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Development and Characterization of Sustainable Load-Bearing Masonry Units Incorporating Coconut Shell Ash and Recycled Polyester Fabric

M.M.V.S. Mapa [a], W.D.C.C. Wijerathne [a] *

[a]Department of Science and Technology, Uva Wellassa University, Badulla, Sri Lanka.

*** Corresponding author email address**: chathura@uwu.ac.lk

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Abstract

Agricultural and industrial waste have received considerable attention in Sri Lanka as potential raw materials for developing sustainable masonry units. This study investigates the development of high-performance load-bearing masonry units by partially replacing ordinary Portland cement (OPC) with coconut shell ash (CSA) and recycled polyester fabric scraps. CSA was incorporated as a partial cement replacement at levels of 1%, 3%, 5%, 7%, 9%, 11%, 13%, and 15% by weight, while a constant 1% recycled polyester fabric (by weight of binder) was incorporated in all modified mixes. The performance of the masonry units was evaluated in terms of compressive strength, water absorption, and Fourier Transform Infrared (FTIR) spectroscopy to identify the optimum mix composition. The mix containing 7% CSA and 1% polyester fabric achieved the minimum 7-day water absorption of 4.4% and the maximum 28-day compressive strength of 13.9 MPa. FTIR analysis provided clear evidence of pozzolanic activity through the formation of additional Calcium silicate hydrate (C-S-H) gel. The developed masonry units satisfy both ASTM C90 and SLS 855 requirements for load-bearing applications in Sri Lanka. The present study focuses on compressive strength, water absorption, and FTIR characterization of the developed masonry units. Further studies on tensile strength, flexural strength, ductility, and long-term durability are recommended to provide a comprehensive evaluation of the reinforcing effect of recycled polyester fabric.

Keywords: coconut shell ash, recycled polyester fabric, load-bearing masonry units, compressive strength, water absorption, pozzolanic activity.

1. Introduction

Concrete remains one of the most widely used construction materials globally, with annual production exceeding 10 billion tons and expected to reach 18 billion tons annually by 2050 [1,2]. However, the production of ordinary Portland cement (OPC) is responsible for approximately 7% of global carbon dioxide (CO_2) emissions due to raw material extractions, high energy consumption during clinking, and limestone decomposition [3,4]. Consequently, Sri Lanka's construction sector continues to experience increasing demand for cement-based materials, while large volumes of agricultural biomass waste (especially coconut shells) and post-industrial textile waste (mainly polyester fabrics) are generated annually [5]. These materials are often disposed of through open burning or landfilling, contributing to environmental pollution.

During cement hydration, OPC forms calcium silicate hydrate (C-S-H) gel as the principal strength-contributing phase along with calcium hydroxide ($Ca(OH)_2$) [6]. Pozzolanic materials containing sufficient amorphous SiO_2, Al_2O_3, and Fe_2O_3 can react with $Ca(OH)_2$ in the presence of moisture to form additional C-S-H, thereby improving strength and durability [7]. Coconut shell ash (CSA) produced under control carbonization, contains 37.97% SiO_2, 22.12% Al_2O_3, and 12.4% Fe_2O_3 (totalling 72.49%), satisfying the ASTM C618 minimum requirement of 70% for pozzolans [8].

Previous studies have demonstrated the potential of CSA as a partial cement replacement in load-bearing and non-load-bearing applications [2,9,10]. Concrete is inherently brittle and exhibits low tensile strength and limited crack resistance [11]. Synthetic fibers such as polyester have been introduced to improve toughness, ductility, and durability through a crack-bridging mechanism that controls microcrack propagation [1,12,13]. Although individual applications of CSA and polyester fibers are well documented, limited research exists on their combined use in load-bearing masonry units, particularly with locally available post-industrial textile waste in the Sri Lankan context [14,15].

The performance of load-bearing masonry units is primarily evaluated by compressive strength and water absorption, as specified in ASTM C90 and SLS 855. Accordingly, this study investigates the development of sustainable load-bearing masonry units incorporating

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coconut shell ash as a partial cement replacement and recycled polyester fabric. Compressive strength, water absorption, and Fourier Transform Infrared (FTIR) analyses were conducted to evaluate the developed masonry units and identify the optimum mix composition.

2. Materials and Methods

2.1 Materials

Ordinary Portland cement (OPC), river sand (maximum size 4.75 mm) and crushed granite (maximum size 20 mm) served as the base materials. Potable tap water was used for mixing. Coconut shell ash (CSA) was produced from locally collected coconut shells in Sri Lanka. The shells were washed, sun-dried for 48 hours, and carbonized in a closed metallic container for 2 hours under limited oxygen supply to promote the formation of amorphous silica, which is essential for pozzolanic reactivity [7,9]. The resulting ash was cooled, ground and sieved through a 75 µm mesh.

Polyester fabric scraps (≥95 % polyethylene terephthalate) were collected from nearby tailor shops. The scraps were washed to remove dust, sizing agents and any surface contaminants, sun-dried for 24 hours, and cut into uniform 10 mm × 10 mm pieces using sharp scissors. This fabric size and preparation method ensure uniform dispersion and minimizing clustering within the concrete matrix [11,13].

2.2 Mix Proportions and Sample Preparation

Fig. 1. 100 mm × 100 mm × 100 mm masonry unit specimen fabricated using ordinary Portland cement, coconut shell ash, and recycled polyester fabric reinforcement for experimental evaluation.

The masonry units were prepared using 1:2:3 [(OPC+CSA): sand: gravel] mix ratio by weight with a water-cement ratio of 0.40, which is widely adapted for structural masonry applications to achieve adequate workability and strength [2,10]. CSA was used as a partial replacement for OPC at levels of 0%, 1%, 3%, 5%, 7%, 9%, 11%, 13%, and 15% by weight of cement. The replacement levels were selected to systematically evaluate the pozzolanic contribution of CSA while identifying the optimum dosage; previous studies have shown that the beneficial effects are typically maximized between 5% and 10%, beyond which excess CSA leads to cement dilution and reduced strength [2,9,10]. A constant 1% polyester fabric addition (by weight of binder) was maintained across all modified mixes, as 0-2% has been reported to provide optimal crack bridging, toughness, and durability enhancement without causing fiber agglomeration or significant loss of workability [1,11,13].

The Dry ingredients (cement, CSA, sand, and gravel) were first mixed thoroughly for three minutes using a margin trowel. The polyester fabric scraps were then added and mixing continued for an additional two minutes to ensure homogeneous distribution. Water was gradually added and mixing was continued for three more minutes until a homogeneous mixture was obtained. The fresh mixture was cast into an oiled wooden mould of 100 mm × 100 mm × 100 mm in three layers, with each layer compacted using a tamping rod (25 strokes per layer) to remove entrapped air.

The specimens were demoulded after 24 hours and cured in a water bath under ambient laboratory conditions (25 ± 2°C, 70 % relative humidity) for 28 days.

Table 1
Compositions of different masonry units made using coconut shell ash and recycled polyester fabrics.

Sample	CSA %	Cement (Parts)	Polyester (Parts)	Sand (Parts)	Gaval (Parts)	Polyester %
CSA-0	0	1	0	2	3	1
CSA-1	1	0.99	0.01	2	3	1
CSA-3	3	0.97	0.03	2	3	1
CSA-5	5	0.95	0.05	2	3	1
CSA-7	7	0.93	0.07	2	3	1
CSA-9	9	0.91	0.09	2	3	1
CSA-11	11	0.89	0.11	2	3	1
CSA-13	13	0.87	0.13	2	3	1
CSA-15	15	0.85	0.15	2	3	1

2.3 Testing Methods

Compressive strength test was conducted at 3 and 28 days of curing using an HLC-100 Universal Testing Machine at a constant loading rate of 0.2 kN/s in accordance with ASTM C39 standards. Cubic specimens (100 mm × 100 mm × 100 mm) were tested under uniaxial compression until failure.

Fig. 2. Experimental setup for compressive strength testing of masonry unit specimens using a universal testing machine under uniaxial loading conditions.

Water absorption studies followed ASTM 67-07. Samples were first heated to 105 °C for 24 h to remove moisture and the dry weight (W_1) was recorded. The samples were then immersed in clean water bath and wet weight (W2) was recorded intermittently at 12 h intervals. Prior to recording the wet weight (W2), the surface was dried with a moist cloth to remove excess surface water. The water absorption percentage was calculated using the following equation:

$$\textit{Water absorption}\ (\%) = \frac{W_2 - W_1}{W_1} \times 100\ \% \qquad (1)$$

Fourier Transform Infrared (FTIR) spectroscopy was performed on powdered samples from the control mix (CSA-0) and the optimal mix (CSA-7), as well as OPC, CSA, and polyester fabric. Spectra were recorded using a Bruker ALPHA Platinum ATR spectrometer in the wavenumber range of 500–4000 cm^{-1}.

3. Results and Discussion

3.1 Water Absorption

The water absorption of masonry units decreased with increasing CSA content up to 7%, reaching a minimum value of 4.4% at 7 days. Beyond 7% replacement, the water absorption increased gradually, recorded 6% water absorption at 15% CSA (Fig. 3).

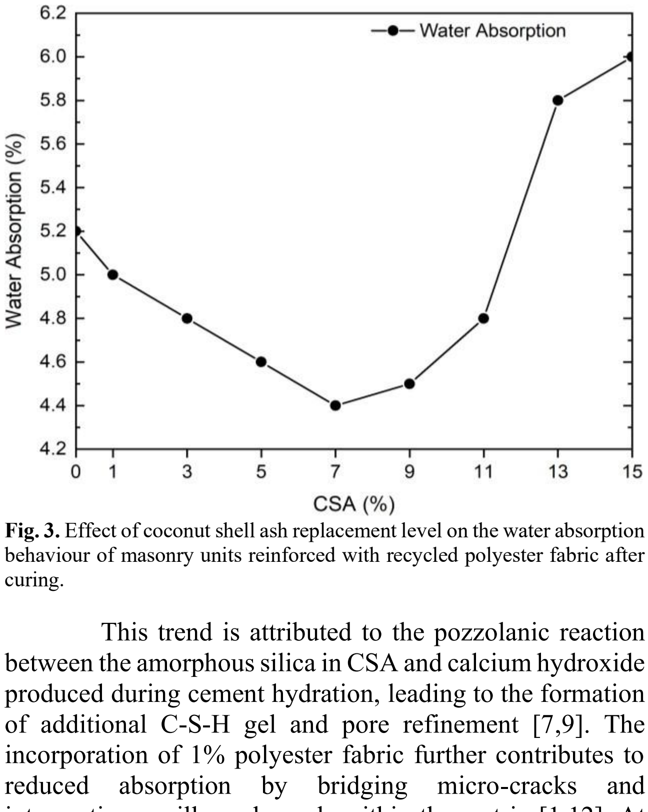

Fig. 3. Effect of coconut shell ash replacement level on the water absorption behaviour of masonry units reinforced with recycled polyester fabric after curing.

This trend is attributed to the pozzolanic reaction between the amorphous silica in CSA and calcium hydroxide produced during cement hydration, leading to the formation of additional C-S-H gel and pore refinement [7,9]. The incorporation of 1% polyester fabric further contributes to reduced absorption by bridging micro-cracks and interrupting capillary channels within the matrix [1,12]. At higher CSA replacement levels (>7%), excess unreacted CSA particles act as inert fillers, creating micro-voids and weak interfacial transition zones that increased porosity [2,10].

To further understand the individual and combined effects of the two addictive, additional control mixes were tested. The masonry unit containing only 1% CSA (without polyester) exhibit higher water absorption of 5.48 % compared to CSA-1, confirming the inherent porosity introduced by CSA. In contrast, the masonry unit containing only 1% polyester fabric (without CSA) showed lower water absorption of 4.81%. The combined CSA-1 mix (1% CSA + 1% polyester fabric) recorded an intermediate water absorption value of 5.0%. This pattern demonstrates a clear balance between the two effects; polyester fibers effectively limit water ingress by bridging micro-cracks, while CSA content introduces porosity. Consequently, water absorption followed the order: polyester-only < combined mix < CSA-only, indicating that the combined interaction between CSA and polyester becomes more effective at higher replacement levels. Overall, the lowest water absorption of 4.4% achieved in the CSA-7 remains well below the 5% threshold generally accepted for durable load-bearing masonry units in tropical environments [10].

3.2 Compressive Strength

The compressive strengths of the masonry units at 3 and 28 days of curing are illustrated in Fig. 4. As expected, the 28-day compressive strength were considerably higher than the corresponding 3-day strengths across all mixes, reflecting the progressive nature of cement hydration and pozzolanic reactions over time. The 28-day compressive strength increased steadily with CSA replacement level up to 7 %, attaining a maximum value of 13.9 MPa (13.9 ± 1.0 MPa), and subsequently decreased at higher replacement levels.

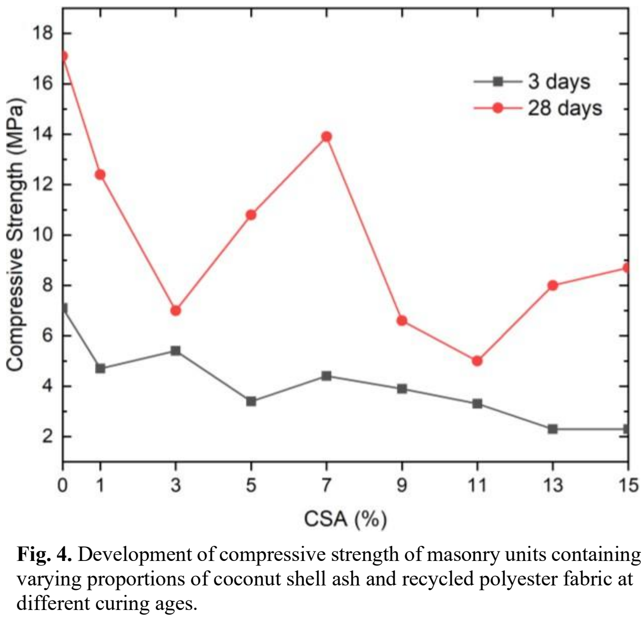

Fig. 4. Development of compressive strength of masonry units containing varying proportions of coconut shell ash and recycled polyester fabric at different curing ages.

The optimum performance at 7 % CSA can be attribute to the combined pozzolanic reactivity of CSA (which generates additional C-S-H gel) and its micro-filler effect that densifies the matrix, all without causing significant dilution of the cement phase [2,9]. At higher

CSA contents (>9%), the reduction in strength is likely due to insufficient availability of calcium hydroxide for complete pozzolanic reaction, resulting in excess unreacted ash particles that act as inert fillers and weakening the interfacial transition zones [2,10]. The 28-day compressive strength of 13.9 MPa for the 7 % CSA mix exceeds the minimum requirement of 13.8 MPa specified in ASTM C90 for load-bearing concrete masonry units and comfortably satisfies the SLS 855 requirement of 7.0 MPa used in Sri Lanka

Table 2
Compositions of different masonry units made using coconut shell ash and recycled polyester fabrics.

Composition	Water absorption min (%)	Compressive strength max (MPa)	Source
7 % CSA + 1% Polyester + 93 % Cement	4.4% (7 days)	13.90 MPa (28 days)	This work
Regular Concrete Block	5.50% (7 days)	27.31 MPa (28 days)	This work
9.5 % CSA + 91.5% Cement (Paving blocks)	2.35 %	40.45 MPa	[10]
10% CSA + 0.16% CF + 90% Cement	Not Specified	40.45 MPa	[19]
5% CSA + 95 % Cement	29.41 % (28 days)	11.9 MPa (28 days)	[20]
4% Cement + 2% CSA (Earth Blocks)	13.5 % (14 days)	3.78 MPa (28 days)	[21]
0.3% Polyester Fiber in High Strength Mix	Not Specified	89.27 (28 days)	[22]

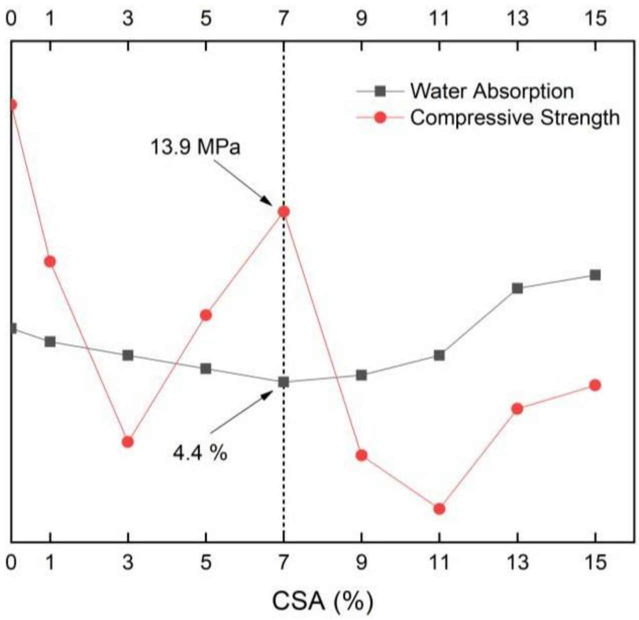

Fig. 5. Relationship between compressive strength and water absorption of masonry units incorporating coconut shell ash and recycled polyester fabric, highlighting the optimum mix composition.

It is noted that the absolute compressive strength values obtained in this study are lower than those reported in some previous studies previous studies listed in Table 2. This difference can be ascribed to several factors, including the relatively lean 1:2:3 mix ratio adopted for masonry units (as opposed to richer structural concrete mixes used in the literature), variations in the quality of locally sourced raw materials (river sand and crushed granite), and laboratory-scale water-curing conditions that may not have been as consistently controlled as in some reported works [2,9,10]. Despite these differences, Fig. 5 clearly identifies the 7 % CSA composition as the optimum, providing the best balance of maximum compressive strength and minimum water absorption.

3.3 Spectroscopic Analysis of Chemical Interactions in Raw Materials and Masonry Units.

The FTIR spectra of coconut shell ash (CSA), Ordinary Portland Cement (OPC), recycled polyester fabric, the control masonry unit (CSA-0) and the optimum masonry unit (CSA-7) are shown in Fig. 6 and were used to identify the functional groups present and the chemical changes resulting from CSA and polyester fabric incorporation into cementitious matrix.

The FTIR spectrum of CSA exhibits a distinct asymmetric Si–O–Si stretching band in the range of 1050–1100 cm^{-1} and a symmetric Si–O–Si stretching band at approximately 790–800 cm^{-1}. The presence of these characteristic absorption bands confirms the existence of amorphous silica, which is responsible for the pozzolanic reactivity of CSA and its ability to react with calcium hydroxide during cement hydration to form additional calcium silicate hydrate (C-S-H) gel [23,27].

The FTIR spectrum of OPC exhibits characteristic absorption bands related to carbonate and hydration products. The bands at approximately 1420 cm^{-1} and 875 cm^{-1} are assigned to the asymmetric stretching and in-plane bending vibrations of C–O bonds in CO_3^{2-}, respectively. Furthermore, the absorption band around 1116 cm^{-1} attributed to the symmetric stretching vibration of Si–O bonds in the ettringite phase, whereas the band near 520 cm^{-1} corresponds to the out-of-plane bending vibration of Si–O bonds [24,27].

The FTIR spectrum of the polyester fabric exhibits characteristic absorption bands corresponding to its chemical structure. The bands observed in the range of 3000–2850 cm^{-1} are attributed to C–H stretching vibrations, while the prominent peak at 1720–1730 cm^{-1} corresponds to the C=O stretching vibration of the ester functional group. In addition, the absorption bands between 1300 and 1000 cm^{-1} are assigned to C–O stretching vibrations, confirming the presence of ester linkages in the polyester fabric [11,13].

Compared with the control mix (CSA-0), the FTIR spectrum of CSA-7 exhibits increased intensity of the O–H bands at approximately 3400 cm^{-1} and 1640 cm^{-1}, corresponding to the O–H stretching and H–O–H bending vibrations of water associated with hydration products, including C–S–H gel and portlandite ($Ca(OH)_2$) [27]. Furthermore, the absorption band in the range of 1000–1035 cm^{-1}, together with the more pronounced peak at approximately 960 cm^{-1}, is attributed to the Si–O stretching

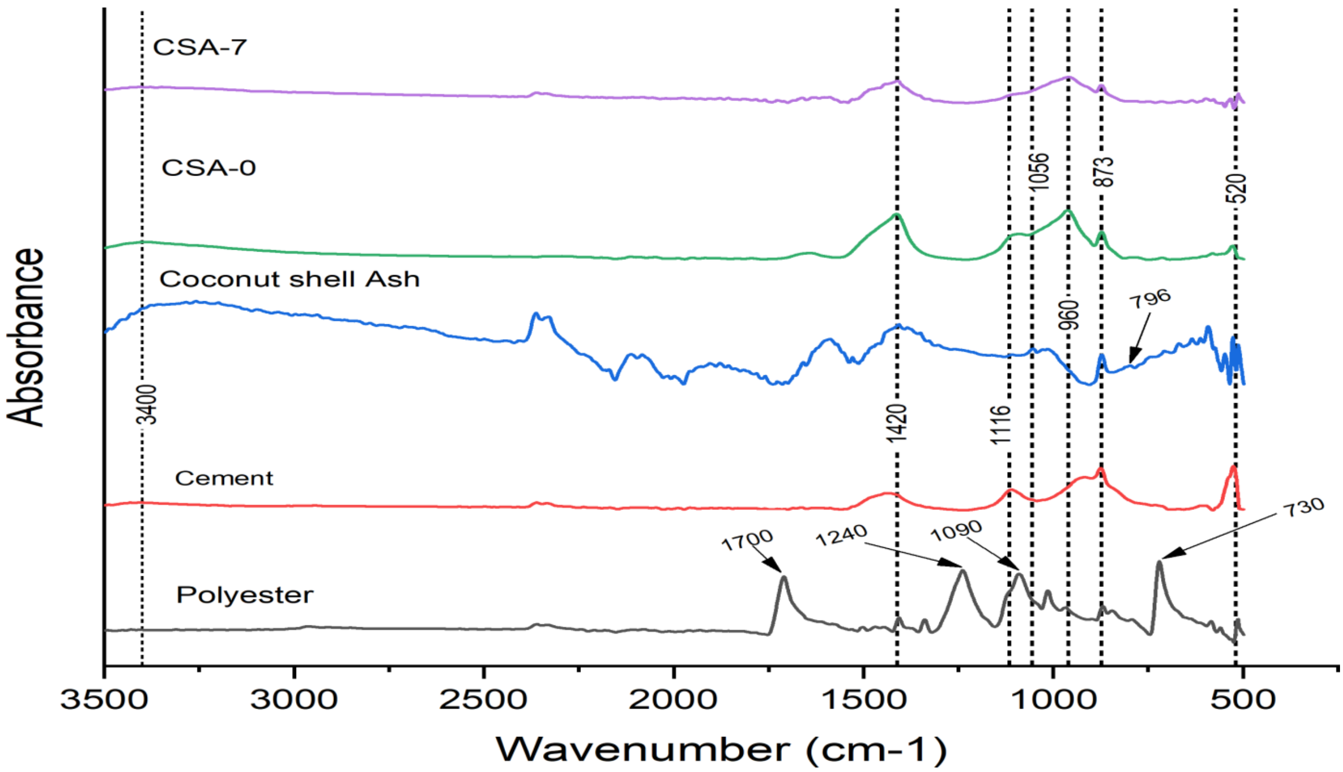

Fig. 6. FTIR spectra of ordinary Portland cement (OPC), coconut shell ash (CSA), recycled polyester fabric, control masonry unit (CSA-0), and optimum masonry unit (CSA-7), illustrating the chemical interactions and pozzolanic reaction products within the cementitious matrix

vibration of C–S–H gel, indicating the formation of additional C–S–H through the pozzolanic reaction of CSA [25],[26]. In contrast, the carbonate-related bands at around 1410–1420 cm^{-1} and 873 cm^{-1} remain present but exhibit lower intensity than those in CSA-0, reflecting the partial replacement of cement by CSA.

The characteristic absorption bands of the polyester fabric, particularly those associated with C=O and C–O stretching vibrations, are not distinctly observed in the CSA-7 spectrum, likely due to the low polyester content (1 wt.%) and the heterogeneous nature of the composite matrix. Moreover, no new absorption bands indicative of chemical interactions between the polyester fabric and the cementitious matrix were detected. These findings suggest that the recycled polyester fabric remains chemically inert within the cementitious matrix and functions primarily as a reinforcing material rather than participating in chemical bond formation.

Overall, the FTIR results confirm the pozzolanic activity of coconut shell ash, as evidenced by the formation of additional C–S–H gel. This enhanced hydration is considered responsible for the improved mechanical performance and lower water absorption exhibited by the optimum CSA-7 mix.

4. Conclusion

This study successfully developed sustainable load-bearing masonry units by partially replacing ordinary Portland cement with coconut shell ash (CSA) and incorporating recycled polyester fabric as reinforcement. The optimum mix containing 7% CSA and 1% polyester fabric achieved a 28-day compressive strength of 13.9 MPa, satisfying the ASTM C90 minimum requirement (13.8 MPa) and the SLS 855 requirement (7.0 MPa) for load-bearing masonry units. The same composition also exhibited the lowest water absorption of 4.4% after 7 days. FTIR analysis confirmed the pozzolanic activity of CSA through the formation of additional C-S-H gel, which contributed to the improved mechanical performance and reduced water absorption. These findings demonstrate the technical feasibility of utilizing locally available agricultural biomass waste and post-industrial textile waste in the production of sustainable masonry units. This approach has the potential to reduce Portland cement consumption, lower associated carbon emissions, and promote circular resource utilization within the Sri Lankan construction industry.

Although the present study confirms the suitability of the developed masonry units based on compressive strength, water absorption, and FTIR characterization, additional investigations are required to establish their long-term structural performance. Future studies should evaluate flexural strength, split tensile strength, impact resistance, and durability under aggressive environmental conditions, including chloride penetration, freeze-thaw exposure, and wetting-drying cycles. Further work should also examine the thermal and acoustic performance of the developed masonry units and validate their behaviour in full-scale block production and field applications to facilitate their wider adoption in the Sri Lankan construction industry.

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Competing Interests

The authors have no competing interests to declare

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