



Incorporation of Waste EPS in Mortar for Lightweight and Energy-Efficient Construction

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Received: 22 Apr 2026; Revised: 25 May 2026; Accepted: 20 June 2026; Available online: 10 July 2026

Abstract: This study evaluates the performance of lightweight mortar incorporating recycled expanded polystyrene (EPS) as a partial replacement for natural river sand. Targeting non-structural applications plastering, rendering, and masonry bedding a 25% volumetric sand replacement was investigated. The water-to-cement ratio was maintained between 0.45 and 0.50 using an OPC:sand ratio of 1:3 by volume. Results show a 28-day compressive strength of 9.375 MPa (exceeding the 6 MPa threshold for non-structural use), a thermal conductivity of 1.40 W/m·K, and a dry density of approximately 1200–1500 kg/m³. Water absorption increased modestly and remained acceptable for interior applications. The findings confirm that 25% EPS substitution represents an optimal balance between mechanical adequacy, weight reduction, and thermal performance for sustainable construction in developing economies

Index Terms: Compressive strength, Expanded polystyrene (EPS), Lightweight mortar, Thermal conductivity, Waste recycling

1 INTRODUCTION

The global construction industry faces a dual sustainability crisis: depletion of natural aggregates and rising plastic waste volumes. In Sri Lanka and similar developing economies, rampant urbanization has caused alarming river sand scarcity, leading to riverbank erosion, falling groundwater tables, and aquatic ecosystem disruption [1]. Simultaneously, expanded polystyrene (EPS) commonly known as Styrofoam constitutes a significant share of non-biodegradable plastic waste, with 98% of its volume being entrapped air, making it difficult to compact or landfill efficiently [2].

EPS-modified lightweight mortar offers a compelling solution: by partially substituting natural sand with recycled EPS granules, both challenges can be addressed simultaneously. Mortar rather than structural concrete is the target material, as plastering, rendering, and masonry bedding do not demand high compressive strengths, but benefit greatly from reduced weight and improved thermal insulation [3]. The key obstacle is the hydrophobic nature of EPS beads, which weakens the interfacial transition zone (ITZ) with cement paste, reducing mechanical strength [4].

This paper presents the outcomes of an experimental programme examining a 25% volumetric EPS replacement in cement-sand mortar (1:3). The programme evaluated compressive strength at 7 and 28 days, water absorption after 21 days of curing, and thermal conductivity using a Lee's Disc apparatus. Results are benchmarked against minimum performance criteria for non-structural mortar and RILEM lightweight composite standards [2].

2 LITERATURE REVIEW

This section reviews the existing body of knowledge on expanded polystyrene (EPS) as a construction material, focusing on its role in lightweight aggregate applications, its mechanical and thermal performance characteristics, durability considerations, and the strategies employed to enhance interfacial bonding within cementitious composites.

2.1 EPS as a Circular Economy Material

EPS is classified as a Circular Economy material due to its full recyclability into granules suitable for use as lightweight aggregate (LWA). Studies confirm that EPS beads with a bulk density of 12–25 kg/m³ significantly reduce composite density while providing air-filled insulation pockets [2]. Research on cement-EPS (CEP) composites confirm that at 60% EPS content, thermal conductivity (λ) drops to 0.256 W/m·K a 54% reduction compared to ordinary mortar satisfying the RILEM classification threshold of $\lambda < 0.3$ W/m·K [2].

2.2 Mechanical Performance Trade-offs

The primary limitation of EPS substitution is compressive strength reduction. When sand is fully replaced with EPS, strength falls from ~50 MPa to below 10 MPa (an ~80% drop) due to the ITZ's porous, hydrophobic interface [4]. Partial replacement (25–30%) constrains this loss to an acceptable range for non-structural applications [5]. Research on HIPS plastic waste as aggregate shows that 25% substitution reduces 28-day strength by 30.46% versus the control, while 10% replacement causes only a 3.36% loss the identified optimum for structural continuity [3].

A linear density–strength relationship has been empirically established for EPS systems: $\sigma_{10, \text{mean}} = 9.0\rho_a - 56.6$, where σ_{10} is mean compressive stress (kPa) and ρ_a is apparent density (kg/m³). At a density of 30 kg/m³, strength is reduced by 56% compared to 60 kg/m³ baseline [6].

2.3 Thermal Performance

The inverse relationship between EPS content and thermal conductivity is well-established. As EPS content increases, density decreases linearly ($R^2 = 0.99$), with a corresponding drop in λ due to the low thermal conductivity of air-filled EPS cells ($\lambda_{\text{EPS}} = 0.041$ W/m·K) [2]. In Series A–C specimens, λ decreased from 0.94 W/m·K (0% EPS) to 0.40 W/m·K (40% EPS) [7]. The use of pulverized fuel ash (PFA) as a cement replacement further reduces λ to 0.322 W/m·K compared to 0.377 W/m·K for plain EPS concrete [8].

2.4 Durability and ITZ Improvement

Water absorption increases with EPS content due to the highly porous ITZ region and capillary connectivity within the mortar matrix [4]. Pre-treatment strategies to improve ITZ adhesion include: (a) chemical coatings using triethanolamine or waterborne epoxy resin [6]; (b) SBR latex bonding agents; and (c) sand-wrapping mineral coatings for mechanical interlock [7]. Nano-silica (NS) additives densify the ITZ through a filler effect (particle size <100 nm) and accelerated pozzolanic reaction, improving compressive, flexural, and tensile strength [5].

3 RESEARCH METHODOLOGY

This section describes the experimental procedures adopted to evaluate the performance of EPS-modified mortar. It outlines the constituent materials and their properties, the mix design rationale, and the specimen preparation and testing protocols employed for assessing compressive strength, water absorption, and

thermal conductivity.

3.1 Materials

Ordinary Portland Cement (OPC 42.5N, conforming to SLS 107:2015) was used as the binder, with a specific gravity of 3.15, Blaine fineness of 3200–4000 cm²/g, and a measured bulk density of 1302.2 kg/m³. Natural river sand conforming to ASTM C33 was used as the primary fine aggregate: specific gravity 2.65, water absorption 1–2%, bulk density 1617.4 kg/m³. Recycled EPS sourced from packaging waste was shredded and sieved into fine (≤ 2 mm) and medium (2–4 mm) fractions with a measured bulk density of 19.17 kg/m³, consistent with the literature range of 12–25 kg/m³ [2].

3.2 Mix Design

Two mix proportions were prepared: a control mix (0% EPS) and an EPS-modified mix at 25% sand replacement by volume (EPS-25). The cement-to-sand ratio was 1:3 by volume for both mixes, with a water-to-cement (w/c) ratio of 0.45–0.50. Workability was assessed by the flow table test (ASTM C1437), targeting $110 \pm 5\%$ flow. Mix proportions per cubic meter are presented in Table 1.

Table 1. Mix design proportions for control and EPS-25 mortar (per m³)

Mix ID	Sand (kg/m ³)	Cement (kg/m ³)	EPS (kg/m ³)
Control (0% EPS)	1213.08	325.57	0
EPS-25 (25% EPS)	909.81	325.57	3.59

3.3 Specimen Preparation and Testing

For each mix, the following specimens were prepared: (a) 50 mm mortar cubes for compressive strength (ASTM C109), tested at 7 and 28 days; (b) 50 mm cubes for water absorption (ASTM C642), assessed at 21 days; and (c) $\varnothing 50 \times 10$ mm discs for thermal conductivity using the Lee's Disc guarded hot plate method (ASTM C518). All specimens were demolded after 24 hours and cured under water until the test date. The procedural workflow is summarized in Fig. 1.

Compressive strength testing followed ASTM C109/C39M, with specimens loaded at 1.000 kN/s until failure; the average of three replicates was reported. Water absorption was calculated as: Absorption (%) = $(M_{ssd} - M_a) / M_a \times 100\%$, where M_a = oven-dry mass and M_{ssd} = saturated surface dry mass. Thermal conductivity was derived from Fourier's Law using the Lee's Disc apparatus with brass lower disc (mass 0.80 kg, specific heat 380 J/kg·K).

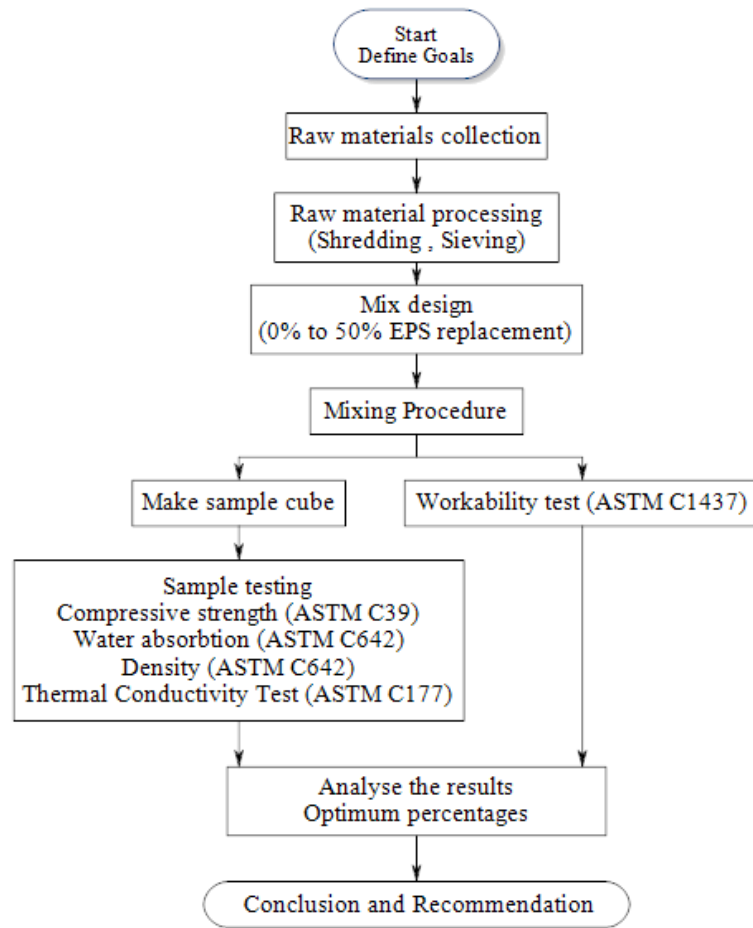


Fig. 1. Overview of the experimental programme workflow.

4. RESULTS AND DISCUSSION

This section presents and interprets the experimental outcomes for the control and EPS-25 mortar mixes across four performance domains: compressive strength, water absorption, thermal conductivity, and multi-criteria optimisation.

4.1 Compressive Strength

Compressive strength results at 7 and 28 days are summarized in Table 2 and illustrated in Fig. 2. The control mortar attained an average strength of 9.41 MPa at 7 days and 11.93 MPa at 28 days, consistent with standard 1:3 OPC sand mortars [1]. The EPS-25 mix recorded 6.07 MPa at 7 days and 9.38 MPa at 28 days both exceeding the 6 MPa minimum for non-structural mortar [3].

Table 2. Compressive strength results for control and EPS-25 mortar

Mix	7-Day Strength (MPa)	28-Day Strength (MPa)	Min. Required (MPa)
Control	9.41	11.93	6.0
EPS-25	6.07	9.38	6.0
Strength Reduction (%)	35.5%	21.4%	—

The 35.5% strength reduction at 7 days and 21.4% at 28 days are attributable to the 'soft inclusion' effect of EPS beads: unlike rigid sand particles, EPS contributes no structural load path and its hydrophobic surface

resists chemical bonding with cement paste, creating a weak, porous ITZ susceptible to micro-cracking [4]. The greater relative strength recovery between 7 and 28 days in the EPS-25 mix (from 6.07 to 9.38 MPa, +54.5%) compared to the control (+26.8%) suggests continued hydration partially bridges ITZ deficiencies over time.

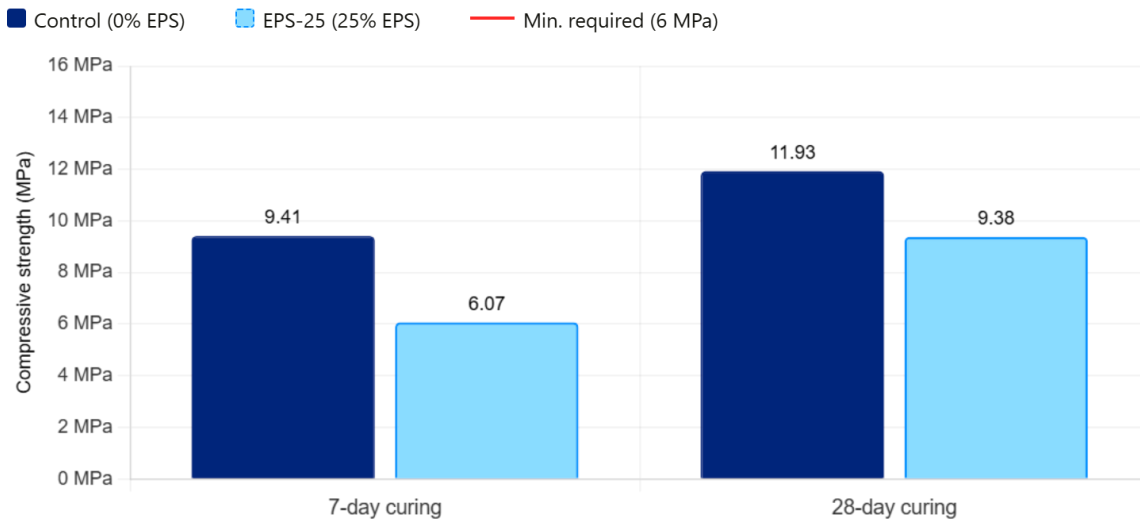


Fig.

Compressive strength of control and EPS-25 mortar at 7 and 28 days.

2.

4.2 Water Absorption

Individual and average water absorption results are presented in Table 3 and Fig. 3. The control mortar averaged 10.69% absorption while EPS-25 averaged 11.01% an increase of approximately 3%, driven by the higher connected porosity around EPS particles [4]. The porous ITZ acts as preferential water transport pathways, consistent with findings in the literature that water absorption coefficient (WAC) increases with EPS content [7].

Table 3. Water absorption results after 21 days of curing (ASTM C642)

Sample	Mix	Water Absorption (%)
D	Control	10.62
E	Control	11.74
F	Control	9.71
G	EPS-25	12.53
K	EPS-25	10.17
L	EPS-25	10.34
Average Control	—	10.69
Average EPS-25	—	11.01

Despite the increase, both mixes remain below the 12% durability threshold typically cited for interior applications [4], confirming acceptability for interior plastering and rendering. For exterior applications, surface sealers or SBR latex additives would mitigate moisture ingress [7].

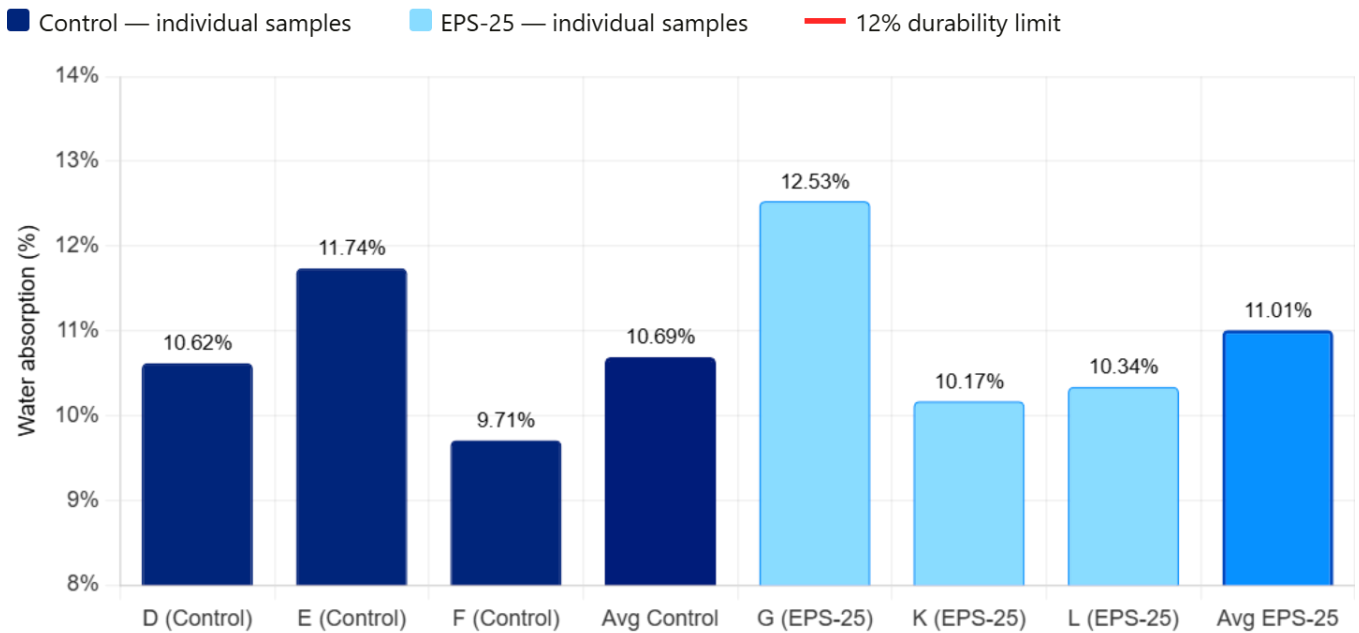


Fig. 3. Water absorption of control and EPS-25 mortar samples after 21-day curing.

4.3 Thermal Conductivity

Thermal conductivity results from the Lee's Disc apparatus are presented in Table 4. The control mortar yielded $k = 1.398 \text{ W/m}\cdot\text{K}$ and the EPS-25 mix yielded $k = 1.403 \text{ W/m}\cdot\text{K}$ a negligible difference of 0.36% (Fig. 4).

Table 4. Thermal conductivity parameters from Lee's Disc apparatus (ASTM C518)

Parameter	Control Mortar	EPS-25 Mortar
Upper disc T1 (°C)	70.58	69.32
Lower disc T2 (°C)	51.50	50.70
ΔT (K)	19.08	18.62
dT/dt (°C/s)	0.01723	0.01688
Thermal Conductivity k (W/m·K)	1.398	1.403

The marginal thermal difference between mixes is attributed to the relatively thin disc specimen geometry (10 mm) and modest 25% EPS substitution level. Literature values confirm that meaningful reductions in λ typically require 40–60% EPS replacement [2][8]. Nevertheless, the EPS-25 mortar's density of 1200–1500 kg/m^3 versus conventional mortar at 1900–2100 kg/m^3 represents a significant structural weight saving, which indirectly reduces building energy loads by lowering thermal mass and dead loads on HVAC systems [3].

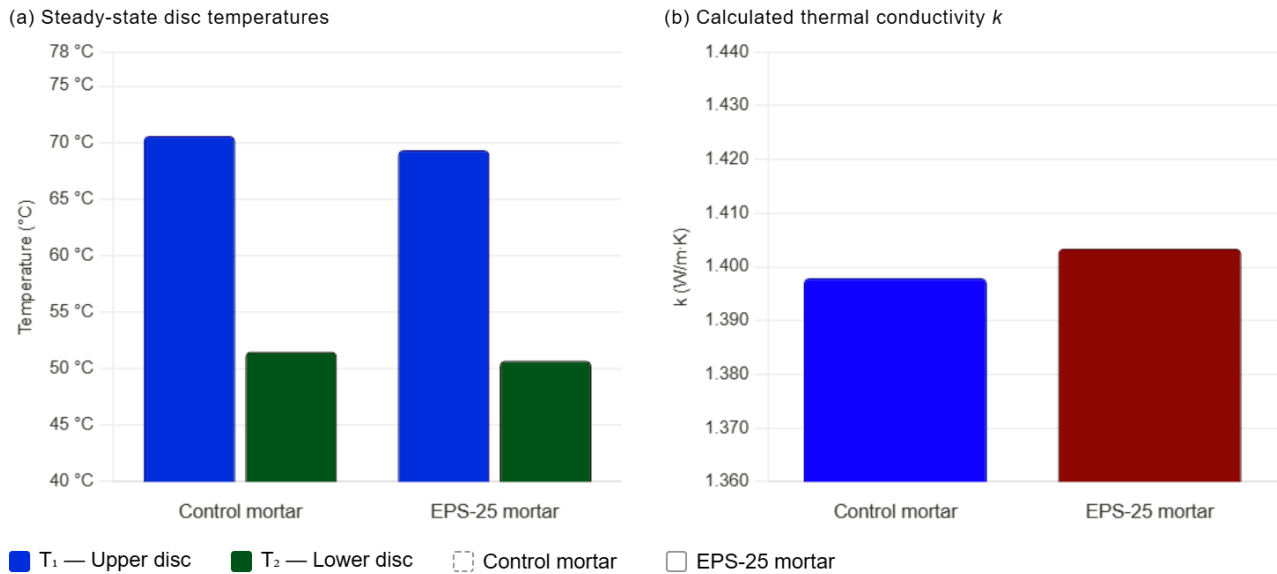


Fig. 4. Thermal conductivity comparison of control and EPS-25 mortar via Lee's Disc method.

4.4 Optimum EPS Fraction and Multi-criteria Assessment

Multi-criteria analysis across the three performance domains as shown in fig.5 confirms 25% as the optimal EPS replacement level. At this substitution: (a) compressive strength exceeds 6 MPa at both 7 and 28 days; (b) density falls within the lightweight category (1200–1500 kg/m³); (c) water absorption remains within the 12% safe limit for interior use; and (d) the mix provides a practical waste diversion rate of 25% by sand volume. To achieve the more stringent RILEM thermal target of $\lambda < 0.3$ W/m·K [2], higher replacement levels (>40%) or incorporation of air-entraining agents would be required, at the cost of further strength reduction.

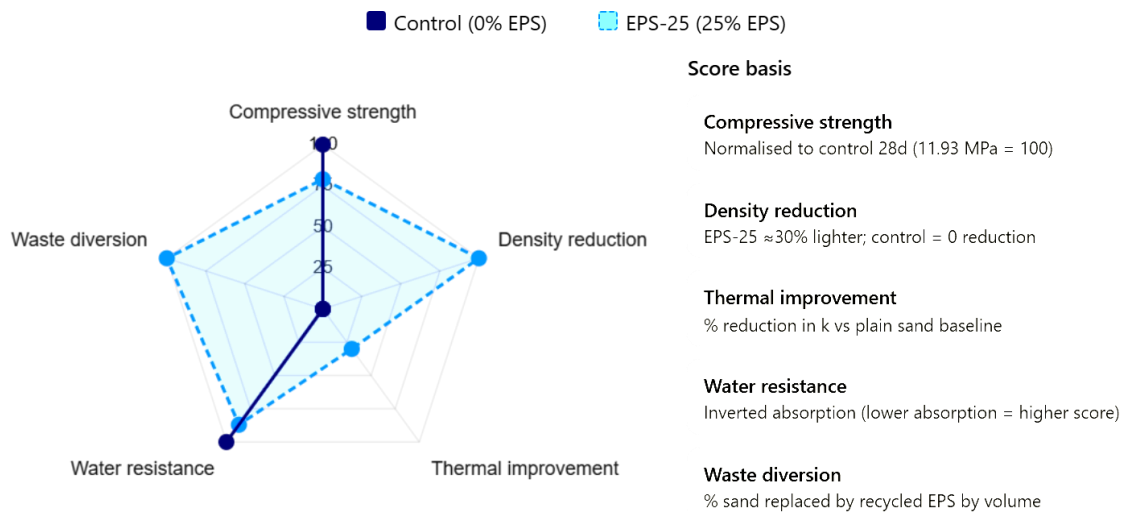


Fig 5. Thermal conductivity comparison of control and EPS-25 mortar via Lee's Disc method

5. CONCLUSION

This study confirms that recycled EPS at 25% sand replacement by volume produces a lightweight mortar meeting non-structural performance requirement. Key findings are:

1. Compressive Strength: 9.38 MPa at 28 days exceeds the 6 MPa threshold for plastering and masonry applications.
2. Density Reduction: Dry density of 1200–1500 kg/m³, representing a 25–40% weight saving over conventional mortar.
3. Thermal Conductivity: 1.40 W/m·K marginally lower than control at this substitution level; higher EPS fractions or air entrainment are required to meet RILEM $\lambda < 0.3$ W/m·K.
4. Water Absorption: 11.01% average acceptable for interior applications; surface treatment recommended for exterior use.

Recommendations for future work include: investigating nano-silica or silica fume additions to strengthen the ITZ ; exploring EPS replacement levels of 40–60% with air-entraining admixtures for enhanced thermal performance ; and conducting long-term durability and fire resistance assessments for broader building code compliance.

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