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ACOUSTIC AND MECHANICAL PERFORMANCE OF STYROFOAM-BASED LIGHTWEIGHT CONCRETE

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Abstract

Noise pollution and the growing issue of Styrofoam waste are major environmental concerns in urban areas. This study investigates the potential of utilizing Styrofoam as a partial aggregate in lightweight concrete to address both challenges. Styrofoam, a non-biodegradable material, contributes significantly to environmental pollution, while noise pollution impacts public health and productivity. Incorporating Styrofoam into concrete mixtures offers a dual benefit of reducing waste and enhancing acoustic insulation, especially for non-structural applications. The research evaluates the mechanical and acoustic performance of Styrofoam-based lightweight concrete, with a focus on mixtures with varying Styrofoam content. Results show that the incorporation of Styrofoam reduces the concrete density to a range of 1000–1300 kg/m³, with the lightest mix yielding a density of 1097.88 kg/m³. While the addition of Styrofoam significantly improves sound absorption—especially in mid-frequency ranges—there is a notable decline in mechanical properties, particularly flexural strength, which limits its application for structural purposes. The highest flexural strength observed was 44.12 kg/cm², significantly lower than that of conventional concrete. The findings indicate that Styrofoam-based lightweight concrete, particularly with a thickness of 15 cm and high Styrofoam content, is well-suited for non-structural applications such as partition walls due to its favorable acoustic performance and reduced weight. However, to enhance its mechanical properties, future research is recommended to explore reinforcement techniques. This study fills a critical gap by simultaneously addressing the environmental concerns of Styrofoam waste and the need for effective sound insulation in urban development.

Keywords: Lightweight Concrete, Styrofoam, Noise Reduction, Compressive Strength

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INTRODUCTION

Noise pollution and Styrofoam waste represent two significant environmental challenges in today's urban development. Noise pollution—driven by transportation, industrial activity, and urbanization—poses serious health risks and affects human productivity (Daigle, 2001; Finegold & Schomer, 2001). International and national institutions such as I-INCE have stressed the need for innovative noise reduction solutions (Boué, 2025; Chen et al., 2023). For instance, studies in Malaysia have documented excessive noise levels near hospitals, raising urban planning concerns (Mohd Nasir et al., 2024), while limited public participation further complicates sustainable development (Marzukhi et al., 2022). At the same time, the reuse of non-biodegradable materials such as Styrofoam in concrete and landscape elements has emerged as a cost-effective and sustainable approach (Ahmad et al., 2022).

Styrofoam (expanded polystyrene, EPS), due to its durable and non-biodegradable nature, contributes significantly to global environmental pollution by accumulating in landfills and ecosystems (D. Kumar et al., 2024; Siyal et al., 2012). Traditional disposal practices like incineration or landfilling are increasingly seen as environmentally harmful, prompting exploration of reuse alternatives (Himawanto, 2012; Nurherdiana et al., 2023; Yanto et al., 2019). Incorporating Styrofoam as a partial aggregate in lightweight concrete offers a dual benefit: reducing styrofoam waste and enhancing acoustic insulation, particularly for non-structural applications (Ngudi Hari Crista, 2024; Novizal et al., 2019). While such mixtures reduce concrete density to 1000–1300 kg/m³ and improve sound absorption (Cahyono et al., 2022; Ngudi et al., 2024), they also lower compressive strength significantly (Abiansyah & Rifdah, 2020; Nisumanti et al., 2024).

Although previous studies have explored ways to improve the mechanical properties of Styrofoam-based concrete—such as through fiber reinforcement (Aditama et al., 2024) and enhanced bonding techniques (Andryanto & Kushartomo, 2023)—few have comprehensively examined both mechanical and acoustic performance in a single study. Given the potential of Styrofoam to improve sound absorption while reducing density, this research addresses a critical gap by evaluating its suitability for lightweight concrete panels intended for non-structural and sound-insulating wall applications.

RESEARCH METHODOLOGY

This research adopted a quantitative laboratory-based experimental approach aimed at evaluating both the acoustic performance and mechanical strength of lightweight concrete incorporating post-consumer Styrofoam waste as a partial replacement for fine aggregates. The study was conducted in two main phases: acoustic performance testing and mechanical strength testing, each supported by thorough material characterization and strict quality control. The primary

materials used included Type I Portland Cement, natural river sand as fine aggregate sieved through a 2.36 mm mesh to complying with SNI 03-6821-2002, cleaned and dried Styrofoam waste, and clean water. Prior to mixing, the Styrofoam waste was meticulously cleaned of any dirt, oil, or organic matter, and sieved through a 4.75 mm mesh to meet the fine aggregate gradation standard as per SNI 03-2834-2000.

The water–cement ratio (w/c) of 0.645 was selected based on preliminary workability trials intended to balance fluidity and cohesion in lightweight concrete mixtures containing styrofoam. Previous investigations on styrofoam-modified concretes have employed w/c ratios ranging from 0.6 to 1.0 to address workability challenges induced by this hydrophobic aggregate, with specific trials at 0.6, 0.8, and 1.0 demonstrating significant influences on slump and mix homogeneity (Herki, 2017). These studies underscore the necessity of fine-tuning the w/c ratio to achieve optimal consistency, thereby justifying the intermediate value of 0.645 adopted in the present work (Herki, 2017).

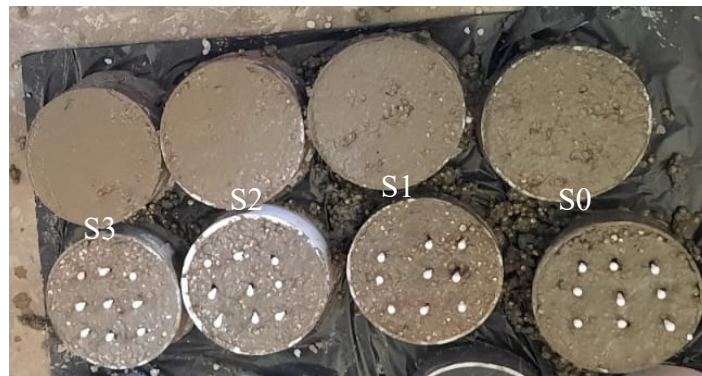


Figure 5: Mixture Variations

Four mix variations (Figure 5) were developed with the following proportions: 1PC:2Sand:3Styrofoam (S1), 1PC:1.5Sand:2.5Styrofoam (S2), and 1PC:1.25Sand:2.75Styrofoam (S3), a control mix (S0) containing no Styrofoam was also prepared for comparison. The mix composition of lightweight concrete specimens is shown in Table 4.

Table 4: Test Specimens

Sample Code	Mix Ratio (PC:Sand:Sty)	Portland Cement (kg/m ³)	Sand (kg/m ³)	Styrofoam (kg/m ³)	Water (kg/m ³)
S0	1:2:0	450	900	0	290.25
S1	1:2:3	300	600	90	193.5
S2	1:1.5:2.5	300	450	75	193.5
S3	1:1.25:2.75	300	375	82.5	193.5

Sieve analysis was conducted for both coarse and retained fine aggregates to evaluate particle size distribution. All test results, including acoustic and mechanical performance, were analyzed using statistical methods such as mean, standard deviation, and graphical trend analysis to observe variations in compressive strength and sound absorption performance. Correlation analysis was also conducted to explore the relationship between Styrofoam composition and the acoustic-mechanical performance of the concrete.

Sample Preparation for Mechanical Strength Test

Mechanical strength testing consisted of two tests: compressive strength test and flexural strength test. First, the fresh concrete was mixed using a pan mixer and cast into two types of molds: 30 × 15 cm cylindrical molds for compressive strength test and 50 × 15 × 5 cm rectangular molds for flexural strength test. Each mold was filled in three layers, with each layer compacted 25 times using a tamping rod. After 24 hours, the specimens were demolded and cured in water for 7, 14, and 28 days. Table 5 presents the mix composition of lightweight concrete used for specimens in the mechanical strength tests.

Table 5: Mechanical Strength Test Specimens

Sample Code	Mix Ratio (PC:Sand:Sty)	Portland Cement (g)	Sand (g)	Styrofoam (g)	Water (g)	Type
C-S0	1:2:0	2385.6	4771.3	0.0	1538.7	Compressive
F-S0	1:2:0	1687.5	3375.0	0.0	1088.4	Flexural
C-S1	1:2:3	1590.4	3180.9	477.1	1025.8	Compressive
F-S1	1:2:3	1125.0	2250.0	337.5	725.6	Flexural
C-S2	1:1.5:2.5	1590.4	2385.6	397.6	1025.8	Compressive
F-S2	1:1.5:2.5	1125.0	1687.5	281.3	725.6	Flexural
C-S3	1:1.25:2.75	1590.4	1988.0	437.4	1025.8	Compressive
F-S3	1:1.25:2.75	1125.0	1406.3	309.4	725.6	Flexural

Compressive strength tests were conducted using a universal testing machine in accordance with ASTM C109 (2008), while flexural strength tests followed the BS EN 1015-11 (2019) standard.

Sample Preparation for Acoustic Test

For the acoustic tests, each mix was cast into cylindrical specimens with a 10 cm diameter and two thicknesses, namely 10 cm and 15 cm. Each variation was duplicated, resulting in a total of 32 samples. Specimens were cured for 28 days under controlled conditions (temperature of 25 ± 2°C and humidity of 90%). The mix composition of lightweight concrete for the cylindrical specimens used in the acoustic test is shown in Table 6.

Table 6: Acoustic Test Specimens

Sample Code	Mix Ratio (PC:Sand:Sty)	Portland Cement (g)	Sand (g)	Styrofoam (g)	Water (g)	Thickness (cm)
A-10-S0	1:2:0	353.4	706.9	0.0	228.0	10
A-15-S0	1:2:0	530.1	1060.3	0.0	341.9	15
A-10-S1	1:2:3	235.6	471.2	70.7	152.0	10
A-15-S1	1:2:3	353.4	706.9	106.0	228.0	15
A-10-S2	1:1.5:2.5	235.6	353.4	58.9	152.0	10
A-15-S2	1:1.5:2.5	353.4	530.1	88.4	228.0	15
A-10-S3	1:1.25:2.75	235.6	294.5	64.8	152.0	10
A-15-S3	1:1.25:2.75	353.4	441.8	97.2	228.0	15

The sound absorption coefficient tests were performed at the Acoustics Laboratory using the Impedance Tube Method, in accordance with ASTM E-1050-98 (Abdillah et al., 2019). The evaluation of sound absorption characteristics under normal incidence commonly employs the ASTM E1050-98 standard using a Brüel & Kjær impedance tube (4206 series, 30 mm diameter) with a dual-microphone setup to analyze incident and reflected sound waves from a broadband source, enabling accurate measurement of absorption coefficients across frequencies (Jena et al., 2019). Measurements were taken at eight different frequencies: 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, 9000 Hz, and 10000 Hz. Each specimen was tested three times, and the absorption coefficient was calculated as the average of the three values. The absorption coefficient represents the proportion of incident sound energy absorbed by a material, ranging from 0 (no absorption) to 1 (perfect absorption).

ANALYSIS AND DISCUSSION

Concrete Compressive Strength Test

For compressive strength test, a total of 12 specimens were produced, divided into 3 age groups with 4 specimens per age. The fresh and dry unit weights of the lightweight concrete were also measured after 28 days. The targeted compressive strength ranged from K-50 to K-175 kg/cm², determined using a modified mix design method based on the American Concrete Institute (ACI). Detailed material proportions used for the 12 cylindrical test samples are outlined in Table 7.

Table 7: Average Compressive Strength for each Age Styrofoam Concrete Samples

Sample Code	Mix Ratio	Age 7 Day kg/cm ²	Age 14 Day kg/cm ²	Age 28 Day kg/cm ²
C-S0	1PC:2Sand:0Sty	75.81	119.37	149.36
C-S1	1PC:2Sand:3Sty	63.24	82.03	98.99
C-S2	1PC:1.5Sand:2.5Sty	51.48	62.22	78.65
C-S3	1PC:1.25Sand:2.75Sty	37.33	49.79	66.77

The compressive strength development of lightweight concrete incorporating styrofoam shows a steady upward trend over time, influenced by the mix proportions used. A mix ratio of 1PC:2Sand:3Sty demonstrated the highest strength among styrofoam-based mixes, reaching 98.99 kg/cm² at 28 days, with a cube-equivalent of 119.26 kg/cm² and an adjusted characteristic strength of 107.13 kg/cm². A second mix with 1PC:1.5Sand:2.5Sty achieved slightly lower results, culminating at 78.68 kg/cm² (cube-equivalent: 94.73 kg/cm²; characteristic strength: 84.73 kg/cm²). The third formulation, with the highest styrofoam content (1PC:1.25Sand:2.75Sty), produced the lowest values—66.75 kg/cm² at 28 days, corresponding to a cube strength of 80.41 kg/cm² and a characteristic strength of 71.93 kg/cm². These outcomes support previous findings that increased styrofoam content reduces compressive strength due to higher void ratios and weaker interfacial bonding (Rathika et al., 2023; Srividya et al., 2022).

In contrast, conventional concrete without Styrofoam exhibited significantly higher compressive strength, reaching 149.33 kg/cm² at 28 days, equivalent to a cube strength of 179.91 kg/cm² and a characteristic strength of 164.92 kg/cm² after statistical adjustments. While styrofoam-modified concrete demonstrates sufficient strength progression for non-structural applications, it remains mechanically inferior to standard concrete. This underscores the need for further optimization—such as the use of reinforcing fibers or additives—to enhance its structural viability. The comparative results of all tested mixes are illustrated in Figure 6, highlighting the trade-offs between weight reduction and strength performance.

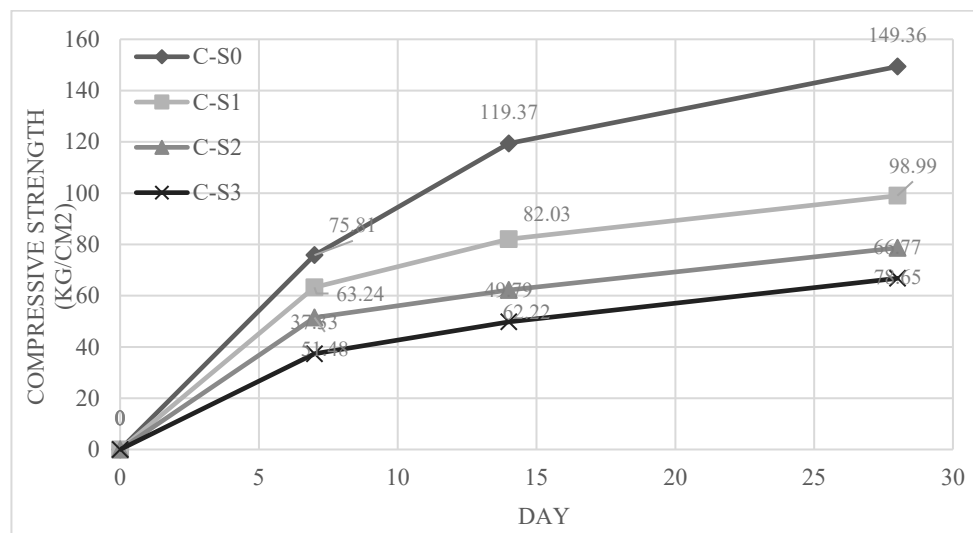


Figure 6: Compressive Strength of 28-Day Concrete Samples

Concrete Density

An in-depth analysis of concrete mix variations incorporating Styrofoam as a lightweight aggregate substitute revealed that all tested specimens achieved fresh concrete densities well below the 1900 kg/m³ threshold. This qualifies them as lightweight concrete, in accordance with commonly accepted classifications such as those outlined in ACI 213R-14. Across all mixture types, the fresh concrete densities consistently fell within the range of approximately 1000 to 1300 kg/m³, confirming the effectiveness of Styrofoam in significantly reducing the overall weight of the concrete matrix (P. Kumar et al., 2023).

Among the evaluated combinations, the mix ratio 1PC:1.25Sand:2.75Sty produced the lightest material, with cylindrical specimens recording a fresh density of 1097.88 kg/m³. This significant reduction is directly attributed to the high proportion of Styrofoam—a material with exceptionally low specific gravity and a cellular structure that introduces numerous internal air voids into the concrete mixture (Mahmoud et al., 2023).

Other mixtures demonstrated similar trends. The 1PC:2Sand:3Sty mix yielded a fresh density of 1279.89 kg/m³, while the 1PC:1.5Sand:2.5Sty mix reached 1242.56 kg/m³. These values clearly indicate a consistent inverse relationship between Styrofoam content and fresh concrete density. As more Styrofoam is added, the volume fraction of lightweight polymer replaces a portion of the heavier sand aggregate, thereby reducing the total weight of the concrete (Rathika et al., 2023; Srividya et al., 2022).

Although the inclusion of greater amounts of Styrofoam contributes to density reduction, this must be carefully optimized. Higher Styrofoam content may compromise the mechanical integrity of hardened concrete, particularly its compressive and flexural strength. As illustrated in Figure 7, the downward trend in unit weight is evident with increasing Styrofoam content.

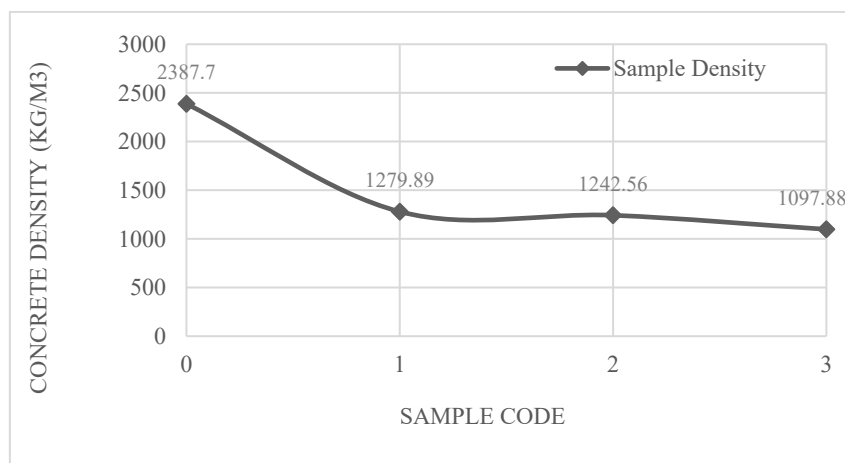


Figure 7: Density of 28-Day Concrete Samples

Concrete Flexural Strength Test

A total of 20 specimens were prepared for the flexural strength test, comprising 5 specimens for each mix ratio. The results presented in Figure 8 demonstrate the flexural strength development of various concrete mix variations after 28 days of curing. A subtle trend can be observed, in which slight increases in Styrofoam content correspond to marginal improvements in flexural strength; however, the overall values remain considerably low. This pattern suggests that while Styrofoam may moderately influence certain mechanical properties of lightweight concrete, its effect on flexural performance is minimal and, in many cases, detrimental. The integration of Styrofoam beads into the concrete mix leads to the formation of numerous air voids within the matrix, significantly lowering the material's density—a favorable characteristic for reducing dead loads in structural design (Mahmoud et al., 2023; Rathika et al., 2023).

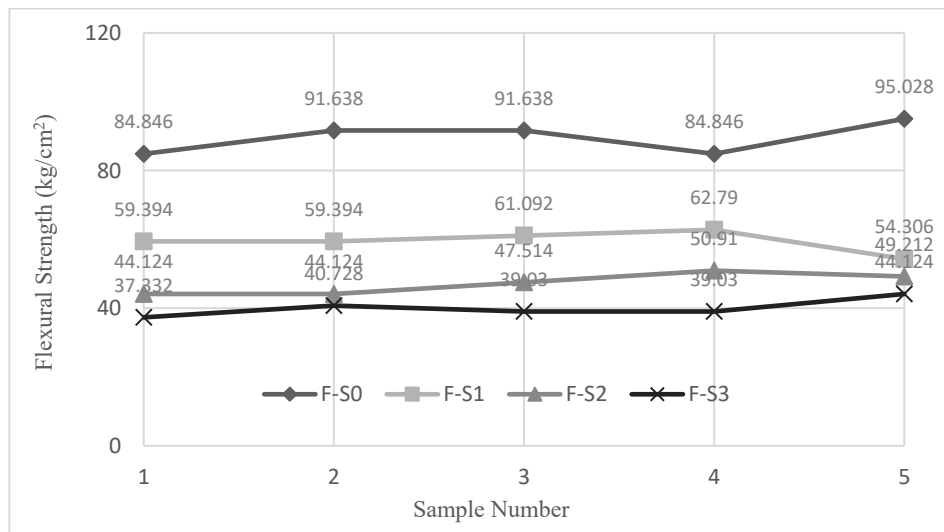


Figure 8: Tensile Strength of 28-Day Concrete Samples

However, this reduction in density comes at the cost of compromised structural integrity, particularly in terms of flexural resistance. The soft, non-rigid nature of Styrofoam, combined with the presence of internal voids, weakens the bond between the cement paste and aggregate particles, diminishing the concrete's ability to resist bending stresses (P. Kumar et al., 2023; Solikin et al., 2019). Empirical studies have shown that high Styrofoam content—especially in mixtures where it replaces 50% or more of the volume—results in markedly reduced flexural strength, thus limiting their application mainly to non-structural or insulation purposes (Srividya et al., 2022). In this study, conventional concrete exhibited superior flexural strength values ranging from 84.84 kg/cm² to 95.03

kg/cm² at 28 days. In contrast, the mix with the highest Styrofoam content (sample F-S3 with a ratio of 1PC:1.25Sand:2.75Styrofoam) showed a significant drop in flexural strength, recorded in the range of 37.33 kg/cm² to 44.12 kg/cm². This stark contrast underscores the critical trade-off between density reduction and mechanical performance, highlighting the importance of careful optimization of Styrofoam dosage in structural concrete. Although the use of Styrofoam is advantageous for achieving lightweight properties, the negative implications on flexural strength must be addressed—potentially through refined mix design and supplementary reinforcement strategies.

Acoustic Performance Test Results 10 cm Thickness

Acoustic testing of lightweight concrete specimens incorporating varying proportions of Styrofoam was conducted in a controlled laboratory environment to evaluate their sound absorption and sound insulation capabilities. The tests focused on determining both the Sound Absorption Coefficient (SAC) and the Sound Transmission Loss (STL) of concrete panels, each measuring 10 cm in thickness. Three distinct concrete mixtures, identified as A-10-S1, A-10-S2, and A-10-S3, were formulated with increasing Styrofoam content, while a reference sample, A-10-S0, was prepared using conventional aggregate (split) with no Styrofoam. As shown in Table 8, these composition variations were designed to investigate the effect of lightweight porous fillers on acoustic performance under standardized conditions (Fediuk et al., 2021).

Table 8: Sound Absorption Coefficient of 28-Day Concrete Samples (10 cm Thickness)

Sample Code	Sample Ratio	Frequency (hz)							
		250	500	1000	2000	4000	8000	9000	10000
A-10-S0	1PC:2Sand:0Sty	0.01	0.11	0.05	0.12	0.07	0.13	0.10	0.11
A-10-S1	1PC:2Sand:3Sty	0.06	0.53	0.21	0.31	0.21	0.24	0.22	0.26
A-10-S2	1PC:1.5Sand:2.5Sty	0.05	0.16	0.28	0.16	0.25	0.15	0.20	0.24
A-10-S3	1PC:1.25Sand:2.75Sty	0.08	0.65	0.25	0.36	0.23	0.18	0.23	0.28

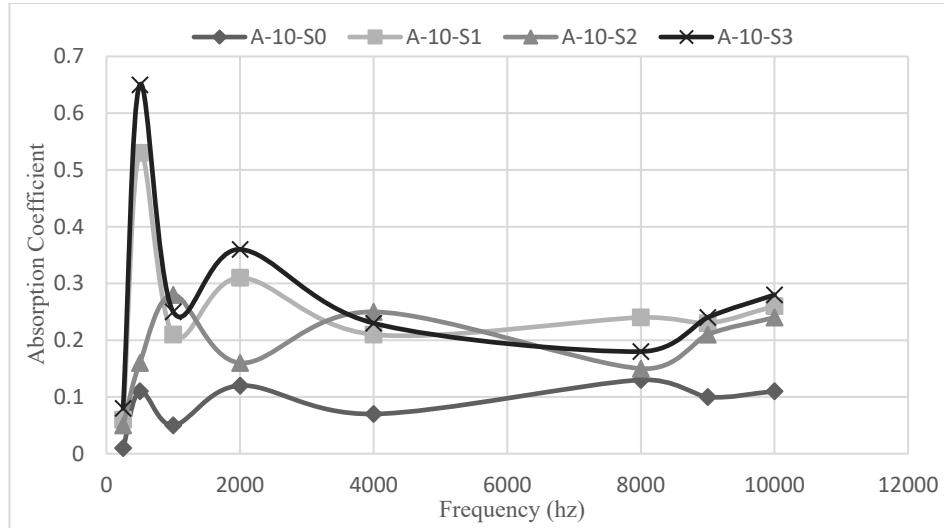


Figure 9: Sound Absorption Performance of 28-Day Concrete Samples (10 cm Thickness)

The results, presented in Figure 9, revealed a strong correlation between increased Styrofoam content and improved sound absorption performance. Among the tested samples, A-10-S3, containing the highest Styrofoam content (1PC:1.25Sand:2.75Sty), exhibited the highest absorption coefficient, peaking at 0.65 at a frequency of 500 Hz—indicating a significant acoustic response within the mid-frequency range. In contrast, the control sample A-10-S0, composed of 1PC:2Sand:3Sty, displayed minimal acoustic effectiveness due to the absence of porous or damping components like Styrofoam. Meanwhile, samples A-10-S1 and A-10-S2, with intermediate Styrofoam volumes, demonstrated moderate absorption peaks at 0.16 and 0.53 respectively at the same frequency. These results confirm that the inclusion of Styrofoam enhances sound absorption in lightweight concrete, particularly within low to mid-frequency ranges, due to the increased internal porosity and air void content introduced by the expanded polystyrene material (Fediuk et al., 2021).

Acoustic Performance Test Results 15 cm Thickness

As reflected in Table 9, the acoustic performance of 15 cm thick lightweight concrete samples reveals that increasing material thickness does not consistently result in higher sound absorption coefficients, particularly at higher frequency ranges. Although it is commonly assumed that thicker materials provide superior acoustic insulation, the results suggest otherwise—indicating that thickness alone is not the dominant factor. For instance, mixtures with higher porosity due to Styrofoam inclusion may outperform thicker but denser samples with fewer air

voids. This implies that internal composition and material structure play a more critical role than sheer thickness in enhancing acoustic properties. The observation aligns with prior studies that emphasized the importance of pore structure and distribution in facilitating energy dissipation from incident sound waves (Cai et al., 2018).

Table 9: Sound Absorption Coefficient of 28-Day Concrete Samples (15 cm Thickness)

Sample Code	Sample Ratio	Frequency (hz)							
		250	500	1000	2000	4000	8000	9000	10000
A-15-S0	1PC:2Sand:0Sty	0.01	0.1	0.01	0.12	0.05	0.16	0.1	0.11
A-15-S1	1PC:2Sand:3Sty	0.063	0.67	0.21	0.42	0.21	0.31	0.23	0.3
A-15-S2	1PC:1.5Sand:2.5Sty	0.07	0.32	0.28	0.33	0.25	0.27	0.21	0.28
A-15-S3	1PC:1.25Sand:2.75Sty	0.085	0.73	0.25	0.46	0.23	0.35	0.24	0.31

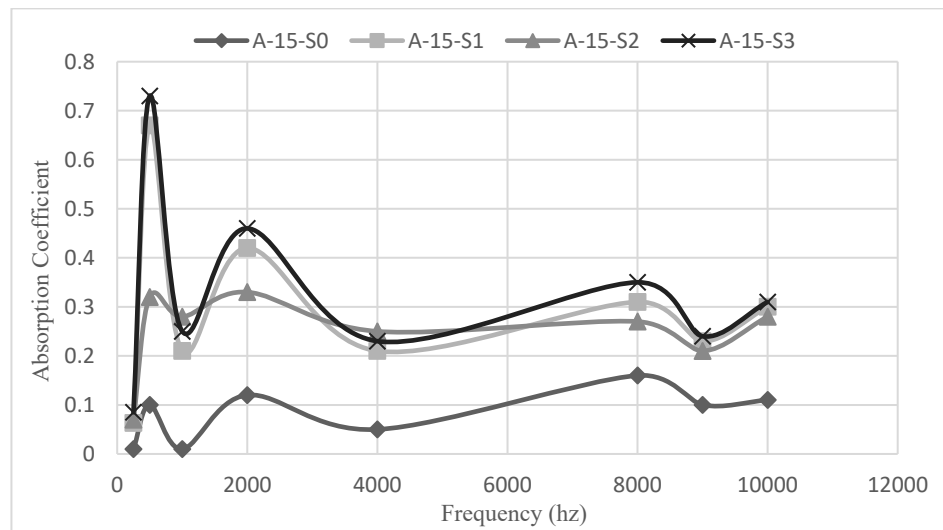


Figure 10: Sound Absorption Performance of 28-Day Concrete Samples (15 cm Thickness)

As shown in Figure 10, among the 15 cm thick samples, the mixture variation of 1PC:1.25Sand:2.75Sty (sample A-15-S3) yielded the highest sound absorption coefficient, peaking at 0.73 around 500 Hz—an important low-frequency range relevant to typical indoor environments. This improvement is attributed to the enhanced pore content from the increased styrofoam ratio, which elevates the material's ability to dampen sound through greater internal friction and scattering. Additionally, the absorption performance remained consistently strong across a broad frequency spectrum of 500 Hz to 2000 Hz, with values ranging from 0.46 to 0.73, making this mix suitable for use in residential or office interior walls. Sample A-15-S1 also showed commendable absorption (0.42–0.67), while A-15-S2 displayed moderate effectiveness (0.32–0.33) in the same

frequency range. These results reinforce the understanding that while thickness may contribute to increased acoustic mass, it is the synergy between porosity and material composition that ultimately governs sound absorption performance, particularly in low-frequency domains (Cai et al., 2018).

CONCLUSIONS

This study has demonstrated that incorporating Styrofoam into lightweight concrete mixtures significantly reduces the material's density, classifying it as lightweight concrete with fresh concrete weights ranging from 1000 to 1300 kg/m³. The densest mix was observed in the composition of 1PC:2Sand:3Sty, yielding a fresh concrete density of 1279.89 kg/m³, while the lightest mix, 1PC:1.25Sand:2.75Sty, exhibited a density of 1097.88 kg/m³ (Mahmoud et al., 2023; Rathika et al., 2023). This reduction in weight is directly attributed to the high Styrofoam content, which introduces numerous internal air voids.

The compressive strength results revealed that the mix ratio of 1PC:2Sand:3Sty achieved the highest strength (98.99 kg/cm² at 28 days), but all Styrofoam-modified mixes showed lower compressive strength compared to conventional concrete, which reached 149.33 kg/cm² (Rathika et al., 2023; Srividya et al., 2022). The mix with the highest Styrofoam content (1PC:1.25Sand:2.75Sty) displayed the lowest compressive strength at 66.75 kg/cm². These results underscore that while Styrofoam-modified concrete demonstrates promising lightweight characteristics, its compressive strength remains inferior to normal concrete, limiting its potential for structural applications.

In terms of flexural strength, the highest Styrofoam content mix (1PC:1.25Sand:2.75Sty) showed the lowest flexural strength, ranging from 37.33 to 44.12 kg/cm², which is significantly lower than conventional concrete's range of 84.84–95.03 kg/cm² at 28 days (P. Kumar et al., 2023; Solikin et al., 2019). This reduction in flexural strength is attributed to the presence of Styrofoam's internal voids, which weaken the bond between the cement paste and aggregate particles, diminishing the material's ability to resist bending stresses. Therefore, while Styrofoam-modified concrete is advantageous for reducing dead load, its mechanical performance, especially in flexural strength, limits its application to non-structural uses.

Acoustic performance tests revealed that the integration of Styrofoam into the concrete mix significantly enhanced sound absorption. For 10 cm thick samples, the sound absorption coefficient peaked between 0.53 and 0.65 at 500 Hz, while for 15 cm thick samples, the absorption coefficient reached up to 0.73, particularly in the 500-2000 Hz range (Fediuk et al., 2021). These improvements are attributed to the increased internal porosity and air voids introduced by Styrofoam, which facilitate better sound dampening. The highest absorption values were observed in the 1PC:1.25Sand:2.75Sty mix, demonstrating the

effectiveness of higher Styrofoam content in enhancing the material's acoustic properties.

In conclusion, lightweight concrete with high Styrofoam content and a thickness of 15 cm is suitable for non-structural applications such as partition walls in residential and office buildings, due to its reduced weight, improved sound absorption, and ease of handling. However, to address its mechanical limitations, especially in terms of flexural strength, future research should explore the integration of reinforcing elements like steel fibers or alternative natural/synthetic fibers. These developments could enhance the material's strength without compromising its acoustic performance, potentially expanding the application of Styrofoam-based lightweight concrete beyond non-structural elements.

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