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The Effectiveness of Styrofoam Mixtures in Lightweight Concrete Walls

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Abstract: - This research explores the potential use of styrofoam concrete as a sustainable construction material with excellent acoustic properties. Considering variations in the thickness of styrofoam concrete, the study employs the NoiSee application on smartphones as an affordable and flexible noise measurement tool. The results investigate the potential of using styrofoam to reduce noise. The findings indicate that styrofoam, especially at a thickness of 4 cm, exhibits high effectiveness with a noise reduction of up to 60%. Additionally, the addition of styrofoam waste to brick mixtures can enhance the sound absorption coefficient at 800 Hz frequency. Styrofoam is effective in sound absorption below 1000 Hz, with thickness ranging from 1 cm to 3.5 cm improving sound absorption performance at various frequencies, while a thickness of 4 cm proves effective at 1000 Hz frequency. Overall, the combined results affirm the potential of styrofoam as a customizable soundproofing material for various acoustic applications.

Keywords: Concrete, Styrofoam, Soundproof

1. INTRODUCTION

Plastic waste has become a big environmental problem. The impact of plastic waste on marine organisms, humans and the environment is widely a matter of public concern, and requires saving the ecosystem and life within it. Despite the fact that plastic is very useful in everyday life, the toxic chemicals in its production need to be thoroughly monitored to ensure environmental and health safety. Reducing public exposure to toxins from plastic waste will increase the chances of creating a clean environment and healthy society.[1] This material is said to be eternal waste which is very difficult for the soil to decompose. Polystyrene contains dangerous materials produced by Styrofoam and has a solid cell plastic texture made from molding small circles or pearls and contains 96-98% of trapped air from pearls [2] Lightweight concrete can be made from a mixture of concrete and EPS granules, the compressive strength obtained from Styrofoam concrete blocks is very low and can be used as a substitute for bricks as a non-structural element. Environmental pollution can be reduced by applying recycled Styrofoam, so emissions from burning bricks can be reduced . Blocks consisting of cement, styrofoam and sand have lower water absorption and better strength than a mixture of total sand replacement with EPS. Total replacement of aggregate with Styrofoam can reduce strength to some extent but replacement of 30% of fine aggregate with EPS increases strength. Production costs are also relatively cheaper than bricks.[3] EPS granules can be incorporated into the concrete mix to make lightweight concrete. Styrofoam concrete blocks have low compressive strength and can only be used as an alternative to bricks for non-structural elements. Can reduce about 50% dead load of partition walls. The application of recycled styrofoam to concrete blocks can indirectly reduce environmental pollution and brick burning emissions. Blocks consisting of cement, styrofoam and sand have lower water absorption and better strength than a mixture of total sand replacement with EPS. Total replacement of aggregate with Styrofoam reduces strength to some extent but replacement of 30% of fine aggregate with EPS increases strength. Production costs are also relatively cheaper than bricks.[3]

Low-weight Styrofoam panels exhibit greater strength and durability compared to their high-weight counterparts. Poplar panels made with high-density Styrofoam achieved the lowest heat transfer among all the tested panels..[4] Mixing Styrofoam beads into concrete molds offers two benefits: it boosts the molds' thermal insulation and lightens their overall weight. Researchers studied how adding Styrofoam balls to concrete molds affects both heat transfer and compressive strength. They also explored using different amounts of these particles in the concrete mix and methods to achieve a uniform distribution of the lightweight foam concrete. The study found that while

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a certain amount of lightweight foam concrete can significantly improve thermal insulation (around 30% increase at this concentration), it can also lead to a decrease in compressive strength (around 12% loss at this concentration). However, this trade-off allows for the creation of concrete molds with a reduced weight, making them easier to handle. In conclusion, using composite lightweight foam concrete offers advantages in insulation and weight reduction for cast objects, but it comes at the cost of some structural strength.[5] The focus here is figuring out the right amounts of each ingredient in a concrete mix. This involves using polystyrene beads, like tiny balls, instead of the usual larger rocks (coarse particles) in the mix. By doing this, the final concrete will be much lighter. [6] While lightweight aggregates (LWA) offer advantages in construction, their effectiveness relies on proper preparation. This includes pre-wetting the LWA to enhance bonding and minimizing water absorption by sealing pores with polymers. Research confirms that LWA can successfully replace coarse aggregate in self-consolidating concrete (SCC) without sacrificing its performance. Interestingly, further studies suggest LWA can also be used as a substitute for fine aggregate in SCC, even with or without adding cement-based additives. [7]

The experiment investigated the effect of Styrofoam content on the flexural strength of concrete.

Concrete specimens were prepared with Styrofoam volume fractions of 0% (control), 10%, and 30%.The average flexural strength at 28 days was 7.00 MPa, 6.59 MPa, and 6.07 MPa, respectively.

Compared to the control concrete, adding 10% and 30% Styrofoam resulted in a decrease in flexural strength of 5.85% and 13.28%, respectively.These results indicate that as the volume of Styrofoam in concrete increases, the flexural strength decreases.[8]

Tests were conducted to assess the suitability of concrete with varying Styrofoam substitution levels for lightweight structures by measuring their compressive strength. The reference standard specifies a compressive strength range of 7 - 17 MPa for lightweight concrete in such applications.

Concrete with 60% Styrofoam substitution performed well, exceeding the minimum requirement with a compressive strength of 10.54 MPa.Similarly, concrete with 80% Styrofoam substitution met the minimum requirement, achieving a compressive strength of 7.57 MPa. However, 100% Styrofoam substitution resulted in a lower compressive strength of 5.27 MPa, making it more suitable for non-structural elements like partition walls and canopies. [9] Experiments were conducted on a composite material made with a mixture of sand and polystyrene flakes (fine aggregate) combined with cement at a ratio of 1:4 and 1:6. Varying amounts of polystyrene waste, 0%, 20%, 40%, 60%, and 80%, were incorporated into the mixture. An Impedance Tube test (ISO 140-3) was used to measure the sound absorption coefficient of the resulting composites. The tests revealed that the highest sound absorption coefficient was achieved at a frequency of 800 Hz. In the 1:4 cement mixture with 80% styrofoam, the sound absorption coefficient was 0.4100 dB. Similarly, for the 1:6 cement mixture with 40% styrofoam, the highest sound absorption coefficient of 0.5870 dB was attained at 800 Hz..[10]

In this study, researchers used a Sound Level Meter to measure sound intensity before and after it passed through gypsum, plywood, and styrofoam. Their results showed that gypsum absorbed the most sound (highest absorption coefficient) at frequencies between 600 and 1000 Hz, followed by plywood and then styrofoam. Therefore, gypsum provided the best dampening among these three materials in this frequency range.. [11]

Sound-absorbing materials are a popular noise reduction technique, and their effectiveness is gaining growing attention from researchers. [12]. Research on sound-absorbing materials has boomed, with a particular focus on developing sustainable options. [13] with a particular focus on developing sustainable options. Additionally, researchers are pinpointing key material properties that can be incorporated into numerical simulations to predict sound absorption. [14].

Styrofoam concrete is an innovative material applied in construction known for its lightweight and durable characteristics. Despite being environmentally friendly, styrofoam poses a challenge in waste management due to its non-biodegradable nature. The review of literature suggests that styrofoam concrete demonstrates satisfactory mechanical strength and durability, making it suitable for use in civil engineering projects [15]. Waste materials, such as styrofoam, have the potential to enhance concrete's sound absorption ability, supporting environmental sustainability in the construction sector [16]. Styrofoam possesses sound insulating properties, high thermal conductivity, and lightweight features, making it suitable for concrete applications [17]. Given this background, styrofoam is a promising material for further exploration, particularly regarding its sound-absorbing capabilities in buildings.

Research on partition walls has been carried out from several different study points of view, research related to the implementation of the use of Styrofoam as a sound dampening material with a hearing frequency range[18] has been carried out previously. Regarding polystyrene panel walls as sound dampeners, there has been previous research, namely the effect of polystyrene panels as sound dampeners on rolling mill setup unit saws and saveh profiles[19]. Regarding lightweight concrete materials, there has been research on lightweight concrete using Styrofoam as a substitute for coarse aggregate [20]

The research that the researcher will carry out is an update and development of previous research, namely that the researcher will carry out research starting from analyzing the calculation of lightweight concrete mixtures made from Styrofoam granules, testing the weight and compressive strength of lightweight concrete as well as testing the sound absorption capacity by mixing the concrete material with Styrofoam.

2. Literature Review

A. Lightweight Concrete

Concrete comprises a solid mass created through the combination of cement, aggregate, and water [21], [22], [23]. When cement and water interact, they create a cement paste that acts as a binder for aggregates. On the other hand, the function of aggregates is to serve as a filling material and strengthen the concrete. Over time, the concrete will achieve the planned strength and harden.

Lightweight concrete has a lower density than normal concrete due to the inclusion of lightweight aggregate with significant voids, defined as concrete containing lightweight aggregate and having a density of no more than 1900 kg/m^3 [24].

Table 1 Types of Concrete Based on Density and Applications [25]

Types of Concrete	Density of Concrete (kg/m^3)	application
Very lightweight concrete	< 1000	Non-structural
Lightweight concrete	1000 – 2000	Light structural
Normal concrete	2300 – 2500	Light structural
Heavy concrete	> 3000	X-ray shielding

B. Aggregate

Aggregate serves as a filler in concrete mixtures and typically constitutes 70% of the concrete volume, sourced from natural mineral materials [26]. The significance of aggregate in shaping concrete characteristics is substantial, and the careful choice of aggregate types is a crucial element in the concrete manufacturing process. Aggregates can be categorized into stones (for particles larger than 40 mm), gravel (for particles sized 5–40 mm), and sand (for particles sized 0.15–5 mm). In terms of dimensions, aggregates are differentiated into fine aggregates and coarse aggregates.

Fine aggregate fills the spaces between coarse aggregate particles, enhancing concrete bond strength [27]. It is essential to note that fine aggregates should not contain mud or organic matter. Meanwhile, coarse aggregates include gravel and crushed stone, where gravel can be divided into three types: river gravel, excavation gravel, and beach gravel. Excavation gravel tends to contain mud, sand, and organic materials, while river gravel and sand are usually free of contaminants, have a smooth surface, and are rounded. On the other hand, aggregates produced by breaking natural rocks using a stone crusher machine or manually with a hammer are called crushed stone [28].

C. Composite Portland Cement

Cement, when mixed with water, has the ability to bind aggregate materials [29]. Cement is classified into five types of Portland cement, distinguishing them based on specific characteristics [30]:

a. Portland cement categorized as Type I can be employed without specific prerequisites.

b. Type II denotes Portland cement possessing moderate resistance to heat hydration.

c. Portland cement falling under Type III is characterized by its high initial strength.

d. Type IV designates Portland cement with low heat hydration properties.

e. Type V represents Portland cement known for its high resistance to sulfate.

D. Water

Water plays a crucial role in the concrete production process [31]. Its presence allows the interaction between cement and water, forming a paste that acts as a binder for aggregate materials [6]. However, excessive addition of water can have negative consequences on the quality of concrete. For instance, incorporating an excessive amount of water can render the concrete mixture more manageable for handling [32], [33]. Therefore, managing the appropriate amount of water in the concrete mixture becomes a crucial aspect to achieve an optimal balance between the hardness and workability of the concrete.

E. Styrofoam

Styrofoam, or expanded polystyrene, is commonly chosen as packaging material for electronic goods. Possessing a density of 1.050 kg/m3, a flexural modulus of approximately 3 GN/m2, a shear modulus of around 0.99 GN/m2, and an achieved tensile strength of 40 MN/m2 [34], granular styrofoam has low unit weight, ranging from 13 to 16 kg/m^3 [35]. In the context of concrete mixtures, the use of Styrofoam is considered as an air entrainment, offering advantages compared to hollow concrete by enhancing tensile strength.

Controlling the density or unit weight of concrete can be achieved through the planning of concrete mix proportions. The addition of Styrofoam not only results in lighter concrete but also functions as fibers that can enhance the ductility of the concrete [36]. Therefore, Styrofoam contributes not only to reducing the weight of concrete but also to overall improvements in mechanical properties.

Figure 1 Styrofoam [37]

F. Smartphone-based Sound Level Measurement

Smartphones have evolved into devices with computational capabilities rivaling computers. Every smartphone has the potential to be converted into a noise measurement device, thanks to its integrated microphone. The widespread prevalence of smartphones enables the creation of noise measurement applications, readily accessible through established software stores. Although there are numerous noise measurement applications accessible on various mobile platforms, only a limited number demonstrate sufficient accuracy for evaluating noise levels, particularly as a viable alternative to professional sound level measurement tools. The NoiSee app adheres to the sound level meter standards set by ANSI (American National Standards Institute) and IEC (International Electrotechnical Commission). Findings indicate that both the noise measurement application and the external microphone fulfill the majority of criteria for Class 2 as outlined in the IEC 61672/ANSI S1.4-2014 standard [38].

Figure 2 NoiSee Application in iOS

3. RESEARCH METHODS

Noise measurements were conducted using the NoiSee smartphone application. This device and application function as an affordable yet powerful sensor network representation, widely used and flexible enough to be portable compared to static placement [39]. The research method adopts variations in the thickness of styrofoam concrete material, similar to the approach taken by Taban, with samples of 25, 35, and 45 mm [40]. In the meantime, Thamrin's research utilized four cylindrical samples, each with varying thicknesses: 1.15 cm, 1.95 cm, 2.95 cm, and 4.05 cm [41].

The research steps include preparing tools and materials, constructing styrofoam concrete walls with thicknesses ranging from 1 cm to 4 cm, arranging tools according to the research scheme, setting the sound generator frequency to 200 Hz inside the box, turning on the sound level meter inside the box, recording the recorded sound intensity on the sound level meter, inserting styrofoam concrete walls with a thickness of 1 cm as a sound insulator, recording sound intensity, repeating the process with variations in sound insulator thickness (1.5 cm to 4 cm), and repeating the process by changing the sound generator frequency to 400 Hz, 600 Hz, 800 Hz, and 1000 Hz. The NoiSee application for Android and iOS is used as a noise measurement tool providing reliable sound level measurements and supporting dBA, dBC. Measurements and graphs are displayed in real-time, including the main frequency, making it suitable for use in almost all conditions [42].

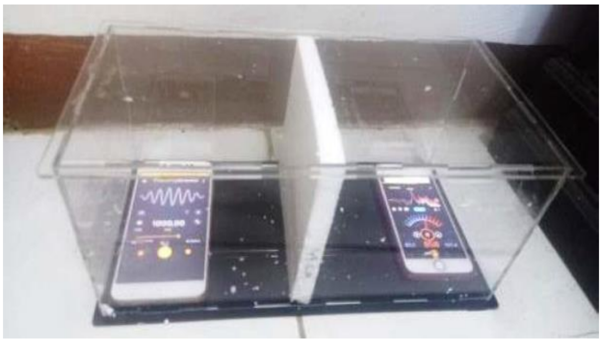

Figure 3 Research Model [26]

Roberts asserts that smartphones hold considerable utility as survey tools and sound level meters in resource-limited regions. Additionally, these devices can be employed for mapping environmental noise in communities by leveraging the built-in GPS feature of smartphones. Due to advancements in sensor technology, it is now feasible to gather data on various physical risks concurrently by utilizing a smartphone as a device for storing and outputting data from sensors [43].

The utilization of smartphones for environmental noise measurement, though in its initial phases, holds considerable promise for future applications, particularly in monitoring crowd-generated noise [44]. The first aspect is that these devices represent an affordable yet robust sensor network, widely used and capable of operating on a large scale. The second dimension is that mobile phones can serve as mobile sensors carried by individuals rather than being confined to static locations [45].

4. Result and Discussion

In Fieldyati Nur's investigation into noise absorption caused by trains in the classrooms of Widoro Public Elementary School, Yogyakarta, the study utilized Styrofoam-based sound absorbers with two different thicknesses: 2 cm and 4 cm. Sound levels were measured using a Sound Level Meter (SLM). The primary objectives were to determine the noise levels following the application of Styrofoam with 2 cm and 4 cm thickness and evaluate the efficacy of noise reduction. The findings revealed that the noise levels after the Styrofoam treatment were below the average threshold value established by Ministerial Decree No. 48/MNLH/11/1996 concerning noise level limits for school areas and similar environments. The effectiveness of noise reduction averaged 14% for Styrofoam with a thickness of 2 cm and 60% for Styrofoam with a thickness of 4 cm [46].

In Sjahrul Meizar's exploration of Styrofoam-infused bricks, the aim was to explore their potential as sound absorbers for noise control, with a preventive role in mitigating the rising incidence of hearing impairments. This study involved the formulation of fine aggregates (sand and Styrofoam) with a cement mixture at ratios of 1:4 and 1:6, incorporating polystyrene waste at levels of 0%, 20%, 40%, 60%, and 80%. Acoustic property assessments of the mixtures were carried out by examining the sound absorption coefficient (α) through the Four Microphones Impedance Tube (ISO 140-3). Results revealed that the highest absorption coefficient value was observed at 800 Hz frequency with an 80% Styrofoam addition in the 1:4 composition, measuring 0.4100 dB. Additionally, at 800 Hz frequency with a 40% Styrofoam addition in the 1:6 composition, the absorption coefficient was recorded as 0.5870 dB [47].

In Allif Silfiyana's investigation into the sound reduction capabilities of Styrofoam material, the research employed the Decibel X:dB Sound Level Meter app along with a sound generator as the audio source. Styrofoam served as the acoustic material, with thickness variations ranging from 1 cm to 4 cm. The obtained average absorption coefficients displayed variability, registering values such as 0.023 at a thickness of 1 cm, 0.031 at 1.5 cm, and 0.040 at 2 cm. Notably, the average sound absorption coefficient at thicknesses of 2.5 cm and 3 cm was identical, measuring 0.039. Similarly, at thicknesses of 3.5 cm and 4 cm, the average sound absorption coefficient exhibited similar values, measuring 0.038. The study concluded that significant sound absorption occurred at frequencies below 1000 Hz. Specifically, at frequencies of 200 Hz, 400 Hz, 600 Hz, and 800 Hz, the average sound absorption increased proportionally with the thickness of Styrofoam from 1 cm to 3.5 cm. However, at a thickness of 4 cm, there was no discernible increase in sound absorption, indicating effectiveness primarily at a frequency of 1000 Hz [48].

In construction, the incorporation of recycled materials like tyre crumb, miscanthus fibers, and EPS flakes has emerged as a sustainable practice, offering improvements in sound and thermal insulation properties [49], [50], [51]. Additionally, Styrofoam waste finds application as a binder in wood-styrofoam composite panels, providing an alternative bonding material for interior uses, albeit with a reduction in mechanical properties compared to traditional plywood panels [52]. This approach not only addresses environmental concerns but also contributes to reducing pollution and waste. Moreover, advancements in concrete technology have been made, with Styrofoam and polypropylene fibers enhancing the density, compressive strength, and flexural strength of concrete [53]. Furthermore, the development of lightweight Polystyrene concrete using RFCC as an additive has met technical standards while also reducing costs, demonstrating its potential for widespread adoption in the construction sector [54]. Alongside these innovations, modified geopolymer concrete incorporating lightweight aggregates has shown promise in enhancing various properties, further promoting sustainability in construction practices [55], [56].

In terms of insulation and noise absorption, considerations such as temperature, moisture content, and bulk density significantly influence the thermal conductivity of building insulation materials [57]. Lightweight concrete with polystyrene beads exhibits improved water resistance due to the non-absorbent nature of the beads, while compressive strength correlates with density [58]. Moreover, sound insulation properties vary based on factors such as density, mechanical properties, and layer thicknesses of concrete compositions [59]. Additionally, double panel structures, when augmented with absorbing materials, offer superior sound insulation capabilities [60]. Meanwhile, rubberized lightweight aggregate concrete has been developed to enhance noise insulation, addressing environmental concerns while meeting performance requirements [61], [62], [63], [64], [65]. Adjusting cavity width and incorporating sound-absorbing material can effectively shift resonance frequency, further improving sound insulation properties [66].

Furthermore, Styrofoam plays a role in meeting thermal protection requirements for exterior wall panels, contributing to energy efficiency in building design [67]. Addressing the issue of plastic waste is imperative due to its detrimental environmental impact, necessitating effective management strategies and sustainable alternatives [68]. Additionally, prefabricated lightweight foamed concrete wall panels offer seismic resilience while meeting regulatory standards, enhancing safety and sustainability in construction projects [69]. Moreover, the utilization of recycled paper residues has been explored to reduce thermal conductivity in ceramic products, presenting an innovative approach to sustainable materials utilization [70]. Finally, EPS granules have been integrated into concrete to produce lightweight blocks suitable for non-structural elements, effectively reducing wall loads while offering cost-effective and environmentally friendly alternatives to traditional construction materials [71].

5. Conclusion

The comprehensive analysis of the studies conducted by Fieldyati Nur, Sjahrul Meizar, and Allif Silfiyana highlights the significant potential of Styrofoam in noise reduction and sound absorption applications. Fieldyati Nur's investigation demonstrated that Styrofoam-based sound absorbers, particularly those with a thickness of 4 cm, can effectively reduce noise levels, meeting established regulatory thresholds. Similarly, Sjahrul Meizar's exploration revealed that incorporating Styrofoam waste into brick mixtures enhances sound absorption coefficients, particularly at critical frequencies. Allif Silfiyana's study further emphasized the effectiveness of Styrofoam in sound reduction, with varying thicknesses demonstrating notable absorption coefficients, particularly at frequencies below 1000 Hz. Moreover, the broader context of sustainable construction practices underscores the importance of incorporating recycled materials like Styrofoam into building materials. These materials not only offer improvements in sound and thermal insulation properties but also contribute to reducing pollution and waste in the construction industry. Advances in concrete technology, such as the integration of Styrofoam and polypropylene fibers, demonstrate potential enhancements in the density and mechanical properties of concrete, further promoting sustainability in construction practices.

In conclusion, the utilization of Styrofoam in construction materials holds promise for addressing acoustic challenges while advancing sustainability goals in the construction industry. The findings from the reviewed studies provide valuable insights into the effective use of Styrofoam for noise reduction and sound absorption applications, contributing to the broader discourse on sustainable construction practices and materials utilization.

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