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INVESTIGATION OF THE MECHANICAL AND DURABILITY PROPERTIES OF LIGHTWEIGHT CONCRETE WITH POLYSTYRENE BEADS

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ABSTRACT:
Purpose: This study evaluates the balance between weight reduction and compressive strength in innovative concrete mixes by using polystyrene beads as a partial replacement for coarse aggregates in lightweight concrete to reduce the environmental impact while maintaining structural functionality.
Design/Methodology/Approach: Using a methodical experimental design, concrete cubes with dimensions of 150 mm × 150 mm × 150 mm were prepared with varying polystyrene beads replacement levels (0%, 10%, 15%, and 20%), and their properties were assessed through standard tests of compressive strength, density, and workability over 28 days of curing.
Research Limitation: The study did not address the effects of incorporating advanced admixtures or hybrid aggregate solutions.
Findings: The findings reveal that while increased polystyrene beads content reduces density and compressive strength, the 15% replacement level achieves an optimal balance, retaining adequate strength (16.87 MPa) for nonstructural applications. Workability decreased with higher replacement levels, emphasising the need for admixtures to enhance performance.
Practical Implication: The study proposes a partial replacement of polystyrene beads by up to 15% in coarse aggregates for the production of lightweight concrete with the required mechanical strength and durability for non-load-bearing applications.
Social Implication: The use of polystyrene beads in concrete would lead to the reuse of waste plastic materials, which negatively impacts the environment, including water bodies. This would then improve the environment for the safe living of man.
Originality/Value: These findings have significant implications for industries seeking sustainable and cost-effective building solutions and underscore the need for further research to address durability and long-term performance.

Keywords: *Compressive strength. lightweight concrete. polystyrene beads. sustainable construction. workability and density*

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INTRODUCTION

Concrete remains one of the most widely utilised construction materials, valued for its versatility, durability, and cost-effectiveness (Raza et al., 2024; Sharma et al., 2024). However, traditional concrete composition relies heavily on natural aggregates, raising significant environmental concerns regarding habitat destruction and carbon emissions during extraction and processing.

In response to global sustainability imperatives, the construction industry has increasingly focused on lightweight concrete alternatives. These materials offer a strategic approach to structural optimisation by reducing dead loads on structural elements and enabling smaller section sizes, resulting in decreased foundation requirements, enhanced material efficiency, reduced construction costs, and improved structural performance (Mousa, Mahgoub, & Hussein, 2018; Singh, 2016; Kumar & Kumar, 2010). This optimisation cascade extends throughout the construction lifecycle, substantially reducing embodied carbon in material production and transportation (Fraile-Garcia et al., 2019).

Sustainable alternatives to traditional aggregates have gained global attention (Wu et al., 2024; Hamada et al., 2024). Among these alternatives, expanded polystyrene (EPS) beads have emerged as a promising partial replacement for natural aggregates (Ahmed & Mohammed, 2024; Seethapathi et al., 2024; Utkarsh & Jain, 2024). Recent studies by Coppola et al. (2016), Dharmadhikari (2024), and Trykoz et al. (2024) have demonstrated that polymeric aggregates from recycled plastics can enhance concrete's thermal and acoustic properties. This innovation offers dual benefits: environmentally, by providing a recycling pathway for non-biodegradable plastic waste (Alam et al., 2022; Musalaiah & Madhavi, 2022), and structurally, by reducing concrete self-weight. Research indicates that replacing 40% of coarse aggregates with EPS beads can reduce concrete weight by 13% to 16% (Bhoomesh et al., 2024).

While Thorneycroft et al. (2017) have demonstrated the effectiveness of polystyrene aggregates in reducing concrete density for non-structural applications, significant research gaps persist. Notably, Zulkernain et al. (2021) and Rajput (2024) highlighted challenges related to the organic composition of plastic aggregates and their potential to form weaker bonds within the concrete matrix. The optimal replacement levels that balance density reduction with sufficient compressive strength remain underexplored.

This research aims to determine the optimal replacement percentage of natural aggregates with polystyrene beads to achieve acceptable compressive strength; evaluate the density and weight reduction of polystyrene-bead concrete; and assess the workability and practical implications of polystyrene-bead concrete in construction. Through comprehensive laboratory testing of concrete specimens with varying replacement levels of polystyrene beads, this study contributes to the growing body of knowledge on sustainable construction materials while addressing plastic waste management challenges. The findings will provide empirical evidence and practical guidelines for the implementation of polystyrene beads in lightweight concrete applications.

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LITERATURE REVIEW

Concrete, one of the most widely used construction materials in the world, is versatile, strong, and flexible. Concrete made of cement, fine aggregate, coarse aggregate, and water is well known for its strength characteristics; however, because it is brittle and dense, it has limitations (Onaizi et al., 2024; Cui et al., 2017). Traditional concrete often results in inefficient sections for specific applications because its density ranges from 2200 kg/m³ to 2600 kg/m³.

On the other hand, free-volume concrete with densities ranging from 1440 to 2010 kg/m³ typically contains lightweight materials such as polystyrene beads and is primarily used for non-structural applications (Vinay Kumar et al., 2021; Surendra et al., 2016; Ashish et al., 2016). This lightweight material offers the following benefits: reduced structural loads, improved tall-building construction, better seismic performance, and suitability for modern use (Sahoo et al., 2022).

However, challenges persist in achieving specific compressive strength requirements for structural applications (Coppola et al., 2016). Common issues include workability limitations, reduced bond strength between cement matrix and lightweight aggregates, and difficulty meeting structural strength requirements.

Polystyrene, produced through polymerisation, consists of a long hydrocarbon chain, resulting in material characteristics including homogeneous structure, lightweight properties, poor heat conductivity, and low impact strength (Bradshaw, 2024).

Research has shown that polystyrene aggregates do indeed provide the required density for lightweight concrete, but only through the sacrifice of compressive strength (Kusnadi et al., 2024; Fořt et al., 2024). These challenges include surface properties and moisture sensitivity effects, that is, weak bonding with the cement matrix (round and smooth texture), excess water deteriorating its strength (Prasittisopin et al., 2022), and Hani et al. (2019) noted that the water ratio is challenging to manage. Based on these results, it was concluded that the shape and surface morphology of the aggregates could be improved to increase the workability and bond strength.

The integration of polystyrene beads in construction presents both environmental and economic advantages, particularly in addressing contemporary sustainability challenges. This application serves a dual purpose: reducing plastic waste through recycling and providing an alternative to natural aggregates in construction materials. Research indicates that incorporating recycled waste materials into concrete formulations contributes significantly to environmental conservation by reducing pollution (Mashaan & De Silva, 2024; Awoyera & Adesina, 2020). This is particularly relevant for non-load-bearing structural applications. However, critical perspectives suggest that the recycling of plastics in construction merely delays rather than eliminates their environmental impact. Furthermore, concerns persist regarding their chemical stability and long-term durability (Coppola et al., 2016).

However, the presence of these factors casts doubt on sustainability, although the economic incentives are clear. Polystyrene beads in lightweight concrete demonstrate that the recycling project is not only

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a theoretical but also a practical way to save money in construction. The created material has some advantages in terms of weight; however, its durability and lifecycle requirements remain unknown.

The utilisation of polystyrene-based lightweight concrete is particularly suited for specific construction applications with minimal structural demands such as partition walls, insulating layers, and precast structural elements. These applications capitalise on the material's advantageous properties, specifically its low weight, superior thermal performance, and enhanced acoustic properties.

However, significant limitations exist, primarily related to the material's relatively low compressive strength, which restricts its use in applications requiring substantial flexural resistance. It is argued that these structural limitations considerably constrain the material's potential applications, suggesting that integration with high-strength materials may be necessary (Adhikary & Ashish, 2022).

There remain knowledge gaps in the adoption of polystyrene beads in the production of lightweight concrete; research should focus on identifying optimal aggregate types and qualities, developing complementary admixture formulations, engineering solutions to mitigate inherent strength limitations, and investigating long-term performance characteristics.

MATERIALS AND METHODS

Materials

River sand, coarse aggregates, polystyrene beads, cement, and water were the primary materials used to produce the lightweight concrete specimens used in this study. The river sand sample was sourced from the Kakum River bank located at Wiomoah in the Abura-Asebu-Kwamankese District of the Central Region, Ghana. The sand was packed into sacks and transported from the site to the Civil Engineering Materials and Geotechnical Laboratory Facilities of the Cape Coast Technical University. The river sand sample (Figure 1a) underwent a sun-drying process for a duration of two weeks, followed by sieving through a 19 mm sieve filter to eliminate cobblers and stones. This preparation was conducted prior to the grading test, which adhered to the standards outlined in BS 812: section 103.1:198.

Polystyrene beads were procured from a market in Accra as a partial replacement material. The lightweight polystyrene beads were small, impermeable balls of 2 mm-8 mm in diameter used to prepare concrete (Figure 1b).

Cement was obtained from a market in Cape Coast, Ghana. Ordinary Portland cement of grade 32.5R was used for the concrete preparation per BS EN197-1. The cement sample used is shown in Figure 1c. This type of cement was chosen because of its high early strength, as the "R" indicates "rapid" strength development, indicating that the concrete will reach a significant portion of its final strength quickly after pouring, allowing for faster formwork removal and earlier loading of the structure (Cangussu et al., 2023). The water used for mixing in the experiment was directly obtained from the

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tap at the Civil Engineering Materials and Geotechnical Laboratory Facilities of Cape Coast Technical University. This tap water was confirmed to be of potable quality.

The coarse aggregate (Figure 1d) for the concrete was between 10 mm and 40 mm, conforming to BS 882–1992, and was obtained from a quarry site on the Cape Coast – Takoradi highway. The aggregates were packed into sacks and transported from the site to the Civil Engineering Materials and Geotechnical Laboratory Facilities of the Cape Coast Technical University.

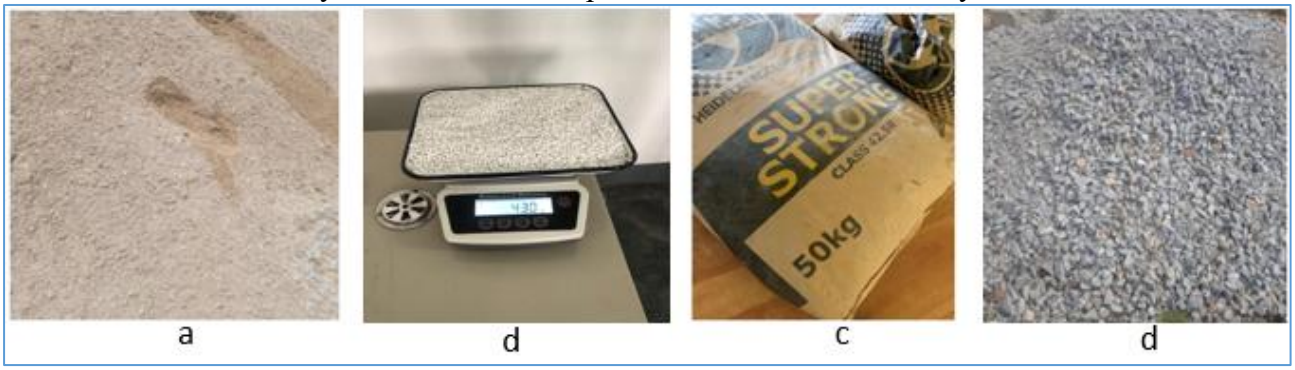


Figure 1: Sample raw materials: (a) river sand, (b) polystyrene beads, (c) Portland cement and (d) coarse aggregate

Experimental procedure

Sieve Analysis

This was conducted using the guidelines from BS 812: Section 103.1:1985. The Coefficient of Uniformity (Cu) and Coefficient of curvature (Cc) were computed using Equations 1 and 2.

Coefficient of Uniformity, $Cu = \frac{D_{60}}{D_{10}}$ .....Equation 1

Coefficient of curvature, $Cc = \frac{(D_{30})2}{D_{60}\ x\ D_{10}}$ .....Equation 2

Where D_{10}, D_{30}, D_{60} - particle diameters at which 10%, 30%, and 60% of the aggregate (by weight) pass through, respectively, obtained via interpolation from the gradation curve.

Silt test

A silt test was performed as prescribed in BS 812 to determine the amount of clay or silt in the fine aggregate. The percentage of silt was calculated using Equation 3.

$$\text{Average percentage of silt} = \frac{V2}{V1} X\ 100\% \quad \text{..... Equation (3)}$$

Slump test

BS1881-102 was used for the slump test of the newly mixed concrete (Figure 2c). A cleaning process was performed before the start of the test to ensure that the mould, base plate, and all testing materials were clean and free of any remnants. To prevent the two surfaces from grinding against each other and creating excessive surface friction, the inner surfaces of both the base and the mould were dampened before starting the test. Subsequently, fresh concrete was poured into the mould in three layers. A rounded-end steel rod was used to uniformly tamp each layer 25 times. Excess concrete

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from the top of the cone was removed and levelled. It was then carefully lifted vertically from the cone. As a result, the unsupported concrete slumped, and the decrease in height was measured to the nearest 5 mm (approximately 0.25 inch) at the centre point. Therefore, a true slump occurred when the concrete mass fell evenly without disintegration and the desired test result. The slump test should be repeated if there is shear, collapse, or zero slump. However, if the slump test fails on the second attempt, the concrete batch is deemed unfit for use according to the specified safety standards.

Preparation of Polystyrene Beads Concrete (PBC) specimens

The polystyrene beads of 10, 15, and 20% by weight as partially replacing coarse aggregate and mix ratio of 1:2:4 and a water-cement ratio of 0.55 were batched into a concrete mixer using suitable equipment (Figures 2a and 2b). Half of the required water was placed in the drum of the mixer, and the remaining half was carefully added as the drum of the mixer revolved. The concrete mixer was allowed to whirl for approximately three minutes before stopping. Well-mixed concrete was poured and slump-tested while still fresh (Figure 2c). After producing the concrete mix according to the specified mix proportions, it was cast into concrete moulds measuring 150 mm × 150 mm × 150 mm (see Figure 2d), and sufficient compaction was achieved using a tamping rod with 35 blows on each of the three levels. The polystyrene beads concrete (PBC) was cast and compacted in the same manner as the conventional concrete. The concrete surface was then finished using a trowel. The cubes were labelled accordingly. The cubes were cured before being removed from the concrete mould. The concrete cubes were then entirely submerged in fresh water enclosed in a curing tank (see Figure 2g), and samples were taken for testing on the 7th, 14th, 21st, and 28th days of curing for their properties to be determined. The overarching methodology for the preparation of the PBC samples is shown in Figure 4.

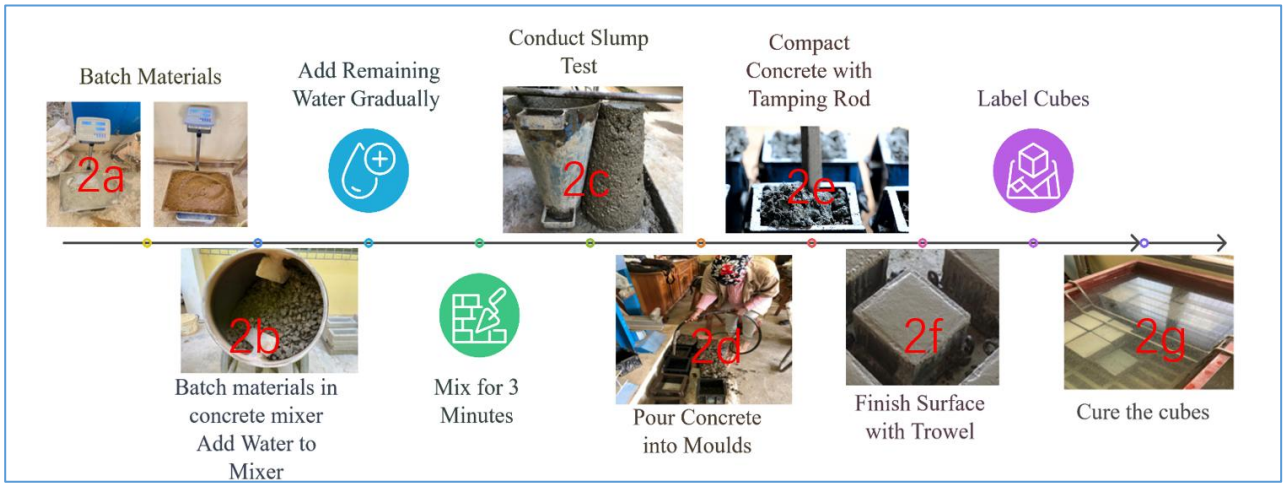


Figure. 2: Preparation of PBC samples

Testing of polystyrene beads concrete (PBC) specimens

To determine the characteristics of the PBC, assessments were carried out focusing on compressive

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strength, specific gravity, and water absorption. Nine (9) solid cubes of the specimens were used as controls, and 36 were cast with the mix. A total of 45 concrete cubes were cast. Three (3) cubes from each sample were evaluated for their properties.

Compressive strength

The compressive strength test was conducted following BS EN 12390-3:2019. The compressive strengths of the PBC specimens were determined using a universal test machine (Matest S.R.L Treviolo with 500kN capacity). To maintain consistent loading, the PBC specimens were placed centrally between the two plates and the compressive strength testing equipment, as shown in Fig. 3. Typically, the specimens were subjected to a steady load which was progressively applied until failure. The maximum crushing force at which the concrete specimens were crushed was measured, and the strength was determined using Equation (4):

$$fc=F/A \quad \text{..... Equation (4)}$$

where fc = compressive strength in N/mm^2; F = highest force at which the PBC specimens were crushed in N; A = area of the PBC specimens where the force was applied in mm^2.



Figure 3: Compressive strength testing of PBC samples

Relative Density (Specific Gravity) Tests

The specific gravity test followed the BS 812:2 procedure. The samples were subjected to oven-drying at 105 °C for a duration of 24 hours, after which they were weighed using a balance scale and the measurements were documented. The recorded values were calculated using Equation 5 to test the PBC specimens:

$$\boldsymbol{SG = \frac{W_4}{W3-(W1-W2)}} \quad \textbf{..... Equation (5)}$$

Where: W1 = Sample immersed in water; W2 = weight of mesh bucket; W4 = acceptable weight.

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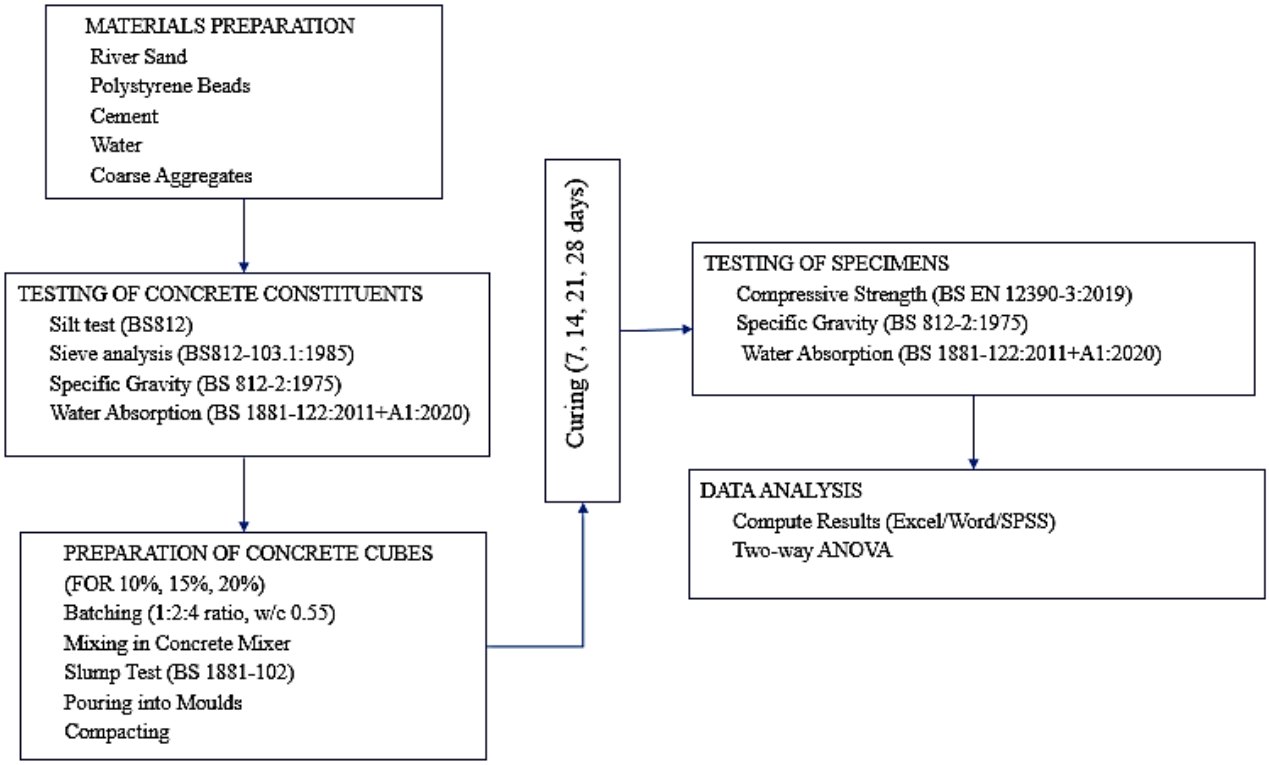


Figure 4: The overarching methodology of preparation of PBC samples

Water absorption tests

A water absorption test was conducted on 28-day-cured PBC specimens following BS 1881-122:2011+A1:2020. The PBC specimens were oven-dried at 105 °C for 24 hours. The water tank was filled with water, and the samples were immersed for 24 hours.

The cubes were removed and weighed, and their weights were recorded. The water absorption capacity of the PBC specimens was determined using Equation 6:

$$\mathbf{WA} = \frac{\boldsymbol{W3-W4}}{\boldsymbol{W4}} \boldsymbol{X}\ \mathbf{100\%} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation (6)}$$

Where: WA = water absorption by capillary in %; W3 = weight of the PBC specimens after oven-drying in kg; and W4= the weight of absorbed PBC specimens in kg.

Analysis of data

The data obtained were analysed and presented in figures and tables using Microsoft Excel, Word, and SPSS. A Two-way ANOVA was used to assess significant differences among the test results.

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RESULTS AND DISCUSSION

The results obtained from the physical properties of river sand and coarse aggregates (particle size distribution, silt,), slump, mechanical properties (compressive tests), specific gravity tests and durability properties (water absorption tests) are presented in detail below.

Physical properties

Table 1 shows the results of the sieve analysis.

Table 1: Sieve Analysis Results

Fine Aggregates % Passing	Coarse Aggregate % Passing
98.75	100
98.49	9.72
97.27	0.08
92	0.08
73.12	0.08
31.82	0.08
8.49	0.08
3.17	0.08
3.17	0
0.84	
0.07	
0	

The particle size distribution curves of the fine and coarse aggregates are shown in Figures 5 and 6, respectively. The nuanced aggregate particle distribution analysis showed a poorly graded composition with a coefficient of uniformity (Cu) of 2.04 and a curvature (Cc) of 0.7. Poorly graded aggregates can affect the workability of concrete by requiring more cement paste to fill voids. This is consistent with previous studies (Sun et al., 2023) that emphasise the impact of fine aggregate grading on the cohesiveness and strength of concrete.

Unlike aggregates with better grading, poorly graded sands typically compromise strength and workability, necessitating adjustments to the mix design. These findings suggest that supplementary admixtures or better-graded fine aggregates may be required for optimisation. Similarly, coarse aggregates exhibited poorly graded characteristics (Cu = 1.22; Cc = 0.97). Adequately graded aggregates are crucial for achieving high-density durable concrete mixes. This aligns with Okonkwo et al. (2023), who emphasised that poorly graded aggregates reduce concrete density and increase the risk of segregation. Owing to the lower density requirements, the grading here seems to have less impact on lightweight concrete than on traditional concrete mixes. Optimising the aggregate grading might enhance the strength and durability of polystyrene-based concrete.

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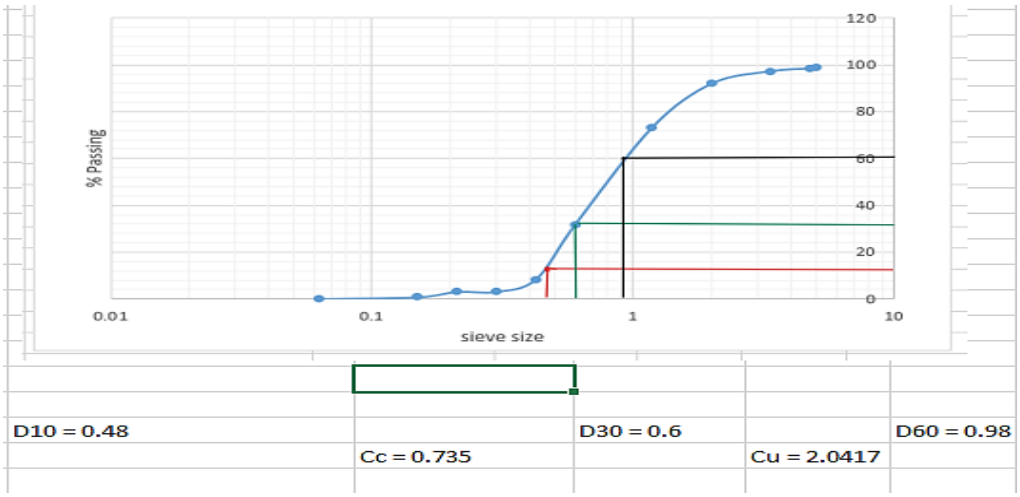


Figure 5: Fine aggregate's particle distribution curve

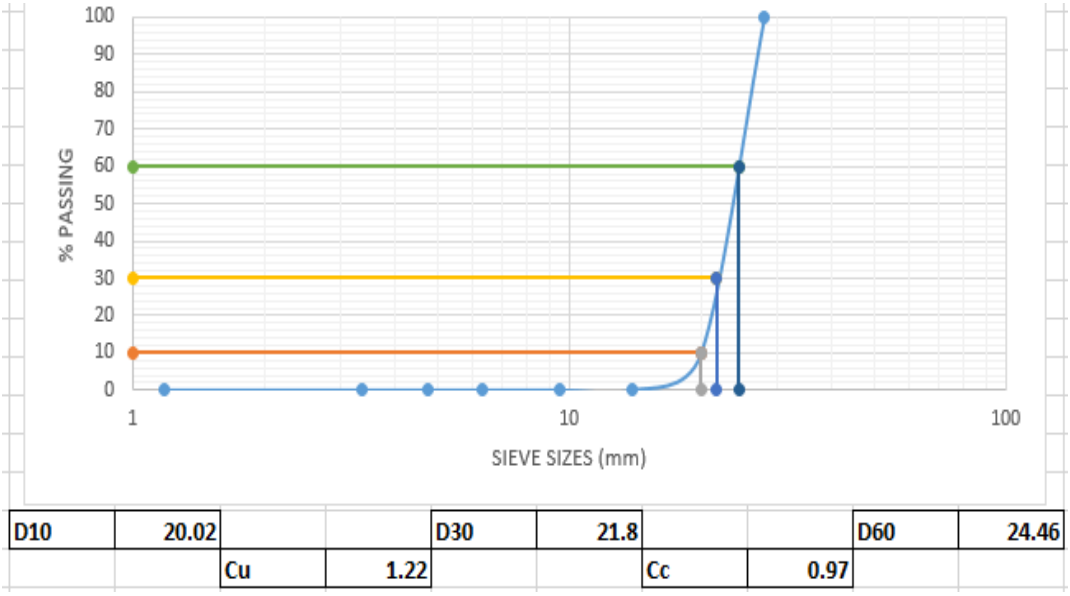


Figure 6: Coarse aggregate's particle distribution curve

Silt Test

Table 2 shows that the average silt content of the fine aggregate was 5.31%, well within the permissible limit of 8% as per IS 2386-2. This indicates that fine aggregates are suitable for concrete production. Previous studies by Sahoo et al. (2022) align with this finding, emphasising that fine aggregates with silt contents below 8% contribute to optimal bonding and reduced porosity in concrete

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mixtures. In some cases, aggregates with even lower silt content (approximately 2%-3%) are preferred for high-performance concrete. The slightly higher silt content suggests potential challenges in achieving ultra-high strength, but remains acceptable for general and lightweight concrete. These results underscore the importance of adhering to the standard silt content limits to ensure workability and stability. For industries, it emphasises quality control during material procurement to avoid variability in concrete performance.

Table 2: Average silt content of the fine aggregate for concrete production

Description	**Samples**		
	S1 (ml)	**S2 (ml)**	**S3 (ml)**
Level of content	180	180	180
Depth of sand without silt (V1)	96	85	85
Thickness of visible silt (V2)	4	4.6	5.4
Volume of water	80	90.4	89.6
Percentage of silt (%)	4.17	5.41	6.35
Average content (%)	**5.31**		

Workability or Slump Test

The slump test results ranged from 15 to 25 mm for various batches, indicating a relatively low to medium workability, as shown in Table 3 and Figure 2c. A higher polystyrene bead content resulted in reduced slump values. Concrete with 10% replacement displayed moderate workability, whereas concrete with 15% and 20% replacement levels exhibited increasingly stiff mixes, consistent with previous studies on lightweight aggregates. This is a characteristic of lightweight concrete mixes with high replacement levels of polystyrene beads. Studies by Adhikary and Ashish (2022) support this, stating that polystyrene aggregates tend to reduce workability because of their smooth surfaces and lightweight nature. Thorneycroft et al. (2017) reported that adding admixtures can significantly improve workability, a factor not explored in this study. Researchers can investigate the use of water-reducing admixtures or plasticisers to enhance workability in future experiments. Low workability may necessitate the use of mechanical techniques and account for the use of admixtures, which limits the applicability of the findings for large-scale projects requiring higher fluidity in concrete mixes.

Table 3: Slump Test Results

Cement Type	Batch	Slump Height (mm)	Mix Ratio
Ordinary Portland Cement (II/BL32.5R)	1st batch	15	1:2:4
	2nd batch	15	1:2:4
	3rd batch	25	1:2:4
	4th batch	25	1:2:4

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Mechanical Properties

The compressive test results were used to assess the mechanical properties of the polystyrene concrete mixes. Figures 7, 8, and 9 illustrate the compressive strength trends for the control concrete and mixes with 10%, 15%, and 20% polystyrene bead replacements after 7, 14, 21, and 28 days of curing. The control mixes consistently achieved the highest strength values, whereas increasing the bead content resulted in progressive reductions in strength. At 28 days, the compressive strengths were 29.33 MPa (control), 20.61 MPa (10% replacement), 18.82 MPa (15% replacement), and 15.34 MPa (20% replacement). These results are consistent with those of Saikia and de Brito (2012), who demonstrated a linear decrease in compressive strength with a higher lightweight aggregate content. Common factors are the reduced density and weaker bonds between the polystyrene beads and cement matrix.

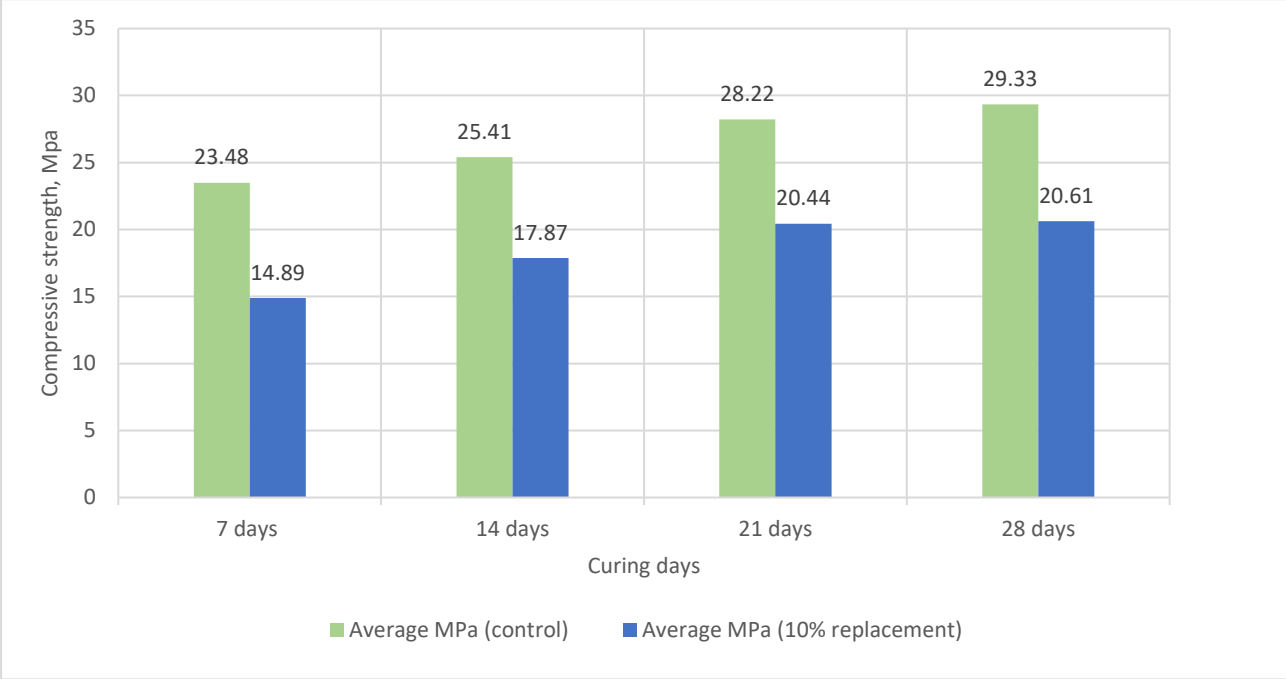


Figure 7: Average Compressive Strength Between the Control and 10% Replacement

A Two-way ANOVA was performed to statistically validate these observations on the effects of the polystyrene bead replacement levels and curing durations on the compressive strength. The analysis showed a significant main effect for both variables ($p < 0.001$): polystyrene content increased with reduced compressive strength, and curing duration increased with increasing compressive strength. This duality forms the basis of a balance between the material composition and hydration time, as described by Thienel et al. (2020), in which prolonged curing increases strength, while the poor bond between the polystyrene beads and the cement matrix prevents the full realisation of potential.

Furthermore, Levene's Test was performed to assess the quality of variance across groups, with results indicating no significant violation of the assumption of homogeneity ($p = 0.352$), as shown in

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Table 5. This confirms that the variability in the compressive strength across different replacement levels and curing times was consistent, ensuring the reliability of the ANOVA results. Notably, the interaction effect in the ANOVA indicated that strength reductions due to polystyrene replacement became more pronounced with longer curing durations, underscoring the material's unique response to curing relative to traditional concrete mixes.

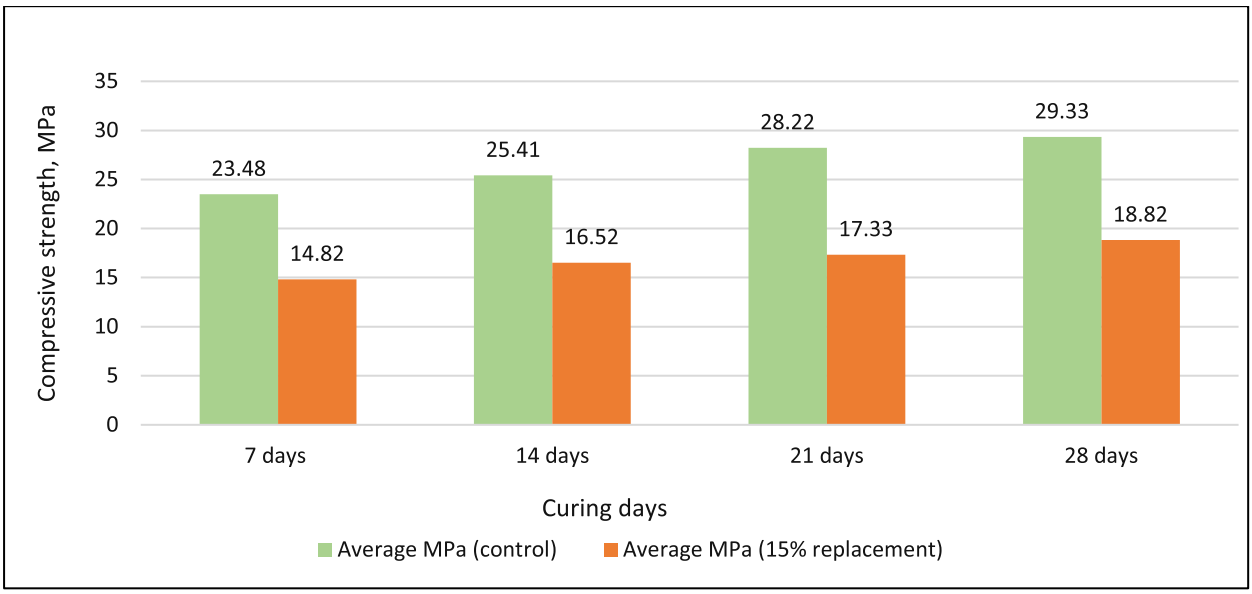


Figure 8: Average Compressive Strength Between the Control and 15% Replacement

Pairwise comparisons further revealed significant differences in compressive strength between the control and all levels of polystyrene replacement. However, the 15% replacement mix demonstrated a relatively moderate reduction in strength (52.45% lower than the control), suggesting an optimal balance between weight reduction and structural performance. This finding aligns with Adhikary and Ashish (2022), who emphasised the importance of uniform variance in comparative studies for deriving valid conclusions. For practical applications, this suggests that a 15% replacement level may be suitable for non-load-bearing or low-load-bearing components where reduced weight is prioritised over peak strength.

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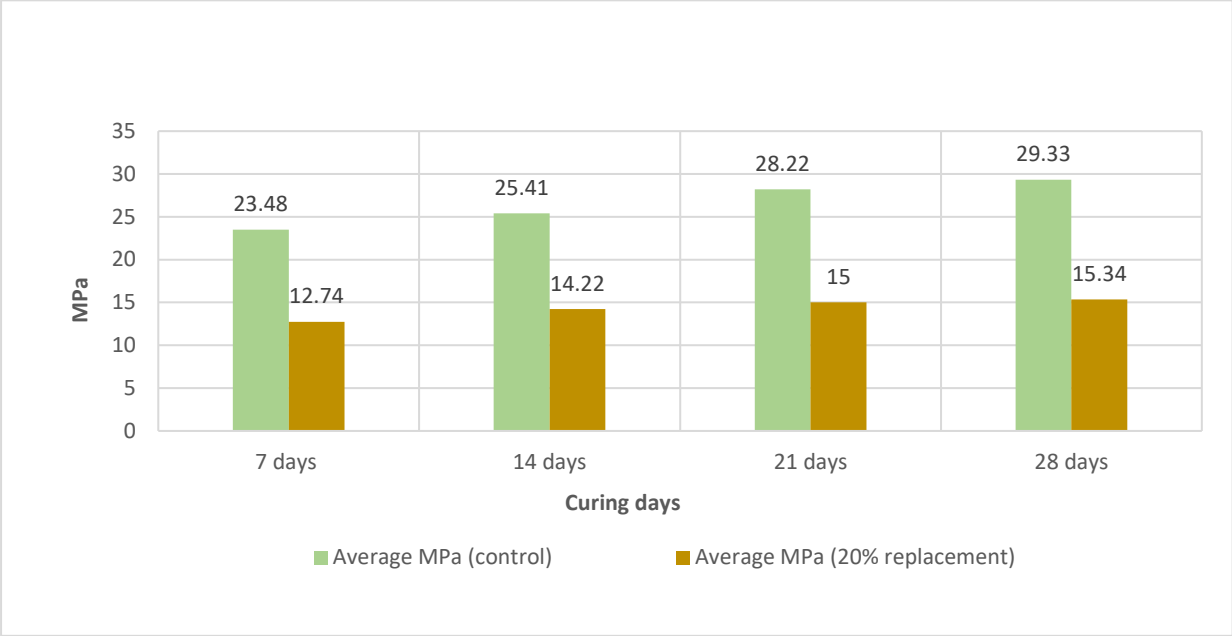


Figure 9: Average Compressive Strength Between the Control and 20% Replacement

Durability Properties

Water Absorption and Specific Gravity Test

The results of the water absorption and specific gravity tests indicated that the coarse aggregates had an average specific gravity of 2.5 and a water absorption rate of 1.2%. Both values were within the acceptable ranges for concrete aggregates (specific gravity: 2.0–3.0; water absorption: 0.1–2.0%), suggesting that the coarse aggregates used were suitable for construction purposes. This demonstrates their low porosity and validates their use in lightweight concrete mixtures. These results align with the findings of Adhikary and Ashish (2022), who observed that aggregates with lower water absorption and adequate specific gravity contribute to higher durability of lightweight concrete. Such properties minimise the risk of water-induced deterioration. Unlike studies emphasising the variability in water absorption across recycled aggregates, this work confirms consistent performance, likely owing to controlled material selection.

To statistically assess the influence of polystyrene bead content and curing time on these durability properties, a Two-way ANOVA was conducted. The analysis revealed that the level of polystyrene bead replacement had a significant effect on water absorption and specific gravity ($p < 0.001$) while curing duration did not exhibit a statistically significant impact ($p > 0.05$). This suggests that durability characteristics are primarily governed by the composition of the lightweight aggregates rather than the length of curing. Furthermore, Levene's Test confirmed the assumption of equal variance across the groups ($p > 0.05$), ensuring the reliability of these statistical findings (Table 5).

These results align with Thorneycroft et al. (2017), who highlighted that increased replacement levels of lightweight aggregates like polystyrene beads tend to elevate water absorption due to their higher

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porosity. However, despite this increase, the absorption rates remain within acceptable limits for non-load-bearing applications, such as partition walls and insulation panels. This underscores the suitability of polystyrene-based lightweight concrete for scenarios where weight reduction and thermal insulation are prioritised over minimal water permeability.

Table 4. Average Compressive Strength and Density and Strength Reductions

Polystyrene replacement (%)	Average compressive Strength (MPa)	Average density (kg/m^3)	Reduction in compressive Strength (%)	Reduction in density (%)
0	25.48	2438.26	0	0
10	18.45	2266.93	47.99	7.03
15	16.87	2006.66	52.45	17.66
20	14.33	1985.43	59.6	18.57

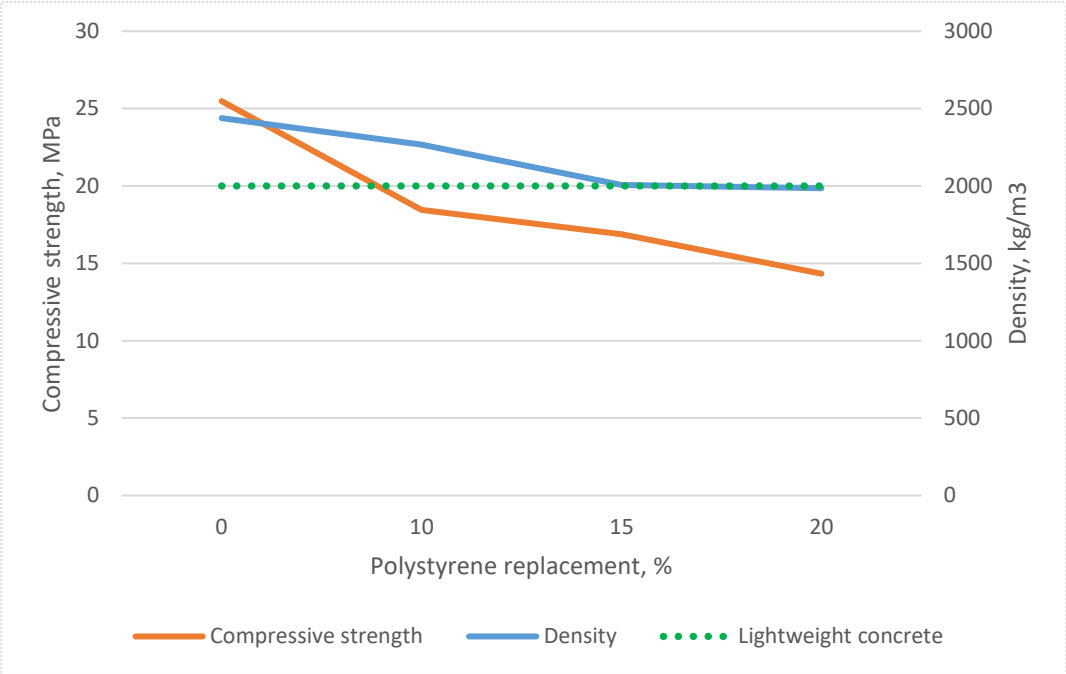


Figure 10: Average compressive strength and average density of PBC samples

Relative Density (Specific Gravity) Tests:

The relationship between the control mix and polystyrene-replaced mixes was examined in terms of the density and compressive strength, see Table 4 and Figure 10. The control mix had the highest compressive strength (25.48 MPa) and density (2438.26 kg/m³), whereas increasing replacement levels progressively reduced both properties. At 10% replacement, the compressive strength and

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density dropped to 18.45 MPa and 2266.93 kg/m³, respectively. These values declined at 20% replacement, with strengths as low as 14.33 MPa and 1985.43 kg/m³ densities. It is noted that only 20% replacement achieves true lightweight concrete status; concrete with a density less than 2000 kg/m³ (ACI 213R and EN 206). However, at 20% replacement, the compressive strength drops significantly to 14.33 MPa. This creates a trade-off between achieving lightweight status and maintaining adequate strength. The closest to achieving lightweight concrete with appreciable compressive strength is the concrete samples with15% replacement of coarse aggregate with polystyrene beads.

These trends corroborate the findings of Saikia and de Brito (2012), who noted that generally, the use of lightweight aggregates leads to a reduction in density and compressive strength of concrete. In addition, the density reductions which were achieved ranged between 7.03% (10% replacement) and 18.57% (20% replacement), while the compressive strength reductions were obtained between 47.99% to 59.6%. These figures highlight the effect of polystyrene beads on these two critical properties.

To ensure that the observed reduction in density was statistically significant, the current study utilised a two-way Analysis of Variance (ANOVA) to compare density as influenced by the amount of polystyrene beads and curing time. The results revealed that the replacement of polystyrene affected the concrete density ($p < 0.001$), whereas the curing time had no effect ($p > 0.05$), thereby implying that density reduction is a result of the comparatively 'foamy' polystyrene beads used in concrete. Furthermore, the results of Levene's Test indicated that the variances across groups were homogeneous, again supporting the credibility of these outcomes at $p > 0.05$.

These results align with the observations made by Adesina (2018), who highlighted that while there is an improvement in reducing the dead loads of structures through the use of lightweight aggregates, the associated drawbacks include low density and compressive strength. But according to the gathered data, a 15% replacement level is ideal for achieving enhanced strength and weight reduction in non-structural applications where lightweight material is preferred. This affirms the suitability of polystyrene-based lightweight concrete for sustainable construction practices, especially in areas with high-density structures, where material quantification and handling are easier.

Table 5: Levene's Test of Equality of Error Variances

Strength of concrete (MPa) Based on	Levene Statistic	df1	df2	Sig.
Mean	1.156	15	32	0.352
Median	0.206	15	32	0.999
Median and with adjusted df	0.206	15	19.675	0.998
Trimmed mean	1.039	15	32	0.445

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CONCLUSION

This study aimed to identify the possibility of using polystyrene beads as a partial replacement for coarse aggregates in the manufacture of lightweight concrete. This research was prompted by ecological issues related to plastic use and the search for environmentally friendly construction materials, and aimed to assess the effects of replacing polystyrene beads in concrete on its characteristics.

This paper presents the results of systematic laboratory tests on compressive strength, density, and workability, which can greatly contribute to the assessment of the viability and possible utilisation of lightweight concrete mixes. It was also observed that the concrete density steadily decreased with increasing polystyrene bead content, making it ideal for lightweight structures. The compressive strength of concrete decreases as the degree of replacement increases, whereas the selected 15% replacement level shows a moderate loss in strength with reasonable weight savings.

The results of the slump test clearly revealed a decrease in concrete workability as the bead concentration increased, which likely called for the use of admixtures or an adjustment to the water-to-cement ratio to improve the mix's performance. These outcomes are consistent with the existing literature, which focuses on the advantages and disadvantages of lightweight concrete and provides readers with fresh insight into optimising replacement levels for intended uses. Therefore, this research adds to the existing literature on sustainable construction materials, with a focus on lightweight concrete.

This provides empirical evidence for the feasibility of employing recycled polystyrene beads as a partial replacement for aggregate. Additionally, the conclusions point to a 15% replacement level as an ideal for strength and weight reduction, providing clear directives for pursuing further research on hybrid mixes and performance-enhancing additives.

In the construction industry, this study offers practical guidelines for incorporating polystyrene aggregates into lightweight concrete. The results suggest that such mixes are best suited for nonstructural applications, such as partition walls, insulation panels, and low-load-bearing elements. The reduced density and enhanced thermal insulation properties make these mixes particularly attractive for energy-efficient and sustainable building design. This study contributes to the broader societal goals of environmental sustainability and waste management by repurposing plastic waste.

Using polystyrene beads in concrete reduces reliance on traditional aggregates, helps conserve natural resources, and mitigates the ecological impact of plastic pollution. These innovations align with the principles of a circular economy, promoting a more sustainable approach to construction practices. Although this study provides a robust foundation, certain limitations must be acknowledged. The study did not address the effects of incorporating advanced admixtures or hybrid aggregate solutions. Future research should focus on these areas to fully realise the potential of polystyrene-based lightweight concrete. Investigating the economic feasibility of large-scale implementation and exploring the environmental impact throughout the material's lifecycle would also strengthen the case

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