align with the Sustainable Development Goals (SDGs), particularly SDG 9: Industry, Innovation, and Infrastructure and SDG 11, Sustainable Cities and Communities.

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