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UTILIZATION OF NATURAL WASTE COIR FIBER FOR ENHANCED COMPRESSIVE STRENGTH OF FOAMED CONCRETE

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ABSTRACT: Foamed concrete is a lightweight material known for its excellent thermal insulation, soundproofing, and fire resistance properties, making it ideal to use for structural components. With densities of 300-1600 kg/m³, foamed concrete reduces the dead load of structures, allowing for more cost-effective and efficient design. Despite these advantages, foamed concrete often suffers from low compressive strength, and toughness, limiting its use in other applications. To address these, this experimental study aimed to develop and design foamed concrete with brown coir fiber as an additive and assess its compressive strength. The researchers prepared foamed concrete with varying percentages of 0%, 2.5%, 3.0%, and 3.5% by volume as an additive. The coir fibers were oven-dried and cut into 25mm length. TR-A plant-based foaming agent was used for a 0.6895MPa pressurized foam generator in preparing foam that was added to concrete mixture. The compressive strengths were determined at 7, 14 and 28 days of curing and the study found that the inclusion of coir fiber significantly enhances the compressive strength of foamed concrete. Coir fiber percentage significantly contributed to the compressive strengths while the curing duration and its interaction with fiber content do not significantly change the effect. Optimal results occurred at 2.5 % fiber content showing mean value of 5.799MPa increasing the strength of the control by 47.42%. Excessive fiber content led to strength reduction. Considering its significant increase in compressive strength it has a potential to be used in other structural elements but further studies may be needed while considering different lengths.

Keywords: Concrete, Foamed concrete, Coir fiber, Dead load reduction, Compressive strength

1. INTRODUCTION

One of the primary advantages of foamed concrete lies in its great soundproofing, thermal insulation, and fire-resistant properties, making it highly suitable for applications in slabs, floors, and wall panels. From an economic standpoint, it also offers greater cost-effectiveness compared to conventional normal-weight concrete. [1-2]

Foamed concrete significantly reduces the overall density of a building, which in turn decreases the dead load. This reduction in load can lead to lighter foundations, smaller structural members, and overall savings in construction materials and costs [3-4].

Increasing the foam content in mortar reduces the density of foamed concrete, making it a lightweight alternative for structural and non-structural uses. Foamed concrete demonstrates a strength-to-density ratio capable of producing 0.4–12 MPa at 300–900 kg/m³. This allows for its use in passive house foundations. [5]. With densities typically between 300 and 1600 kg/m³—lower than normal concrete's 2200 to 2600 kg/m³—foamed concrete offers easier handling, reduced structural loads, and cost-effective benefits for modern construction. [6].

Aesthetics in concrete design must balance functional, environmental, and economic considerations. Design goals should be integrated to ensure economic efficiency, emphasizing cost reduction without compromising quality [7]. Though many have enough of aggregates, some other countries do not have enough means to sustain their needs. For instance, the Netherlands lacks hard rock. Austria has a scarcity of gravel and sand. Other places like the United States of America, the Colorado Plateau, and the Great Plains have limited coarse gravel and high-quality rocks [8].

Larger-scale applications of foamed concrete have resulted from notable advancements in surfactant manufacturing and quality over the last 20 years, as well as the usage of certain additives [9]. When fiber was added, the strength of foamed concrete increased more than that of regular concrete.

As building technologies and materials continue to evolve, the principle of load management remains a cornerstone of engineering practice, ensuring that our built environment remains safe and resilient [10].

Density is closely related to the physical property of foamed concrete thus, considering it as the main design criterion. Table 1 below shows the recommended usage of foamed concrete as tabulated by S. Nandi, et.al. [11].

Foamed concrete, valued for its high energy absorption and low density, has gained significant attention in construction. However, its low strength, susceptibility to cracking, and poor toughness limit its broader use.

Foamed concrete utilized in building and construction applications—whether as a structural or non-structural element—must satisfy specific serviceability performance criteria to ensure adequate functionality and durability. Researchers have explored various natural and synthetic fibers—such as coir, polypropylene, basalt, steel, PVA, carbon, and others—to enhance the physical and mechanical properties of foamed concrete. Adding coir fiber notably improved the modulus of elasticity, plastic deformation capacity, and energy absorption of foamed concrete. Overall, fiber reinforcement, whether natural or synthetic, enhances mechanical properties like split tensile, flexural, and compressive strength, potentially enabling foamed concrete's use in structures beyond current applications. While synthetic fibers tend to be stronger but more expensive than natural ones, further research is recommended to better understand the impact of fiber reinforcement on foamed concrete's strength. [12].

Table 1. Recommended Usage of Foamed Concrete

Density (kg/m³)	Recommended Usage
300-600	Fire protection. Thermal insulation. Uses only cement or fly ash, foam, and water. Can be pumped easily. Stiff foam for slopes on roof top.
700-800	Used for void-filling. Producing building blocks.
900-1100	primarily produces blocks and other non-load-bearing construction components, including fence walls, partitions, balcony railings, and parapets.
1200-1400	Pre-fabricated and pre-cast in situ walls, load bearing & no-load-bearing. Used for floor screeds (sound & insulation, plus weight reduction).
1600-1800	slabs and other components of buildings that bear weight, where greater strength is required.

Coir fiber is a plant fiber that is renewable and recyclable. It comes in two varieties: brown fiber, which is found in mature coconuts, and white fiber, which is found in immature ones. It is well established that brown fibers possess robustness, greater thickness, and high resistance to abrasion. In addition to its strength that retain even in wet condition, coir fiber has other benefits including being resistant to rot, fungus, and moths, being unaffected by wetness and humidity, regaining its shape even after usage, being static-free, and being simple to clean [13]. It has a tensile strength ranging from 131MPa-343MPa. On average, their tensile strength is approximately 0.2 to 0.4 times that of mild steel. Coir has the highest elongation at break among typical natural fibers, capable of taking a strain 4–6 times greater than others. Its elongation property is about 0.3 times that of mild steel. [14].

A certain study, the physical properties of lightweight foamed concrete that incorporates coir fiber composites with varying volume percentages of fibers (0.2 and 0.4) were used. Two densities of lightweight foamed concrete, 1200 and 850 kg/m³, were experimented. The test's findings demonstrated that the quantity of coir fiber and the length of curing days improved the concrete's physical characteristics. [14].

Unlike other fibers, natural coir fiber is environmentally friendly and enhances concrete strength, making it the chosen additive in this study.

It was shown on a past study that the mechanical property of materials that are cement-based may be developed when coir fiber was used. The dynamic behavior of coir fiber reinforced concrete under drop-weight impact loadings was investigated by Wang and Chouv [14]. According to the study, the characteristics of coir fiber-reinforced concrete under repeated impact are influenced by the length of the coir fiber. Coir fiber measuring 25 and 50mm in length had better impact resistance than 75mm.

A study showed a substantial effect in improving the cement-based material's mechanical properties. Concrete with coir fiber increased in compressive strength with a coir fiber content of 2.0%. The coir concrete used in this was prepared with 75mm coir fiber of different fractions of 0, 0.5, 1.0, 1.5, 2.0, and 2.5% by volume [15].

Another study investigates the effects of natural fibers (basalt, coir, and sisal) on the mechanical properties and microstructure of foamed concrete. Fiber concentrations of 0.15%, 0.30% and 0.45% by cement weight were used. Results showed that the 10mm coir fibers significantly improved compressive strength, with a 42.19% increase at 0.30% content. However, too much fiber increased pore size and reduced microstructural integrity. The study recommends using optimal amounts of coir/sisal fibers to develop durable, high-performance foamed concrete with coir fiber [3].

Ordinary concrete was one of the focuses of many researches in the past. Coir fiber or coconut fiber were added to these regular concretes using conventional fibers. However, very few studies led to coir fiber's application in foamed concrete.

A study examined the effects of adding 0.1%, 0.2%, and 0.3% coir fiber by cement weight to foamed concrete. Using 25 mm fibers in a 1400 kg/m³ density mix, results showed that 0.3% coir fiber most effectively controlled crack propagation and significantly improved the foamed concrete's modulus of elasticity, compressive strength, and tensile strength, demonstrating coir fiber's potential to enhance lightweight concrete's mechanical properties. [16].

An experimental study on lightweight foamed concrete reinforced with coir fibers showed that coir fiber delayed and controlled tensile, flexural, and shear cracking. Coir fibers of 34 mm length were used in volume fractions from 0.2%-0.4%. The mix with 0.4% coir fiber exhibited the most significant strength improvement, attributed to increased cement paste bonding due to smaller and more numerous pores in the foamed concrete [17]. Due to this, it is concluded that coir fiber has the potential to be used in composites for various purposes.

Different studies used different lengths of coir fibers such as 10mm, 20mm, 25mm, 34mm, 50mm, and 75mm. Only 25, 50mm and 75mm were compared having 25mm and 50mm with greater result. Due to this, the researcher incorporated 25mm length of coir fiber but 50mm length may be considered for future studies.

In addition to this, different concentrations were seen on different studies. Some calculated the percentage by volume and some by cement weight. One study showed positive result on 2% coir fiber by volume using 75mm coir fiber. These studies were not enough. Therefore, this research focused on developing foamed concrete reinforced with varying percentages of 25mm coir fiber (2.5%, 3.0%, and 3.5%) and evaluating its compressive strength. The study aimed to compare the performance of different fiber contents and to design an optimal foamed concrete mix that enhances compressive strength while preserving the lightweight properties as well.

The subsequent sections of this study show: the research significance, focusing on the potential for sustainable and cost-effective innovations in the construction industry; the materials and methods, detailing a four-phase experimental methodology that covers, standardized compressive strength testing procedures, and the statistical tools used for data analysis; the results and evaluation of the compressive strength tests to identify the optimal fiber dosage; and the conclusion, which provides final remarks and practical recommendations for future engineering applications.

2. RESEARCH SIGNIFICANCE

This research advances the state of practice by establishing foamed concrete with coir fiber as a viable, sustainable alternative to conventional building materials. By validating the use of free and abundant agricultural waste, the study introduces a technical solution that enhances mechanical performance and durability while significantly reducing material costs compared to synthetic fibers. Furthermore, it impacts the construction materials by providing a framework for reducing structural dead loads in building applications. Ultimately, this work supports the construction industry's transition toward a circular economy, offering a scalable model for low-cost, eco-friendly, and efficient infrastructure development.

3. MATERIALS AND METHODS

This research employed an experimental design and was structured into four (4) distinct phases, each aimed at systematically addressing the objectives of the study. Figure 1 below shows the IPO conceptual framework.

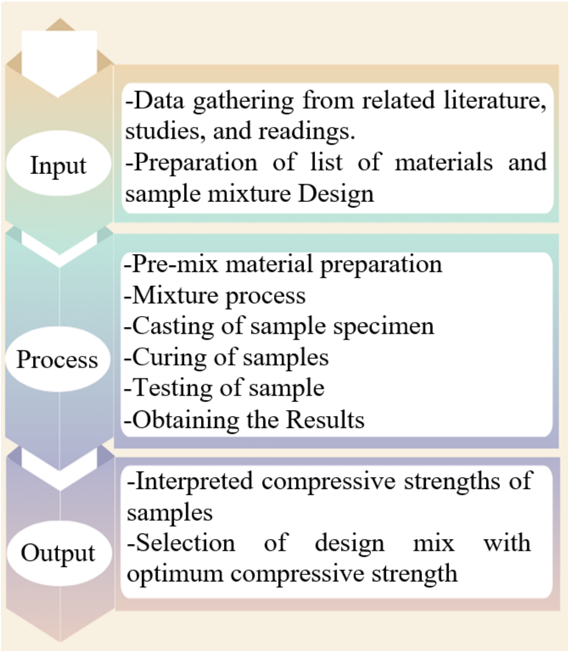

Fig.1 IPO conceptual framework

3.1 Development of Ideas

This study conducted an extensive review of literature on foamed concrete and coir fiber to build a solid theoretical foundation, focusing on enhancing foamed concrete's compressive strength with coir fiber additives. The experimental phase followed ASTM C796/C796M-19 standards to ensure reliable and valid results. Using a controlled experimental design, the research evaluated the impact of coir fiber incorporation on the compressive performance of foamed concrete.

3.2 Sampling Method

Materials used in this study were gathered and prepared in accordance with ASTM C796/C796M-19, the standard specification for foamed concrete. Brown coir fiber was selected as the reinforcing material, as it is known to possess greater strength and durability compared to white coir fiber. Additionally, a commercially available TR-A foaming agent (plant-based) was procured for use in producing the foamed concrete mix.

The materials were prepared ahead of time for the testing process. The complete list of materials utilized in the study is presented in Table 2 below.

After collection, coir fiber was cut into lengths of 25mm and then oven-dried (no chemical treatment involved) to remove any excess moisture. The fine aggregates used in the mix conformed to the ASTM C33 standard. Sieved and washed sand was utilized to ensure consistency and quality in the mixture.

Table 2. Materials and equipment used.

Qty	Unit	Description
1	set	TR11 1100W CLC lightweight concrete cement aircrete foam generator
1	set	(TR-A) foaming agent
1	set	electric drum mixer
6	bags	portland cement
8	kg	coir fiber cut in 25mm length
1	load	Sand (fine aggregates)
1	unit	soil oven
9	pcs	cylindrical mold (6” diameter)

The proportioning of materials, particularly the varying percentages of coir fiber, was determined and implemented. Treatment mixtures incorporating coir fiber were prepared alongside a control mixture consisting of lightweight foamed concrete without any fiber reinforcement. These mixtures were designed to evaluate the effects of coir fiber on the compressive strength of foamed concrete. Table 3 below presents the detailed mix proportions used for the preparation of cylindrical test specimens. All mixtures were accurately measured, and the concrete was cast into standard cylindrical molds, following the appropriate procedures and proportioning guidelines. The water-cement ratio of 0.6 was used. The foam amount was determined by using Eq. (1).

$$V_{foam=}(V_{cement} + V_{sand})\ x\ 1.8\% \quad (1)$$

Table 3. Mixture proportion of foamed concrete samples with target density of 800-1600kg/m³.

Treatment name	Measurement by Volume (Cubic Centimeters)				
	Cement	Sand	Water	Foam	Coir Fiber
Control (0%)	12510	4170	7.50	300	0
2.5% CF	12510	4170	7.50	300	437
3.0% CF	12510	4170	7.50	300	517
3.5% CF	12510	4170	7.50	300	600

Note: The mixture was prepared by batch of 3.

The prepared cement, sand, and water were mixed thoroughly in a concrete drum mixer until a homogeneous mortar mixture was achieved. Then, low-density foamed concrete was produced using the pre-foaming method.

A solution of the foaming agent and water was prepared separately using a TR11 1100W CLC lightweight concrete cement foam generator. To prepare the foam, a solution was created by mixing 31 mL of the plant-based foaming agent with every liter of water. This mixture was then processed through a pressurized foam generator at 0.6895 MPa to produce the stable pre-foam used in the concrete. with density of 50 ± 2.5 kg/m³. The foam was measured and was gradually added to the mortar while mixing it for 3 minutes. The coir fiber was then added to the mixture while continuously mixing it for another 3 minutes. The fig. 2 illustrates the formed foam and foamed concrete. The mixture was prepared by batch of 3 (3pcs each for control-7 days curing, 2.5% coir fiber-7 days curing, and so on).

Fig.2 Preparation of foamed concrete with coir fiber: (a) the generated foam and (b) the foamed concrete with coir fiber.

Though the target density was 800-1600kg/m³, the recorded wet density of the samples was 1620 for 0%, 1564kg/m³ for 2.5%, 1503kg/m³ for 3.0% and 1471 kg/m³ for 3.5%. An assessment of workability was also conducted during this stage. The figure 3 and table 4 below shows the actual procedure and result of the slump test. Slump measurement was reported to ensure consistency. It was observed that fiber addition significantly affected the mixing process and subsequent compaction, necessitating careful handling to maintain a homogeneous distribution.

The mixture was cast into cylindrical molds, covered, and demolded after 48 hours.

A published study comparing natural and synthetic foaming agents examined the compressive strength of hardened foamed concrete at 7, 14, and 28 days. Most curing process for foam concrete involved misting ang continuous watering. Since there is no recent study on the effect of curing process on the compressive strength of foamed concrete with coir fiber, all of the specimen were cured by submerging into water but further studies may compare different curing processes and its effect to foam concrete with coir fiber. All concrete specimens undergone curing for 7, 14, and 28 days. Prior to testing, all samples were removed from the water and allowed to air dry for 48 hours. The table 5 below shows the quantity of the samples prepared.

Fig.3. Slump flow test of foamed concrete.

Table 4. Slump Test Result of Foamed Concrete

Treatment name	Slump Flow (cm)		Slump (cm)
	X	Y	
Control	71	79	29.20
2.5% CF	46	48	24.10
3.0% CF	42	43	22.20
3.5% CF	39	39	20.30

Table 5. Quantity of Sample Specimen Prepared, Cured and Tested

Treatment name	Qty. of Specimen Cured and Tested Per Days of Curing		
	7 Days	14 Days	28 Days
Control	3 pcs	3 pcs	3 pcs
2.5% CF	3 pcs	3 pcs	3 pcs
3.0% CF	3 pcs	3 pcs	3 pcs
3.5% CF	3 pcs	3 pcs	3 pcs

Note: CF stands for coir fiber. The mixture was prepared by batch of 3.

3.3 Testing of Samples

The samples prepared after casting and curing, were tested to acquire the compressive strengths using a properly calibrated Compressive Machine. See figure 4 below. The order of casting was not considered and samples were selected randomly but all of the specimen prepared and cured were tested.

Fig.4 Sample testing using a compressive machine

The compressive strengths of the foamed concrete as a control specimen and the foamed concrete with different percentages of coir fiber as an additive were obtained and used in the last phase. Figure 5-8 below shows the cracked samples viewed under Scanning Electron Microscope (SEM).

The images on fig. 5-8 demonstrate that the inclusion of coir fiber directly impacts the foamed concrete's porosity. The coir fiber prevents individual air bubbles from merging during the mixing process. This results in more uniform air voids and a decrease in pore size as the fiber percentage increases. The figures allow for the visual inspection of fiber bonding. Strong bonding between the coir fibers and the cement paste is a primary reason why the coir fiber addition changed the compressive strength. Excessive fiber content (3.0% and 3.5%) actually leads to a reduction in compressive strength. The SEM images in Figures 7 and 8 help researchers visualized how very high fiber concentrations might disrupt the structural integrity or reduce the hardened density (as seen in Table 6), despite the continued reduction in pore size. The density decreases as the percentage of coir fiber increases.

Table 6. Average hardened density of foamed concrete

Treatment name	Average Density (kg/m³) Per Days of Curing		
	7 Days	14 Days	28 Days
Control	1581	1576	1556
2.5% CF	1465	1444	1394
3.0% CF	1431	1371	1298
3.5% CF	1405	1366	1296

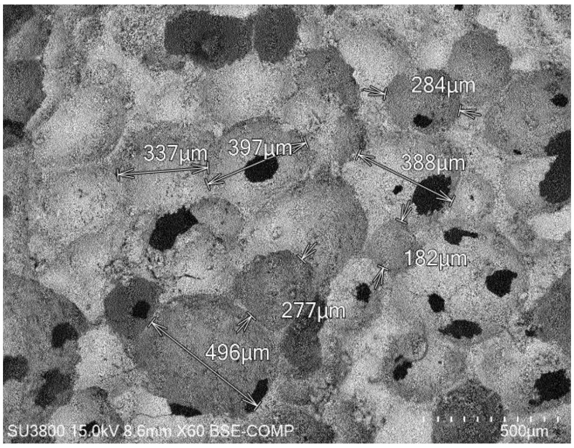

Fig.5 Image under SEM of cracked foamed concrete with 0% coir fiber

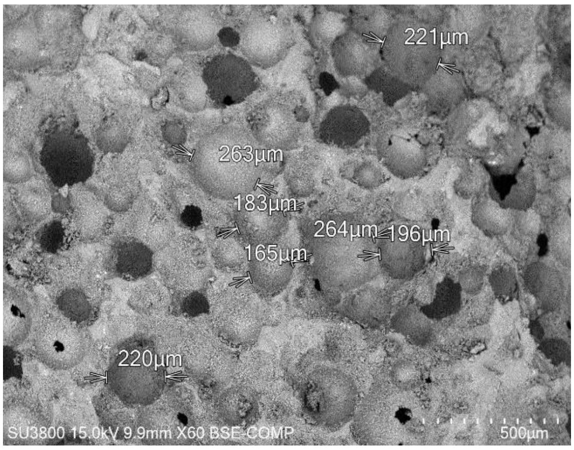

Fig.6 Image under SEM of cracked foamed concrete with 2.5% coir fiber

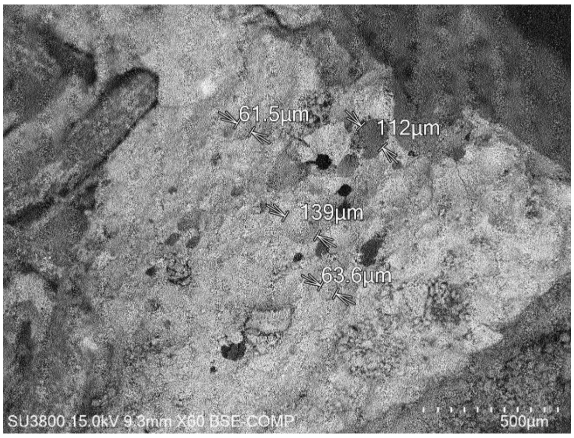

Fig.7 Image under SEM of cracked foamed concrete with 3.0% coir fiber

3.4 Statistical Tools

This research utilized multiple statistical methods to analyze the effects of coir fiber content on the compressive strength of foamed concrete. Analysis of Variance (ANOVA) was employed to assess the significance of coir fiber percentage, curing days, and its interaction then Tukey Test was used as a post-hoc test. Correlation analysis examined the strength and direction of the relationship between coir fiber percentage and compressive strength, revealing whether higher or lower fiber content corresponded to changes in strength. Finally, regression modeling was employed to quantify and predict the relationship between fiber content and compressive strength, developing a predictive model and validating the fiber percentage as a reliable predictor of strength variations. [19].

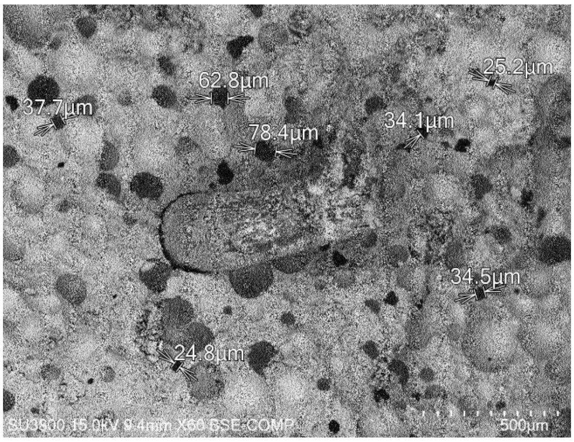

Fig.8 Image under SEM of cracked foamed concrete with 3.5% coir fiber

3.5 Results, Analysis and Evaluation

Table 7 shows the details of the results and analysis of compressive strength tests on foamed concrete with 0%, 2.5%, 3.0%, and 3.5% coir fiber. Using statistical methods such as ANOVA, Tukey Test, Correlation Analysis, and Regression Modeling, the study evaluated the impact of coir fiber on compressive strength.

Table 7. Compressive strength result

Curing Days	Blk No.	Compressive Strength (MPa)			
		0%CF	2.5%CF	3.0%CF	3.5%CF
7	1	2.885	4.541	3.625	4.325
	2	2.463	4.566	4.002	4.655
	3	1.521	3.896	4.772	5.059
	Mean	2.290	4.334	4.287	4.680
14	1	1.588	5.085	5.569	5.065
	2	3.764	6.080	1.540	4.788
	3	2.260	4.922	1.374	4.454
	Mean	2.537	5.362	2.828	4.769
28	1	3.859	6.148	6.295	4.867
	2	3.365	5.266	5.156	4.905
	3	4.578	5.984	1.852	6.054
	Mean	3.934	5.799	4.434	5.275

The significant differences between groups, variable relationships, and developed predictive models. The findings offer a comparative assessment of foamed concrete mixtures with varying coir fiber content. The compressive strength results are shown in Fig.9.

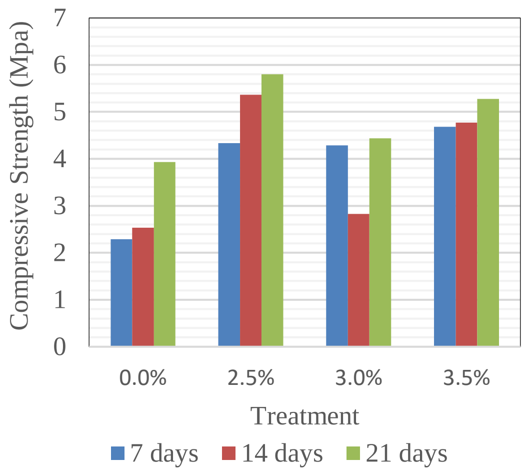

Fig.9 Graph of the compressive strength result

The compressive strength varies depending on the treatment with percentages of coir fibers and days of curing. The mean ranges from 2.289MPa to 5.799MPa. The first treatment (0 Coir fiber) during the 7 days of curing has the lowest mean (2.289MPa), while the 2nd treatment (2.5 Coir fiber) during the 28 days of curing has the highest mean (5.799MPa).b The provided data was run into a Two-Way ANOVA analysis to evaluate the effects of two independent variables: Treatment (fiber percentage) and Days of Curing on the compressive strength of foamed concrete. Table 8 below shows the ANOVA results on the compressive strengths of foam concrete with different percentages of coconut fiber as an additive.

Table 8. Two-way ANOVA result

Source of Variation	Type III Sum of Squares	df	Mean Square	F	p-value
Corrected Model	42.193	11	3.836	3.099	0.010
Intercept	634.435	1	634.435	512.580	0.000
Treatment	29.088	3	9.696	7.834	0.001
Curing Days	7.908	2	3.954	3.194	0.059
Interaction	5.197	6	0.866	0.700	0.652
Error	29.705	24	1.238		
Total	706.334	36			
Corrected Total	71.899	35			

It shows that the treatment comparisons have a statistically significant difference in compressive strength, which indicates a varying percentage of coconut fiber significantly affecting the compressive strength of the foam concrete. However, the curing days do not have a statistically significant difference in compressive strength at the 0.05 level. Same with the interaction between treatment and curing days, which is also not statistically significant, suggesting that the effect of coconut fiber percentage on compressive strength is consistent across the different curing periods. Overall results imply that the percentage of coconut fiber added is a key factor that influences the compressive strength of foam concrete, while the curing duration and its interaction with fiber content do not significantly change the effect.

The Post Hoc Tests (Tukey Test) of the two way ANOVA results on the compressive strengths of foam concrete with different percentages of coconut fiber as an additive confirmed the statistically significant results specifically in between some treatment pairs such as the 0% CF differs significantly from 2.50% CF and 3.50% CF , which suggest that adding these levels of coconut fiber significantly alters the compressive strength compared with the control mix.

Overall results implies that the post hoc analysis confirms that coconut fiber content influences the compressive strength particularly when comparing the fiber-reinforced mixes with the non-fiber control but the differences among the higher fiber concentrations are not statistically significant.

Regression analysis revealed that both coir fiber concentration and curing duration significantly influence compressive strength, with p-values of 0.033 and 0.002, respectively. The model predicts a 0.511MPa increase in strength per unit increase in fiber concentration and a 0.0509MPa increase per additional day of curing. Starting from a baseline strength of 2.216MPa, this represents roughly a 2.30% increase per unit fiber concentration and a 23.10% increase per curing day. Correlation analysis showed a moderate positive relationship between fiber concentration and strength, while curing days had no significant linear correlation. The regression model explained 33.6% of the strength variability (R^2 = 0.336) and was statistically significant (p=0.001), confirming fiber concentration and curing duration as meaningful predictors of foamed concrete compressive strength.

4. CONCLUSION

The primary objective of this experimental study was to develop and design foamed concrete incorporating coir fiber as an additive and to evaluate its compressive strength. Throughout the research process, foamed concrete mixtures with varying coir fiber contents—specifically 0%, 2.5%, 3.0%, and 3.5% by volume. The compressive strength of each mixture was determined using a standardized compressive testing machine.

The experimental results demonstrated that the incorporation of 25mm coir fiber into foamed concrete significantly enhanced its compressive strength. The addition of coconut fiber is the primary driver of the change in compressive strength and is consistent in different curing periods. The optimum performance was observed at a coir fiber dosage of 2.5%, yielding a mean compressive strength of 5.799MPa, which corresponds to a 47.42% improvement over the control specimen. More than 2.5% fiber, however reduced pore size, density and compressive strength, demonstrating the importance of moderation in fiber use to improve mechanical properties.

Though 25mm coir fiber achieved the optimum compressive strength, other studies showed 50mm coir fiber giving similar impact resistance to that of 25mm. As a recommendation, 50mm may be used for further study. Since there is no evidence showing the effect of curing process on the compressive strength of foamed concrete with coir fiber, future researchers may opt to do experiments on the effect of curing process on foamed concrete especially with coir fiber as an additive. Furthermore, other mechanical tests like flexural strength, splitting tensile test, drying shrinkage, and water absorption may be considered to validate the results of the effectiveness of 2.5% coir fiber as an additive.

5. ACKNOWLEDGEMENTS

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