
AN EVALUATION OF THE MECHANICAL PROPERTIES OF SANDCRETE MORTAR CONTAINING POLYSTYRENE WASTE AND FLY ASH

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ABSTRACT

The increasing accumulation of polystyrene waste and the environmental impact associated with cement production have necessitated the search for sustainable alternatives in the construction industry. The study evaluated the properties of sandcrete mortar containing polystyrene waste and fly ash with a view to developing a lightweight and environmentally friendly material for potential use in non-load-bearing sandcrete blocks. A cement-to-sand mix ratio of 1:6 and a constant water-cement ratio of 0.50 were used to produce the sandcrete mortar cubes of 50x50x50 mm and cylinders of 70mm diameter x100mm height. Fine aggregate was replaced with polystyrene at 0, 5, 10, 15, 20, and 25% by volume, while fly ash was maintained at a replacement level of 10% of cement. In the fresh state, the mixes were tested for consistency using a flow test, while in the hardened state, the sandcrete mortar samples were tested for compressive strength, tensile strength, and density. Furthermore, the morphology of the sandcrete mortar specimens was assessed using Scanning Electron Microscopy (SEM). The results show that the compressive strength of the specimens decreased as the polystyrene content increased from 5 to 25%. However, the mix containing 5% polystyrene and 10% fly ash achieved a compressive strength of 3.125 N/mm² at 90 days, compared with 3.375 N/mm² for the control mix, representing a 7.4% reduction in compressive strength. SEM analysis confirmed a denser cementitious matrix in fly ash-modified mixes due to secondary calcium silicate hydrate (C-S-H) formation, while higher polystyrene contents produced larger interfacial voids that contributed to strength reduction. The 5% polystyrene and 10% fly ash mix was identified as the optimum modified mix, achieving a compressive strength of 3.125 N/mm², exceeding the 2.5 N/mm² minimum requirement reported for non-load-bearing sandcrete blocks under NIS 87:2007, indicating its potential suitability for non-load-bearing applications.

Keywords: fly ash; sandcrete blocks; polystyrene waste; mechanical properties

1.0 INTRODUCTION

The construction industry is increasingly seeking sustainable methods of producing building materials without compromising performance. The utilization of industrial by-products and waste materials in construction can reduce dependence on natural resources while providing useful applications for materials that would otherwise contribute to environmental pollution. The use of waste materials as lightweight aggregates has therefore received increasing attention because of their availability and potential to reduce the weight of construction products (Arshad, 2014; Khatib, 2009). Polystyrene is a lightweight, non-biodegradable thermoplastic commonly used for food packaging, disposable cups, cartons, and other consumer products. Its closed-cell structure and low density make it attractive as a lightweight material for cement-based products (Kan, 2009). However, its widespread disposal creates environmental challenges. Polystyrene waste can accumulate in drainage systems, streets, and disposal sites, while inappropriate disposal and burning may contribute to environmental pollution (Murana, 2020; Kehinde & Babatunde, 2020; Olutoye et al., 2022).

The incorporation of polystyrene waste into construction materials offers an alternative approach to managing this waste. Previous studies have indicated that polystyrene can reduce the density of cement-based materials; however, increasing its content may reduce mechanical strength due to its low density and relatively weak bonding with the cementitious matrix (Haidar & Khalil, 2002; Babu & Babu, 2003; Kehinde & Babatunde, 2020).

Fly ash is an industrial by-product with pozzolanic characteristics. Its silica and alumina content allows it to react with calcium hydroxide produced during cement hydration to form additional calcium silicate hydrate (C–S–H), which can contribute to strength and matrix densification (Mehta & Monteiro, 2020; Abbas et al., 2021). Studies revealed that fly ash can improve the performance of cement-based materials and provide environmental benefits by reducing cement consumption (Freedra, 2010; Zhang et al., 2022; Olutoge et al., 2023).

In Nigeria, sandcrete blocks are widely used for external and internal wall construction because of their availability and affordability (Anosike, 2012). However, their relatively high density contributes to the dead load of buildings. The use of polystyrene as a partial replacement for fine aggregate can reduce this weight, while fly ash can be used as a partial cement replacement to improve the sustainability of the material (Dadu, 2020; Akinyele & Adediji, 2021).

Although studies have separately investigated polystyrene and fly ash in cement-based materials, few studies have examined their combined application in sandcrete mortar under local Nigerian conditions. The present study therefore evaluates the mechanical properties of sandcrete mortar blocks containing polystyrene waste as a partial replacement for fine aggregate and fly ash as a partial replacement for cement.

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Fine Aggregate

The fine aggregate used for the experiment was river sand sourced from Zaria metropolis, Kaduna State, Nigeria. The sand was sieved through a 4.75 mm sieve to remove large particles and impurities.

2.1.2 Polystyrene Waste

Polystyrene waste was collected from dump sites, event centres, and drainage channels within Zaria metropolis. The collected waste was manually sorted to remove contaminants such as paper, soil, and organic materials. It was then shredded using a locally fabricated grinder into particle sizes not exceeding 4.75 mm. Sieve analysis was subsequently conducted to establish the particle-size distribution.

2.1.3 Cement

Limestone Portland Cement of Dangote brand conforming to BS EN 197-1:2011 specifications was used.

2.1.4 Fly Ash

Fly ash was obtained from BUA Cement Plant, Okpella, Edo State. It was stored in airtight containers to prevent moisture contamination and sieved through 45 µm before use. The physical and chemical characteristics of fly ash are important in determining its suitability and performance as a supplementary cementitious material in cement-based materials (Akhatar & Tarannum, 2018).

2.1.5 Water

Portable water fit for drinking was used for both mixing and curing

2.2 Mix Proportioning

A cement-to-sand mix ratio of 1:6 was adopted, representing one part cement to six parts fine aggregate, in accordance with the provisions of NIS 87:2004. A constant water-cement ratio of 0.50 was maintained for all mixes. Fly ash was incorporated as a 10% replacement of cement, while polystyrene waste was used to replace fine aggregate at 0%, 5%, 10%, 15%, 20%, and 25% by volume. The summary of the materials used to produce the samples is presented in Table 1.

2.3 Preparation of Samples

The constituent materials were thoroughly mixed using a mortar mixer to achieve a uniform mixture. The fresh mixes were subsequently cast into 50 × 50 × 50 mm cube molds and 70mm diameter x100mm height cylindrical molds and compacted manually to ensure adequate consolidation. After setting and hardening, the specimens were demolded and fully immersed in a water-curing tank until the specified testing ages.

Table 1: Mix Proportioning of Materials

Polystyrene repl. (%)	Cement (kg/batch)	Fly Ash (kg/ batch)	Fine Agg. (kg/ batch)	Polystyrene (kg/batch)
0	3.243	0.00	19.46	0.00
5	2.908	0.323	18.413	0.00493
10	2.908	0.323	17.445	0.00985
15	2.908	0.323	16.476	0.01478
20	2.908	0.323	15.507	0.01971
25	2.908	0.323	14.538	0.024633

2.4 Testing of Samples

In the fresh state, the mortar mixes were evaluated for consistency using the flow-table test in accordance with the procedure outlined in BS EN 1015-3:1999. The measured spread diameters were subsequently classified based on the consistency criteria adopted from the relevant provision of IS 4031. At the hardened state, Density, compressive strength, and splitting tensile strength were measured at 7, 14, 28, 56, and 90 days in compliance with the provisions of BS EN 12390-3 (2002) and BS EN 12390-6 (2009). Three replicate samples were tested for each mixture at each curing age for compressive strength, splitting tensile strength, and density. The results were expressed as the mean value of the three replicates, together with the corresponding standard deviation. Furthermore, the morphology of the mortar cubes were assessed using a scanning electron microscope (SEM).

3.0 RESULTS AND DISCUSSION

3.1 Chemical Composition of Fly Ash

Table 2: Chemical Composition of Fly Ash

S/no.	Constituent	Elements	Test Result (% by mass)	ASTM Requirement	C618
1	Silicon Dioxide	SiO ₂	53.42	—	
2	Aluminum Oxide	Al ₂ O ₃	27.18	—	
3	Iron Oxide	Fe ₂ O ₃	8.63	—	
Sub-total	(SiO₂ + Al₂O₃ + Fe₂O₃)	—	89.23	≥ 70.0%	
4	Calcium Oxide	CaO	5.36	—	
5	Magnesium Oxide	MgO	1.45	≤ 5.0%	
6	Sulfur Trioxide	SO ₃	1.10	≤ 5.0%	
7	Sodium Oxide	Na ₂ O	0.76	—	
8	Potassium Oxide	K ₂ O	1.45	—	
9	Titanium Dioxide	TiO ₂	1.10	—	
10	Phosphorus Pentoxide	P ₂ O ₅	0.12	—	
11	Loss on Ignition (LOI)	—	1.85	≤ 6.0%	

Table 2 shows the chemical composition analysis of fly ash. It can be observed that the combined proportions of SiO₂, Al₂O₃, and Fe₂O₃ are 89.23%, which exceeds the minimum value of 70%

prescribed by ASTM C618 for the classification of fly ash. The loss on ignition (LOI) was 1.85%, which is also within the recommended limit. This implies that the fly ash was suitable for use as pozzolanic material.

3.2 Consistency of Fresh Mortar

Table 3: Flow of Mortar Mixes

Fresh Mixes Samples	Spread Diameter (mm)	Remark
0%	125mm	High consistency
5%	123mm	High consistency
10%	114mm	Moderate consistency
15%	110mm	Moderate consistency
20%	105mm	Moderate consistency
25%	100mm	Stiff

Source: Experiment (2025)

Table 3 presents the consistency of the fresh mortar mixes containing polystyrene and fly ash. It was observed that the flow of the mixes decreased with an increase in polystyrene content. The control mixture recorded a spread diameter of approximately 125 mm, while the spread decreased slightly with increasing polystyrene replacement, reaching approximately 100 mm at 25% replacement.

This represents a reduction of approximately 20% between the control and the 25% polystyrene mixture. The reduction in consistency is associated with the physical characteristics of the polystyrene particles and their influence on particle packing within the fresh mortar. Based on IS 4031, the spread values of the mortar mixes obtained fall within the range of high to moderate consistency, except for the 25% polystyrene sample. This implies that 5-20% polystyrene mortar mixes will be easy to work with. However, the consistency of the 25% polystyrene mixes could be improved by the use of water-reducing admixtures.

3.3 Density

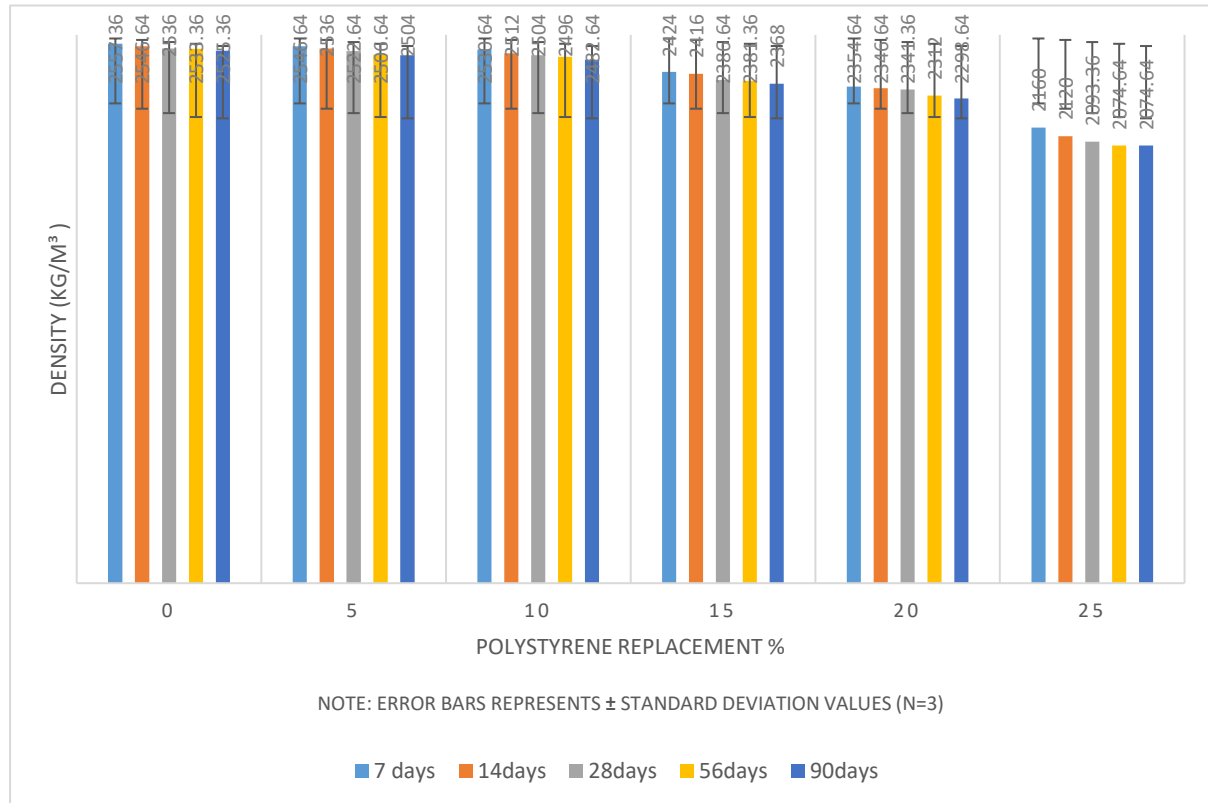


Figure 1: Density

Figure 1 presents the dry density of the hardened sandcrete mortar samples at curing ages of 7, 14, 28, 56, and 90 days. The results show that dry density generally decreased with increasing polystyrene replacement, particularly at replacement levels above 10%. At 7 days, the density decreased from 2557.36 kg/m³ for the control mix to 2160.00 kg/m³ at 25% polystyrene replacement. Similarly, at 14 days, the density decreased from 2546.64 kg/m³ to 2120.00 kg/m³ for the control and 25% replacement mixes, respectively. At 28 days, the density decreased from 2536.00 kg/m³ to 2093.36 kg/m³, while at 56 days, it decreased from 2533.36 kg/m³ to 2074.64 kg/m³ for the control and 25% replacement mixes, respectively. At 90 days, the density further decreased from 2525.36 kg/m³ for the control mix to 2074.64 kg/m³ at 25% polystyrene replacement.

The reduction in density is attributed to the significantly lower density of polystyrene compared with natural fine aggregate. The effect of curing age on density was relatively small compared with the effect of polystyrene replacement. At lower replacement levels of 5% and 10%, only slight reductions in density were observed, whereas higher replacement levels of 15–25% produced more substantial reductions. The findings demonstrate that increasing polystyrene content is effective in reducing the unit weight of the hardened mortar, supporting its potential application in lightweight construction.

The large difference between the densities of polystyrene and sand explains the reduction in the unit weight of the resulting mortar as the replacement percentage increased. This finding supports previous research identifying polystyrene as a suitable lightweight material for cement-based construction products (Kan, 2009; Miled & Boulay, 2004; Khatib, 2009).

3.4 Compressive Strength

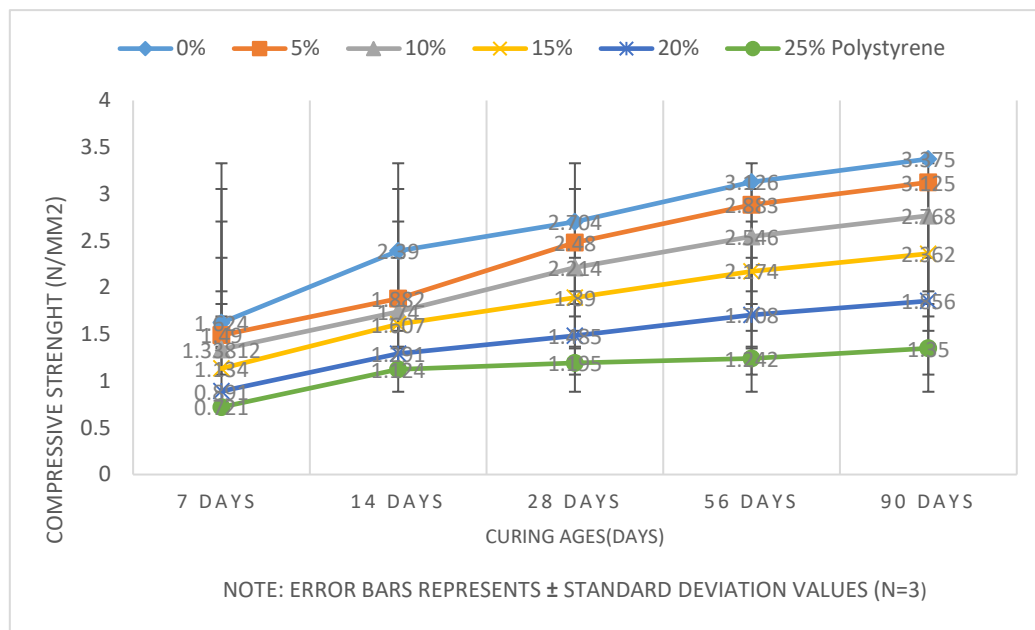


Figure 2: Compressive Strength of Sandcrete Mortar Samples at Different Curing Ages

Figure 2 shows the compressive strength of the mortar samples at different polystyrene replacement levels. The compressive strength increases with age. At 90 days, the control sample recorded a compressive strength of 3.375 N/mm², while the values decreased to 3.125, 2.805, 2.445, 2.085, and 1.725 N/mm² for 5%, 10%, 15%, 20%, and 25% polystyrene replacement, respectively. Compared to the control sample, these values represent reductions of approximately 7.4%, 16.9%, 27.6%, 38.2%, and 48.9%, respectively. The results indicate that although prolonged curing improved the strength of all samples, increasing the proportion of polystyrene progressively reduced compressive strength. The relatively small reduction observed at 5% replacement indicates that a low level of polystyrene can be incorporated while retaining a substantial proportion of the control samples' strength. However, higher replacement levels resulted in progressively greater strength reductions. The reduction can be attributed mainly to the low density and relatively weak bonding of polystyrene particles within the cementitious matrix. Similar observations have been reported in studies of polystyrene-containing

cement-based materials (Haidar & Khalil, 2002; Kehinde & Babatunde, 2020). The continuous increase in strength with curing age is associated with continued cement hydration and the contribution of fly ash through pozzolanic reactions.

3.5 Splitting Tensile Strength

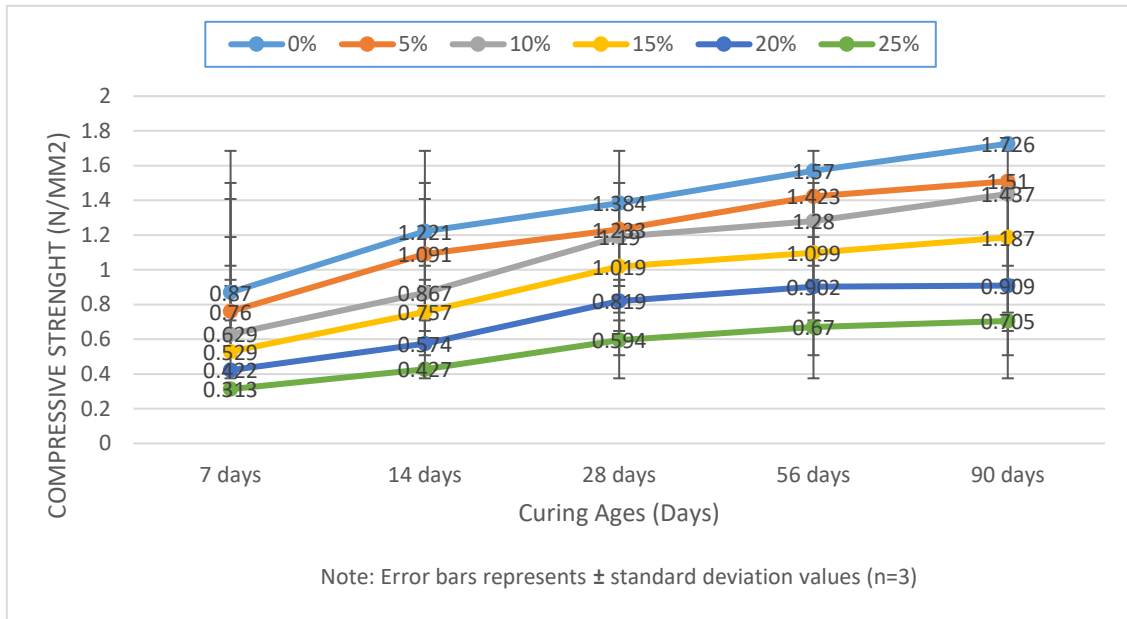
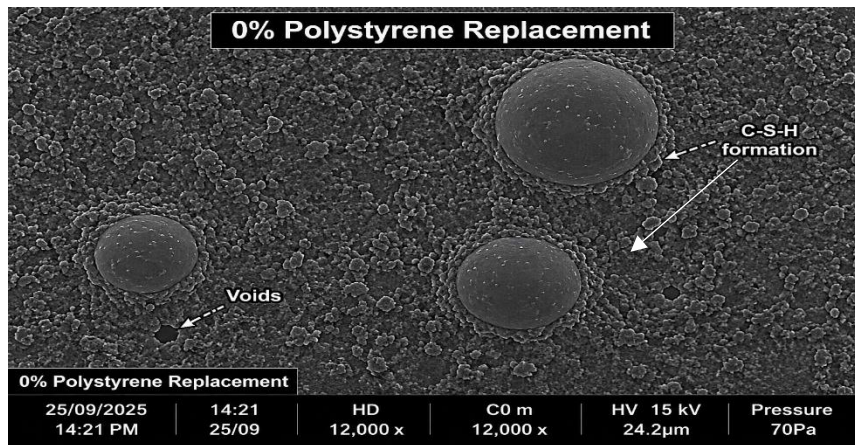


Figure 3: Split Tensile Strength of Sandcrete Mortar Sample at Different Curing Ages

Figure 3 presents the split tensile strength of the mortar samples containing polystyrene and fly ash. The tensile strength of the mortar samples exhibited a trend similar to that of compressive strength, whereby increasing polystyrene replacement resulted in progressive reductions in tensile strength. At 90 days, the control mix recorded a tensile strength of 1.726 N/mm², while the 5%, 10%, 15%, 20%, and 25% polystyrene mixes attained tensile strengths of 1.510, 1.437, 1.187, 0.909, and 0.705 N/mm², respectively. Compared to the control sample, these values represent reductions of 12.51%, 16.74%, 31.23%, 47.28%, and 59.15%, respectively. This indicates that increasing the proportion of polystyrene progressively reduced the mortar's tensile performance. The reduction may be attributed to the low density and weak mechanical properties of polystyrene particles, which can increase void spaces within the matrix and reduce the bond between the cement paste and aggregate particles. The observed decrease in tensile strength agrees with the findings of Ya'u et al. (2024), who reported that the mechanical properties decreased with an increase in polystyrene content.

Despite the reduction in tensile strength with increasing polystyrene content, all mixes exhibited continuous strength development with curing age. For instance, the 25% polystyrene mix increased from 0.313 N/mm² at 7 days to 0.705 N/mm² at 90 days. The continuous increase in strength with curing age may be associated with the ongoing hydration of cement and the contribution of fly ash content to the development of the cementitious matrix through pozzolanic reactions.

3.6 Scanning Electron Microscopy Analysis (SEM)



Vods

Plate I: Sample A (Control Mix containing 0% Polystyrene Replacement and 0% fly ash replacement)

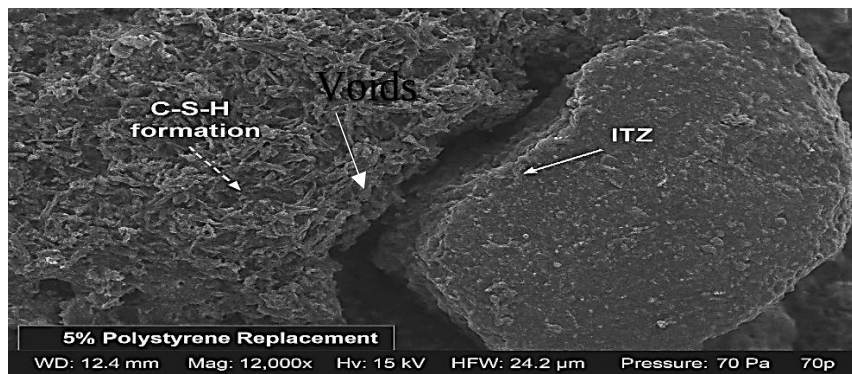


Plate II: Sample B (5% Polystyrene Replacement and 10% fly ash Replacement)

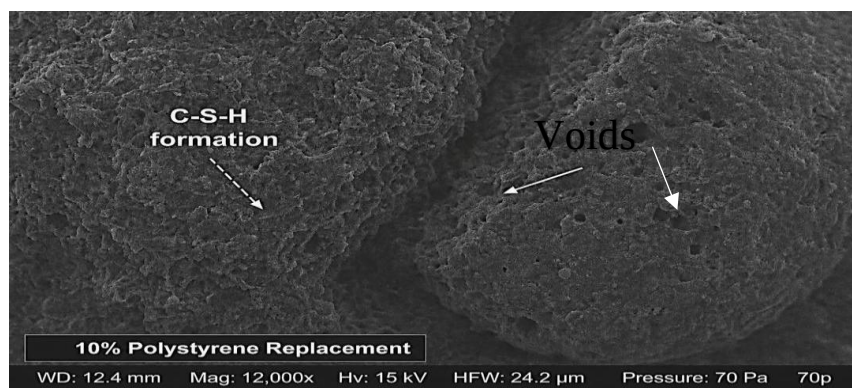


Plate III: Sample C 10% Polystyrene Replacement and 10% fly ash replacement

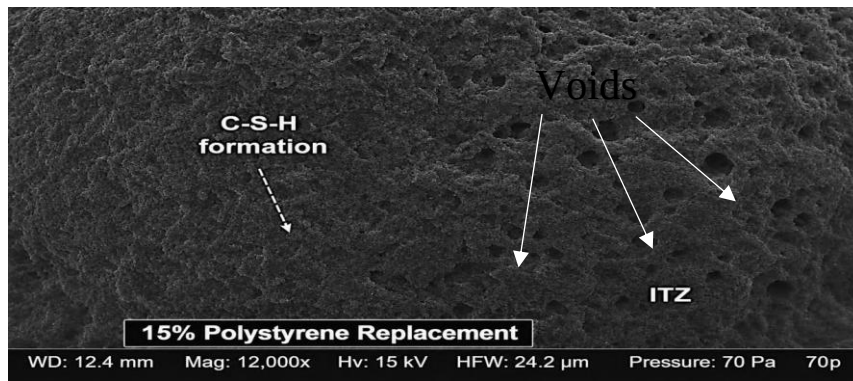


Plate IV: Sample D (15% Polystyrene Replacement and 10% fly ash replacement)

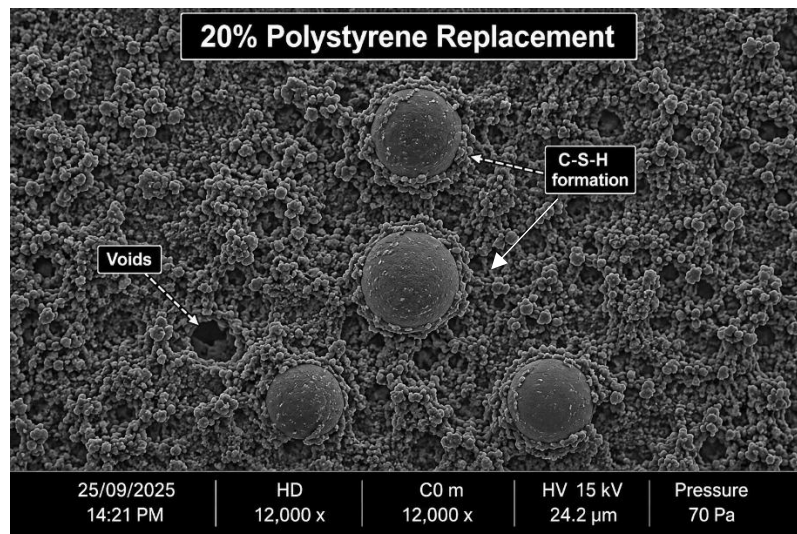


Plate V: Sample E (20% Polystyrene Replacement and 10% fly ash replacement)

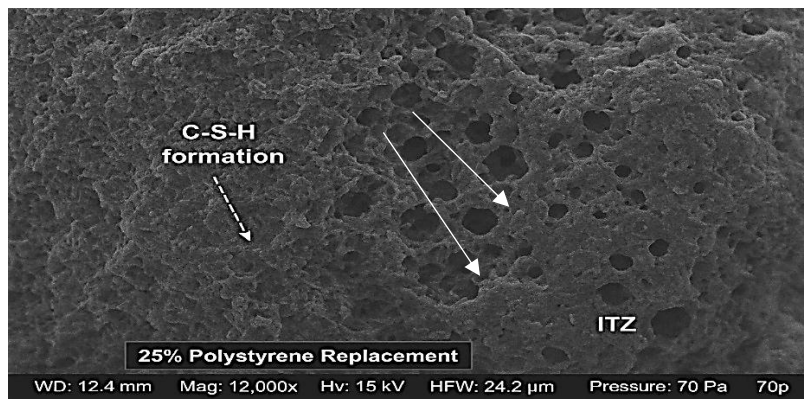


Plate VI: Sample F (25% Polystyrene Replacement and 10% fly ash replacement)

The microstructural properties of the mortar samples were evaluated using Scanning Electron Microscopy (SEM) at 12,000× magnification as shown in Plates I-VI. The SEM observations provided microstructural evidence supporting the mechanical-strength results. The control specimen exhibited a relatively dense and compact microstructure with extensive C–S–H gel formation and a well-bonded interfacial transition zone. The limited number of voids and microcracks corresponded with the relatively high mechanical strength of the control specimen.

At 5% polystyrene and 10% fly ash, small spherical voids associated with the polystyrene particles were observed. However, the matrix remained relatively dense because of the pozzolanic activity of the fly ash, which promoted secondary C–S–H formation. This helped maintain relatively good microstructural integrity.

At 10% polystyrene, the number of voids increased, and the interfacial transition zone became less compact. At 15 to 25% replacement, the microstructure became progressively more porous and discontinuous, with larger voids, weak interfacial zones, and localized microcracking. The 20% and 25% specimens exhibited highly porous matrices with poor particle bonding and fragmented hydration products.

The SEM results therefore support the observed reduction in compressive and tensile strength with increasing polystyrene content. They also provide evidence for the improved performance of the 5% polystyrene + 10% fly ash specimen.

4.0 CONCLUSION

- i. The 5–20% replacement levels exhibited high to moderate consistency and were considered workable, whereas the 25% mix became relatively stiff.
- ii. Based on the density results, increasing polystyrene content can be effectively used to produce lighter mortar suitable for non-structural applications.
- iii. Compressive and tensile strength decreased with increasing polystyrene content. However, 5% polystyrene and 10% fly ash specimens retained 92.6% of their strength. Therefore, 5% polystyrene and 10% fly ash is the optimum for producing cement mortar
- iv. Increasing polystyrene content resulted in greater porosity, larger voids, weaker interfacial zones, and localized microcracking. In contrast, the lower polystyrene replacement level exhibited a relatively denser matrix with improved C–S–H gel formation associated with the presence of fly ash.

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