Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Utilization of Construction and Demolition Waste in Eco-Friendly Non-Bearing Bricks: A Study on Latex–Cement Synergistic Binders

Asmaa N. Al Mamlouk[1]*, Hassan F. Imam[1], Ayman A. El-Midany[1]

[1]*Mining and Geological Engineering Department, Cairo University, Giza, 12613, Egypt*

Abstract

Recycling construction and demolition waste (CDW) offers a valuable application toward reducing environmental impact and promoting sustainable construction practices. This study examines the synergistic combination of styrene–butadiene rubber (SBR) latex and Ordinary Portland Cement (OPC) as chemical modifiers to improve the mechanical and physical performance of reclaimed CDW-based non-bearing bricks produced under ambient curing conditions. Untreated CDW displayed very low compressive strength (<0.1 MPa) and excessive porosity. A 30% cement mixture achieved a compressive strength of 5.95 MPa, which meets the Egyptian standards for load-bearing walls. 30% of SBR produced moderate strength (0.74 MPa) and dramatically reduced water absorption. 10% cement – 10% SBR demonstrated a synergistic effect of compressive strength of 3.6 MPa, achieving the requirement of non-bearing bricks, which can be used in partitions and many other applications. Water absorption of 9.3%. Durability tests, including immersion and wet–dry cycling, provided strong evidence of improved structural resistance. Microstructural studies showed increased inclusiveness of particles and matrix densification attributed to C–S–H formation and latex film encapsulation. These results suggest that low-energy, ambient-cured, and chemically modified CDW composites have potential as sustainable alternatives to bricks that comply with the circular economy, sustainable development goals, and apply according to Egyptian standards of bearing and non-bearing bricks.

Keywords: Construction and demolition waste; Eco- Friendly Non- Bearing bricks; Styrene Butadiene Rubber Latex; Ordinary Portland Cement; Compressive Strength; Sustainable development.

1. Introduction

The construction sector is a significant consumer of natural resources and energy, generating various types of waste, particularly construction and demolition waste (CDW). CDW is estimated to be generated globally at 7–10 billion tons per year, with a significant portion sent to landfills or poorly managed, leading to severe ecological degradation, a resource extraction deficit, or greenhouse gas emissions [1,2]. With the current global shift towards circular economy models and sustainable urbanization, CDW has been increasingly recognized as a raw material for reuse in new construction elements [3–5].

One of the most interesting uses of recycled CDW is in the manufacture of green, non-load-bearing bricks, which can be used in many applications. Using CDW-based composites instead of conventional fired clay bricks decreases embodied energy and CO_2 emissions and supports Sustainable Development Goals (SDGs) [6], such as SDG 11 Sustainable Cities and Communities, SDG 12 Responsible Consumption and Production, and SDG 13 Climate Action.

Nevertheless, raw CDW often does not have sufficient mechanical strength, water resistance, and durability for utilization in construction applications. A number of studies have ended due to the incorporation of many chemical additives, such as silica fume, lime, slag, and many others [7–10], as well as Ordinary Portland Cement (OPC) and polymer modifiers, to improve their bonding and structural integrity [7–10]. While cement-based stabilization is said to improve compressive strength through hydration and calcium silicate hydrate (C–S–H) formation, it is typically accompanied by increased brittleness and high-water demand [11].

Alternatively, Styrene–Butadiene Rubber (SBR) latex is a synthetic copolymer that is used extensively to increase the flexibility, waterproofing, and durability of cementitious systems [12,13]. Previous research provides evidence that the SBR latex can form a polymer film that seals pores and improves the particle cohesion of SBR latex modified systems, demonstrating its application in mortar repair, waterproof coatings, and concrete composites [13,14]. However, few studies have combined SBR with CDW in non-bearing bricks under ambient curing without firing.

This study aims to investigate the effect of SBR latex, OPC, and their combination as a dual-modifier system on the mechanical, thermal, microstructural, and durability performance of bricks made entirely from recycled CDW. The goal is to

*Corresponding author e-mail:asmaalmamlouk@hotmail.com
Received Date: 23 July 2025, Revised Date: 12 August 2025, Accepted Date: 24 August 2025
DOI: 10.21608/EJCHEM.2025.407001.12092

determine whether a low-percentage, unfired dual-modifier system can achieve sufficient strength, durability, and water-resistance for non-load-bearing masonry applications (and no significant energy-intensive processing).

2. Materials and Methods

2.1. Materials

Construction and Demolition Waste (CDW) was manually sourced from dumping areas in Nazlet El-Samman, Giza, Egypt. It was ensuredthatthesamplewasrepresentative of the typical mixed waste from demolition activities. Non-mineral contaminants (such as metals, wood, plastics, and electrical wires) were removedmanually to keep the material homogeneous. The CDW obtained was stillheterogeneousenoughtoresemblematerialobtainedfrom actual demolition waste,thereforemaking the studymoreapplicableinpractice.

The cement used in the study was an Ordinary Portland Cement (OPC) sourced from the Helwan Cement Co. (a subsidiary of Heidelberg Cement Group), which conforms to Egyptian standard ES 4756-1/2009 (EP), ensuring consistent performance and chemical reactivity.

The SBR latex was supplied byProkem Company for Specialty Chemicals, the copolymer latex manufactured to enhance flexibility, adhesion, and water resistance in the cementitious system, and has the physicochemical properties as mentioned in Table 1.

Table 1: Physicochemical properties of SBR latex

Color	Milky water
Density	1.02+0.01/ 1.02-0.01 Kg/lit
Solid content %	32-33%
Whiteness	77-78
Bond to concrete	4-5 N/mm^2

2.2. Sample Preparation

After preliminary sorting was carried out, the construction and demolition waste (CDW) was subjected to mechanical crushing and grinding, so that the maximum particle size would not exceed 4 mm. The material was washed to remove dust and fines, which improved surface reactivity and binder adhesion. After washing, the CDW was screened through a mesh stack (4 mm to 300 µm) to classify the CDW and to maximize granular grading for compaction. After screening, the aggregate was classified as 300 µm to 4 mm. The SBR latex-modified mixes used had a latex-to-water volume ratio of 1:2 to improve penetration and workability. Cement was added to the mix at 10%, 20%, and 30% based on the weight of CDW, separately or concurrently with latex at the same ratios. The mixing was done manually to ensure that all the components were properly mixed and distributed. The paste was molded into 50 mm cubes. The cube specimens were cured for a total of 28 days at ambient temperature (25-30 °C, shaded) and without any heat or moisture treatment, and with lacked hydration during the curing process to mimic low-energy production settings.

Manual mixing was used to reflect lower-resource construction contexts... The samples were cured at ambient temperature (25–30°C, shaded) for 28 days in order to demonstrate the possibility of low-energy, non-fired production systems.

To assess the full range of binder performance, there were two additive dosage levels used in the test. Water absorption testing was executed on bricks that had low binder contents (10% cement and/or 10% SBR latex) to quantify the initial stages of porosity and the amount of water absorbed by the bricks. Durability test involving greater wet-dry cycling and immersion test was executed on bricks with higher binder dosages (30% cement and/or SBR latex) to factor in the potential effects of increased binder dosage, stabilizing the matrix, and improving the long-term property of the bricks. This was important for both the lower (basic) and upper end properties of the bricks, and to explore the optimum grade of binder, within the additive dosage matrix for a sustainable construction and demolition waste brick production trial [15].

2.3. Particle Size Distribution

Granulometric analysis was conducted using a FRITSCH 03-502 vibratory sieve shaker with six sieves: 4 mm, 2 mm, 1.25 mm, 1 mm, 0.5 mm, and 0.3 mm mesh sizes. The sieving operation was run for 20 minutes with constant amplitude (level 6), and the retained mass on each sieve was recorded and measured to establish the cumulative distribution curve. The **median particle diameter** d_{50}**,** calculated to be approximately 0.6 mm, indicates a fine-to-medium granular mix optimal for compaction and inter-particle binding.

2.4. Water Absorption Testing

The water absorption test was performedaccordingto ASTM C642-13 for the evaluation of the volume of permeable pore space in the cementitious samples made from CDW-based raw materials. Thismethodologyhas been employed for recycled aggregate and CDW-based masonry units in earlierwork [16],therebymaintaining relevant consistency and comparability of results. This test provides insights into the material's porosity. Durability and the potential of water ingress.

Each specimen was first dried in a dryer at 105 ± 5 °C for 24 hours, until nofurther reduction in dry mass (W_d) was determined. After drying, the samples were allowed to cool to room temperature. Aftercooling, the samples were completelysubmerged in clean water at room temperature for 24 hours to allow full saturation.The samples were removed from the water, and their surfaces were carefully wiped with a damp towelwhileleaving the absorbed content intact. The saturated surface-dry mass (Ws) of the sample was then weighed [17]. The water absorption value was determined using the following expression:

$$\text{Absorption\%} = (Ws - W_d/W_d) \times 100 \qquad (1)$$

To ensure accuracy, the average of three measurements of the absorption values was taken

2.5. Mechanical Strength Testing

The mechanical performance of bricks based on CDW was assessed using uniaxial compressive strength testing, using the methodology detailed in the test standard ASTM C109/C109M-21. All tests were undertaken using the Shimadzu Universal Hydraulic Testing Machine, which has a maximum load of 500 KN. All specimens were tested after 28 days of ambient curing to ensure sufficient cement hydration and development of the polymer film. For each mix formulation, a minimum of three cube specimens (50 mm × 50 mm × 50 mm) were subjected to compression testing, and the average compressive strength was reported for statistical validity [18].

Three replicates were completed for each formulation, and the recorded compressive strength is the average result. This still reflects the minimum requirements of ASTM C109/C109M, but it is acknowledged that more replicates would produce better statistical analysis; therefore, the future work will include testing larger sample sizes to allow confidence interval calculations and variability analysis.

The compressive strength was calculated using the following equation:

$$\sigma_c = F/A \quad (2)$$

Where:
F = Maximum load at failure (N)
A= Loaded surface area (A)

2.6. Durability Testing

2.6.1. Wet–Dry Cycle Resistance

The CDW-based bricks were subjected to repeated wet–dry cycling experiments to evaluate their environmental durability using the methodology from ASTM D559. Each cycle consisted of two phases: first, the specimens were submerged in clean water at room temperature for 24 hours; the second phase consisted of drying the specimens using an oven at 105 ± 5 °C for 24 hours. Then the specimens underwent another 10 cycles. After each cycle, their weight was taken, and any visible damage (crack, surface flaking, or disintegration) was recorded. The mass retention% after the last cycle of immersion and drying was an indicator of the specimen's physical durability in response to moisture variation [19].

2.6.2. Immersion Strength Retention

Long-term water resistance was assessed by completing a water immersion test according to ASTM C267. Cured brick specimens were immersed in clean water at room temperature for 14 days. The compressive strength was measured both immediately before immersion and then again after immersion to determine a strength retention percentage, indicating the material's ability to withstand deterioration or absorb moisture from extended exposure to wet conditions while maintaining mechanical integrity [19,20]

2.7. Curing Time Testing

To assess the impact of curing time on strength development, compressive strength testing was performed at four ages of curing, 7, 14, 21, and 28 days, on a series of cement-modified mixes to determine the progression of hydration and mechanical performance over time. Curing occurred under standard environmental conditions (25–30 °C, shaded area) with no thermal or humidity control to simulate realistic low-energy construction sites.

3. Results and Discussion

3.1 CDW Characterization

The chemical composition of the construction and demolition waste (CDW) was analyzed via X-ray fluorescence (XRF) to identify the distribution of elemental oxides in the different particle size fractions. The concentration of elemental oxides indicated that Si, which existed principally as silica (SiO_2), was the dominant element, particularly in the coarse to medium fractions, while both Ca and Fe concentrations differed more significantly (as differences in oxides for each element vary depending on the material source, such as sand and/or clay, or concrete) as particle sizes changed. As summarized in Table 2, Si was highest in particles from 1 - 4 mm, indicating the presence of granular siliceous materials (e.g., sand, brick or concrete), while the finest size fraction (<0.3 mm), generally contained less Si, but was singularly higher in both Fe and S, which likely came from cement componentry, mortar dust and/or ceramic fines.

Table 2: XRF analysis of different particle size fractions of CDW

Size, mm	Wt%	Si	Ca	Fe	S	Ti	K	Ba	Cl
- 4.0 + 2.0	8.3	18.2	11.8	3.24	1.02	0.68	0.58	0.20	0.087
-2.0+1.25	12.4	19.5	5.7	0.86	0.6	0.17	0.17	0.11	-
-1.25+1.0	13.1	20.6	6.3	1.05	0.87	0.2	0.19	0.074	0.02
-1.0+0.50	22.0	20.0	5.53	1.0	0.8	0.17	0.44	0.06	-
-0.50+0.30	21.4	20.0	4.33	1.25	0.96	0.25	0.42	0.07	-
-0.30	22.8	12.9	8.15	3.75	1.11	0.73	0.55	0.2	0.037

• **High Si content** in coarse fractions indicates residues from bricks and concrete rich in minerals.
• **High Fe and S concentrations** in fine fractions may indicate hydrated cementitious residues and possibly oxidized metallic residues.

The variability in elemental compositions between size fractions represents the heterogeneous nature of CDW, and affects their reactivity and binder compatibility [21].

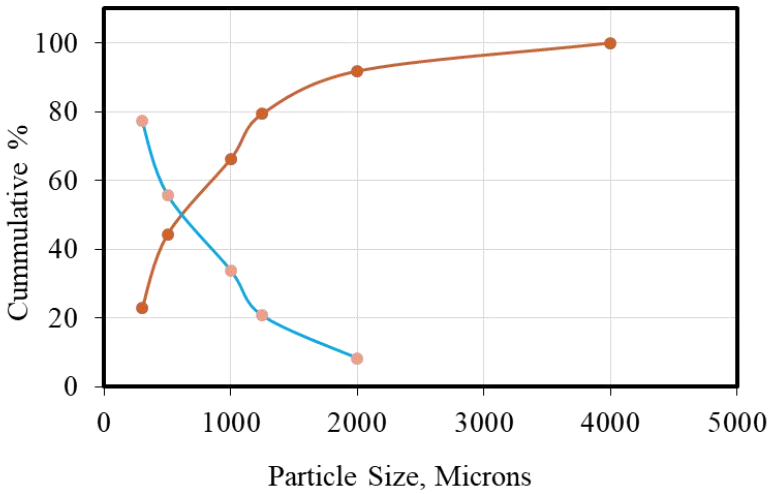


Fig. 1. Cumulative particle size distribution curve of CDW.

The cumulative particle size distribution curve Fig. 1 indicates a well-graded mix with a d_{50} ≈ 0.6 mm. The grading profile makes it possible to obtain a good packing arrangement, which minimizes voids and enhances interparticle bonding in cementitious composites.

To explore the influence of binder concentration on brick performance under different test conditions. The additive dosages in Tables 3 and 4 were intentionally varied. Water absorption tests in Table 3 were conducted on samples with the lower binder content (10% cement and/or 10% SBR latex) to track the initial changes in porosity and water absorption. Durability tests in Table 4 were conducted using a higher binder dosage (30% cement or 30% SBR latex) to more aggressively test the wet-dry cycle and immersion caused by cycling/displacement to maximize the stabilization of the matrix/concrete and provide a sense of long-term durability. By testing bricks with different dosages of binder, we were able to conclude both a baseline performance level as well as an improved performance level (i.e., with a larger binder amount). This dual-dosage approach suited the overall framework of the research, emphasizing both 'good' and 'better ' Brick design and, most importantly, allowing us to develop a sense of the optimal binder contents for bricks that are both sustainable as well as durable using CDW [22].

3.2 Water Absorption of CDW-Based Bricks

Table 3 shows the results of the water absorption test. The control mix (M0) without any additives showed the highest water absorption (18.4%), whichis indicative of a porous internal structure and loosely bonded particles. When cement was added at 10% (M1), the absorption decreased to 13.2% indicating better particle cohesion and filling of voids, through cement hydration products such as C-S-H gel. Use of 10% SBR latex alone (M2) resulted in lower absorption (11.7%) causedby the SBR latex particles forming a polymer film, partially sealing the pores and givingSBR latex hydrophobic properties [22]. The combination mix (M3) of cement and SBR latex exhibited the lowest absorption (9.3%), primarily due to the synergistic effect of both additives: cement differentiating the matrix and the SBR latex sealing microcracks and capillary pores.

The control mix (M0) without additives had the highest water absorption (18.4%), indicatinga porous internal structure with loosely bonded particles. Basedona 10% cement addition (M1), a much lower absorption wasobserved(13.2%),whichindicatesthatsomewaterabsorptioncouldbeattributed to better cohesion when cement hydratestofillvoids, becoming gelatinous (via C-S-H gel). Themixture with 10% SBR latex (M2) achievedthenext lowest absorption results (11.7%);but this is like the first mix only shows the effects of residual voids not filled by the SBR latex particles due to the SBR latex permeability, where the particles form polymer film, partially sealing pores, and giving SBR latex hydrophobic properties.The mixturethatuseda 10% cement + 10% SBR latex (M3) form of added cement had the next lowest absorption results (9.3%) basedon the jointadditiveeffects, cement differentiating the matrix, and the SBR latex sealing microcracks and capillary pores. The decrease in water absorption in SBR-modified bricks supports previous studies for polymer-modified mortars, in which polymer film formation in the matrix reduced capillary porosity [23,24].

Note: Mix IDs M1 and M2 represent consistent additive proportions across tests; although Table 4 uses higher cement/latex contents for durability evaluation, the IDs are maintained for comparative purposes, and values are stated explicitly.

Table 3: Water absorption% of CDW-based bricks with low binder dosages (10% cement and/or 10% SBR latex) to assess initial effects on porosity and water uptake.

Mix. ID	Additive(s) used	Water absorption %
M_0	CDW control	18.4
M_1	10% cement	13.2
M_2	10%SBR latex	11.7
M_3	10% cement+ 10%SBR latex	9.3

3.3 Durability Testing

Table 4 presents the durability results for the different CDW-based brick formulations, and Fig. 2 shows the results graphically. The control sample (M0), which had no additives, deteriorated nearly immediately and failed after just two wet-dry cycles. These results demonstrate that the control sample is highly porous and unstable. The durability results for the cement-modified sample (M1) were notable, with a loss of 14.7% mass (85.3% mass retained) and 19% retained strength (81% strength retained) after immersion. These durability measures can be attributed to the formation of C-S-H gel (calcium silicate hydrate gel), which binds the particles together, reducing voids.

The SBR latex mix (M2) showed a mass loss of 19.8% (80.2% mass retained) and a strength retention 62% after the wet-dry cycles. The SBR latex-modified bricks (M2) performed better than the control (M0). Although the latex does improve water repellency by forming a hydrophobic polymer film, it does not have sufficient internal cohesion after repeated wetting and drying. The dual-modified brick (M3) combination of 10% cement and 10% latex provided satisfactory durability, with 7.3% mass loss
(92.7% retained) and 12% compressive strength loss (88% retained). Together, the cement hydration products and polymer film provided the best durability; the cement hydration products precipitating added a layer of protection, while the polymer film formation seals the pores, reduces or combines cracking, and strengthens the internal structure [24,25].

Table 4: Durability test results for CDW-based bricks with higher binder contents (30% cement or 30% SBR latex) to evaluate long-term performance under wet-dry cycling

Mix ID	Additives	Mass retention% % after 10 wet-dry cycles	Strength retention% % after 14-day immersion
M_0	None	0	0
M_1	30% Cement	85.3	81
M_2	30% SBR	80.2	62
M_3	10%Cement+ 10% Latex	92.7	88

3.4 Compressive Strength Analysis

3.4.1 Unmodified CDW

Raw CDW without any additives exhibited negligible compressive strength (<0.1 MPa), rendering it unsuitable for standalone use in load-bearing or structural applications. This highlights the necessity of incorporating binders to improve mechanical performance.

3.4.2 Influence of Cement

Incorporation of cement significantly improved the strength of CDW composites. As shown in Table 5, compressive strength increased with cement content: 0.96 MPa at 10%, 3.08 MPa at 20%, and 5.95 MPa at 30%. This strength enhancement is primarily attributed to cement hydration reactions forming calcium-silicate-hydrate (C–S–H) gels, which contribute to the development of a cohesive and load-bearing matrix [26].

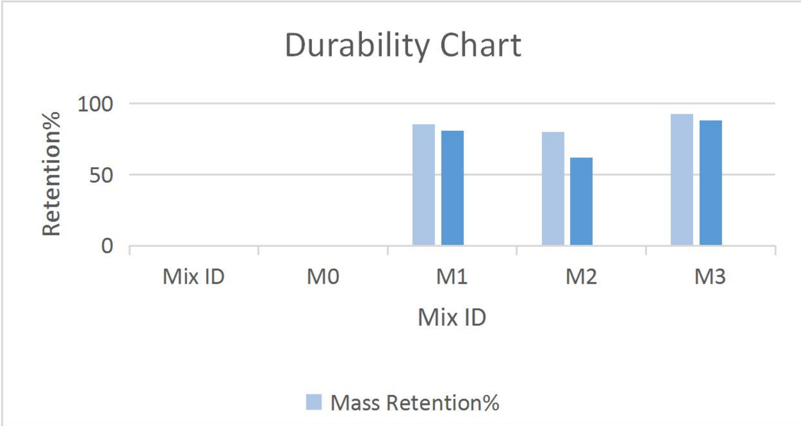


Fig. 2. Durability test results for CDW-based bricks.

Table 5: Effect of cement on compressive strength

Cement, %	Compressive strength, MPa
10	0.96
20	3.08
30	5.95

3.4.2.1. Effect of particle size of CDW with cement

Fig. 3. presents the compressive strength results of incorporating varying particle sizes of construction and demolition waste after adding different percentages of cement. The blended fraction (-4 mm) produced the highest strength among the coarse (-4+2 mm), medium (-2+1 mm), and fine (-0.3 mm). This is explained by better **packing density** and **interparticle bridging**. The improved internal bridging and superior particle packing provided by multi-size grading also improve matrix continuity and minimize voids [27].

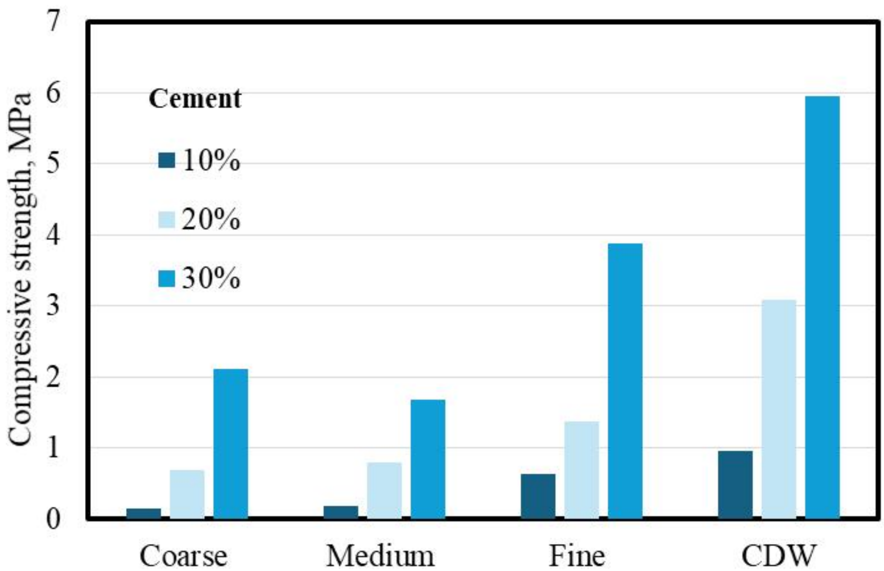


Fig. 3. Effect of cement with different grain sizes of CDW.

3.4.2.2 Effect of curing time on strength

The development of strength is consistent with what we might expect with the hydrated kinetics of Ordinary Portland Cement (OPC), where initial strength is provided through the early formation of C–S–H and $Ca(OH)_2$, and later age strength is dominated by microstructural densification as well as connectivity between pores.

Table 6, as well as Fig. 4 below, shows the constant gain in strength that occurs without the use of accelerated curing (steam, autoclave) shows that the ambient curing regime was effective, even if slower than in an industrial manner.

Thus far, there are no indications of strength plateauing even at 12 weeks, showing that there remained gains to be made.

Table 6: Effect of curing time on CDW- Cement brick's strength

Mix	Additives	Compressive Strength MPa				
CDW(-4mm)	Cement	1 Week	2 Weeks	3 Weeks	4 Weeks	12 Weeks
100%	30%	1.5	2	3	4	6
		1.8	2.5	3.5	4.2	6.5
		2.04	3.33	3.64	4.25	7
		Avg. 1.78	Avg. 2.61	Avg. 3.38	Avg. 4.15	Avg. 6.5

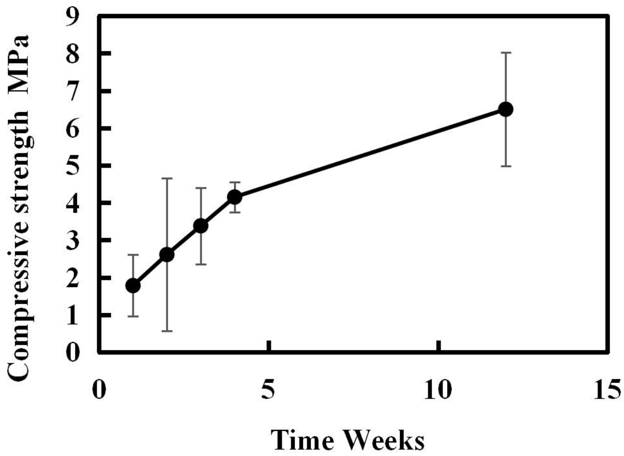


Fig. 4. Effect of Curing time on CDW Cement brick's Strength.

3.4.3. Effect of SBR latex

Table 7 presents the compressive strength of CDW, particle size (-4 mm), with various percentages of SBR latex content of 10%, 20%, and 30%. As the latex increases, the strength also increases; however, the increase in strength from adding latex at 10% and 20% is linear. However, once the latex is increased to 30% the increase in strength begins to level out, meaning any subsequent addition of latex will not improve the strength of the brick, like the cement.

Table 7: Effect of adding different percentages of SBR latex on the strength of CDW

Latex Additive, %	Compressive strength MPa
10	0.3
20	0.6
30	0.74

3.4.4. Effect of cement and SBR latex mixture

A combination of latex and cement was tested to investigate whether they could enhance the strength properties compared to using either material separately. Fig. 5. presents the compressive strength of CDW with varying proportions of latex and cement. The mixtures were prepared, consisting of different ratios of latex and cement. The compressive strength of each mixture was evaluated after 28 days of curing.

Fig. 5 demonstrates a significant enhancement in compressive strength when combining cement and latex with construction and demolition waste (CDW). While 100% of CDW exhibited negligible compressive strength, adding 10% cement improved the strength to 0.96 MPa. Similarly, 10% latex with CDW yielded a modest compressive strength of 0.3 MPa. However, the synergistic effect of combining both 10% cement and 10% latex resulted in a substantial increase in compressive strength to 3.6 MPa.

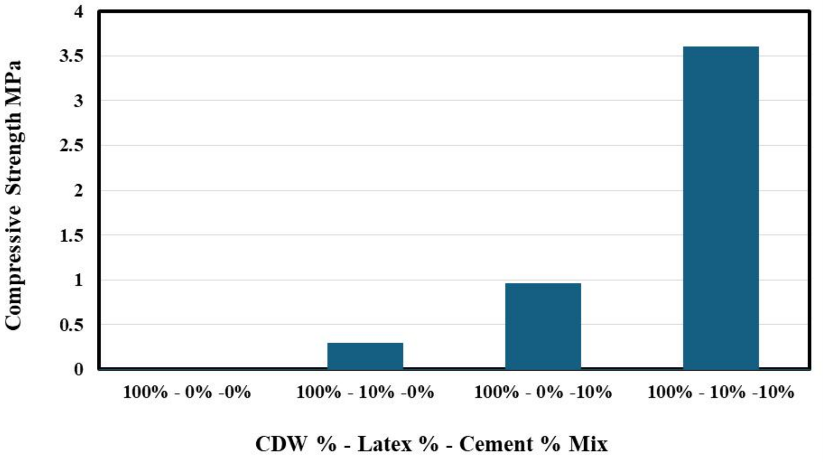


Fig. 5. Effect of latex and cement on enhancing CDW strength.

To contextually assess the performance of the developed materials, as a point of reference, "to average the compressive strength of commercial non-load-bearing red bricks in Egypt" (3.5-5.5 MPa) was used. The dual-modified CDW brick (10% cement + 10% latex) had a formed compressive strength of 3.6 MPa, putting the CDW brick at the allowable lower strength range as stated by Egyptian national standards for redundant applications such as partition walls or internal blockwork. The achieved maximum strength using 30% cement alone (5.95 MPa) was above this range, suggesting full compliance with Egyptian standards [28].

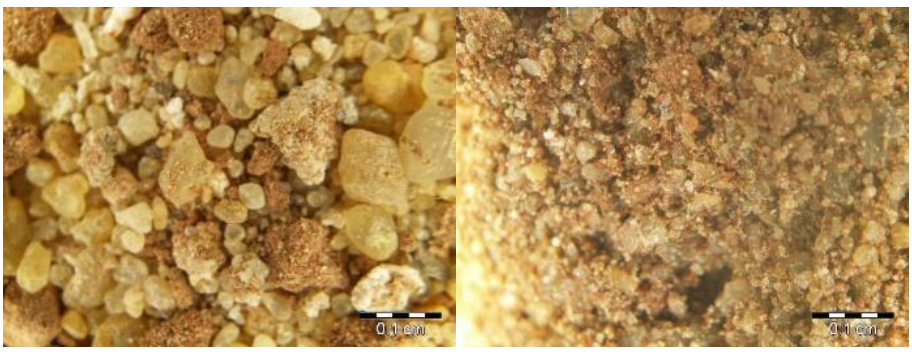
3.5 Visual observation under the optical microscope

A close-up microscopic image of demolition waste, Fig. 6, illustrates its heterogeneous composition as the waste sample contains a variety of particles that differ in color and texture. It likely has fragments of various building materials such as concrete, brick, sand, and ceramic. Optical microscopy was conducted using the Olympus Image Analyzer, equipped with a digital imaging system.

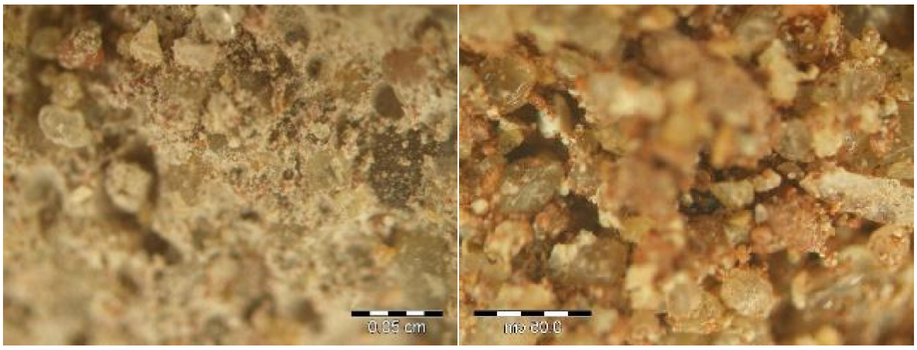
Adding SBR latex, Fig. 6a- b, shows a marked improvement in bonding the discrete particles by a rubbery matrix, enhancing the overall structural integrity. While the waste grains remain discernible within the latex-bound material, their distribution appears more uniform. After adding cement, Fig. 6a-b shows a more cohesive and homogeneous appearance than the original waste or latex-modified sample. The waste grains are encompassedby a cementitious matrix.

A combination of cement and SBR latex, Fig. 6a- b, reveals a significant improvement in material cohesion and resilience. The image showcases a more homogeneous and tightly bound microstructure, with the individual particles effectively embedded within a cementitious matrix enhanced by the addition of SBR latex. The crystalline structures and mineral grains are still visible, more uniformly distributed, and securely anchored within the composite material.

The wide size distribution results in high porosity or voids between the particles. Adding SBR latex reduces the porosity by filling voids and creating a more cohesive structure. Cement further decreased porosity by forming a matrix that filled some of the gaps. However, the combination of cement and latex resulted in a moderate porosity, possibly due to the latex introducing additional voids or air pockets[29,30].



a) b)

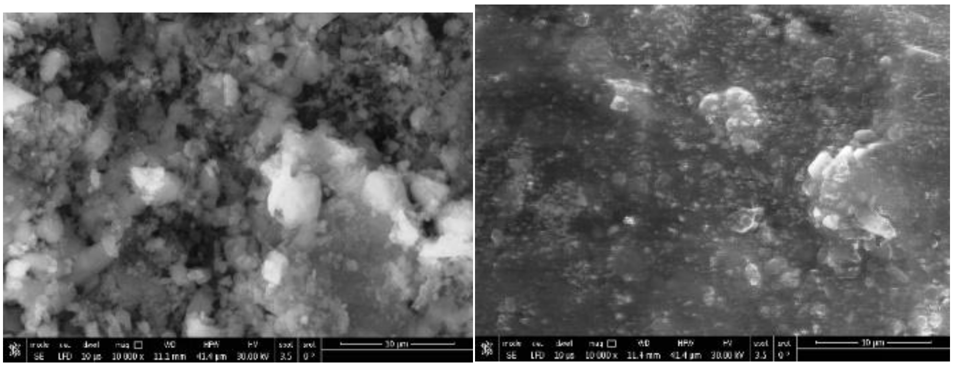


c) d)

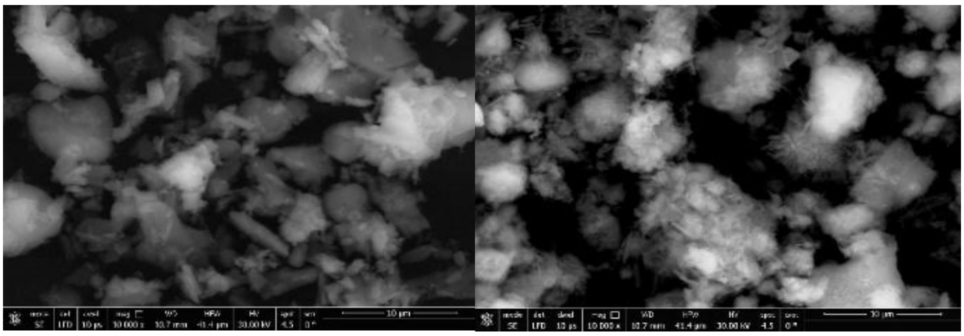
Fig. 6. Visual observations of CDW with additives under the optical microscope: a) raw CDW, b) with latex, c) with cement, and d) with latex and cement.

3.6 SEM for CDW alone and with additives

The scanning electron microscope (SEM) was used, andthe images are represented in Fig.7 (a-d). The particle morphology of the construction waste samples washighly different before and after the additives, and this also depended on which additive was used. The construction waste exhibited irregular angular particles with sharp edges, typical of inorganic material. When mixed with SBR latex, the particles got more rounded and smoother, indicating that the latex might have filled voids and coated the CDW particles, providing a more cohesive structure. With the addition of cement, a morecompact,dense matrix formed, with the cement hydrate matrix surrounding the particles. SEM micrographs verified denser microstructure in the dual-modified mix, in which the polymer film and hydration products fromcement work together to fill voids and strengthen matrix integrity. The impactofdensificationsupports findings that were reported in a previous study [31]. Finally, inthesampleofcementwithlatex,the CDW particle morphology wassimilar,whilethe latex may have supplied fibrous or elongated particles. SEM imaging was performed using a Zeiss LEO Supra 55VP Field Emission Scanning Electron Microscope (FE-SEM).



a) b)



c) d)

Fig. 7. SEM photos of CDW with additives a) raw CDW, b) with latex, c) with cement, and d) with latex and cement.

3.7 Deduced binding mechanisms
3.7.1. Effect of cement
Whencementisaddedto the construction and demolition waste (CDW) matrix, it is impacted by both chemical and physical pathways. The chemical process primarily involves the hydration of cement, producing C-S-H gel. This binding phase fills voids in the CDW particles and contributes to the strength and density of the composite [8,11]. Thehydrationalsoproduces calcium hydroxide ($Ca(OH)_2$),which influences the overall microstructure as shown in the equations below [32]:

$2(3CaO{\cdot}SiO_2) + 6H_2O \rightarrow 3CaO{\cdot}2SiO_2{\cdot}3H_2O + 3Ca(OH)_2$ (Calcium silicate hydrate, C-S-H) (3)
$3CaO{\cdot}SiO_2$ (tricalcium silicate) + $2H_2O \rightarrow Ca_3Si_2O_7{\cdot}2H_2O$ (C-S-H) (4)
$3CaO{\cdot}Al_2O_3$ (tricalcium aluminate) + $6H_2O \rightarrow 2Ca(OH)_2 + Ca_3Al_2O_6{\cdot}6H_2O$ (ettringite) (5)

Physical interactions, including particle packing and capillary action, are also contributoryfactorsfor the properties of the composite. Sincethe size distribution and shape of the CDW willinfluence the packing density in the cement paste, this will, in turn, directly affect porosity and strength. Capillary forces draw water into the porespace in CDW, whichcould affect both the hydration kinetics and the development of microstructure [32].

3.7.2. Effect of SBR latex
SBR latex has a rubbery characteristic, owing to the copolymers of styrene ($C_6H_5CH{=}CH_2$) and butadiene ($CH_2{=}CH{-}CH{=}CH_2$) [28]. The butadiene characteristic from the polymer chain provides a rubbery elastic characteristic, and the styrene segments provide rigidity and strength. The carboxyl (-COOH) groups attached to SBR latex can form hydrogen bonds with hydroxyl (-OH) groups attachedtotheCDW, whichwill promote adhesion (or better dispersion of particles whichwill significantly enhance the density and thus the interfacial bonding of the latex to the CDW producing a more consistent and stronger composite material [29,30]. The mixing was done at pH neutral, about 7, to eliminate any electrostatic repellent forces, with the negatively charged carboxylate groups on the SBR latex and our negatively charged surfaces in our CDW.MixingatpH7,these electrostatic forces could produce a better way to distribute the latex uniformly throughout the CDW matrix, thusavoidingclumpsandaffecting the morphology of the composite. Bycontrast,when Latex is applied to waste, it produces a continuous film. This film acts as a barrier and repels water ifitis hydrophobic. It may also encapsulate waste particles byfilling the void, bridging themvia a new hydrophobic layer, affectinganimportantpartofwaste cohesion across waste particles.

3.7.3. Effect of the Interaction of SBR latex with cement
Additives such as cement and latex can develop synergistic outcomes towards improving the overall properties of composite materials made from construction and demolition waste (CDW).
Latex fills the voids that cement cannot fill because, at the first stages of hydration, the cement is less viscous than latex, which is why the cement does not penetrate the voids. Latex penetrates micro-cracks and voids within the cement-waste matrix as a filler material. Ultimately, this reduces the potential for crack propagation and details the overall structural integrity of the composite [33].

As a sandwich structure, the latex will be between the cement aggregates, presuming added benefits as the rubbery property of SBR helps absorb and distribute the load, which will require an additional force to be applied to it to cause a deformity of the sample further under the load. Also, latex can absorb and dissipate energy under compressive loading; this can lessen the tendency toward brittle failure and enhance the toughness of the overall composite [33-35].

A combination of SBR latex and cement provides a synergistic improvement in mechanical properties. While cement provides compressive strength and rigidity, SBR latex has improved the flexural strength, impact resistance, and ductility. This means more balanced, all-around material with much better overall performance. However, cement hydration is still the main contributor to the strength of the composite, and latex is merely a supporting player to improve overall performance. The direct contribution to strength is confined because the polymer film is relatively weak compared to cement hydration. Most significant is the SBR latex encapsulation of cement particles, ultimately leading to faster dehydration and bonding of the cement. It may happen due to the incorporation of water in its stretching, leading to faster drying of the cement and higher bonding. When incorporated into a cement mix, SBR latex in some cases can increase the adhesion, flexibility, and overall performance of the composite. The encapsulation effect can also provide better bonding and provide the composite with greater resiliency and strength [33-36].
Numerous field applications and studies provide proof of enhanced mechanical properties and durability through latex-modified cement, which supports this point of view. The latex provides faster drying and bonding, which can be an asset when early strength is desired [35-37]. Furthermore, latex and cement combine to allow the particles to reorient themselves under load, allowing for absorption of more stress and leading to greater strength.
Interactive water dynamic movement between the latex and cement allows for more rubbery behavior of the latex and speeds up cement curing, allowing the latex to potentially reach higher strengths in shorter times than the time required in the absence of latex. The latex can have a performance influence on the behavior of the composite material under load. The addition of SBR provides flexibility to the cement matrix, allowing elastomer rubber particles to orient themselves as load is applied, which can lead to a more even distribution of stress and improve overall mechanical performance of the composite material [37-39]

Table 8: Summary of Microstructural Features in CDW Bricks under Optical and SEM Analysis

Sample ID	Additives	Microstructure Description	Observed Effects
CDW (control)	None	Loose, heterogeneous particles with visible gaps and voids.	High porosity, poor cohesion, minimal bonding.
CDW+SBR latex	5-30% Latex	Particles coated in a thin polymer film; improved but incomplete bonding.	Latex bridges small gaps and seals micropores; it improves cohesion modestly.
CDW+ Cement	10-30% Cement	Dense matrix with visible C–S–H gel around particles; fewer voids.	Strong chemical binding, reduced porosity, and good internal densification.
CDW+Cement+ SBR latex	10% Cement+ 10% Latex	Uniform, cohesive matrix with polymer film encapsulating a hydrated cement binder.	Best performance: synergistic interaction improves both strength and impermeability.

3.8 Classification of Produced Bricks Based on Egyptian Standards

Compressive strength results of the developed CDW-based bricks were compared against the Egyptian Standard ES 1554-1/2005 and ECP 204-2020 for non-load bearing and load bearing masonry unit standards [40], as shown in Table 9, to evaluate the applied use of the bricks once commercially available. The codes listed a minimum strength of 3.5 MPa for non-load bearing walls (interior use), but for load bearing walls and external applications strength of 5.0 MPa and up.

The dual-modified sample (M3), which contained 10% cement and 10% SBR latex, achieved a strength of 3.6 MPa, which meets the requirements for non-load-bearing brick applications for internal partitions. The plain cement-only mix with 30% replacement (M1) reached 5.95 MPa, positioning it into the load-bearing walls category in low-rise construction.

This comparison justifies the structural applicability of the proposed eco-friendly bricks and demonstrates the possibilities of the synergistic benefits of latex-cement composites to meet regulatory requirements of incorporating recycled "green" CDW aggregate to specifications.

Table 9: Classification of Developed CDW-Based Brick Mixes According to Egyptian Compressive Strength Standards

Mix ID.	Compressive Strength MPa	Egyptian Standards range	Suitability
M_0	0.1	≥ 3.5	Not Suitable
M_1	5.95	≥ 5	Load-bearing walls
M_2	2.1	≥ 3.5	Below Standards
M_3	3.6	≥ 3.5	Non-load-bearing Partitions

3.9 Sustainability perspective

The proposed technique to produce green bricks from construction and demolition waste (CDW), modified with cement and SBR latex, generates considerable sustainability and environmental benefits. This method achieves this by redirecting CDW from landfills and not relying on energy-intensive fired clay bricks, thus tackling various implementations of the Sustainable Development Goals (SDGs) [6].

The proposed system is feasible in that it regards the CDW as a second raw material, thus improving resource efficiency, decreasing embodied energy, and carbon footprint from traditional construction materials. Without any high-temperature firing and instead using an ambient cure involves less energy and fewer greenhouse gas emissions, especially in terms of CO_2 emissions from kilns.

In addition, the mechanical and durability properties of the bricks are improved, meaning the bricks can replace non-structural and partition walls, etc. This supports circularity of materials while also providing a low-cost, local solution for developing countries that may not have access to traditional building materials.

The approach aligns with several of the United Nations Sustainable Development Goals (SDGs), including:

SDG 11: Sustainable Cities and Communities – through the increased access to environmentally-friendly construction alternatives.

SDG 12: Responsible Consumption and Production – by converting waste into viable construction materials.

SDG 13: Climate Action- the objective is to lower carbon emissions through climate-resilient infrastructure.

This study demonstrates the ability of chemically engineered composites derived from waste to facilitate sustainable construction practices, and it presents a viable, scalable option for addressing waste and material issues globally.

3.10 Preliminary cost study

The economic viability of the developed CDW-based bricks was assessedaswe compared their preliminary production costs withthetraditional market bricks in Egypt. "In a report published in 2022 by Enterprise Press, itindicatedthat clay bricks in Egypt soldfor approximately EGP 900–1,000 per 1,000 units sold, with further incrementsanticipated due to rising energy costs in brick kilns -specifically natural gas. In late 2023, Al- Ahram Weekly (via IDSC Construction Materials Price Tracker)

illustrated consumer prices of cement in Greater Cairo were EGP 3,000 per ton, highlightingthat cement price volatility isa factor in the retail bricks cost structure.
The selection of the M3 mix (CDW, 10% cement, 10% SBR powder) for the analysis was due to its efficient performance in relation to the other mixes. The numbers used for the expected material costs are based on approximate market prices as of 2024 - 2025 in Egypt, excluding labor, equipment, and overhead etc.
The estimated price for the materials needed to make 1,000 M3 bricks took approximately 260 EGP (0.26 EGP/brick). This mix (M3) contains around 30kg of cement (2.5 EGP/kg) and about 2–3 kg of SBR powder (90 EGP/kg), while CDW was collected for free. A recent report from market prices listed that the average cost of red clay bricks in Egypt is between 900 - 1,000 EGP for 1,000 bricks (0.90 - 1 EGP per unit), based on retail price marking disclosed (2022-2023). The comparison of preliminary costs is illustrated in Tables 10 and 11 as follows.

Table 10: Estimated material cost for producing 1,000 bricks of M3 mix

Material	Quantity(est.)	Unit price (EGP)	Total Cost (EGP)
CDW	~100 Kg	0-50 per ton	~5
Cement	~30Kg	2.5EGP/Kg	~75
SBR	~2-3Kg	90EGP/Kg	~180
Total	-	-	~260

Table 11: Market price comparison of conventional bricks in Egypt (2024–2025 estimates)

Brick Type	Cost per 1000 bricks (EGP0	Unit Cost (EGP)	Notes
CDW-based brick (M_3)	~260	0.26	Sustainable, ambient cured
Red clay brick (Market)	900-1,200	0.9-1.2	Fired-commonly used
Hollow Sand/lime brick	1,500-6,500	1.5-6.5	Energy intensive

3.11 Comparative Assessment of Similar Studies

To demonstrate the technical and environmental advantages of our developed unfired bricks, which consist of 100% construction and demolition waste (CDW) mixed with binder cement and SBR latex, we conducted a comparative assessment with recent studies, as shown in Table 12. This comparative assessment is a crucial consideration for properly situating the performance of the proposed mix in context with other environmentally friendly unfired brick systems that utilize additives or alternative binders. The studies chosen had the same intentions of improving strength, durability, and sustainability, although they differed in the raw material sources, the nature of the binder, production method, and mechanical performance [25,41]. These comparisons help to clarify the meaningful distinctions of the present formulation, particularly about CDW usage, water retention, and production ease.

Table 12: Comparative Overview of This Study and Selected Recent Studies on CDW Composites

Criteria	This study (CDW+Cement+SBR)	Liu et al., 2024 (Aeolian Sand–Loess Composite) [40]	Liu & Fan, 2024 (CDW + Compound Additive) [24]
Source Material	100%CDW (< 4.75mm)	Aeolian+ Loess (natural sand)	100%CDW (< 4.75mm)
Binders	10% Cement + 10% SBR Latex	9.17% Cement + 2.4% Fly ash + 0.4% PP fiber	10% Cement + 3.15% Compound Additive (silica, fiber, etc.)
Production Method	Unfired, ambient cured	Unfired, ambient cured	Unfired, ambient cured, compacted ~20 MPa
Comp. Strength MPa	3.6 MPa	3.2-4.5MPa	Up to 8.4 MPa
Water Absorption %	9.3%	8.8-17% varies by mix	Not specified
Durability	92.7% strength retained 12% loss	~84% strength retained ~16% loss	Retention improved by 61% Softening coefficient ~0.934
Sustainability	100% CDW, minimal binder, no special treatment	No CDW relies on natural soil and industrial ash	CDW base but required advanced compound additives
Ease of application	Simple, scalable (no pressing or curing chamber needed)	Moderate complexity (fiber mix required)	Complex (compound mix and controlled pressing)

The mix produced demonstrates better sustainability and interesting mechanical performance in comparison to other current unfired brick studies:

Material Efficiency: This study, unlike Liu et al. (2024), only used virgin soils (aeolian sand and loess), while this study incorporated 100% recycled CDW as aggregate, working on principles of the circular economy.
Durability: The mix retained 92.7% strength after freezing and thawing, which is superior to Liu et al.'s 84%, and closer to Liu & Fan (2024) with their advanced additive system that had several chemical enhancers.
Simplicity: The present mix did not use pressure, nor custom-made additives, instead, SBR latex was readily available in contrast to Liu & Fan (2024). Ordinary cement was also used, contributing to practicality for large-scale application in the field.
Water Performance: The bricks produced have water absorption of 9.3%, which is comparable with the target limits and could potentially compete with or be better than other referenced systems.
These comparisons speak to the ability of the present formulation to strike a good balance between environmental responsibility, technical performance, and usability, making it a very viable option for sustainable construction.
The present study presents an unfired brick based on 100% recycled construction and demolition waste (CDW) that was blended with 10% cement and 10% styrene–butadiene rubber (SBR) latex powder. To illustrate the performance and sustainability of this blend, two recent studies that had similar objectives and methodology were chosen for comparison: Liu et al. (2024), who studied Aeolian sand-loess composite bricks, and Liu and Fan (2024), who developed bricks from CDW with a compound additive system.
In terms of raw material composition, the proposed mixture stands out from Liu et al. (2024) and Liu & Fan (2024) because it uses CDW as the only source of aggregate component, and contains no natural soil, sand, or clay. Liu et al. (2024) conducted their research using virgin soils, namely Aeolian sand and loess, and Liu & Fan (2024) only used fine particles from CDW, but added multiple chemical additives. By using CDW only, this study more fully aligns with the principles of the circular economy because it adds more waste to value.
In terms of mechanical performance, the resulting bricks developed in this study made it to a compressive strength of 3.6 MPa - this strength is within the range of Liu et al. (3.2-4.5 MPa) and suitable for use as a non-load bearing application. Liu and Fan demonstrated higher strength values of up to 8.46 MPa, which required high-pressure compaction and materials with precision-controlled compound additives; this would provide very limited options for communities without access to economic and technical means. This formulation achieved sufficient compressive strength with more widely available material inputs and by allowing for curing in ambient conditions, thus making for a more feasible option for community use.
In terms of durability, the developed bricks were exemplary, with 92.7% retention of strength after freeze-thaw cycles, demonstrating a high degree of resistance to degradation due to environmental conditions. The above durability was better than that presented by Liu et al. (2024) at a strength retention of only 84% under similar testing conditions. When examining freeze-thaw performance through a more complex additive system, Liu and Fan (2024) demonstrated the highest freeze-thaw. However, Liu and Fan's formulation described much of the simplicity and ease in the production process described in this study.
Additionally, the developed bricks showed a water absorption of 9.3%, which meets the acceptable thresholds for moisture-based resistance. Liu et al. reported a higher and more variable water absorption (8.8-17%) compared to this report. Additionally, Liu and Fan did not report absorption directly; instead, they assessed frost softening indirectly through the use of durability coefficients.
This comparative analysis shows that the proposed unfired bricks based on CDW provide a suitable mix for sustainability, performance, and practical application. The proposed brick formulation differs from others that rely on high-cost additives, natural soils, or pressurized forming, and also demonstrates how a relatively simple mix design (using CDW, cement, and SBR latex) can result in a brick that meets strength and superior durability requirements by relying exclusively on recycled content.

4. Conclusions and recommendations

The combination of Ordinary Portland Cement (OPC) and Styrene Butadiene Rubber latex (SBR) at a modified proportion of 10% each demonstrated a synergetic effect on improving the mechanical and durability of CDW-based produced bricks. The compressive strength demonstrated a maximum strength of 3.6 MPa, and water absorption reduced from about 12.5% to 9.3%. The maximum compressive strength of 5.95 MPa measured at 30% by mass of cement is appropriate for non-load-bearing masonry applications. The combined chemical interactions (hydration product formation and polymer encapsulation) further promote matrix densification and moisture resistance, and the optical and SEM images show a prototypical densified microstructure, tighter packing, and the binder had a more uniform distribution with minimized voids.
The research is a technically and chemically stable sustainable approach to recycling construction demolition waste (CDW), with reduced impact on Earth, lower embodied energy for construction materials, and advances in green chemistry towards resource efficiency. These findings also have practical relevance for circular economic work within the construction industry. Future work must pursue durability performance, thermal behavior, scale of production (industrial production), material variability, and long-term environmental stability.

5. Conflict of Interest: The authors declare that they have no conflicts of interest.
Data availability: The authors confirm that the data supporting the findings of this study are available within the article.

6. Funding: No funding to be declared

7. Acknowledgment
The authors gratefully thank the Minerals Technology and testing lab, Mining, Petroleum, and Metallurgical Engineering Dept., Faculty of Engineering, Cairo University, for providing the help, guidance, and the needed equipment and instrumentation for conducting the experiments of this work.

8. References

1. Ferronato, N., Rada, E.C., Gorritty Portillo, M.A., Cioca, L.I., Ragazzi, M., and Torretta, V. Introduction of the circular economy within developing regions: A comparative analysis of advantages and opportunities for waste valorization. *Journal of Environmental Management*, **230** (2019) 366–378. https://doi.org/10.1016/j.jenvman.2018.09.123
2. Jin, R., Li, B., Zhou, T., Wanatowski, D., and Piroozfar, P. An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. Resources, Conservation and Recycling, **126** (2017) 86–98. https://doi.org/10.1016/j.resconrec.2017.07.034
3. Kabirifar, K., Mojtahedi, M., Wang, C., and Tam, V. Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. Journal of Cleaner Production, **263** (2020) 121265. https://doi.org/10.1016/j.jclepro.2020.121265
4. Gálvez-Martos, J., Styles, D., Schoenberger, H., and Zeschmar-Lahl, B. Construction and demolition waste best management practice in Europe. Resources, Conservation and Recycling, **136** (2018) 166–178. https://doi.org/10.1016/j.resconrec.2018.04.016
5. United Nations Environment Programme (UNEP). World Waste Management Outlook. UNEP, Nairobi, Kenya, (2015). Available from: https://www.unep.org/resources/report/global-waste-management-outlook
6. Bantekas, I., and Seatzu, F. The UN Sustainable Development Goals: A Commentary. Oxford University Press, Oxford, (2023).
7. Kadir, A.A., Sarani, N.A., and Shahidan, S. Sustainable Waste Utilization in Bricks, Concrete, and Cementitious Materials: Characteristics, Properties, Performance, and Applications. Springer Nature, Singapore, (2021).
8. Dubale, M., Vasić, M.V., Goel, G., Kalamdhad, A., and Singh, L.B. Utilization of construction and demolition mix waste in the fired brick production: The impact on mechanical properties. Materials, **16** (2022) 262. https://doi.org/10.3390/ma16010262
9. Al Mamlouk, A.N. Production of green bricks from construction and demolition waste (without firing). M.Sc. Thesis, Faculty of Engineering, Cairo University, Egypt, (2016).
10. Al Mamlouk, A. N., Imam, H. F., & El-Midany, A. A. (2025). Synergistic strength enhancement of CDW-based brick using polycarboxylate ether with cement. Tenside Surfactants Detergents, 62(6), 529–537. https://doi.org/10.1515/tsd-2025-2692
11. Soliman, N. Incorporating construction and demolition waste into non-load-bearing bricks. M.Sc. Thesis, The American University in Cairo, Egypt, (2014).
12. Zhao, Z., Qu, X., and Li, J. Application of polymer-modified cementitious coatings (PCCs) for impermeability enhancement of concrete. Construction and Building Materials, **249** (2020) 118769. https://doi.org/10.1016/j.conbuildmat.2020.118769
13. Barluenga, G., and Hernández-Olivares, F. SBR latex modified mortar rheology and mechanical behaviour. Cement and Concrete Research, **34** (2004) 527–535. https://doi.org/10.1016/j.cemconres.2003.09.006
14. Abbas, Z.H., and Majdi, H.S. Study of heat of hydration of Portland cement used in Iraq. Case Studies in Construction Materials, **7** (2017) 154–162. https://doi.org/10.1016/j.cscm.2017.07.003
15. Dathe, F., Overmann, S., Koenig, A., and Dehn, F. The role of water content and binder to aggregate ratio on the performance of metakaolin-based geopolymer mortars. Minerals, **14** (2024) 823. https://doi.org/10.3390/min14080823
16. Ikechukwu, A.F., and Shabangu, C. Strength and durability performance of masonry bricks produced with crushed glass and melted PET plastics. Case Studies in Construction Materials, **14** (2021) e00542. https://doi.org/10.1016/j.cscm.2021.e00542
17. Bu, Y., Spragg, R., and Weiss, W.J. Comparison of the pore volume in concrete as determined using ASTM C642 and vacuum saturation. Advances in Civil Engineering Materials, **3** (2014) 308–315. https://doi.org/10.1520/acem20130090
18. Lande, I., and Thorstensen, R.T. Towards efficient use of cement in ultra high performance concrete. Nordic Concrete Research, **65** (2021) 81–105. https://doi.org/10.2478/ncr-2021-0017
19. Ikechukwu, A.F., and Shabangu, C. Strength and durability performance of masonry bricks produced with crushed glass and melted PET plastics. Case Studies in Construction Materials, **14** (2021) e00542. https://doi.org/10.1016/j.cscm.2021.e00542
20. ASTM C267-01. Standard Test Method for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes. ASTM International, West Conshohocken, PA, USA. Available from: https://www.scribd.com/document/802088991/ASTM-C267-01
21. Islam, N., Sandanayake, M., Muthukumaran, S., and Navaratna, D. Review on sustainable construction and demolition waste management—challenges and research prospects. Sustainability, **16** (2024) 3289. https://doi.org/10.3390/su16083289
22. Kligys, M., and Girskas, G. Styrene–butadiene rubber latex modified mortars prepared with high early strength Portland cement. Materials, **17** (2024) 6000. https://doi.org/10.3390/ma17236000

23. Li, X., Liu, R., Li, S., Zhang, C., Li, J., Cheng, B., Liu, Y., Ma, C., and Yan, J. Effect of SBR and XSBRL on water demand, mechanical strength, and microstructure of cement paste. Construction and Building Materials, **332** (2022) 127309. https://doi.org/10.1016/j.conbuildmat.2022.127309
24. Matsimbe, J., Dinka, M., Olukanni, D., and Musonda, I. Durability properties of ambient-cured fly ash-phosphogypsum blended geopolymer mortar in terms of water absorption, porosity, and sulfate resistance. Discover Sustainability, **5** (2024) 53. https://doi.org/10.1007/s43621-024-00537-3
25. Liu, H., and Fan, L. Optimization and mechanism analysis of a compound additive for unfired bricks made of construction and demolition wastes. Frontiers in Materials, **11** (2024) 1308884. https://doi.org/10.3389/fmats.2024.1308884
26. Lande, I., and Thorstensen, R.T. Towards efficient use of cement in ultra high performance concrete. Nordic Concrete Research, **65** (2021) 81–105. https://doi.org/10.2478/ncr-2021-0017
27. Arredondo-Rea, C., Peixoto, G., Shaverdin, N., Pedersen, P., & Rojas, C. (2025). *Influence of size and content of recycled aggregate on mechanical properties of concrete.* Buildings, 15(17), 3009. https://doi.org/10.3390/buildings15173009
28. Egyptian Organization for Standardization. Clay Brick Standards and Specifications. EOS Publication No. 567, Cairo, Egypt, (2022).
29. Yuen, J., and De Snaijer, H. Handbook of Styrene Butadiene Rubber. (2016).
30. Wang, R., Lackner, R., and Wang, P.M. Effect of styrene–butadiene rubber latex on mechanical properties of cementitious materials highlighted by means of nanoindentation. Strain, **47** (2011) 117–126. https://doi.org/10.1111/j.1475-1305.2008.00549.x
31. Li, X., Liu, R., Li, S., Zhang, C., Li, J., Cheng, B., Liu, Y., Ma, C., and Yan, J. Effect of SBR and XSBRL on water demand, mechanical strength, and microstructure of cement paste. Construction and Building Materials, **332** (2022) 127309. https://doi.org/10.1016/j.conbuildmat.2022.127309
32. Ndahirwa, D., Hou, P., Stroeven, P., and Ye, G. The role of supplementary cementitious materials in hydration, durability and shrinkage of cement-based materials, their environmental and economic benefits: A review. *Cleaner Materials*, **5** (2022) 100123. https://doi.org/10.1016/j.clema.2022.100123
33. Krakowiak, K.J., Zubelewicz, A., and Ulm, F.J. Nano-chemo-mechanical signature of conventional oil-well cement systems: Effects of elevated temperature and curing time. *Cement and Concrete Research*, **67** (2015) 103–121. https://doi.org/10.1016/j.cemconres.2014.08.008
34. International Concrete Congress. 10th International Concrete Congress "Recent Advances in Concrete Technology", Turkey, May 2019. Available from: http://betonkongresi.imo.org.tr/EN/index.asp?sayfa=konular
35. Yazdimamaghani, M., Vashaee, D., Tayebi, L., and Chen, G. Synthesis and characterization of encapsulated nanosilica particles with an acrylic copolymer by in situ emulsion polymerization using thermoresponsive nonionic surfactant. *Materials*, **6** (2013) 3727–3741. https://doi.org/10.3390/ma6093727
36. Alimardani, M., and Abbassi-Sourki, F. New and emerging applications of carboxylated styrene butadiene rubber latex in polymer composites and blends: Review from structure to future prospective. *Journal of Composite Materials*, **49** (2014) 1267–1282. https://doi.org/10.1177/0021998314533363
37. Silvestre, J.D., Silvestre, N., and De Brito, J. Polymer nanocomposites for structural applications: Recent trends and new perspectives. *Mechanics of Advanced Materials and Structures*, **23** (2016) 1263–1277. https://doi.org/10.1080/15376494.2015.1068406
38. Hwang, E., Ko, Y.S., and Jeon, J. Effect of polymer cement modifiers on mechanical and physical properties of polymer-modified mortar using recycled waste concrete fine aggregate. *Journal of Industrial and Engineering Chemistry*, **13** (2007) 387–394.
39. Li, X., Liu, R., Li, S., Zhang, C., Li, J., Cheng, B., Liu, Y., Ma, C., and Yan, J. Effect of SBR and XSBRL on water demand, mechanical strength and microstructure of cement paste. *Construction and Building Materials*, **332** (2022) 127309. https://doi.org/10.1016/j.conbuildmat.2022.127309
40. Egyptian Organization for Standardization. Available from: https://www.eos.org.eg/en
41. Liu, D., Guo, Y., Zhang, Y., Zhu, Z., Xu, P., Zhang, S., and Ren, Y. Mechanism of strength formation of unfired bricks composed of Aeolian sand–loess composite. *Materials*, **17** (2024) 1184. https://doi.org/10.3390/ma17051184