Engineered Science
DOI: https://dx.doi.org/10.30919/es1492

Eco-Innovative Hollow Concrete Blocks with Diatomite and Sugarcane Bagasse Ash: Advancing Sustainability in Construction Material

Panuwat Joyklad,[1, 2] Burachat Chatveera,[3,*] Ali Ejaz,[4] Panumas Saingam,[5] Natt Makul,[6] Qudeer Hussain,[7] Mohammad Noor Jan Ahmadi,[8] Kriti Shrestha[9] and Gritsada Sua-iam[10,*]

Abstract

This paper examines diatomite (DM) and sugarcane bagasse ash (SBA) for use as partial replacements for fine aggregates in the manufacture of hollow concrete blocks, which are used in non-structural applications. Several key findings were recorded through tests on mechanical and durability performance. Substitution of fine aggregates with DM or SBA significantly reduced the bulk density, with SBA having a slightly higher reduction. Concrete compressive strength stabilizes after 28 days, with 20% replacement of DM and SBA resulting in significant strength reductions-83.7% for DM and 46.2% for SBA. Thermal conductivity showed a remarkable reduction of 65.4% and 47.3%, respectively. Moreover, the DM addition significantly improved the sound absorption capacity due to the increased void fraction. These results underline the viability of DM and SBA as sustainable alternatives to fine aggregates, exhibiting superior thermal and acoustic performances besides offering solutions to environmental concerns on the use of wastes.

Keywords: Hollow concrete block; Diatomite; Sugarcane bagasse ash; Non-structural masonry; Durability; Construction material; Buildings; Concrete; Recycling; Sustainable development.
Received: 19 January 2025; Revised: 10 March 2025; Accepted: 04 April 2025.
Article type: Research article.

1. Introduction

Waste management has become significantly expensive due to the high financial investments and efforts involved, often leading to the contamination of water resources. Its low biodegradability and strict environmental regulations pose considerable challenges for recycling and disposal.[1-3] Consequently, utilizing these materials in construction contributes to environmental protection by conserving scarce natural resources like aggregates, lowering energy consumption, and reducing carbon dioxide emissions.[4-8] However, despite these environmental advantages, the implementation of such sustainable practices remains limited in scale, highlighting the necessity of developing innovative markets to diversify their use into new products.[9-12]

Hollow concrete blocks are among the most commonly utilized units in building construction, especially in underdeveloped nations. Their popularity is largely due to their low thermal conductivity and efficient material utilization, making them an economically and environmentally favorable choice for constructing concrete walls in primarily hot and arid regions. Masonry walls built with these blocks offer multiple benefits, including structural support, sound insulation, and fire resistance.[13] Recently, innovative approaches to partially substitute traditional

[1] *Department of Civil and Environmental Engineering, Faculty of Engineering, Srinakharinwirot University, Nakhonnayok, 26120, Thailand*
[2] *Center of Excellence in Rail System Technology and Civil Engineering Material Innovation for Sustainable Infrastructure, Strategic Wisdom and Research Institute, Srinakharinwirot University, Bangkok, 10110, Thailand*
[3] *Department of Civil Engineering, Faculty of Engineering, Thammasat University (Rangsit campus), Pathum Thani, 12121, Thailand*
[4] *National Institute of Transportation, National University of Sciences and Technology, Islamabad, 44000, Pakistan*
[5] *Department of Civil Engineering, School of Engineering, King Mongkut's Institute of Technology, Bangkok, 10520, Thailand*

components analogous to cement or aggregates with substitute resources, like plastic or rubber, have gained significant traction.[14-17] Numerous studies have explored the development of environmentally sustainable hollow concrete masonry blocks.[18,19] These studies focus on achieving sufficient compressive strength while incorporating waste materials into the mix, ultimately aiming to reduce production costs and minimize environmental pollution.

Shekhar and Godihal investigated the exploitation of recycled concrete aggregates (RCA) and fly ash (FA) to produce rectangular and circular hollow concrete blocks, substituting 30%–90% of natural aggregates and 15%–45% of cement.[20] Their findings showed at least a cost reduction of 17% and a 30%–40% reduction in CO_2 emissions during production. The study emphasizes the environmental and economic advantages of adopting RCA and FA in sustainable construction practices. Wu *et al*.[21] developed fired hollow blocks using shale, building, and industrial waste to address energy overuse and environmental issues in China. They produced 365 mm × 248 mm × 249 mm blocks having a density of 850 kg/m³, achieving high compressive strength and dependable insulation behavior that met Chinese standards. These self-insulating blocks eliminate the need for additional insulation in masonry, reducing construction costs and energy consumption while promoting sustainable building practices. Herrera-González *et al*.[22] explored using chemical industry waste in Mexico as a partial substitute for Portland cement in manufacturing hollow concrete blocks to reduce environmental impact and promote sustainability. The hollow concrete blocks produced demonstrated low water absorption, slightly improved thermal conductivity, and compressive strengths suitable for commercial use. The study highlights the minimal pre-treatment required for the waste material, reducing carbon footprints and enhancing its practicality through microstructural characterization techniques.

[6] *Department of Civil Engineering Technology, Faculty of Industrial Technology, Phranakhon Rajabhat University, Bangkok, 10220, Thailand*

[7] *Department of Civil Engineering, Kasem Bundit University, Bangkok, 10250, Thailand*

[8] *Civil Department, Engineering Faculty, Shaikh Zayed University, Khost, 2501, Afghanistan*

[9] *Consultant Architect for Gautam Buddha International Airport, Kathmandu, 32900, Nepal*

[10] *Department of Civil Engineering, Faculty of Engineering, Rajamangala University of Technology Phra Nakhon, Bangkok, 10800, Thailand*

**Email:* cburacha@engr.tu.ac.th (B. Chatveera); gritsada.s@rmutp.ac.th (G. Sua-iam)

Sureshchandra *et al*.[23] explored the use of quarry dust as an alternative for natural sand in hollow concrete block construction, testing partial (50%) and full substitution with and without admixtures. Compressive strength ranged from 4.07–7.33 MPa for blocks without admixtures and 5.69–8.10 MPa for those with admixtures. The study concluded that 50% replacement with quarry dust performs better than conventional blocks, and the inclusion of admixtures further enhances performance, making these blocks suitable for load-bearing masonry structures. Al Tarbi *et al*.[24] developed innovative hollow concrete blocks employing perlite, vermiculite, scoria, and polystyrene to enhance thermal insulation and sustainability. Perlite and scoria blocks, with dry densities of 1544 and 1673 kg/m³, were classified as lightweight, offering over 60% lower thermal conductivity compared to conventional blocks. Scoria blocks emerged as the most cost-effective, improving heat resistance by 144% and reducing energy costs by approximately 150%, from $272 to $109/m² over 40 years. Additionally, scoria blocks reduced CO_2 emissions by 2.5 and 1.15 times compared to standard and control blocks, highlighting their ecological and financial benefits. Terra *et al.*[25] investigated the effects of integrating quartzite and coconut fibers into masonry blocks on their physical, mechanical, and thermal characteristics. Quartzite replaced 0%–100% of sand, while coconut fibers were added at 2.5% of gravel volume. Results showed increased porosity (11.7% to 16.0%) and water absorption (7.0% to 8.5%) but reduced compressive strength beyond 50% quartzite content. Moreover, utilization of recycled aggregates such as plastic wastes and E-wastes in masonry and cement products has gained prominence for their eco-friendly qualities. The use of plastic waste may decrease strength and workability but surface modification such as coating with sand increases properties.[26,27] Glass fibers help to enhance strength and minimize cracking, and geopolymer technology offers a green alternative.[28] As environmental problems increase and disaster-resilient construction is a must,[29,30] more studies should be conducted to enhance the use of recycled materials in non-load-bearing concrete blocks.

Diatomite is a biogenic sedimentary rock rich in natural amorphous silica, primarily present as diatom frustules and, to a lesser extent, as sponge spicules, silicoflagellate skeletons, or radiolarian remains. This silica (opal-A) reacts with calcium hydroxide ($Ca(OH)_2$) to form calcium silicate hydrates (CSH), which contribute to strength development. In addition to opal-A, diatomite typically contains other components like carbonates, clay minerals, quartz, feldspar, and volcanic glass.[31] Several works have explored the possible benefits of utilizing diatomite powder in cement, mortar, and concrete.

Degirmenci and Yilmaz investigated diatomite as a partial substitute for cement in mortar production.[32] Their findings showed that a 5% substitution of Portland cement with diatomite yielded satisfactory results in terms of compressive and flexural strength, freeze-thaw response, sulfate defiance, and water-absorbing potential. Xu and Li,[33] as well as Costa *et al*.[34] incorporated diatomite with other aggregate types and paraffin to create stable phase change materials (PCMs), demonstrating an improvement in the thermal performance of cementitious mortars. Li *et al*.[35] investigated the initial performance, mechanical characteristics, and environmental effects of ecological concrete incorporating diatomite and limestone as partial replacements for cement clinker. The study showed that a 30% substitution of cement clinker with diatomite led to reductions of more than 30% in global warming capability, energy consumption, and air pollutant emissions while simultaneously enhancing the strength growth of the concrete. Saridemir *et al*.[36] observed that calcined diatomite enhanced the mechanical and microstructural characteristics of high-strength mortars when subjected to both normal and elevated temperature conditions.

Sugarcane is a globally cultivated agricultural crop widely used in various food products. It is believed to have originated in Papua New Guinea and the South Pacific Islands, with its initial documented manufacturing in India.[37] When all the sugarcane worldwide is processed to extract juice targeting sugar and ethanol trades, it is approximated that between 370 and 561 million tonnes of bagasse are generated yearly.[38] A few studies have explored the integration of sugarcane bagasse ash as a partly substitute for natural fine aggregates in concrete. Santhosh *et al.*[39] investigated two kinds of greatly crystalline agro-industrial sugarcane bagasse ash, replacing natural fine aggregates in concrete at proportions of 10%, 20%, and 30%. Several tests, targeting the mechanical and durability properties were performed to assess the performance of concrete at intervals of 28, 60, 90, and 240 days. The findings suggested that incorporating both types of sugarcane bagasse ash resulted in lighter concrete. At a 10% substitution level, the compressive strength enhanced by more than 4% at a 28-day period, while higher dosages of sugarcane bagasse ash led to a reduction in strength. Earlier works have also reported that incorporating sugarcane bagasse ash up to a certain threshold can enhance compressive, tensile, and flexural strength, workability, and capillary suction resistance, while reducing water absorption, thermal conductivity, dry density, and total carbon emissions.[40-45]

The use of SBA and DM in concrete has been previously explored, mainly as partial replacements for cement or in combination with other aggregates. However, their potential for producing concrete hollow blocks, particularly as partial substitutes for fine aggregates, remains unexplored. This study aims to address this gap by investigating the use of SBA and diatomite in hollow concrete block production. The research focuses on evaluating the mechanical, physical, and durability properties of the manufactured blocks. By incorporating these agro-industrial by-products, the study seeks to enhance the sustainability of concrete production while potentially improving both the strength and environmental performance of the blocks. This innovative approach presents a practical solution for reducing ecological impact by utilizing readily available waste materials.

2. Materials and methods

2.1 Materials

This work explores the manufacturing of hollow, non-load-bearing concrete blocks utilizing a blend of locally sourced materials. Fine aggregate was partially replaced with DM and SBA. The selected materials and block preparation followed the guidelines of ASTM C129 and Thailand Industrial Standard (TIS) No. 58-2560 to meet the minimum quality and durability criteria for non-load-bearing and non-moisture-controlling applications.[46,47] The materials and their properties are detailed as follows.

Type 1 Portland Cement, widely used in the Thai construction industry, was utilized in this study. Supplied by the Siam Cement Group Company, the cement met all the requirements of ASTM C150.[48] It had a specific gravity of 3.15 and demonstrated reliable performance across all test mixtures.

The fine aggregates used in this study were crushed rock fines sourced from a local quarry (Fig. S1). These well-graded, gray-colored particles complied with ASTM C33 specifications.[49] The crushed rock fines exhibited a moisture content of 1.37%, a specific gravity of 2.63, and a bulk density of 1,290 kg/m³, making them suitable as reference fine aggregates for the control mix. The silica-rich mineral DM, sourced from northern Thailand, is a sedimentary material composed primarily of diatoms—single-celled algae. Its porous, cellular structure contributes to its low bulk density and minimal chemical reactivity. The DM used in this study was light brown with a fine texture, enhancing the thermal insulation properties of concrete. It had a moisture content of 6.19%, a specific gravity of 2.12, and a bulk density of 575 kg/m³, making it suitable for lightweight concrete applications. SBA was sourced from a local energy producer that uses sugarcane bagasse—a by-product of the sugar industry—as biomass fuel. The ash, collected after the combustion process, consisted of very fine black particles with smooth, rounded

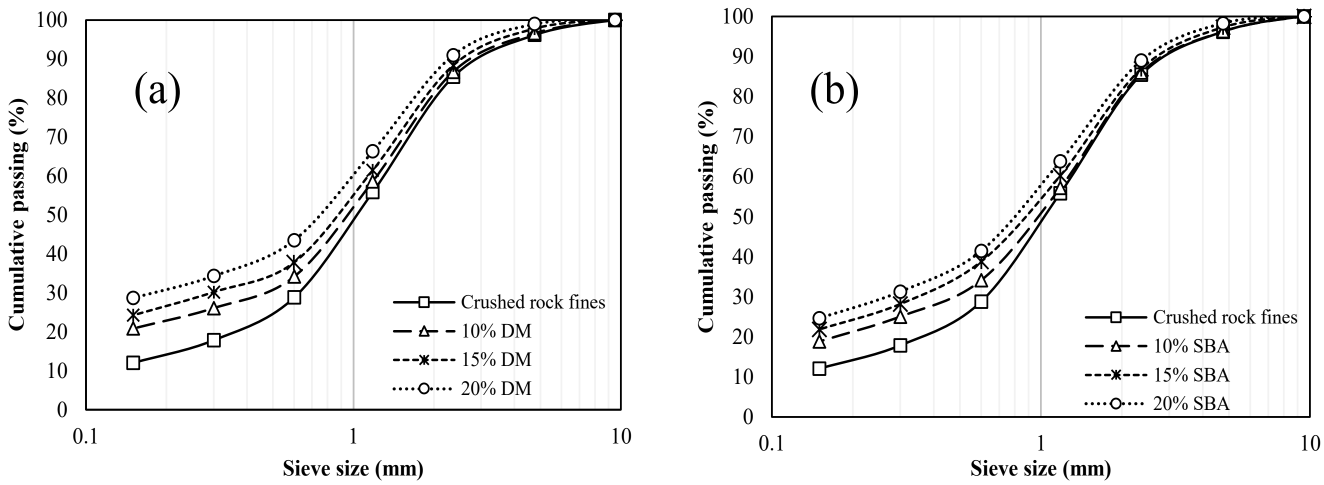

Fig. 1: Sieve analysis of crushed rock fines compared with various replacements of (a) diatomite and (b) sugarcane bagasse ash.

surfaces. SBA had a moisture content of 5.47%, a specific gravity of 1.80, and a bulk density of 444 kg/m³. Its pozzolanic properties contributed to enhancing the strength and durability of the concrete mix.

Clean, potable tap water was utilized to mix and cure the concrete blocks, meeting the requirements of concrete production standards. The water-to-cement (w/c) ratio in the control mix was set at 0.53. However, mixes incorporating DM and SBA required adjustments to the w/c ratio, ranging from 0.57 to 0.63, to achieve optimal workability and moldability.

The sieve analysis comparing crushed rock fines with replacements using DM and SBA revealed notable differences in particle size distribution. Crushed rock fines, used as the control fine aggregate, adhered well to ASTM C33 gradation standards,[49] exhibiting a balanced distribution with moderate fines passing through the No. 100 sieve, ensuring good packing density. Partial replacement with DM at 10%, 15%, and 20% significantly shifted the gradation profile toward finer particles. In contrast, SBA replacements at the same levels also increased the fine content, but to a lesser extent than DM due to SBA's relatively coarser particle size. Fig. 1 illustrates the effects of DM and SBA replacements on the aggregate mix gradation profiles, showing that DM consistently produced a higher percentage of fines (Fig. 1(a)) compared to SBA at all replacement levels (Fig. 1(b)).

2.2 Mix proportions

The mix design for this study included a reference mix of conventional concrete blocks (CC) using 100% crushed rock fines as fine aggregate, with a water-to-cement (w/c) ratio of 0.53 and a cement-to-sand ratio of 1:6 by volume. In the modified mixes, crushed rock fines were partly substituted with DM or SBA at replacement levels of 10%, 15%, and 20% by weight. The w/c ratios for these replacements ranged from 0.57 to 0.63, adjusted to ensure adequate workability for block molding. Table 1 provides the detailed proportions for one cubic meter of each mix design. The cement content remained constant at 326 kg/m³, and adjustments in w/c ratio and water content were made to maintain consistent workability across all mixes. The total weight per cubic meter decreased with increasing levels of DM or SBA replacement due to their lower density compared to crushed rock fines.

2.3 Specimen preparation in the factory: mixing, casting, and curing

The preparation of hollow concrete blocks began with proportioning the materials based on the designed mix ratios and followed ASTM C129.[46] Crushed rock fines, along with either DM or SBA, were weighed and added to the mixer,

Table 1: The volumetric proportions for a one cubic meter of mix design.

Materials	Conventional	Diatomite			Sugarcane Bagasse ash		
		10%	15%	20%	10%	15%	20%
Cement (kg)	326	326	326	326	326	326	326
w/c	0.53	0.57	0.59	0.63	0.55	0.57	0.61
Water (kg)	173	187	192	206	179	185	198
Crushed rock fines (kg)	1745	1545	1420	1276	1501	1357	1206
Replacement fines (kg)	-	175	262	349	174	262	349
Total (kg/m³)	2244	2233	2200	2157	2180	2130	2079

following dry mixing for approximately 1 minute to initiate the process. Cement was then introduced, and mixing continued for an additional 2 minutes to ensure uniform distribution of the binder within the aggregates. After thorough dry mixing, water was included, and the entire batch was mixed for two more minutes until a consistent and workable mix was achieved. The fresh concrete was then transferred to a block-making machine and molded into hollow blocks measuring 7 × 19 × 39 cm^3, a commonly used size in modern construction (Fig. S2).

After casting, the blocks were air-cured in a vertical orientation in a shaded, protected area for at least 24 hours to allow early hydration and initial strength development while preventing premature drying. Following this, the blocks were submerged in water to ensure complete hydration, which is crucial to achieving the required strength and durability. Water curing was maintained for a specified period until the blocks were ready for testing. This curing regime ensured optimal strength and durability by maintaining sufficient moisture for proper cement hydration and enhancing the microstructural integrity of the concrete blocks.

The blocks produced followed the standard of TIS 58-2560 of non-load bearing hollow concrete masonry,[47] implying their application above ground in masonry. This standard aligns with ASTM C129,[46] which establishes the required properties and testing methods for non-load-bearing concrete blocks produced and used in Thailand. Fig. 2 shows the geometry and dimensions of the manufactured hollow concrete blocks.

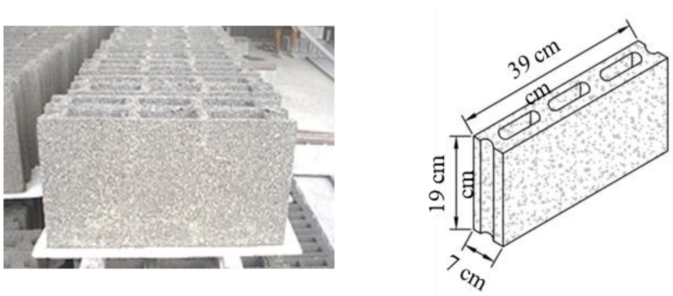

Fig. 2: Geometry and dimension of the manufactured hollow concrete blocks.

2.4 Testing specimens

2.4.1. Bulk density

The bulk densities of three specimens for each batch were determined following ASTM C127.[50] The samples were submerged in water at room temperature for 24-28 hours, with the water level maintained at least 150 mm above the specimens and each sample spaced 3 mm off the container's bottom on a grid. After immersion, each sample was weighed while fully submerged in water (m_i). The samples were then drained on a 10 mm metal grid for 55-65 seconds, surface-dried with a damp cloth, and reweighed (m_s). Subsequently, the specimens were oven-dried at 105-115 °C for a minimum of 24 hours until the weight loss between the two measurements was no more than 0.2%. The final dry mass (m_d) was then recorded. The bulk density (ρ) was computed using Eq. (1):

$$\rho = \frac{\mathrm{m_d}}{\mathrm{m_s - m_i}} \cdot 1000 \tag{1}$$

2.4.2 Compressive strength

Compressive strength tests were conducted on hollow concrete block samples measuring 7 × 19 × 39 cm^3, which were prepared under controlled conditions. Following ASTM C140,[51] the compressive strength was evaluated at 3, 7, 14, 28, 60, and 90 days. For each test, five samples were loaded to failure in a hydraulic compression machine, and the mean strength of these specimens was adopted as the compressive strength for the batch. This testing schedule provided a detailed assessment of strength development over time.

2.4.3 Water absorption

Water absorption tests were conducted following ASTM C140.[51] Three characteristic hollow concrete blocks were first oven-dried to eliminate any moisture. The blocks were then soaked in water at 25 °C for 24 hours, with the initial mass recorded as W_i. After soaking, the blocks were weighed while suspended on a metal wire and fully inundated to measure the submerged weight, W_s. Following immersion, the blocks were drained for 1 minute through a coarse wire mesh, and any excess surface water was wiped off with a damp cloth before recording the final mass. The blocks were then placed in a ventilated oven at 110 °C for 24 hours, or until no significant weight loss was observed, with a weight change of no more than 0.2% (W_d). The water absorption (WA) percentage was calculated using Eq. (2):

$$WA = \frac{Wi - Wd}{Wd} \cdot 1000 \tag{2}$$

2.4.4 Porosity

Porosity was tested according to ASTM D4284 using Mercury Intrusion Porosimetry (MIP).[52] A concrete block was cut to obtain a cylindrical specimen, approximately 20 mm in diameter and 27 mm in height, ensuring uniformity in shape and size. The sample was thoroughly dried to remove any moisture before testing. It was then placed in a glass vial, where a vacuum was created, and mercury was introduced. Pressure was gradually applied until the mercury infiltrated the pore spaces within the sample. The pressure and volume of mercury intruded into the sample were measured using MIP. The data obtained were analyzed to compute the pore size distribution and the overall porosity percentage of the concrete block.

2.4.5 Sound absorption

Sound absorption characteristics were investigated by following ASTM C423,[53] by making a panel of width 1770 mm, length 2000 mm, and thickness 50 mm using 20 such hollow concrete blocks cut longitudinally. Testing was done inside an acoustic chamber, especially designed, having an inside width of 3690 mm, length 4120 mm and height 3280 mm. Testing of the empty chamber preceded exposure of the sample panel on the floor to conduct sound absorption tests at multiple frequencies (125 Hz to 4000 Hz). Coefficients of sound absorption measured were recorded and analyzed to draw valuable data about the performance of blocks against acoustic performances.

2.4.6 Drying shrinkage

Drying shrinkage tests were conducted on 28-day-old concrete blocks by following ASTM C341.[54] The blocks, initially saturated, were subjected to accelerated drying conditions until they reached a moisture equilibrium state. Dimensional changes in length were measured before and after drying to determine the degree of shrinkage. Five blocks were used for this test, with precise measurements taken to assess the extent of shrinkage. This test is crucial for evaluating the dimensional stability and potential cracking behavior of the blocks during service.

2.4.7 Dry-wet cycle

The wetting and drying resistance of the concrete blocks was measured by following ASTM D559.[55] In this study, three 28-day cured blocks were subjected to wet-dry cycles to simulate natural environmental exposure. The blocks were submerged in water for a specified period, following oven drying at 110 °C until the desired drying time was reached. This process was repeated for several cycles to assess the blocks' ability to resist the physical and chemical stresses associated with wetting and drying cycles.

2.4.8 Resistance to acids

The resistance of concrete blocks to acids was tested after 28 days of curing to evaluate their durability in acidic environments. The blocks were immersed in solutions of sulfuric acid (H_2SO_4), nitric acid (HNO_3), hydrochloric acid (HCl), and acetic acid (CH_3COOH), all at pH 1.0. The immersion periods were set for 3, 7, 28, 60, and 90 days. After each immersion period, the weight loss and length change of each block were measured. These tests are crucial for assessing the chemical resistance and durability of the concrete blocks when subjected to aggressive acidic environments, confirming their suitability for applications in environments where acids are present.

2.4.9 Thermal conductivity

The thermal conductivity of the concrete blocks was measured following JIS R 2618 (Fig. S3).[56] One block was oven-dried at 110 °C until its weight stabilized, with a variation of less than 1 gram within 24 hours. The block was then exposed to a thermal conductivity test by placing a heat distribution plate on its surface. The temperature of the block was raised from 3 to 10 °C within 30 seconds to 5 minutes, while a thermocouple measured the temperature change at the lower surface of the block. Data collected, including the thickness and cross-sectional area of the block, were used to estimate the thermal conductivity depending on Fourier's law of heat conduction. This information is crucial for evaluating the insulation properties of the blocks.

3. Results and discussion

3.1 Bulk density

The comparison of bulk density of different mix designs with the control is shown in Fig. 3. The replacement of natural fine aggregates with either DM or SBA reduced the bulk density. It is noteworthy that the reduction in bulk density was more prominent in the case of SBA. For a 20% replacement of natural fine aggregates with either DM or SBA, a decrease of about 24% in the bulk density of hollow blocks was observed. The replacement levels of 10%, 15%, and 20% by DM reduced the bulk density by 11.2%, 20.6%, and 23.6%, respectively. The replacement levels of 10%, 15%, and 20% by SBA reduced the bulk density by 18.8%, 23.3%, and 23.9%, respectively. Previous works exploring the effects of DM replacement on the bulk density of mortar also reported similar findings. Taoukil *et al*.[57] reported that DM has a bulk density approximately 65% lower than that of natural sand. They attributed this to DM's high porosity and low density, which contribute to a reduction in the bulk density of mortar. A similar effect can be expected in hollow blocks where natural fine aggregates are replaced with DM. In this study, the bulk densities of natural sand, DM, and SBA were 1290 kg/m³, 575 kg/m³, and 444 kg/m³, respectively. Notably, SBA had the lowest bulk density among the fine aggregates examined. Consequently, hollow blocks incorporating SBA exhibited a

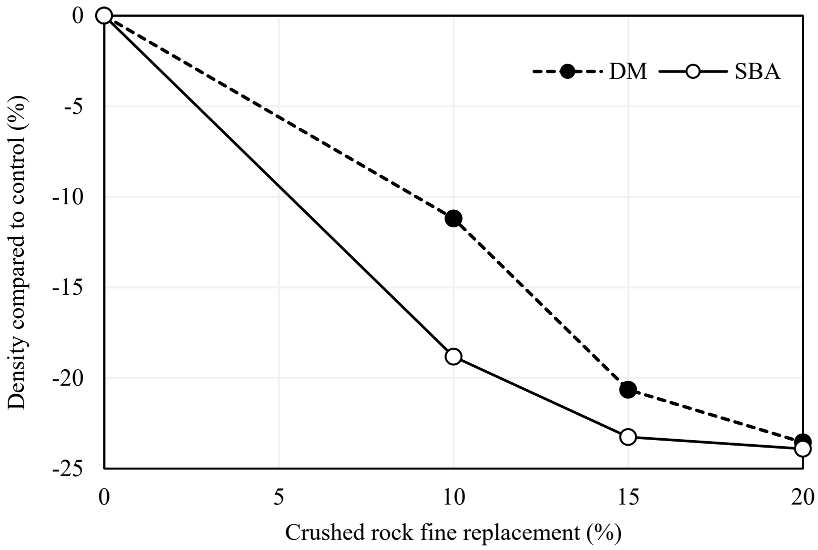

Fig. 3: Decrease in bulk density of hollow concrete blocks specimens.

more significant reduction in bulk density compared to those containing DM.

3.2 Compressive strength

The measured compressive strength of mix designs with different replacement levels of DM versus age is illustrated in Fig. 4(a). As anticipated, the compressive strength stabilized beyond a 28-day period. The 28-day compressive strength for the control, DM10, DM15, and DM20 was 4.05 MPa, 2.53 MPa, 1.00 MPa, and 0.66 MPa, respectively. This reflects a reduction in compressive strength by 37.5%, 75.35, 83.7% for a 10%, 15%, and 20% replacement with DM, respectively. Fig. 4(b) illustrates the compressive strength of various mix designs with different SBA replacement levels over time. At 28 days, the compressive strength values for the control, SBA10, SBA15, and SBA20 were 4.05 MPa, 2.71 MPa, 2.48 MPa, and 2.18 MPa, respectively. This corresponds to reductions of 33.1%, 38.8%, and 46.2% for SBA replacement levels of 10%, 15%, and 20%, respectively. It is noted that a 10% replacement level, the decrease in compressive strength was slightly greater by incorporating DM than SBA. However, beyond 10% replacement, the decrease in compressive strength surpassed 70% for DM whereas it stayed lower than 50% for SBA replacement. Specifically, a 20% replacement with DM and SBA resulted in compressive strength reduction of 83.7% and 46.2%, respectively. This highlights an 81% greater reduction in compressive strength by DM than SBA at a 20% replacement level. The moisture content of DM and SBA were 6.19% and 5.47%, respectively. It has been observed that higher moisture content increases the effective water-to-cement ratio, which weakens the concrete mix and leads to a reduction in compressive strength.[58]

3.3 Water Absorption

The findings of water absorption potential of hollow concrete blocks are graphically compared in Fig. 5. All mix designs with fine aggregate replacement exhibited greater water absorption potential than the control mixture. The water absorbing potential of the control mixture was 8.2%. Mix designs substituting 10%, 15%, and 20% of the fine aggregates with DM demonstrated water absorption of 12.4%, 20.7%, and 20.8%, respectively. Compared to the control mix, this corresponds to an increase of 51.2%, 152.4%, and 153.7%, respectively. Similarly, mix designs incorporating 10%, 15%, and 20% SBA as a substitute for fine aggregates exhibited water absorption rates of 20.8%, 23.7%, and 24.1%, respectively. These values represent increases of 153.6%, 189.0%, and 193.9% compared to the control mix. It is noteworthy that a significant difference in the water absorption was noted between 10% and 15% replacement levels of fine aggregates.

However, the water absorption tended to stabilize as the substitution level enhanced beyond 15%. It is still cautious that the current study did not explore replacement levels exceeding 20%. Therefore, it is difficult to extrapolate this observation to replacement levels beyond 20% and further studies are recommended to explore this. It was noted earlier that SBA possessed relatively lower moisture content compared to DM, which can be associated with the higher water absorption potential of SBA than DM.[59] Furthermore, an inverse relationship between the specific gravity of fine aggregates and their water absorption potential has been reported.[39] This occurs because fine aggregates with lower specific gravity have more open pores, resulting in higher water absorption capacity.

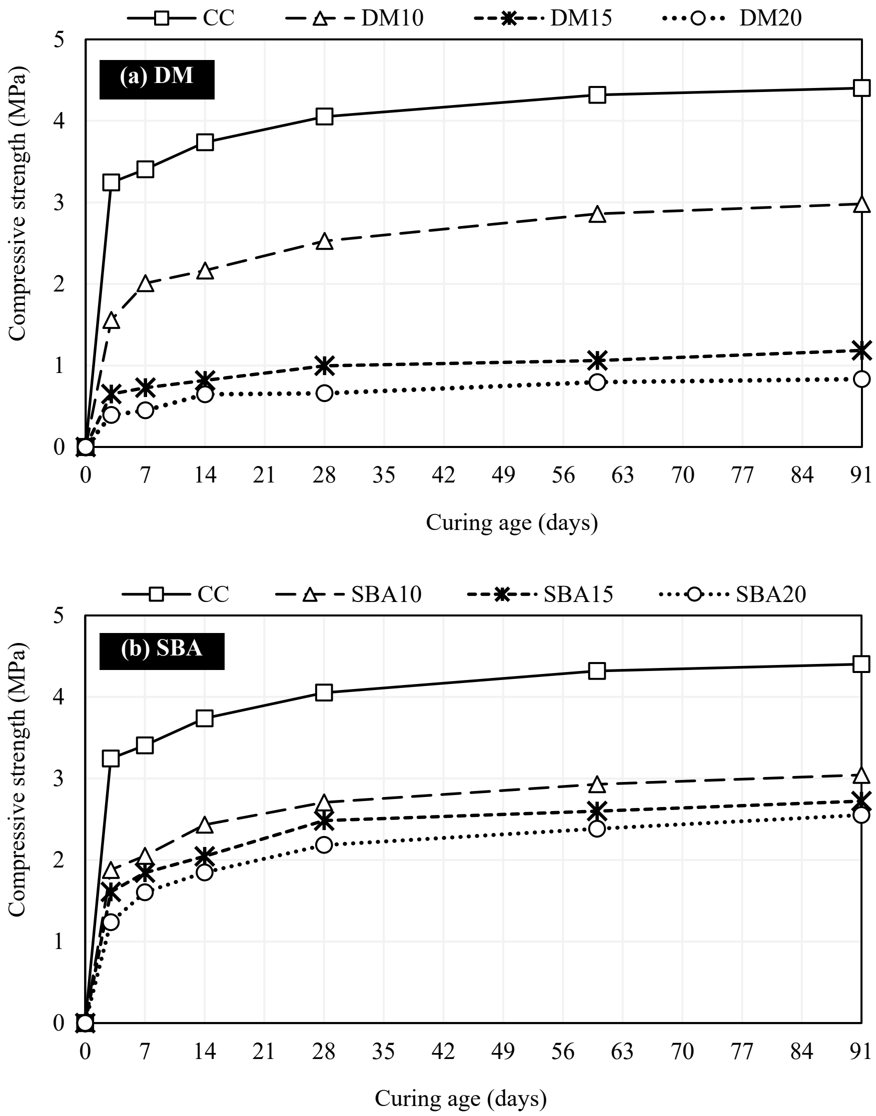

Fig. 4: Compressive strength development of hollow concrete blocks specimens.

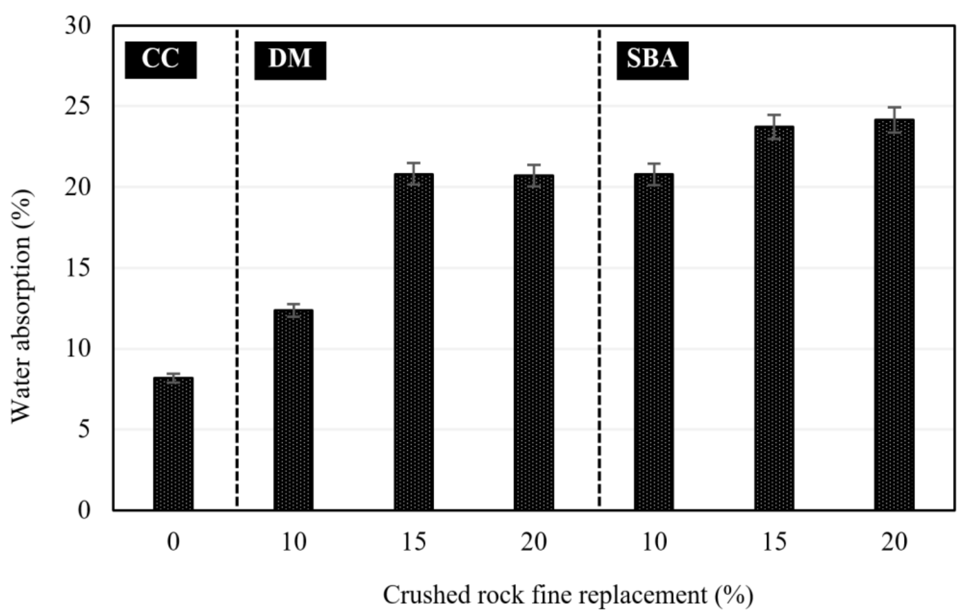

Fig. 5: Water absorption of hollow concrete blocks specimens.

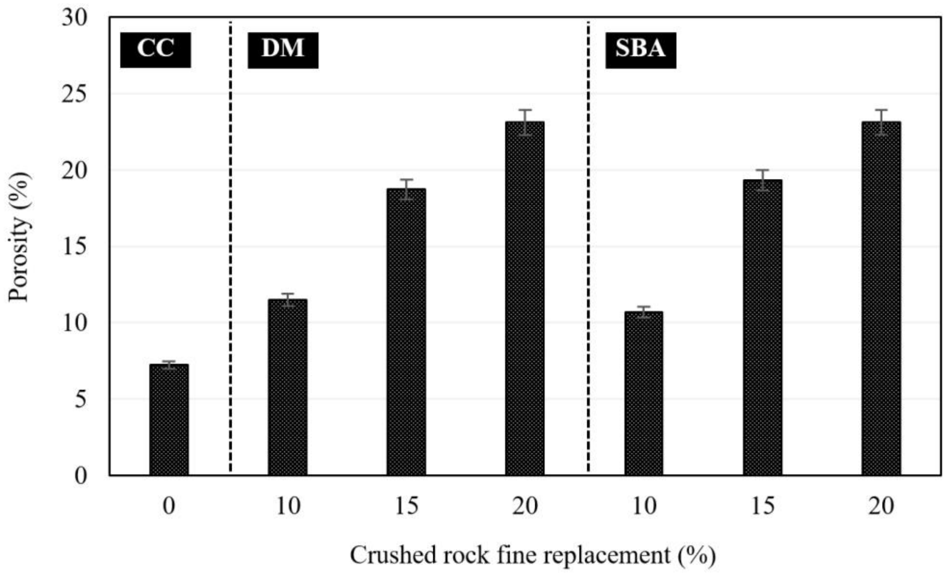

Fig. 6: Porosity of hollow concrete block specimens.

3.4 Porosity

The porosity of hollow concrete blocks is graphically compared in Fig. 6. All mix designs that incorporated fine aggregate replacements exhibited higher porosity compared to the control mix, which had a water absorption rate of 7.2%. For mix designs replacing 10%, 15%, and 20% of the fine aggregates with DM, the porosity was 11.5%, 18.7%, and 23.1%, respectively. These values correspond to increases of 59.7%, 159.7%, and 220.8%, respectively, when compared to the control mix. Similarly, mix designs incorporating SBA as an alternate for fine aggregates demonstrated porosity rates of 10.7%, 19.3%, and 23.2% for replacement levels of 10%, 15%, and 20%, respectively. These values represent increases of 48.6%, 168.1%, and 222.2%, respectively, compared to the control mix.

It is noted that mix designs incorporating DM or SBA exhibited similar porosity at different replacement levels. Santhosh de *et al*.[39] replaced natural fine aggregates in concrete with SBA and observed an increase in concrete porosity. Similarly, Tayeh *et al*.[60] substituted natural fine aggregates in concrete bricks with sugarcane pulp sand and analyzed the microscopic structure of the resulting concrete, also reporting an increase in porosity. This rise in porosity due to aggregate replacement may be attributed to the widening of fracture widths and structural damage. As crack widths expand, the bond between aggregates and cement paste weakens, leading to greater internal deterioration. This process results in a more porous structure and modifications to the pore network, which are influenced by pore size. Taoukil *et al*.[57] also demonstrated an increase in porosity when replacing natural fine aggregates with DM in mortar production.

3.5 Sound absorption

The sound absorption performance of a material is determined by its sound absorption coefficient. A higher coefficient indicates a greater ability of the material to absorb and isolate sound effectively.[61] The acoustic properties of hollow concrete blocks are evaluated using the sound absorption coefficient across various frequency levels, as shown in Fig. 7. This coefficient represents the proportion of incident sound energy absorbed by the material. Testing followed the ASTM C423 standard in a Reverberation Room.[53] The selected mix designs included partial replacements of crushed rock fines with 10% DM and 20% SBA by weight. The results showed that the Noise Reduction Coefficients (NRC) for CC, DM10, and SBA20 were 0.12, 0.20, and 0.07, respectively. It is noted that DM10 performed better than SBA20 and control mix by showing the maximum values of the sound absorption coefficient at various frequencies. This suggests that the sound insulation effect was greatly enhanced by the incorporation of DM. The peak value of the sound absorption coefficient for DM10 and SBA20 was observed at a frequency of 2000 Hz. Beyond this frequency, the absorption coefficient decreased for both DM10 and SBA20. The higher sound absorption coefficient of DM10 highlights its superior sound insulation properties compared to SBA20. When sound waves strike a material's surface, some are reflected, some pass through, and the rest are absorbed. As the waves penetrate the material, they interact with its pore structure, creating friction between air molecules and the pores. This friction converts sound energy into heat, which the material absorbs. A higher void content enhances this process by increasing friction, thereby allowing more sound energy to be dissipated and absorbed within the

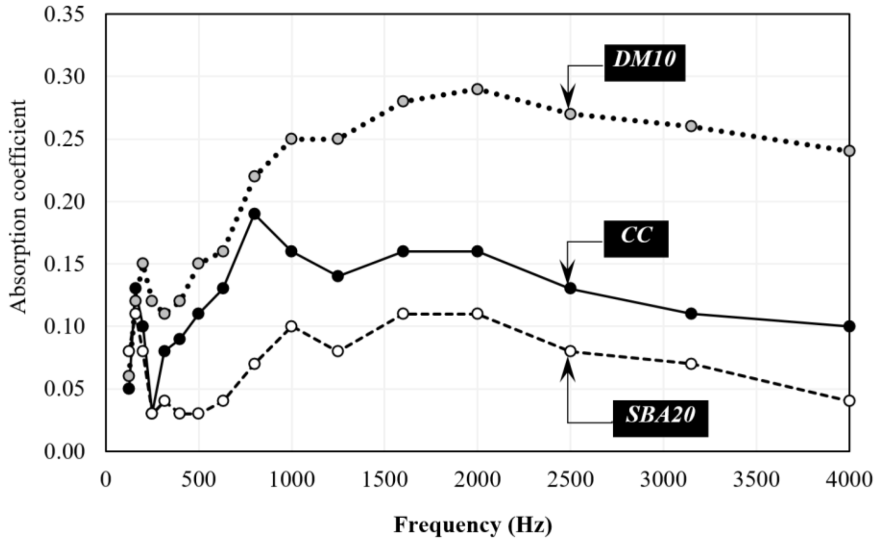

Fig. 7: Sound absorption coefficient of selected hollow concrete block specimens.

voids.[62] Similar findings have also been reported in other studies.

3.6 Drying shrinkage

Drying shrinkage refers to the reduction in volume or contraction of hardened concrete caused by the loss of capillary moisture, which induces capillary tension within the mesoporous structure of the cement matrix.[63] Fig. 8 show the drying shrinkage measured for concrete incorporating DM and SBA, respectively. As shown in Fig. 8(a), the drying shrinkage increased by the addition of DM in concrete mix. A common observation is that the drying shrinkage increased rapidly till the age of approximately 8 days. Beyond this period, the drying shrinkage decreased significantly. The magnitude of the drying shrinkage was positively correlated with the replacement level of DM in concrete mix. By the end of 28 days, the drying shrinkage of the control mix was -0.063% that increased to -0.084%, -0.089%, and -0.105% for 10%, 15%, and 20% replacement of DM, respectively. This corresponds to an increase of 33%, 41%, and 67%, respectively. Similarly, the incorporation of 10%, 15%, and 20% SBA demonstrated a drying shrinkage of -0.092%, -0.100%, and -0.124%, respectively, corresponding to an increase of 46%, 59%, and 97%, respectively, over the control mix, which is shown in Fig. 8(b).

It is clear that the incorporation of SBA resulted in more enhancement in the shrinkage magnitude than DM. Specifically, a 20% incorporation of SBA produced about 18% greater drying shrinkage than that produced by 20% incorporation of DM. The moisture content of DM was greater than the moisture content of SBA. An inverse relationship between the moisture content and the water absorption ratio has been reported.[64] Studies have also shown an increase in drying shrinkage as the water absorption potential of aggregates increases.[65] Therefore, SBA-incorporated mix demonstrated a greater drying shrinkage than DM-incorporated mix.

3.7 Dry-wet cycle

The results of dry-wet cycles are shown in Fig. 9 for DM and SBA-incorporated mix. As shown in Fig. 9(a), the control mix showed the greatest change in weight that ranged between 6100 grams to 6500 grams. The DM10 mix showed the second highest weight change, ranging between 5500 grams to 6140 grams approximately. The DM15 mix showed weight change ranging between 5100 grams to 5800 grams approximately. Finally, the DM20 mix demonstrated a range of weight change from 4700 grams to 5500 grams. It is observed that the range of weight change during wet-dry cycle was 400 grams, 6140 grams, 700 grams, and 800 grams for the control, DM10, DM15, and DM20 mix, respectively. This suggests that the variation in weight change increased with the replacement level of DM. As illustrated in Fig. 9(b), the SBA10 mix showed the second-largest range, varying between 5700 grams and 6400 grams. The SBA15 mix displayed a weight variation from 5250 grams to 6000 grams, while the SBA20 mix ranged from 5000 grams to 5950 grams. During the wet-dry cycles, the observed weight variation was 700 grams, 750 grams, and 900 grams for the SBA10, SBA15, and SBA20 mixes, respectively. This indicates that the weight variation tended to increase with the higher replacement levels of SBA and beyond. Further to that, both the weight change and variation were approximately similar in SBA-incorporated mix as that in DM-incorporated mix.

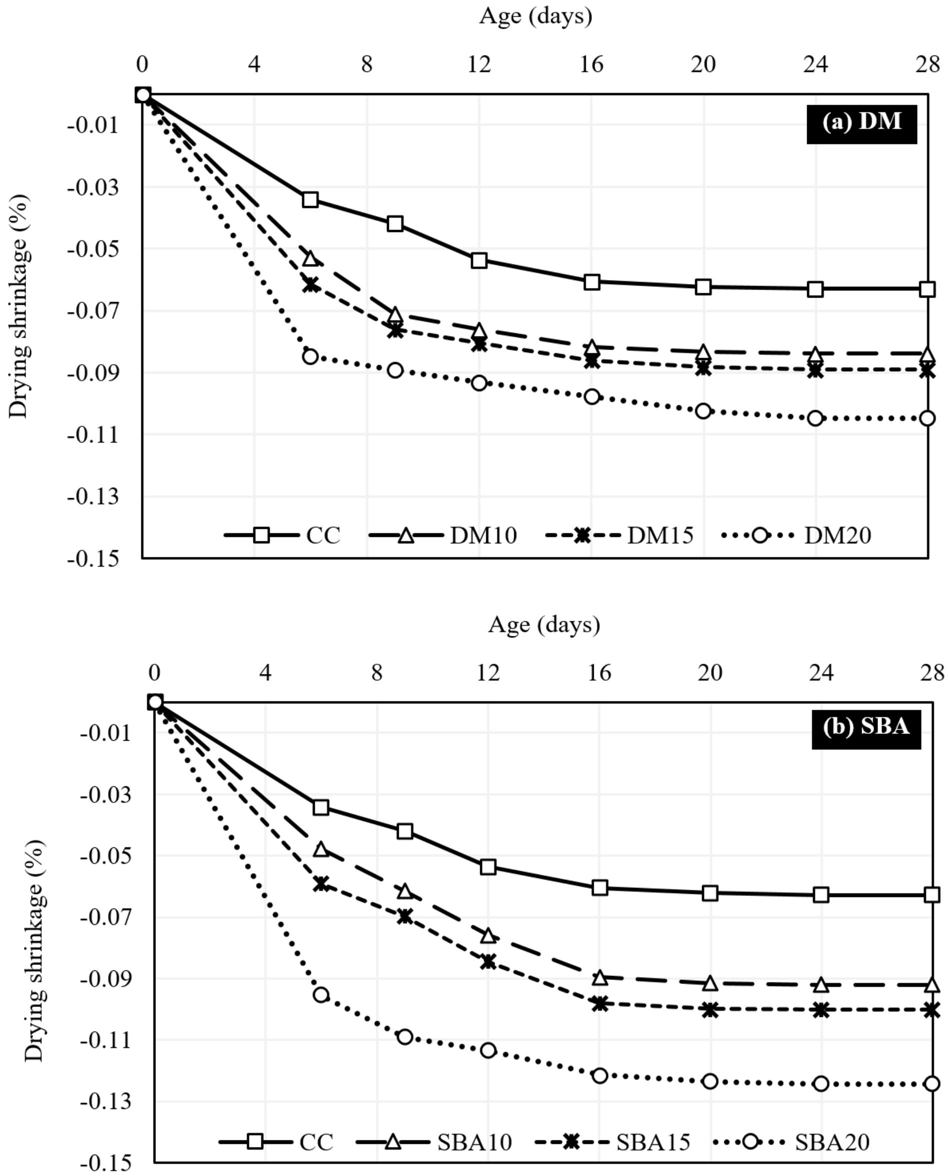

Fig. 8: Drying shrinkage of hollow concrete blocks specimens.

The effect of wet-dry cycle on length change of DM and SBA-incorporated mix are shown in Figs. 10(a) and (b), respectively. For the DM-incorporated mix, as shown in Fig. 10(a), the length change of DM10 was similar to the control mix initially. As the cycles progressed, the length change of the control mix increased and reached 1.6 mm, whereas the length change of DM10 remained stable around 1.52 mm. It is interesting to observe that the length changes of DM15 and DM20 mix were greater than the control mix. Particular attention is given to DM20 mix that demonstrated an ever-increasing length change as a function of dry-wet cycles. The wet-dry cycles of SBA-incorporated mix are shown in Fig. 10(b) with the corresponding change in length. Unlike the control mix, all SBA-incorporated mixes showed smaller length changes than the control mix. Interestingly, the SBA20 mix showed the least change in length.

3.8 Acid resistance

The acid resistance of the various considered mix designs was evaluated, with exposure to sulfuric acid, nitric acid, hydrochloric acid, and acetic acid. The corresponding loss in mass is graphically shown and compared in Figs. 11(a)-(d), respectively. During the first 7 days, all mix designs showed a rapid reduction in mass, irrespective of the type of acid. Beyond this period, the mass loss was reduced and occurred at a uniform rate. The control mix demonstrated a mass loss of2.64%, 4.60%, 4.42%, and 27.84% when subjected to sulfuric acid, nitric acid, hydrochloric acid, and acetic acid, respectively. It is seen that the impact of acetic acid on the durability of the concrete block is most severe. For all other

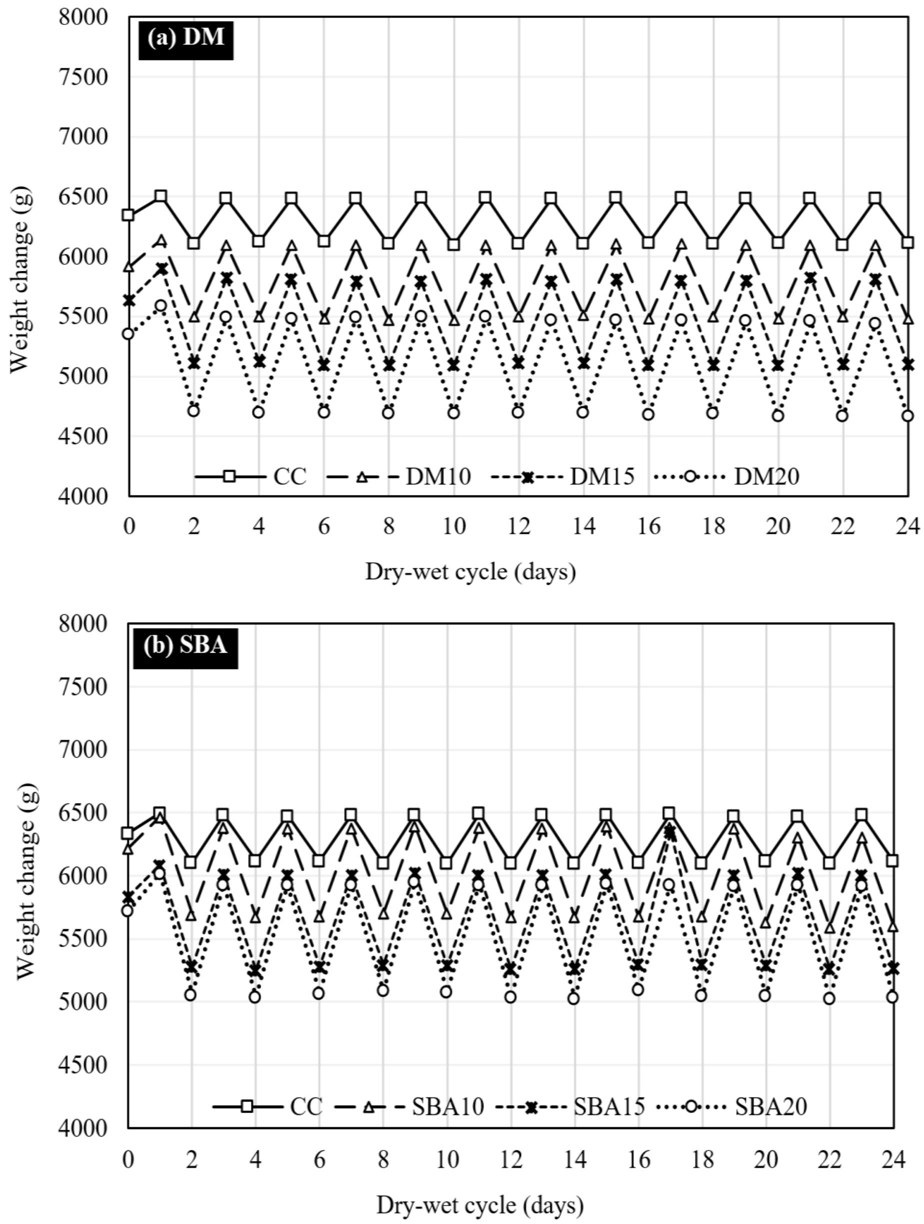

Fig. 9: Variation of the mass of hollow concrete block specimens with dry-wet cycles.

mix designs, the mass loss was more severe than that of the control mix. The exposure to sulfuric acid (for 91 days) for DM10, DM15, and DM20 resulted in a 1.7%, 5.0%, and 8.0%, more mass loss than the control mix. The exposure to sulfuric acid for SBA10, SBA15, and SBA20 resulted in 3.8%, 4.4%, and 6.5%, respectively, more mass loss than the control mix.

The exposure to nitric acid (for 91 days) for DM10, DM15, and DM20 resulted in 1.7%, 4.7%, and 9.0%, respectively, more mass loss than the control mix. The exposure to nitric acid for SBA10, SBA15, and SBA20 resulted in 2.3%, 3.1%, and 7.8%, respectively, more mass loss than the control mix. Exposure to hydrochloric acid for 91 days led to an increased mass loss of 1.0%, 5.3%, and 8.5% for the DM10, DM15, and DM20 mixes, respectively, compared to the control mix. Similarly, the SBA10, SBA15, and SBA20 mixes experienced 3.0%, 4.0%, and 7.5% more mass loss than the control mix under the same conditions.

The exposure to acetic acid (for 91 days) for DM10, DM15, and DM20 resulted in 3.8%, 8.1%, and 12.2%, respectively, more mass loss than the control mix. The exposure to acetic acid for SBA10, SBA15, and SBA20 resulted in 3.9%, 5.4%, and 9.7%, respectively, more mass loss than the control mix. The ongoing discussion and comparison suggest that at 10% replacement level, the incorporation of DM resulted in lower mass loss than SBA. However, as the replacement level increased beyond 10%, the acid resistance in terms of mass loss was superior for SBA-incorporated mix than DM-incorporated mix. Singh and Patel also reported a reduction in mass of concrete by increasing the percentage of SBA as fine aggregate replacement.[32]

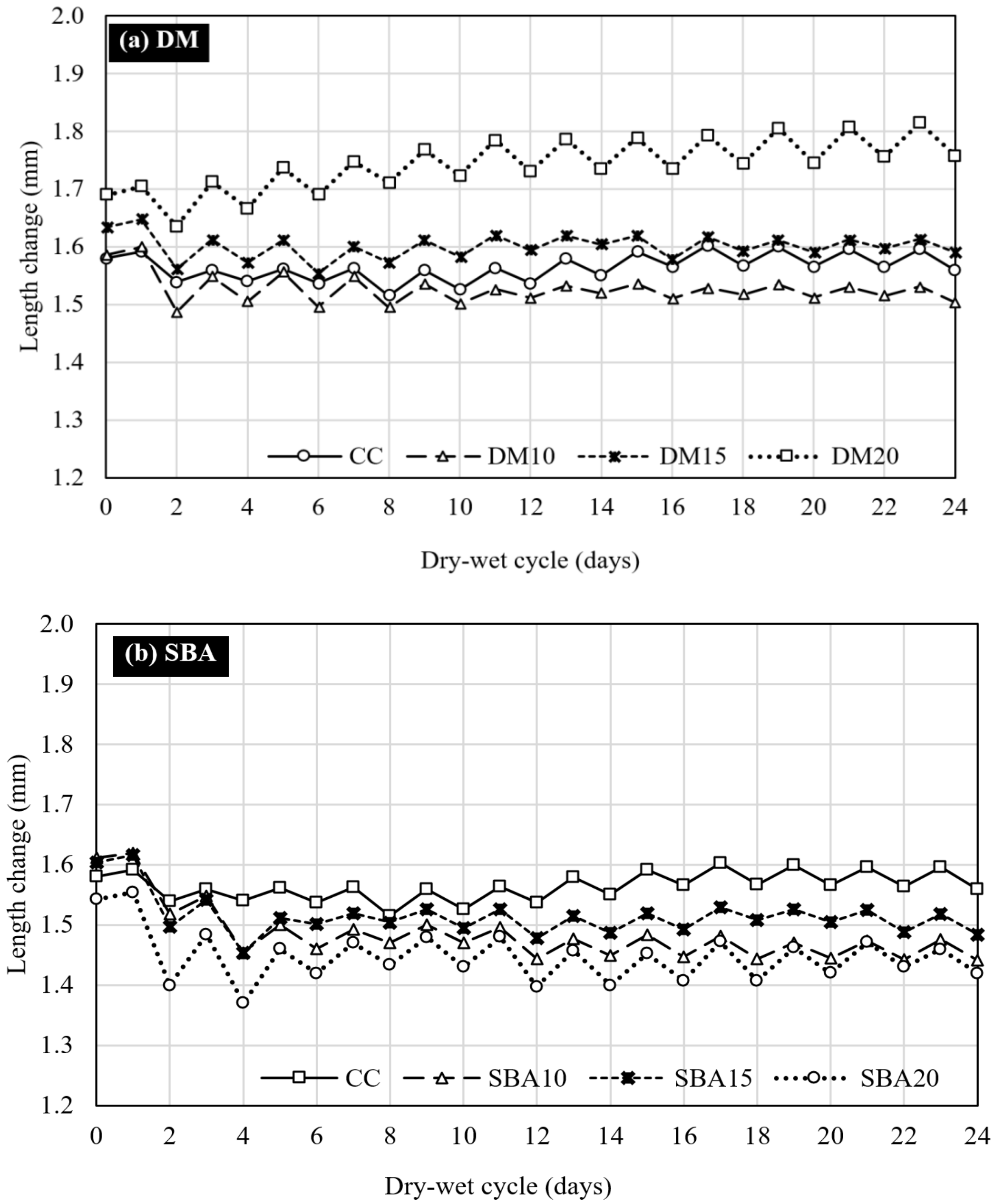

Fig. 10: Variation of the length of hollow concrete block specimens with dry–wet cycles.

3.9 Thermal comfort and less energy consumption in buildings

Thermal conductivity represents a material's capacity to transfer heat through conduction. It is influenced by the material's inherent properties, with lower values indicating better insulating performance.[57] The thermal conductivity results are presented in Fig. 12. Notably, thermal conductivity decreased by the addition of either DM or SBA as natural fine aggregate replacement. Thermal conductivity of the control mix was 1.1 W/mK that reduced to 0.76 W/mK, 0.51 W/mK, and 0.38 W/mK for 10%, 15%, and 20% replacement levels of DM, respectively. This corresponds to a thermal conductivity reduction of 30.9%, 53.6%, and 65.4%, respectively. Similarly, thermal conductivity reduced to 0.67 W/mK, 0.62, and 0.58 W/mK for 10%, 15%, and 20% replacement levels of SBA, respectively. This corresponds to a thermal conductivity reduction of 39.1%, 43.6%, and 47.3%, respectively. The reduction in thermal conductivity can be linked with the enhanced porosity of the corresponding mix designs. The presence of an increased number of voids has the potential to reduce thermal conductivity, as suggested by earlier works.[66-68] Thermal conductivity has also been associated to the density.[69] The modified mix designs also demonstrated lower density than the control mix which is another factor contributing towards their lower thermal conductivity. The comparison of thermal conductivity reduction for DM and

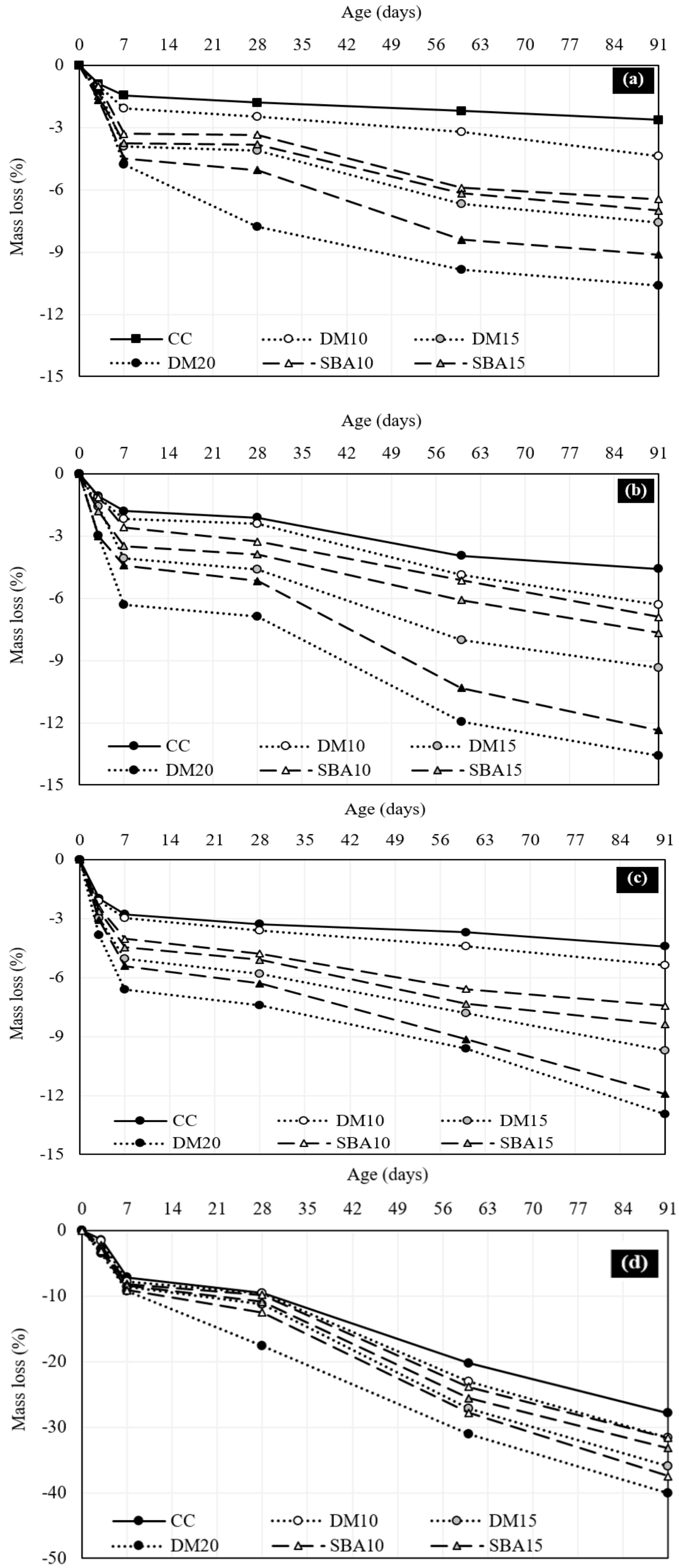

Fig. 11: Acid resistance of hollow concrete blocks specimens: (a) sulfuric acid, (b) nitric acid, (c) hydrochloric acid, and (d) acetic

acid.

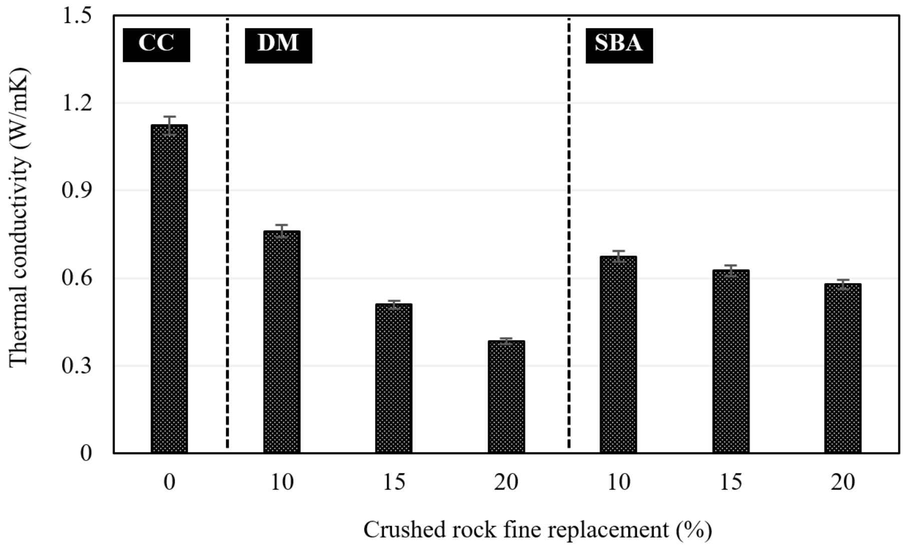

Fig. 12: Thermal conductivity of hollow concrete blocks specimens.

SBA replacement is shown in Fig. 13 for different replacement levels. It is seen that the rate of thermal conductivity reduction is almost linear as a function of the replacement level. However, a steeper slope is observed for DM which suggests that DM-incorporated concrete has better insulation properties than that incorporated with SBA.

4. Conclusion

This study explored the potential of DM or SBA as a partial replacement for natural fine aggregates in the production of hollow concrete blocks that are suitable for non-structural applications. Natural fine aggregates were replaced with either DM or SBA in percentages by weight ranging from 10% to 20%. Mechanical and durability performance of the resulting hollow blocks were assessed, with the following important conclusions deduced.

- Acknowledging the massive waste accumulation of SBA, abundant reservoirs of DM, and excessive use of natural fine aggregates, this study demonstrated that both SBA and DM have the potential to be utilized as a partial substitute for natural fine aggregates.
- Replacing natural fine aggregates with DM or SBA reduced hollow block bulk density, with SBA causing a greater decrease. At 20% replacement, bulk density dropped by about 24%, with DM and SBA showing reductions of up to 23.6% and 23.9%, respectively. This is attributed to the lower densities of DM (575 kg/m³) and SBA (444 kg/m³) compared to natural sand (1290 kg/m³). Concrete compressive strength stabilized after 28 days, with DM and SBA replacements causing significant

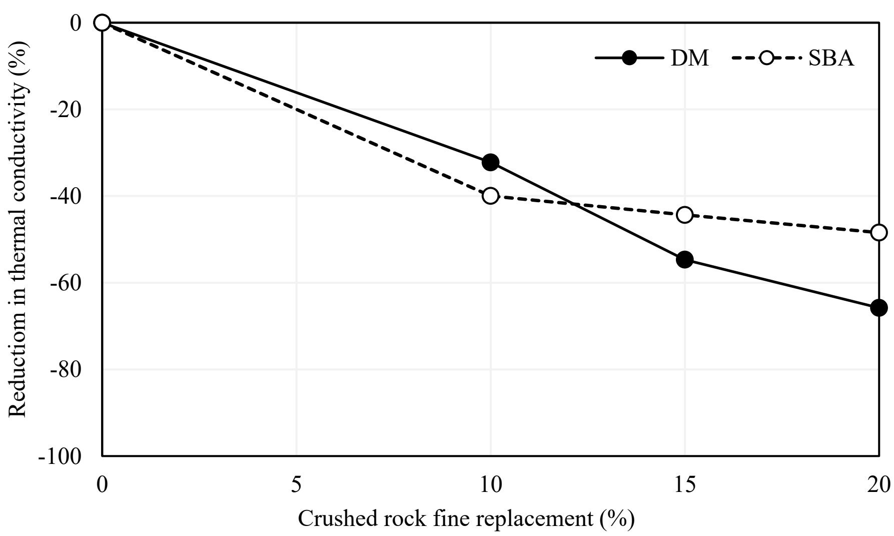

Fig. 13: Reduction in thermal conductivity comparison for DM and SBA replacement.

reductions. At 20% replacement, DM reduced strength by 83.7%, while SBA caused a 46.2% reduction, highlighting an 81% greater impact by DM. The higher moisture content of DM and SBA contributed to this strength reduction by increasing the effective water-to-cement ratio.

- Replacing fine aggregates with DM or SBA significantly increased water absorption, stabilizing beyond 15%. DM replacements of 20% raised absorption by 153.7%, while SBA replacements increased it by 193.9%. The higher absorption of SBA is attributed to its lower specific gravity and higher porosity compared to DM. Replacing natural fine aggregates with DM or SBA significantly increased the porosity of hollow concrete blocks as well, reaching up to 23.1% and 23.2% for 20% replacements, representing over 220% increases compared to the control. Porosity increases were attributed to fracture expansion and weakened aggregate-cement bonding. Both replacements showed similar effects at equivalent levels.
- Thermal conductivity decreased significantly with DM and SBA replacements, reaching reductions of 65.4% and 47.3% at 20% replacement, respectively. Increased porosity and reduced density contributed to these improvements in insulating properties. DM exhibited a steeper reduction, indicating superior insulation performance compared to SBA.
- The inclusion of DM enhanced the sound absorption potential of hollow blocks significantly which can be attributed to the enhanced void content. On the contrary, the drying shrinkage of DM or SBA-incorporated blocks was greater than the control mix. It is suggested to utilize the water reducing admixtures in future works to tackle the water absorption potential of SBA or DM-incorporated mix. The future works should also explore the microstructural analysis on the proposed concrete blocks.
- Advanced analytical methods including scanning electron microscopy or X-ray diffraction should be used in future research to further examine the microscopic effects. In addition, the use of advanced thermal conductivity measuring methods, such the heat flux method, can enhance result validity and provide a clearer understanding of the thermal performance of the material.

Acknowledgments

This study “Received research funding from the Science, Research and Innovation Promotion Fund for Fiscal Year 2024 (Contract Number. 126/2567)”. The authors also sincere gratitude to Thammasat University and Rajamangala University of Technology Phranakhon, for their invaluable support in facilitating this study. Their contributions were instrumental in completing the research successfully.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Applicable.

References

[1] A. Gupta, N. Gupta, A. Shukla, R. Goyal, S. Kumar, Utilization of recycled aggregate, plastic, glass waste and coconut shells in concrete - a review, *IOP Conference Series: Materials Science and Engineering*, 2020, **804**, 012034, doi: 10.1088/1757-899x/804/1/012034.

[2] P. Saingam, Q. Hussain, G. Sua-Iam, A. Nawaz, A. Ejaz, Hemp fiber-reinforced polymers composite jacketing technique for sustainable and environment-friendly concrete, *Polymers*, 2024, **16**, 1774, doi: 10.3390/polym16131774.

[3] M. I. Qureshi, P. Warnitchai, Reduction of inelastic seismic demands in a mid-rise rocking wall structure designed using the displacement-based design procedure, *The Structural Design of Tall and Special Buildings*, 2017, **26**, e1307, doi: 10.1002/tal.1307.

[4] B. Chatveera, P. Hengterm, N. Makul, G. Sua-iam, Enhancing the mechanical and thermal properties of geopolymers prepared by refractory brick dust: an investigation into optimal mix ratios and curing conditions, *Journal of Building Engineering*, 2024, **94**, 110059, doi: 10.1016/j.jobe.2024.110059.

[5] G. Sua-iam, S. Jamnam, Influence of calcium carbonate on green self-compacting concrete incorporating porcelain tile waste as coarse aggregate replacement, *Case Studies in Construction Materials*, 2023, **19**, e02366, doi: 10.1016/j.cscm.2023.e02366.

[6] G. Sua-iam, N. Makul, Recycling prestressed concrete pile waste to produce green self-compacting concrete, *Journal of Materials Research and Technology*, 2023, **24**, 4587-4600, doi: 10.1016/j.jmrt.2023.04.101.

[7] D. O. Oyejobi, A. A. Firoozi, D. B. Fernández, S. Avudaiappan, Integrating circular economy principles into concrete technology: Enhancing sustainability through industrial waste utilization, *Results in Engineering*, 2024, **24**, 102846, doi: 10.1016/j.rineng.2024.102846.

[8] P. Joyklad, N. Ali, S. Verre, H. M. Magbool, A. Elnemr, M. I. Qureshi, Q. Hussain, K. Chaiyasarn, Experimental study on the out-of-plane behavior of brick masonry walls strengthened with mortar and wire mesh: a pioneer study, *Infrastructures*, 2021, **6**, 165, doi: 10.3390/infrastructures6110165.

[9] E. Sodupe-Ortega, E. Fraile-Garcia, J. Ferreiro-Cabello, A.

Sanz-Garcia, Evaluation of crumb rubber as aggregate for automated manufacturing of rubberized long hollow blocks and bricks, *Construction and Building Materials*, 2016, **106**, 305-316, doi: 10.1016/j.conbuildmat.2015.12.131.

[10] M. Shahzad, Y. Qu, S. U. Rehman, A. U. Zafar, Adoption of green innovation technology to accelerate sustainable development among manufacturing industry, *Journal of Innovation & Knowledge*, 2022, **7**, 100231, doi: 10.1016/j.jik.2022.100231.

[11] F. A. Najam, M. I. Qureshi, P. Warnitchai, T. Mehmood, Prediction of nonlinear seismic demands of high-rise rocking wall structures using a simplified modal pushover analysis procedure, *The Structural Design of Tall and Special Buildings*, 2018, **27**, e1506, doi: 10.1002/tal.1506.

[12] J. Fleith de Medeiros, T. Bisognin Garlet, J. L. Duarte Ribeiro, M. Nogueira Cortimiglia, Success factors for environmentally sustainable product innovation: an updated review, *Journal of Cleaner Production*, 2022, **345**, 131039, doi: 10.1016/j.jclepro.2022.131039.

[13] S. A. Babatunde, Review of strengthening techniques for masonry using fiber reinforced polymers, *Composite Structures*, 2017, **161**, 246-255, doi: 10.1016/j.compstruct.2016.10.132.

[14] A. S. Al-Tamimi, O. S. Baghabra Al-Amoudi, M. A. Al-Osta, M. R. Ali, A. Ahmad, Effect of insulation materials and cavity layout on heat transfer of concrete masonry hollow blocks, *Construction and Building Materials*, 2020, **254**, 119300, doi: 10.1016/j.conbuildmat.2020.119300.

[15] U. Khalil, B. Aslam, Z. A. Kazmi, A. Maqsoom, M. I. Qureshi, S. Azam, A. Nawaz, Integrated support vector regressor and hybrid neural network techniques for earthquake prediction along Chaman fault, Baluchistan, *Arabian Journal of Geosciences*, 2021, **14**, 2192, doi: 10.1007/s12517-021-08564-4.

[16] K. Chaiyasarn, N. Poovarodom, A. Ejaz, A. W. M. Ng, Q. Hussain, P. Saingam, H. Mohamad, P. Joyklad, Influence of natural fiber rope wrapping techniques on the compressive response of recycled aggregate concrete circular columns, *Results in Engineering*, 2023, **19**, 101291, doi: 10.1016/j.rineng.2023.101291.

[17] S. Suparp, A. Ejaz, K. Khan, Q. Hussain, P. Joyklad, P. Saingam, Load-bearing performance of non-prismatic RC beams wrapped with carbon FRP composites, *Sensors*, 2023, **23**, 5409, doi: 10.3390/s23125409.

[18] W. A. Al-Awsh, O. S. Baghabra Al-Amoudi, M. A. Al-Osta, A. Ahmad, T. A. Saleh, Experimental assessment of the thermal and mechanical performance of insulated concrete blocks, *Journal of Cleaner Production*, 2021, **283**, 124624, doi: 10.1016/j.jclepro.2020.124624.

[19] M. A. Al-Osta, A. S. Al-Tamimi, S. M. Al-Tarbi, O. S. Baghabra Al-Amoudi, W. A. Al-Awsh, T. A. Saleh, Development of sustainable concrete using recycled high-density polyethylene and crumb tires: Mechanical and thermal properties, *Journal of Building Engineering*, 2022, **45**, 103399, doi: 10.1016/j.jobe.2021.103399.

[20] D. Shekhar, J. Godihal, Sustainability analysis of hollow concrete blocks manufactured using recycled concrete aggregate and fly ash as an eco-friendly construction component, *Journal of Architectural Engineering*, 2024, **30**, 04024001, doi: 10.1061/jaeied.aeeng-1677.

[21] J. Wu, G. Bai, H. Zhao, X. Li, Mechanical and thermal tests of an innovative environment-friendly hollow block as self-insulation wall materials, *Construction and Building Materials*, 2015, **93**, 342-349, doi: 10.1016/j.conbuildmat.2015.06.003.

[22] J. Herrera-González, G. Ortiz-Rabell, J. Xilotl-Domínguez, O. Ojeda-Farias, I. Flores-Vivian, F. Vázquez-Leal, G. Fajardo-San-Miguel, Use of waste material from the chemical industry for the production of low-strength concrete hollow blocks, *Sustainable Materials and Technologies*, 2024, **40**, e00870, doi: 10.1016/j.susmat.2024.e00870.

[23] H. S. Sureshchandra, G. Sarangapani, B. G. Naresh Kumar, Experimental investigation on the effect of replacement of sand by quarry dust in hollow concrete block for different mix proportions, *International Journal of Environmental Science and Development*, 2014, **5**, 15-19. doi: 10.7763/ijesd.2014.v5.524

[24] S. M. Al-Tarbi, O. S. Baghabra Al-Amoudi, M. A. Al-Osta, W. A. Al-Awsh, M. Shameem, M. Sharif Zami, Development of energy-efficient hollow concrete blocks using perlite, vermiculite, volcanic scoria, and expanded polystyrene, *Construction and Building Materials*, 2023, **371**, 130723, doi: 10.1016/j.conbuildmat.2023.130723.

[25] I. C. de Carvalho Terra, F. G. Batista, D. W. Silva, M. V. Scatolino, F. T. Alves Júnior, M. A. Martins, L. M. Mendes, Mining waste and coconut fibers as an eco-friendly reinforcement for the production of concrete blocks, *Environmental Science and Pollution Research*, 2023, **30**, 62641-62652, doi: 10.1007/s11356-023-26493-5.

[26] S. N. Abbas, M. I. Qureshi, M. M. Abid, M. A. U. R. Tariq, A. W. M. Ng, An investigation of mechanical properties of concrete by applying sand coating on recycled high-density polyethylene (HDPE) and electronic-wastes (E-wastes) used as a partial replacement of natural coarse aggregates, *Sustainability*, 2022, **14**, 4087, doi: 10.3390/su14074087.

[27] K. Ali, P. Saingam, M. I. Qureshi, S. Saleem, A. Nawaz, T. Mehmood, A. Maqsoom, M. W. Malik, S. Suparp, Influence of recycled plastic incorporation as coarse aggregates on concrete properties, *Sustainability*, 2023, **15**, 5937, doi: 10.3390/su15075937.

[28] S. N. Abbas, M. I. Qureshi, M. M. Abid, A. Zia, M. A. U. R. Tariq, An investigation of mechanical properties of fly ash based

geopolymer and glass fibers concrete, *Sustainability*, 2022, **14**, 10489, doi: 10.3390/su141710489.

[29] S. U. Khan, M. I. Qureshi, I. Ahmad Rana, A. Maqsoom, Seismic vulnerability assessment of building stock of Malakand (Pakistan) using FEMA P-154 method, *SN Applied Sciences*, 2019, **1**, 1625, doi: 10.1007/s42452-019-1681-z.

[30] M. I. Qureshi, S. U. Khan, I. Ahmad Rana, B. Ali, A. U. Rahman, Determinants of people's seismic risk perception: a case study of Malakand, Pakistan, *International Journal of Disaster Risk Reduction*, 2021, **55**, 102078, doi: 10.1016/j.ijdrr.2021.102078.

[31] D. Kastis, G. Kakali, S. Tsivilis, M. G. Stamatakis, Properties and hydration of blended cements with calcareous diatomite, *Cement and Concrete Research*, 2006, **36**, 1821-1826, doi: 10.1016/j.cemconres.2006.05.005.

[32] N. Degirmenci, A. Yilmaz, Use of diatomite as partial replacement for Portland cement in cement mortars, *Construction and Building Materials*, 2009, **23**, 284-288, doi: 10.1016/j.conbuildmat.2007.12.008.

[33] B. Xu, Z. Li, Performance of novel thermal energy storage engineered cementitious composites incorporating a paraffin/diatomite composite phase change material, *Applied Energy*, 2014, **121**, 114-122, doi: 10.1016/j.apenergy.2014.02.007.

[34] J. A. C. Costa, A. E. Martinelli, R. M. do Nascimento, A. M. Mendes, Microstructural design and thermal characterization of composite diatomite-vermiculite paraffin-based form-stable PCM for cementitious mortars, *Construction and Building Materials*, 2020, **232**, 117167, doi: 10.1016/j.conbuildmat.2019.117167.

[35] J. Li, W. Zhang, C. Li, P. J. M. Monteiro, Green concrete containing diatomaceous earth and limestone: Workability, mechanical properties, and life-cycle assessment, *Journal of Cleaner Production*, 2019, **223**, 662-679, doi: 10.1016/j.jclepro.2019.03.077.

[36] M. Sarıdemir, S. Çelikten, A. Yıldırım, Mechanical and microstructural properties of calcined diatomite powder modified high strength mortars at ambient and high temperatures, *Advanced Powder Technology*, 2020, **31**, 3004-3017, doi: 10.1016/j.apt.2020.05.024.

[37] R. Singh, M. Patel, Experimental and machine learning approaches to investigate the application of sugarcane bagasse ash as a partial replacement of fine aggregate for concrete production, *Journal of Building Engineering*, 2023, **76**, 107168, doi: 10.1016/j.jobe.2023.107168.

[38] M. S. Kawamura, D. P. Ronconi, H. Yoshizaki, Optimizing transportation and storage of final products in the sugar and ethanol industry: a case study, *International Transactions in Operational Research*, 2006, **13**, 425-439, doi: 10.1111/j.1475-3995.2006.00556.x.

[39] K. G. Santhosh, S. M. Subhani, A. Bahurudeen, Cleaner production of concrete by using industrial by-products as fine aggregate: a sustainable solution to excessive river sand mining, *Journal of Building Engineering*, 2021, **42**, 102415, doi: 10.1016/j.jobe.2021.102415.

[40] N. Bheel, S. Khoso, M. H. Baloch, O. Benjeddou, M. Alwetaishi, Use of waste recycling coal bottom ash and sugarcane bagasse ash as cement and sand replacement material to produce sustainable concrete, *Environmental Science and Pollution Research*, 2022, **29**, 52399-52411, doi: 10.1007/s11356-022-19478-3.

[41] S. Ali Khawaja, U. Javed, T. Zafar, M. Riaz, M. S. Zafar, M. K. Khan, Eco-friendly incorporation of sugarcane bagasse ash as partial replacement of sand in foam concrete, *Cleaner Engineering and Technology*, 2021, **4**, 100164, doi: 10.1016/j.clet.2021.100164.

[42] M. Hamza Hasnain, U. Javed, A. Ali, M. Saeed Zafar, Eco-friendly utilization of rice husk ash and bagasse ash blend as partial sand replacement in self-compacting concrete, *Construction and Building Materials*, 2021, **273**, 121753, doi: 10.1016/j.conbuildmat.2020.121753.

[43] G. Sua-iam, N. Makul, Use of increasing amounts of bagasse ash waste to produce self-compacting concrete by adding limestone powder waste, *Journal of Cleaner Production*, 2013, **57**, 308-319, doi: 10.1016/j.jclepro.2013.06.009.

[44] V. Torres de Sande, M. Sadique, P. Pineda, A. Bras, W. Atherton, M. Riley, Potential use of sugar cane bagasse ash as sand replacement for durable concrete, *Journal of Building Engineering*, 2021, **39**, 102277, doi: 10.1016/j.jobe.2021.102277.

[45] S. Subedi, G. A. Arce, H. Noorvand, M. M. Hassan, M. Barbato, L. N. Mohammad, Properties of engineered cementitious composites with raw sugarcane bagasse ash used as sand replacement, *Journal of Materials in Civil Engineering*, 2021, **33**, 04021231, doi: 10.1061/(asce)mt.1943-5533.0003892.

[46] ASTM C129, Standard Specification for Nonloadbearing Concrete Masonry Units. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2023.

[47] TIS 58-2560, Standard for hollow non–load–bearing concrete masonry units, Thai Industrial Standards Institute, Thai Industrial Standards, 1990.

[48] ASTM C150, Standard Specification for Portland Cement. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2007.

[49] ASTM C33", Standard Specification for Concrete Aggregates. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2018.

[50] ASTM C127, Standard Test Method for Relative Density

(Specific Gravity) and Absorption of Coarse Aggregate. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2024.

[51] ASTM C140, Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2013.

[52] ASTM D4284, Standard Test Method for Determining Pore Volume Distribution of Catalysts and Catalyst Carriers by Mercury Intrusion Porosimetry. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA.

[53] ASTM C423, Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method, American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2013.

[54] ASTM C341, Standard Practice for Preparation and Conditioning of Cast, Drilled, or Sawed Specimens of Hydraulic-Cement Mortar and Concrete Used for Length Change Measurements. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2017.

[55] ASTM D559, Standard Test Methods for Wetting and Drying Compacted Soil-Cement Mixtures. American Society for Testing and Materials, ASTM International, West Conshohocken, PE, USA, 2003.

[56] JIS R 2618, Testing Method for Thermal Conductivity of Insulating Fire Bricks by Hot Wire, Japanese Standards Association, Japanese Industrial Standards, Japan, 1995.

[57] D. Taoukil, Y. El meski, M. L. Lahlaouti, R. Djedjig, A. El bouardi, Effect of the use of diatomite as partial replacement of sand on thermal and mechanical properties of mortars, *Journal of Building Engineering*, 2021, **42**, 103038, doi: 10.1016/j.jobe.2021.103038.

[58] E. A. B. Koenders, M. Pepe, E. Martinelli, Compressive strength and hydration processes of concrete with recycled aggregates, *Cement and Concrete Research*, 2014, **56**, 203-212, doi: 10.1016/j.cemconres.2013.11.012.

[59] S. K. Kirthika, S. K. Singh, A. Chourasia, Alternative fine aggregates in production of sustainable concrete- A review, *Journal of Cleaner Production*, 2020, **268**, 122089, doi: 10.1016/j.jclepro.2020.122089.

[60] B. A. Tayeh, S. M. Ahmed, R. D. Abdel Hafez, RETRACTED: sugarcane pulp sand and paper grain sand as partial fine aggregate replacement in environment-friendly concrete bricks, *Case Studies in Construction Materials*, 2023, **18**, e01612, doi: 10.1016/j.cscm.2022.e01612.

[61] J. Wang, B. Du, Experimental studies of thermal and acoustic properties of recycled aggregate crumb rubber concrete, *Journal of Building Engineering*, 2020, **32**, 101836, doi: 10.1016/j.jobe.2020.101836.

[62] P. Pongsopha, P. Sukontasukkul, H. Zhang, S. Limkatanyu, Thermal and acoustic properties of sustainable structural lightweight aggregate rubberized concrete, *Results in Engineering*, 2022, **13**, 100333, doi: 10.1016/j.rineng.2022.100333.

[63] N. P. Tran, C. Gunasekara, D. W. Law, S. Houshyar, S. Setunge, A. Cwirzen, A critical review on drying shrinkage mitigation strategies in cement-based materials, *Journal of Building Engineering*, 2021, **38**, 102210, doi: 10.1016/j.jobe.2021.102210.

[64] B. Mohammadi, M. R. Nokken, Influence of moisture content on water absorption in concrete, *3rd Specialty Conference on Material Engineering & Applied Mechanics*, Montréal, Québec, 2013, 1-9.

[65] W. C. Tang, Y. Lo, A. Nadeem, Mechanical and drying shrinkage properties of structural-graded polystyrene aggregate concrete, *Cement and Concrete Composites*, 2008, **30**, 403-409, doi: 10.1016/j.cemconcomp.2008.01.002.

[66] S. N. Ahmed, N. Hamah Sor, M. A. Ahmed, S. M. A. Qaidi, Thermal conductivity and hardened behavior of eco-friendly concrete incorporating waste polypropylene as fine aggregate, *Materials Today: Proceedings*, 2022, **57**, 818-823, doi: 10.1016/j.matpr.2022.02.417.

[67] A. S. Benosman, M. Mouli, H. Taibi, M. Belbachir, Y. Senhadji, I. Bahlouli, D. Houivet, Chemical, mechanical and thermal properties of mortar composites containing waste pet, *Environmental Engineering and Management Journal*, 2017, **16**, 1489-1505, doi: 10.30638/eemj.2017.162.

[68] N. Hilal, T. A. Tawfik, S. N. Ahmed, N. Hamah Sor, The effect of waste medical radiology as fiber reinforcement on the behavior of eco-efficient self-compacting concrete, *Environmental Science and Pollution Research*, 2022, **29**, 49253-49266, doi: 10.1007/s11356-022-19360-2.

[69] S. P. Mathew, Y. Nadir, M. Muhammed Arif, Experimental study of thermal properties of concrete with partial replacement of coarse aggregate by coconut shell, *Materials Today: Proceedings*, 2020, **27**, 415-420, doi: 10.1016/j.matpr.2019.11.249.

Publisher's Note: Engineered Science Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.