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Exposure-Dependent Mechanical and Physical Properties of Coconut Coir Fiber-Reinforced Concrete

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Abstract

The incorporation of natural fibers into concrete offers opportunities for resource-efficient construction, although their mechanical and physical performance may vary under different exposure conditions. This study investigated the compressive strength, bulk density, and water absorption of coconut coir fiber-reinforced concrete subjected to freshwater and seawater exposure. A laboratory experiment employed four coconut coir fiber contents (0%, 0.1%, 0.5%, and 1.0% of cement mass) and two immersion conditions, producing eight treatment groups with three cylindrical specimens each. Following 26 days of immersion, compressive strength was evaluated at a nominal concrete age of 28 days, alongside physical property measurements. Under freshwater exposure, plain concrete exhibited the highest mean compressive strength (30.61 MPa), whereas the seawater-exposed mixture containing 1.0% fiber achieved the highest strength within its exposure group (28.52 MPa), representing a 20.19% increase relative to the corresponding plain-concrete control. The relative difference in compressive strength between freshwater and seawater exposure decreased to 0.40% at 1.0% fiber. Water absorption was consistently higher under seawater exposure, reaching 0.647% at 0.5% fiber, compared with 0.357% for the corresponding freshwater group. Bulk density showed no consistent trend with increasing fiber content. These findings indicate that coconut coir fiber incorporation is associated with different mechanical and physical responses depending on the exposure environment. Compressive strength and water absorption did not follow equivalent patterns, emphasizing the importance of evaluating these properties independently when assessing coconut coir fiber-reinforced concrete for moisture-exposed construction applications.

Keywords: Coconut coir fiber; Fiber-reinforced concrete; Freshwater and seawater exposure; Compressive strength; Water absorption

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INTRODUCTION

The growing demand for construction materials has increased scientific interest in incorporating renewable resources and agricultural by-products into cementitious composites. Natural fibers have attracted attention because of their availability, relatively low density, and potential to provide reinforcement within conventional cement-based materials. Their utilization also creates opportunities to explore alternative applications for agricultural residues that would otherwise have limited engineering value. However, the environmental relevance of bio-based constituents depends on their functional performance, processing requirements, and suitability for intended service conditions rather than their renewable origin alone. Recent studies have emphasized the potential contribution of natural fiber composites to sustainable material development while identifying substantial challenges involving mechanical reliability, moisture sensitivity, and long-term

compatibility with cementitious matrices (W. Ahmad et al., 2025; Elfaleh et al., 2023; Zaid & Ben Kahla, 2026).

Concrete possesses high compressive load-bearing capacity but exhibits relatively limited resistance to tensile cracking and post-cracking deformation. Fiber reinforcement has therefore been investigated as a means of modifying crack propagation, improving energy absorption, and enhancing selected mechanical characteristics. Nevertheless, the effectiveness of fiber incorporation depends on the properties being evaluated. Improvements in crack bridging and post-cracking behavior do not necessarily correspond to increases in compressive strength, which is strongly influenced by matrix continuity, aggregate characteristics, compaction, and the quality of fiber–matrix interactions. Reviews of fiber-reinforced concrete consistently demonstrate that reinforcement geometry, distribution, dosage, and material compatibility influence mechanical performance, frequently producing nonlinear or property-specific responses (Hassan & Saeed, 2024; Mishra et al., 2025; Pham, 2025; Lingeshwaran et al., 2026). Consequently, the engineering relevance of fiber reinforcement requires consideration of both its mechanical contribution and its influence on the physical characteristics of the cementitious composite.

The incorporation of plant-derived fibers introduces additional complexity because lignocellulosic materials possess moisture-sensitive structures and heterogeneous surface characteristics. Their cellulose, hemicellulose, and lignin components influence water affinity, dimensional stability, and interactions with alkaline cement environments. Variations in fiber morphology and surface chemistry may also affect dispersion, interfacial adhesion, and the formation of local discontinuities within the hardened matrix. These characteristics can influence mechanical resistance and moisture-related behavior through different pathways. Previous assessments of natural fiber-reinforced cementitious composites have highlighted the importance of constituent compatibility, fiber conditioning, and interfacial characteristics in determining material performance (Abdollahiparsa et al., 2023; Gudayu et al., 2025; Olanrewaju et al., 2025). Fiber modification offers potential advantages, although the effectiveness of these approaches remains dependent on the characteristics of the reinforcement and the cementitious system (Zaid & Ben Kahla, 2026).

Coconut coir fiber represents a particularly relevant lignocellulosic reinforcement because it originates from an abundant agricultural by-product and possesses a fibrous morphology capable of interacting mechanically with cementitious matrices. Its flexibility, surface texture, and potential crack-bridging function have encouraged its incorporation into concrete and mortar. Comprehensive reviews have documented the possible contributions of coconut coir to toughness-related characteristics while also identifying variations in compressive strength, workability, density, and moisture absorption across material formulations (J. Ahmad et al., 2022; Ali et al., 2022; Martinelli et al., 2023). These variations demonstrate that coconut coir cannot be treated as a reinforcement whose effectiveness increases consistently with fiber content. Its contribution depends on the balance between mechanical reinforcement, matrix integrity, and the physical characteristics introduced by the fibers.

Experimental investigations provide further evidence of this conditional behavior. Guruswamy et al. (2024) examined the relationship between coconut fiber characteristics, dosage, and the mechanical and fresh-state properties of concrete, emphasizing the importance of reinforcement configuration. Mboungou Londe et al. (2024) investigated raw and treated coconut fibers in high-strength concrete, demonstrating the relevance of fiber condition to mechanical and durability-related characteristics. Bediako et al. (2025) evaluated coconut coir alongside synthetic and hybrid reinforcement systems, considering differences in mechanical and durability performance. Although these studies contribute substantially to understanding coconut fiber reinforcement, their material formulations, fiber characteristics, and performance assessments differ. Their findings indicate that reinforcement dosage alone provides an incomplete basis for predicting concrete behavior, particularly when the material is subjected to different moisture environments.

The physical characteristics of coconut coir-reinforced concrete warrant attention alongside its mechanical properties. Bulk density reflects the combined influence of constituent proportions, consolidation, and the physical condition of the hardened material. Water absorption, in contrast, characterizes moisture uptake under specified conditioning procedures and is influenced by accessible pore structures, moisture-sensitive constituents, and measurement conditions. These properties are related to material characteristics but do not represent interchangeable indicators of concrete performance. In particular, water absorption cannot independently establish pore connectivity, chloride penetration resistance, or long-term durability. Previous research has emphasized the complex relationships among natural fiber incorporation, moisture interactions, and the physical characteristics of cementitious composites (Gudayu et al., 2025; Martinelli et al., 2023; Mutnbak, 2026). Evaluating these characteristics alongside compressive strength is therefore important for understanding whether material formulations exhibit consistent or differing responses across performance criteria.

The surrounding aqueous environment introduces another important consideration. Freshwater and seawater differ in their dissolved constituents and chemical characteristics, which can influence interactions with cement hydration products and the developing microstructure. Seawater contains chloride, sulfate, magnesium, and other dissolved ions whose interactions with cementitious materials depend on binder composition, exposure duration, moisture conditions, and environmental history. Reviews of concrete in marine environments have identified distinct processes associated with hydration, ionic transport, chemical alteration, and long-term deterioration (Yi et al., 2020; Ting & Yi, 2023). Comparative investigations have also demonstrated that chloride transport depends on environmental conditions, including continuous immersion, wetting–drying cycles, and moisture gradients (Li et al., 2024; Dai et al., 2024). Such evidence indicates that the aqueous environment constitutes an important contextual factor in evaluating concrete characteristics.

An essential distinction exists between concrete produced using seawater as a mixing constituent and concrete exposed to seawater after casting. In seawater-mixed concrete, dissolved ions are present during the initial mixing and hydration processes, whereas external immersion introduces a different sequence of interactions between the aqueous medium and the developing or hardened

cementitious matrix. Reviews of seawater-mixed concrete and seawater–sea-sand systems have examined material characteristics, hydration processes, reinforcement corrosion, and durability under a wide range of mixture compositions and environmental conditions (Saxena & Baghban, 2023; Rathnarajan & Sikora, 2023; Chen et al., 2024; Aghajanzadeh et al., 2026; Chao et al., 2026; Jin et al., 2026). Although these investigations establish the importance of saline constituents, their findings cannot be transferred directly to externally immersed concrete without accounting for differences in the timing and nature of seawater contact.

Research involving external marine exposure further illustrates the importance of distinguishing early-age material development from longer-term environmental deterioration. Wilson et al. (2024) investigated chloride ingress in cementitious binders, highlighting the influence of transport characteristics and material development. Kim et al. (2025) examined strength development under contrasting atmospheric, tidal, and submerged marine conditions, demonstrating the relevance of the exposure environment to mechanical behavior. Ouslimane et al. (2026) investigated early-age mechanical performance and chloride ingress in concrete exposed to marine conditions. These investigations establish that exposure history and material maturity are important considerations when interpreting concrete properties. In particular, differences observed during early immersion may involve ongoing cement hydration and environmental conditioning, whereas the assessment of deterioration requires additional evidence concerning chemical alteration and changes over extended exposure periods.

Despite substantial progress in coconut coir-reinforced concrete and marine cementitious materials, the relationship between reinforcement dosage and aqueous immersion conditions remains insufficiently resolved for conventional coconut coir concrete. Existing coconut fiber investigations provide important evidence regarding mechanical characteristics, fiber treatments, mixture composition, and selected durability indicators, while marine concrete studies frequently concentrate on chloride transport, seawater-based mixing constituents, alternative binders, or conventional concrete without natural fiber reinforcement. The available findings therefore do not establish a consistent understanding of how corresponding coconut coir formulations compare across freshwater and seawater immersion conditions when compressive strength, bulk density, and water absorption are considered as distinct performance characteristics (J. Ahmad et al., 2022; Bediako et al., 2025; Ting & Yi, 2023; Mutnbak, 2026). This unresolved relationship is particularly relevant during early-age immersion, when the aqueous environment may influence material development without necessarily indicating long-term degradation or durability performance.

A more specific understanding of this relationship requires distinguishing changes associated with fiber incorporation within a given immersion environment from differences observed between immersion environments at corresponding fiber contents. These comparisons address related but separate aspects of material behavior. Compressive strength provides information concerning resistance to axial loading, whereas density and absorption represent different physical characteristics that may respond differently to reinforcement and aqueous conditioning. The scientific importance lies in characterizing these relationships without assuming that

improvements in one measured property necessarily indicate improvements in the others.

Study Purpose and Research Questions

This study aims to examine the relationships among coconut coir fiber content, freshwater and seawater immersion conditions, and the mechanical and physical characteristics of concrete during early-age material development. Particular attention is directed toward compressive strength, bulk density, and water absorption as complementary properties representing different aspects of concrete performance. The investigation seeks to clarify how these properties vary across coconut coir contents within each immersion environment, how corresponding formulations compare between freshwater and seawater conditions, and whether the relative assessment of material performance differs according to the property considered. Three research questions guide the investigation:

1) How do compressive strength, bulk density, and water absorption vary with coconut coir fiber content under freshwater and seawater immersion conditions?
2) How do these mechanical and physical characteristics compare between the two immersion environments at corresponding fiber contents?
3) To what extent do compressive strength and moisture-related physical properties provide consistent or differing assessments of coconut coir-reinforced concrete?

These questions reflect the need for property-specific evaluation identified in research on coconut fiber reinforcement and marine cementitious materials (Ali et al., 2022; Yi et al., 2020; Zaid & Ben Kahla, 2026).

Novelty of the Study

The contribution of this study lies in its focused examination of coconut coir-reinforced concrete across two aqueous immersion environments, with attention to the relationship between reinforcement content and multiple mechanical and physical properties. Previous investigations have established the relevance of coconut coir as a cementitious reinforcement and demonstrated the importance of moisture exposure to concrete behavior. However, differences in material formulations, exposure regimes, and assessment criteria have limited the direct comparability of these research directions, particularly regarding the combined consideration of compressive strength, bulk density, and water absorption during early-age immersion (Martinelli et al., 2023; Ting & Yi, 2023; Bediako et al., 2025).

The distinctive perspective is the separation of two complementary comparisons: differences among fiber contents within the same immersion environment and differences between immersion environments for corresponding fiber formulations. This distinction enables a more specific examination of whether material characteristics follow comparable patterns across mechanical and physical criteria. It also recognizes that external aqueous immersion represents a different environmental context from seawater incorporation during concrete mixing (Rathnarajan & Sikora, 2023; Aghajanzadeh et al., 2026). By focusing on these relationships, the study contributes comparative evidence relevant to the characterization of coconut coir-reinforced concrete under early-age aqueous conditioning and provides a basis for further investigations of material mechanisms and longer-term environmental performance.

METHODS

Materials

Concrete mixtures were prepared using Type I Portland cement, natural sand as fine aggregate, crushed stone as coarse aggregate, municipal water, and coconut coir fibers. The sand was obtained from Central Lombok, Indonesia, and the coarse aggregate was supplied by a local aggregate producer. Coconut coir fibers were cut to a nominal length of 30 mm and added at 0%, 0.1%, 0.5%, and 1.0% of cement mass. The mixture without fibers served as the plain-concrete reference.

Prior to mixture proportioning, cement and aggregates were characterized through the applicable laboratory examinations, including bulk density, aggregate grading, specific gravity, and abrasion resistance. The constituent properties were considered in determining the mixture proportions. Municipal freshwater was used for mixing and freshwater exposure; natural seawater was collected from a coastal area of Lombok, Indonesia, for the separate seawater-exposure groups.

Experimental Design

The laboratory experiment followed a 4 × 2 factorial treatment arrangement comprising four coconut coir fiber contents (0%, 0.1%, 0.5%, and 1.0% of cement mass) and two exposure conditions (freshwater and seawater). Three cylindrical concrete specimens were assigned to each treatment combination, yielding 24 specimens for the principal comparison. Each cylinder measured 150 mm in diameter and 300 mm in height. Table 1 presents the allocation and identification codes.

Table 1. Experimental Design and Specimen Allocation across Fiber Contents and Exposure Conditions

Fiber content (%)	Freshwater code	n	Seawater code	n
0	BT0	3	BL0	3
0.1	BT01	3	BL01	3
0.5	BT05	3	BL05	3
1.0	BT1	3	BL1	3
Total	4 groups	12	4 groups	12

Note. BT and BL denote freshwater and seawater exposure, respectively. Three specimens were allocated to each of the eight experimental groups.

The 0% fiber groups served as exposure-specific references for estimating changes associated with fiber addition. Comparisons between freshwater and seawater were performed at each corresponding fiber dosage.

Concrete Mix Design

The concrete mixture was proportioned according to the laboratory mix-design procedure based on SNI 03-2834-2000. The design calculation used a specified compressive strength of 20 MPa, a target mean strength of 32 MPa after applying the design margin, a nominal maximum aggregate size of 40 mm, and a free water-to-cement ratio of approximately 0.48. These parameters describe the mixture-design calculation rather than an independently established performance threshold for each experimental group.

Cement, water, fine aggregate, and coarse aggregate masses were maintained constant across the four mixtures, while coconut coir fiber was added

according to the prescribed percentage of cement mass. Table 2 summarizes the laboratory batch quantities.

Table 2. Concrete Mix Proportions and Coconut Coir Fiber Dosages

Fiber (%)	Cement (kg)	Water (kg)	Fine agg. (kg)	Coarse agg. (kg)	Fiber (g)
0	2.351	1.128	3.966	6.753	0.00
0.1	2.351	1.128	3.966	6.753	2.35
0.5	2.351	1.128	3.966	6.753	11.75
1.0	2.351	1.128	3.966	6.753	23.51

Note. Values represent laboratory batch quantities. Fiber dosage is expressed relative to cement mass; the nominal water-to-cement ratio is based on the prescribed mixing-water and cement masses.

Specimen Preparation and Exposure Conditions

The constituents were weighed according to the mixture design and combined using a concrete mixer. Cement and fine aggregate were mixed initially, followed by coarse aggregate. Coconut coir fibers were introduced into the fiber-containing mixtures before addition of the mixing water. Mixing was continued until the components were distributed throughout the mixture. Fresh concrete consistency was assessed using the slump test in accordance with SNI 1972:2008.

Fresh concrete was placed in lubricated cylindrical molds in approximately three layers. Each layer was compacted with 25 tamping strokes, and the mold sides were tapped to release entrapped air. The top surfaces were leveled, and the specimens remained in the molds for approximately 24 h before demolding. Specimens were then immersed in separate freshwater or seawater containers for the prescribed 26-day exposure. Compressive-strength measurements were performed at a nominal concrete age of 28 days.

Physical and Mechanical Testing

Slump was measured as the vertical subsidence of fresh concrete after the slump cone was lifted. Concrete bulk density was determined from measured specimen mass and cylindrical specimen volume and expressed in kg/m³. Water absorption was determined by weighing specimens after immersion and removal of excess surface water, then expressing the difference between saturated and reference masses relative to the reference mass as a percentage.

Compressive strength was measured using a compression testing machine in accordance with SNI 1974:2011. The cylindrical loading faces were prepared using sulfur capping before axial loading. The maximum applied force was divided by the specimen cross-sectional area to obtain compressive strength in MPa. For the nominal cylinder diameter of 150 mm, the cross-sectional area was approximately 17,671.5 mm².

Data Analysis

The measurements were organized by fiber content and exposure condition. For each three-specimen group, the arithmetic mean and sample standard deviation were calculated. Specimen-level observations were retained for presenting within-group dispersion. Absolute differences between exposure conditions were obtained by subtracting the freshwater group mean from the corresponding seawater group mean; percentage differences used the freshwater group mean as the reference.

Changes relative to plain concrete were calculated separately within each exposure condition. Compressive-strength changes were expressed in MPa and as

percentages relative to the corresponding 0% fiber group, while water-absorption differences were expressed in percentage points. The comparisons and graphical summaries were descriptive.

RESULTS AND DISCUSSION

Fresh Concrete Properties

Fresh concrete properties were evaluated for mixtures containing 0%, 0.1%, 0.5%, and 1.0% coconut coir fiber by cement mass. All other mix proportions were held constant across the experimental treatments. Table 3 presents the fiber additions and the slump measured for each mixture.

Table 3. Fresh Concrete Properties at Different Coconut Coir Fiber Contents

Fiber content (%)	Fiber addition (g)	Reported slump (mm)
0	0.00	80
0.1	2.35	80
0.5	11.75	80
1.0	23.51	80

Note. Fiber dosages were calculated relative to a cement mass of 2.351 kg per mixing batch. Slump is presented as the measured value for each mixture.

All four mixtures exhibited a slump of 80 mm across the investigated fiber range. Fiber additions increased from 2.35 g at 0.1% to 23.51 g at 1.0%, with no corresponding change in the observed slump. These results indicate comparable slump values among the four fresh mixtures under the investigated mixing conditions.

Although the slump values were identical across the treatments, the measurements do not resolve differences in within-batch consistency or fiber dispersion. The fresh-state observations therefore describe the consistency attained during specimen preparation, providing context for the subsequent evaluation of hardened concrete properties.

Bulk Density and Water Absorption

Bulk density was evaluated for the hardened concrete specimens across the four fiber contents and two immersion conditions. Table 4 presents mean bulk density and standard deviation for each treatment group, providing a quantitative comparison of physical characteristics across the experimental matrix.

Table 4. Bulk Density of Concrete Specimens under Different Exposure Conditions

Fiber content (%)	Freshwater (kg/m³)	Seawater (kg/m³)
0	2456.00 ± 7.55	2456.00 ± 7.55
0.1	2413.00 ± 18.73	2440.67 ± 17.01
0.5	2448.67 ± 37.00	2459.00 ± 19.16
1.0	2418.33 ± 17.01	2449.67 ± 10.79

Note. Values are mean ± sample SD (n = 3 per group). Bulk density describes the tested specimens; between-group contrasts are not within-specimen changes in density.

Mean bulk density ranged from 2413.00 to 2456.00 kg/m³ among freshwater-exposed specimens and from 2440.67 to 2459.00 kg/m³ among seawater-exposed specimens. The lowest group mean occurred at 0.1% fiber under freshwater exposure, while the highest occurred at 0.5% fiber under seawater exposure. No monotonic relationship between fiber content and mean bulk density was observed.

The dispersion of density measurements also differed across the mixtures. The freshwater group containing 0.5% fiber exhibited the largest standard deviation (37.00 kg/m³), whereas the plain-concrete groups showed standard deviations of 7.55 kg/m³. These results characterize between-specimen variation within the tested groups rather than longitudinal changes during immersion.

Water absorption was determined for three specimens in each treatment group. Table 5 presents the means and sample standard deviations of water absorption across the two immersion conditions, and Figure 1 illustrates the group-level patterns with error bars corresponding to one standard deviation.

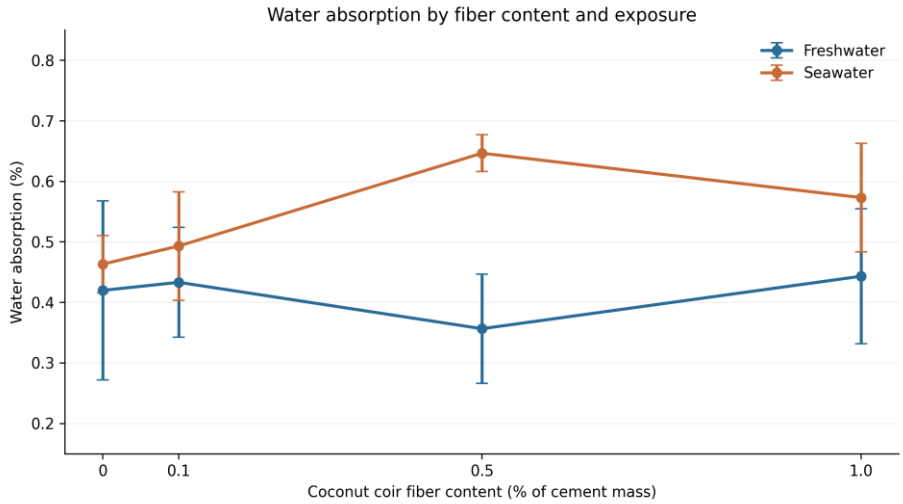
Table 5. Water Absorption under Freshwater and Seawater Exposure

Fiber content (%)	Freshwater absorption (%)	Seawater absorption (%)
0	0.420 ± 0.148	0.463 ± 0.047
0.1	0.433 ± 0.091	0.493 ± 0.090
0.5	0.357 ± 0.090	0.647 ± 0.031
1.0	0.443 ± 0.112	0.573 ± 0.090

Note. Values are mean ± sample SD (n = 3 per group), calculated from individual specimen absorption percentages expressed to two decimal places.

Mean absorption under freshwater exposure ranged from 0.357% at 0.5% fiber to 0.443% at 1.0% fiber. Under seawater exposure, mean absorption ranged from 0.463% in the control group to 0.647% at 0.5% fiber. Thus, the lowest freshwater mean and the highest seawater mean were observed at the same fiber content, indicating that the ranking of mixtures depended on the immersion medium.

At every investigated fiber content, the seawater-exposed specimens exhibited greater mean absorption than their freshwater-exposed counterparts. The largest contrast occurred at 0.5% fiber, with means of 0.647% and 0.357%, respectively. At 1.0% fiber, the corresponding means were 0.573% and 0.443%. Thus, the magnitude of the between-medium difference varied with fiber content.



Note. Points denote group means and error bars denote ±1 SD; n = 3 per treatment combination.

Figure 1. Water Absorption Patterns under Freshwater and Seawater Exposure

Figure 1 presents distinct absorption patterns for the two exposure conditions. In freshwater, the mean fell at 0.5% fiber and increased at 1.0%, whereas in seawater it rose through 0.5% fiber before decreasing at 1.0%. The vertical separation

between the series was greatest at 0.5% fiber. This visualization is consistent with the specimen-level absorption results summarized in Table 5.

The error bars further show differences in specimen-level variability. The seawater group containing 0.5% fiber exhibited comparatively low dispersion around its mean, whereas the freshwater control displayed a wider spread. With three specimens per treatment, these error bars characterize the observed variation without constituting formal tests of differences between means.

Compressive Strength Characteristics

Compressive strength was determined at a specimen age of 28 days for three cylinders within each of the eight combinations of fiber content and immersion medium. Table 6 reports the individual compressive strengths together with the calculated group means and sample standard deviations.

Table 6. Compressive Strength under Freshwater and Seawater Exposure

Exposure	Fiber (%)	Specimen 1 (MPa)	Specimen 2 (MPa)	Specimen 3 (MPa)	Mean ± SD (MPa)
Freshwater	0	29.77	28.63	33.44	30.61 ± 2.51
	0.1	29.37	32.03	26.54	29.31 ± 2.75
	0.5	27.45	26.60	27.11	27.05 ± 0.43
	1.0	28.52	29.60	27.78	28.63 ± 0.92
Seawater	0	22.47	23.82	24.90	23.73 ± 1.22
	0.1	23.48	23.77	23.09	23.45 ± 0.34
	0.5	24.84	26.43	27.56	26.28 ± 1.37
	1.0	28.52	28.86	28.18	28.52 ± 0.34

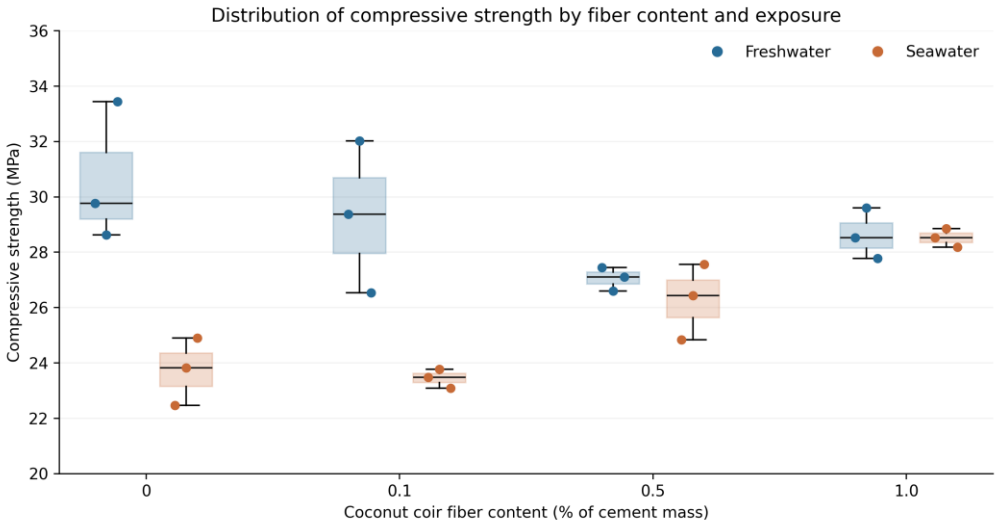
Note. Values are mean ± sample SD (n = 3 per group), calculated from the individual compressive strengths. Group summaries were calculated before rounding.

The highest freshwater mean occurred in plain concrete (30.61 MPa). Mean strength decreased to 29.31 MPa at 0.1% fiber and 27.05 MPa at 0.5% fiber, then increased to 28.63 MPa at 1.0% fiber. None of the fiber-reinforced groups exceeded the freshwater control mean. The pattern therefore involved an initial reduction followed by a partial recovery at the highest tested fiber content.

For specimens immersed in seawater, mean compressive strength was 23.73 MPa for the control, 23.45 MPa for 0.1% fiber, 26.28 MPa for 0.5% fiber, and 28.52 MPa for 1.0% fiber. The highest seawater mean consequently occurred at 1.0% fiber, although it remained below the freshwater control mean. The response across fiber contents differed descriptively between the two immersion conditions.

Figure 2 displays the three individual compressive-strength measurements in every group alongside the within-group distributions. This representation complements the averages in Table 6 by showing the degree to which the individual measurements cluster around, or depart from, their group centers.

Freshwater specimens with 0.1% fiber displayed the largest sample standard deviation, approximately 2.75 MPa, while the freshwater 0.5% fiber group had the smallest variation in that medium (about 0.43 MPa). For seawater exposure, the 0.1% and 1.0% fiber groups both exhibited sample standard deviations near 0.34 MPa. These differences emphasize that within-treatment scatter was not constant across the tested mixtures.



Note. Individual points represent specimens; box summaries are descriptive only because each experimental group contains three measurements.

Figure 2. Compressive Strength Distribution across Fiber Contents and Exposure Conditions

Under seawater exposure, compressive strengths at 0.5% fiber ranged from 24.84 to 27.56 MPa, compared with 28.18 to 28.86 MPa at 1.0% fiber. The latter group combined a higher mean with a narrower observed range. Together with the freshwater measurements, these distributions show that between-specimen variability differed across treatment combinations.

Comparative Performance under Different Exposure Conditions

To quantify between-medium contrasts at identical fiber contents, the seawater mean was compared with the freshwater mean using a consistent sign convention: a negative strength difference indicates a lower mean under seawater exposure. Table 7 reports the corresponding percentage difference relative to freshwater and the difference in mean water absorption in percentage points.

Table 7. Comparative Changes in Concrete Properties between Freshwater and Seawater Exposure

Fiber (%)	Freshwater (MPa)	Seawater (MPa)	Strength Δ (MPa)	Strength Δ (%)	Absorption Δ (pp)
0	30.61	23.73	-6.88	-22.48	+0.043
0.1	29.31	23.45	-5.87	-20.01	+0.060
0.5	27.05	26.28	-0.78	-2.87	+0.290
1.0	28.63	28.52	-0.11	-0.40	+0.130

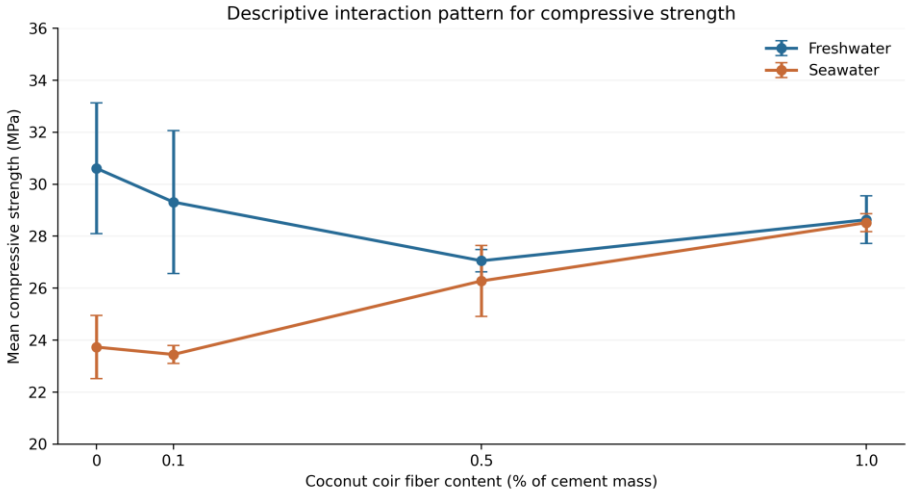
Note. Δ = seawater mean − freshwater mean; the percentage strength change uses freshwater as denominator. Absorption differences are expressed in percentage points (pp). All comparisons use unrounded group means.

The largest relative strength difference occurred in the fiber-free control, for which the seawater mean was approximately 22.48% lower than the freshwater mean. The contrast was also substantial at 0.1% fiber (approximately 20.01%). By comparison, the strength differences were much smaller at 0.5% and 1.0% fiber, with the respective means separated by less than 1 MPa in both cases.

The smaller strength difference at higher fiber contents did not correspond to consistently smaller absorption differences. Indeed, the largest absolute absorption contrast appeared at 0.5% fiber, where the seawater group exceeded its freshwater

counterpart by 0.290 percentage points. These results show that the two outcomes varied differently across the same set of experimental groups and should be reported independently.

The patterns in mean compressive strength across both exposure conditions are presented in Figure 3. The figure connects treatment means in increasing order of fiber content, allowing the direction and separation of the group trends to be examined directly.



Note. Lines connect observed group means; error bars represent ±1 sample SD. The crossing or convergence of descriptive trends is not an inferential test of interaction.

Figure 3. Interaction Patterns between Fiber Content and Exposure Conditions on Compressive Strength

The freshwater means declined from the control to 0.5% fiber and then increased at 1.0%, whereas the seawater means increased substantially between 0.1% and 1.0% fiber. Consequently, the distance between the two series was most pronounced for the control and 0.1% mixtures and became small at 1.0% fiber. This divergence in trend shape provides a descriptive indication that the pattern of group means differed by exposure condition.

The opposing trajectories in Figure 3 reveal a descriptive interaction pattern between fiber content and exposure condition. In particular, the two 1.0% fiber groups exhibited similar mean strengths, whereas the corresponding control groups differed substantially. These observations describe the response across the tested combinations; statistical evidence for an interaction would require a separate factorial analysis.

Changes Relative to Plain Concrete

Fiber-reinforced mixtures were additionally compared with the plain-concrete control under the same immersion condition. Table 8 presents the resulting differences in mean compressive strength and water absorption, with the 0% fiber mixture serving as the control for each exposure medium.

Table 8. Changes in Concrete Performance Relative to Plain Concrete

Exposure	Fiber (%)	Strength (MPa)	Strength Δ (MPa)	Strength Δ (%)	Absorption Δ (pp)
Freshwater	0.1	29.31	-1.30	-4.25	+0.013
Seawater	0.1	23.45	-0.28	-1.19	+0.030

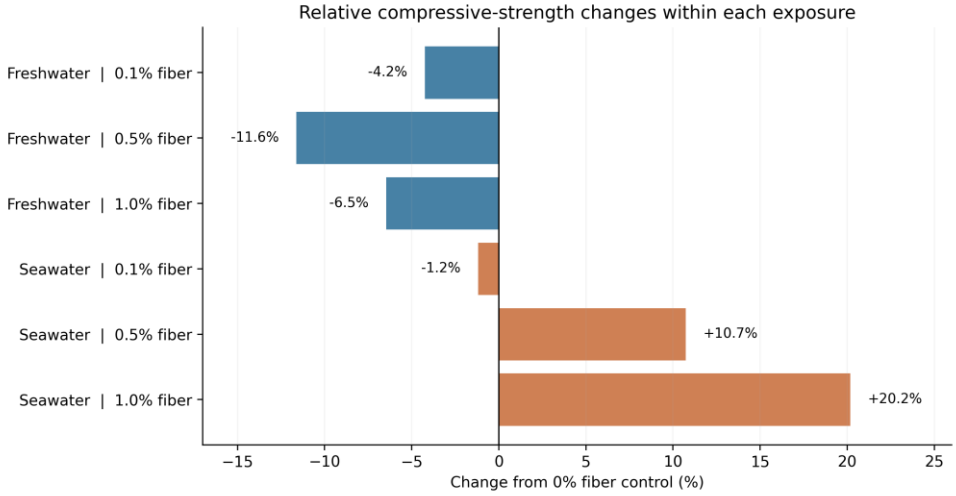
Exposure	Fiber (%)	Strength (MPa)	Strength Δ (MPa)	Strength Δ (%)	Absorption Δ (pp)
Freshwater	0.5	27.05	-3.56	-11.63	-0.063
Seawater	0.5	26.28	+2.55	+10.73	+0.183
Freshwater	1.0	28.63	-1.98	-6.47	+0.023
Seawater	1.0	28.52	+4.79	+20.19	+0.110

Note. Comparisons are against the 0% fiber mixture in the same exposure condition. Differences use unrounded means. A positive value indicates a greater mean than the corresponding control.

In freshwater, fiber addition was associated with lower mean compressive strength relative to the corresponding control at all three investigated dosages. The largest decrease was observed at 0.5% fiber, followed by 1.0% and 0.1%. Water absorption decreased relative to the freshwater control only at 0.5% fiber, whereas the other two fiber additions produced slightly higher mean absorption.

In seawater, the 0.1% fiber mixture exhibited a small negative strength difference relative to plain concrete, while both the 0.5% and 1.0% fiber mixtures had higher mean strength. The relative improvement was greatest at 1.0% fiber, approximately 20.19%. In all three fiber-reinforced seawater groups, mean absorption exceeded that of the plain-concrete control. Accordingly, the observed increase in compressive strength at higher fiber contents did not coincide with lower group-average absorption.

Figure 4 illustrates these control-referenced changes in compressive strength as positive or negative percentage differences. It distinguishes the two immersion media while retaining a common zero reference for plain concrete.



Note. Percentages are calculated from group means, with the 0% fiber group within each medium used as the reference.

Figure 4. Relative Changes in Compressive Strength Compared with Plain Concrete

Relative to plain concrete, all three fiber-reinforced freshwater mixtures showed negative strength changes. Under seawater exposure, the 0.5% and 1.0% fiber mixtures showed positive changes, reaching the largest increase at 1.0% fiber. The zero-centered comparison emphasizes the contrasting group-level responses under the two immersion conditions.

Across the tested mixtures, 1.0% coconut coir fiber produced the highest mean compressive strength under seawater exposure, while plain concrete produced the highest mean under freshwater exposure. The combined strength

and absorption results demonstrate that the ranking of mixtures depended on exposure condition and measured property. These findings characterize the investigated fiber contents and exposure duration.

Discussion

The findings demonstrate that the mechanical response of coconut coir fiber-reinforced concrete depends on the aqueous exposure condition under which its performance is evaluated. The most important observation is the contrasting relationship between fiber content and compressive strength in freshwater- and seawater-exposed concrete. Whereas the incorporation of coconut coir fiber was associated with lower compressive strength than plain concrete under freshwater exposure, the mixtures containing higher fiber contents exhibited greater compressive strength than their corresponding control under seawater exposure. This difference indicates that coconut coir reinforcement cannot be characterized as uniformly beneficial or detrimental across exposure environments. Instead, the response appears to reflect a balance among reinforcement characteristics, the cementitious matrix, and the surrounding moisture conditions. Reviews of coconut coir-reinforced cementitious materials similarly describe substantial variation in compressive performance across fiber contents and mixture compositions, emphasizing that improvements in crack resistance do not necessarily translate into higher compressive strength (Ahmad et al., 2022; Ali et al., 2022; Martinelli et al., 2023). The present findings extend this interpretation by emphasizing the relevance of the exposure medium when assessing the mechanical performance of coconut coir-reinforced concrete.

The interpretation of these exposure-specific patterns is strengthened by recent research on coconut-fiber concrete in marine settings. Zhang et al. (2025) examined coconut-fiber-reinforced coral concrete subjected to seawater corrosion and alternating temperature–humidity cycles and identified a dosage-dependent balance between mechanical retention and pore development. Their material system incorporated coral aggregates and a different exposure regime, so the reported performance levels are not directly interchangeable with those of conventional aggregate concrete. Nevertheless, the study independently demonstrates why reinforcement dosage and saline exposure must be interpreted together rather than as isolated influences. Huang et al. (2025) likewise reported nonmonotonic strength responses to coir addition in concrete incorporating coconut shell aggregates. Because their aggregate replacement and fiber specification differ from those in the present study, the comparison is most useful for understanding the conditional nature of fiber-related strength responses, not for transferring an optimum dosage.

The reduction in compressive strength observed in the freshwater-exposed fiber-reinforced mixtures is consistent with the complex relationship between natural fiber incorporation and the load-bearing capacity of cementitious materials. Unlike conventional concrete, which transfers compressive loads primarily through the hardened cement paste and aggregate skeleton, fiber-reinforced concrete contains additional interfaces between the reinforcing fibers and surrounding matrix. Although these interfaces can contribute to crack bridging and post-cracking behavior, they may also influence material continuity, local compaction, and stress distribution under axial compression. The resulting compressive

response depends on whether the reinforcement-related benefits outweigh any accompanying changes in matrix uniformity and fiber dispersion. Mboungou Londe et al. (2024) reported that the incorporation of coconut fibers into high-strength concrete did not consistently improve its 28-day compressive strength, despite improvements in tensile and flexural behavior. Similar distinctions between compressive performance and other mechanical characteristics have been emphasized in investigations of fiber-reinforced concrete (Guruswamy et al., 2024; Hassan & Saeed, 2024; Mishra et al., 2025). These comparisons suggest that a reduction in compressive strength does not necessarily indicate the absence of other reinforcement benefits, although such benefits must be established using the corresponding mechanical tests.

The role of constituent proportions in shaping this response is also supported by the findings of Ali, Farooq, et al. (2022), who investigated coir fiber and superplasticizer in recycled aggregate concrete. Their work showed that workability control and mixture composition can materially change the balance between mechanical behavior and durability-related outcomes. This comparison is particularly relevant to interpreting why fiber content alone is an incomplete predictor of compressive strength. González et al. (2024), working with concrete blocks containing coconut-derived fibers and other bio-based constituents, similarly showed that density- and strength-related changes arise within a broader compositional system. The blocks, aggregate substitutions, and intended applications differed substantially from the present concrete cylinders; therefore, these studies offer material-level context without constituting direct experimental replications.

The nonmonotonic variation in freshwater compressive strength also suggests that fiber dosage should not be interpreted through a simple linear relationship. The mechanical contribution of a fibrous reinforcement depends on its distribution within the cementitious matrix, the amount of fiber–matrix contact, and the characteristics of the interfacial transition region. Increasing fiber content may introduce additional crack-bridging elements, but it simultaneously increases the number of interfaces whose quality influences the response of the composite. Research on coconut fiber surface modification has demonstrated that changes in fiber morphology and interfacial characteristics can modify the mechanical performance of cement-based materials (Yang et al., 2024). Other studies involving natural fibers have similarly shown that surface treatment, fiber compatibility, and matrix interactions can affect mechanical properties and moisture-related behavior (Biskri et al., 2025; Soares et al., 2026). These mechanisms provide plausible explanations for differences among fiber dosages, although the relative contributions of fiber dispersion, interfacial bonding, and local porosity in the present concrete mixtures cannot be determined solely from compressive-strength measurements.

A second mechanistic consideration concerns the stability of coir within the highly alkaline cement environment. Stapper et al. (2021) reported that short-term coir behavior in cement-based composites cannot be explained by alkalinity alone; compositional and mechanical evidence pointed to distinct degradation pathways and effects of the cement environment. Addis et al. (2022) reviewed degradation and durability enhancement strategies for cellulosic fibers in cementitious and

geopolymer composites, emphasizing the combined role of fiber characteristics and environmental fluctuations. Rocha et al. (2022) likewise summarized differences in natural fiber composition, morphology, and interactions with cement matrices. These studies support considering fiber–matrix compatibility as a possible explanation for variable mechanical performance. They do not establish that chemical degradation, fiber mineralization, or interfacial alteration occurred within the specimens examined here.

A contrasting response emerged under seawater exposure, where the higher coconut coir fiber contents were associated with greater mean compressive strength relative to plain concrete. This finding is particularly relevant because the seawater-exposed mixtures did not exhibit the same ranking observed under freshwater conditions. The difference suggests that the comparative mechanical performance of fiber-reinforced concrete is sensitive to the environment in which the hardened material is exposed. One possible interpretation involves the combined influence of moisture availability, cement hydration, and interactions between the cementitious matrix and dissolved seawater constituents. Marine exposure studies have established that the effects of seawater on cementitious materials depend on exposure duration, binder composition, and the balance between hydration-related processes and chemical alteration (Yi et al., 2020; Ting & Yi, 2023). These processes may contribute differently to mechanical characteristics at early and extended exposure periods. Nevertheless, the higher compressive strength observed in the seawater-exposed fiber-reinforced mixtures should be interpreted as a comparative mechanical response rather than direct evidence that coconut coir fibers suppress chemical deterioration or improve long-term seawater resistance.

The importance of distinguishing exposure-dependent mechanical behavior from established durability performance becomes clearer when considering previous marine concrete investigations. Kim et al. (2025) examined strength development under atmospheric, tidal, and submerged marine conditions and demonstrated that concrete performance depends on both cementitious composition and exposure environment. Their findings illustrate why compressive strength at a particular age cannot be used as a comprehensive measure of resistance to marine deterioration. Similarly, Li et al. (2024) reported that chloride diffusion characteristics differ among stationary, splash, submerged, and pressure-related marine exposures. Dai et al. (2024) further demonstrated that moisture gradients and wetting–drying conditions influence chloride transport in concrete exposed to saline environments. Although these investigations involve different materials and environmental conditions, they establish that exposure history is integral to the interpretation of concrete properties. The present freshwater–seawater comparison therefore contributes to understanding exposure-specific mechanical responses while remaining distinct from studies that directly quantify chloride penetration, chemical degradation, or long-term service performance.

The wider marine-concrete literature also demonstrates why seawater should be treated as a chemically and physically complex exposure medium. Ukpata et al. (2023) reviewed the interaction of external chlorides and sulfates in concrete, showing the importance of coupled ionic environments rather than chloride concentration alone. Mohamed et al. (2024) synthesized fresh, hardened, and

microstructural properties of seawater concrete, while Shrivastava et al. (2024) evaluated short-term properties of confined seawater–sea-sand concrete members. The latter two bodies of evidence involve seawater used in mixture production and, in the case of confined columns, a different structural configuration. They therefore serve to delineate the broader marine-material context, not as direct comparisons with post-casting immersion of unconfined cylinders.

The differences in water absorption provide an additional perspective on the exposure-dependent behavior of coconut coir fiber-reinforced concrete. Water absorption was consistently greater in seawater-exposed specimens than in their freshwater-exposed counterparts, yet the magnitude of this difference varied across fiber contents. The contrasting absorption patterns indicate that the relationship between coconut coir incorporation and moisture uptake is influenced by the exposure condition. This behavior is relevant to the hygroscopic characteristics of lignocellulosic fibers, whose cellular structure and surface chemistry can affect their interaction with water. Research on coconut-fiber-reinforced mortar has shown that fiber preparation and geometry can alter water absorption and electrical resistivity, demonstrating the sensitivity of moisture-related properties to fiber characteristics. In particular, studies comparing raw and boiled coconut fibers identified differences in pore structure and moisture uptake associated with the treatment process. These findings support the importance of evaluating water absorption as an independent physical property rather than assuming that its response can be inferred from fiber dosage alone.

The elevated water absorption observed in the seawater-exposed fiber-reinforced mixtures is also relevant to the quality and continuity of the fiber–matrix interface. Natural fibers introduce a hydrophilic constituent into a predominantly mineral matrix, creating a material system in which moisture interactions may occur through the cement paste, the fiber structure, and the surrounding interfacial region. The relative contribution of these pathways depends on fiber condition, matrix composition, and the arrangement of the composite constituents. Studies involving chemically treated natural fibers have demonstrated that modifying fiber surfaces can influence both interfacial behavior and water-related performance (Biskri et al., 2025; Soares et al., 2026). Experimental investigations of treated natural fiber textiles have also shown that environmental durability depends on the interaction between the fiber system and exposure medium. These findings indicate that moisture-related characteristics are governed by multiple material factors. Consequently, a higher measured absorption value cannot, by itself, be assigned to a particular pore structure, fiber swelling mechanism, or degree of interfacial degradation.

The moisture-related response should also be considered in light of research on fiber aging and surface conditioning. Santana et al. (2021) reviewed vegetable fibers in geopolymer and alkali-activated matrices, identifying binder chemistry and fiber treatment as influential factors in material durability. Hammes et al. (2026) similarly synthesized degradation mechanisms in natural fiber-reinforced alkali-activated composites and found that environmental cycling and interfacial stability shape the retention of properties. These binder systems differ from Portland-cement concrete, but they underscore a transferable conceptual point: moisture exposure and reinforcement–matrix interactions cannot be reduced to fiber content

alone. Santos et al. (2025) demonstrated that chemical and thermal treatments of sisal fibers can affect the properties of cement composites, supporting the need to distinguish untreated and modified plant fibers when interpreting moisture uptake.

One of the most informative findings is that compressive strength and water absorption did not exhibit equivalent response patterns. Under seawater exposure, mixtures with higher mean compressive strength also displayed greater water absorption than plain concrete. The combination demonstrates that mechanical performance and moisture uptake should not be interpreted as interchangeable indicators of concrete quality. Compressive strength reflects the capacity of a specimen to withstand axial loading, whereas absorption describes moisture uptake under the specified conditioning procedure. Although both properties may be influenced by matrix characteristics, they respond to different aspects of material behavior. Comparable distinctions have emerged in previous coconut-fiber studies, where improvements in particular mechanical characteristics were not consistently accompanied by improvements in all durability-related indicators (Mboungou Londe et al., 2024). Conversely, an investigation comparing coconut coir, synthetic, and hybrid fiber reinforcement reported differences among compressive strength, water absorption, porosity, and chloride penetration, reinforcing the importance of assessing each property separately. The present results support this property-specific interpretation and indicate that mechanical and physical performance should be evaluated jointly without assuming a uniform direction of improvement.

The relationship between water absorption and resistance to chloride transport deserves particular consideration because the exposure environment contained seawater. Although absorption measurements are relevant to moisture uptake, they do not directly quantify chloride diffusion, chloride binding, or the concentration of aggressive ions within hardened concrete. Wilson et al. (2024) demonstrated that chloride ingress in cementitious binders depends on transport properties and evolves over extended exposure periods. Their findings highlight the role of binder composition and microstructural development in controlling ionic movement. Related research has demonstrated that chloride transport varies substantially with environmental conditions and the presence of moisture gradients (Dai et al., 2024; Li et al., 2024). Therefore, the absorption differences observed in the present study should be interpreted as physical characteristics of the tested specimens rather than direct indicators of chloride resistance. A mixture exhibiting greater water absorption may still display comparatively high compressive strength, but that combination does not establish its resistance to chemical penetration or long-term deterioration.

It is also important to separate water absorption from processes governing chloride migration. Du et al. (2024) examined chloride transport in unsaturated concrete under different temperature, humidity, and mineral-admixture conditions, while Liu et al. (2024) analyzed the influence of hydrostatic pressure and cation type on transport in marine concrete. Wang et al. (2024) examined chloride-related deterioration under variable-temperature drying–wetting cycles and different water–binder ratios. These investigations show that moisture state, boundary conditions, and binder characteristics alter ionic transport independently of any single gravimetric absorption measurement. Their results support interpreting the

absorption differences here as evidence of distinct moisture-uptake behavior, not as measured chloride permeability or a quantified service-life advantage.

Bulk density provides another dimension for understanding the behavior of the reinforced concrete mixtures. The absence of a consistent monotonic relationship between fiber content and bulk density indicates that adding a low-density natural reinforcement does not necessarily produce a proportional reduction in the measured density of hardened concrete. The bulk density of a concrete specimen reflects the combined influence of constituent proportions, compaction, entrapped air, and hardened material characteristics. Because the principal mixture constituents remained unchanged, the variations among fiber-reinforced groups may reflect changes in how the reinforcement was accommodated within the mixture and the resulting characteristics of the hardened specimens. Investigations of coconut fiber-reinforced high-strength concrete have reported that increasing fiber content can influence fresh density, workability, and air-void-related properties (Mboungou Londe et al., 2024). These observations provide relevant context for the present density patterns. However, bulk-density differences cannot independently establish the distribution of internal voids or the quality of fiber–matrix bonding, both of which require more specific material characterization.

The identical slump values recorded across the investigated mixtures offer an additional point of comparison with existing research. Natural fiber incorporation is frequently associated with changes in fresh concrete consistency because fibers increase the solid surface area requiring wetting and can influence the movement and distribution of constituents during mixing. Studies of coconut coir-reinforced concrete have reported reductions in workability as fiber content increases, although the extent of the response depends on fiber geometry, dosage, and mixture characteristics (Mboungou Londe et al., 2024). The absence of differences in the measured slump values in the present study suggests that the mixtures attained comparable slump under the adopted preparation conditions. This finding should not be interpreted as evidence that fiber content has no influence on all dimensions of fresh concrete behavior, since slump reflects one aspect of consistency rather than fiber dispersion, rheological response, or compaction behavior in their entirety. It does, however, indicate that the measured fresh-state consistency remained comparable across the tested mixtures.

The contrast between freshwater and seawater performance is also relevant to the broader literature on the use of marine resources in concrete production. Research on seawater-mixed concrete has demonstrated that dissolved salts may influence cement hydration, mechanical properties, and durability-related characteristics. Nevertheless, these findings represent a different environmental pathway from exposing already prepared concrete specimens to seawater. When seawater is introduced during mixing, dissolved ions participate in the initial hydration environment, whereas external immersion involves interactions between the exposure medium and a developing or hardened cementitious matrix. The distinction has been emphasized in reviews examining seawater-mixed and sea-sand concrete and its potential applications. Accordingly, findings from seawater-mixed systems can inform the chemical context of saline exposure but should not be used as direct evidence that comparable mechanisms occurred in the present

specimens. Maintaining this distinction helps clarify the interpretation of the observed exposure-dependent differences.

Recent assessments of natural fiber materials reinforce the importance of distinguishing material performance criteria. Siouta et al. (2024) reviewed treated hemp fibers in mortars, highlighting the dependence of composite characteristics on fiber pretreatment and matrix interactions. Hossain and Shuvo (2026) reviewed durability properties of natural fiber-reinforced concrete across several plant fibers and emphasized that responses to permeability, chemical attack, and moisture cannot be inferred from reinforcement inclusion alone. Poso and Calot (2026) similarly reviewed the mechanical and durability-oriented performance of natural fibers in civil engineering applications. These broader syntheses do not yield a transferable numerical prediction for coir-reinforced conventional concrete; rather, they strengthen the rationale for interpreting compressive strength, water absorption, and bulk density as different performance dimensions.

The behavior of coconut coir fibers within cementitious matrices also has implications for the interpretation of the seawater response. The performance of natural fiber reinforcement depends on its resistance to the alkaline environment, interfacial adhesion, and changes associated with moisture exposure. Investigations of raw and chemically treated fibers demonstrate that surface characteristics can substantially alter reinforcement performance, while research on modified coconut fibers has shown that interfacial improvement can influence mechanical response and composite porosity (Yang et al., 2024; Biskri et al., 2025; Soares et al., 2026). These findings suggest that the relative performance of coconut coir fiber-reinforced concrete may arise from competing contributions of reinforcement and matrix-related processes. However, the present observations do not establish whether fiber bridging, chemical modification, additional hydration, or changes in porosity were responsible for the differences between exposure conditions. These explanations are best regarded as plausible material mechanisms rather than experimentally confirmed causes.

The results also illustrate why an apparently favorable response in one property should not automatically determine the preferred fiber content for all applications. A formulation selected primarily on the basis of compressive strength may differ from one selected according to water absorption, bulk density, or other service-related requirements. The highest mean compressive strength under seawater exposure occurred in a fiber-reinforced mixture, but its moisture-absorption characteristics were not identical to those of plain concrete. Conversely, the freshwater control exhibited the highest compressive strength within its exposure condition, whereas a different mixture presented the lowest water absorption. These differences demonstrate that material assessment depends on the performance criterion applied. The broader literature on bio-based and fiber-reinforced cementitious composites similarly emphasizes that reinforcement effectiveness must be judged across relevant mechanical and physical outcomes rather than through a single performance index (Ahmad et al., 2022; Ali et al., 2022; Martinelli et al., 2023).

From an engineering perspective, the findings indicate that coconut coir fiber content and exposure condition should be considered jointly when comparing concrete formulations. A mixture that performs comparatively well under freshwater

exposure may not occupy the same position when assessed after seawater exposure, and the ranking may change further when physical characteristics are considered alongside compressive strength. This observation is particularly relevant to coastal applications, where the exposure environment introduces material demands that differ from those associated with conventional freshwater curing. However, the appropriate engineering interpretation is not that coconut coir reinforcement universally improves marine concrete performance. Rather, the results indicate that the material response is conditional on both the exposure environment and the property used for evaluation. Such a distinction supports a performance-oriented approach to assessing natural fiber-reinforced concrete and avoids generalizations based exclusively on the presence or quantity of renewable reinforcement.

An additional distinction emerges from modern coir modification research. Manuta et al. (2026) studied silica-modified coconut coir in self-healing cementitious composites and reported changes in strength and crack-related performance associated with the modification strategy. This represents an engineered fiber system and should not be conflated with ordinary, untreated coconut coir. Comparing such studies with unmodified coir concrete makes clear that fiber treatment, matrix composition, and performance objectives can alter the apparent benefits of reinforcement. The present strength patterns are therefore more appropriately interpreted within their own material specification than used to assert that any coconut-derived fiber system will exhibit the same exposure response.

The scientific contribution of this study lies in highlighting the distinct mechanical and physical responses of coconut coir fiber-reinforced concrete under different immersion conditions. Variations in compressive strength, water absorption, and bulk density indicate that no single property adequately represents material performance. These observations emphasize the importance of considering both immersion conditions and property-specific responses when evaluating coconut coir reinforcement, without assuming that higher fiber content necessarily leads to superior concrete performance.

CONCLUSION

This study demonstrates that the mechanical and physical properties of coconut coir fiber-reinforced concrete exhibit distinct responses under freshwater and seawater exposure. Under freshwater exposure, plain concrete achieved the highest mean compressive strength of 30.61 MPa, while fiber-reinforced mixtures exhibited lower mean strengths across the investigated fiber contents. Conversely, under seawater exposure, the mixture containing 1.0% coconut coir fiber achieved the highest mean compressive strength of 28.52 MPa, representing a 20.19% increase relative to the corresponding plain-concrete control. The difference in mean compressive strength between freshwater and seawater exposure also decreased with increasing fiber content, reaching approximately 0.40% at 1.0% fiber. These findings establish that the relative compressive performance of coconut coir-reinforced concrete depends on the exposure condition.

The physical properties exhibited different response patterns from compressive strength. Bulk density varied across the fiber contents and exposure conditions without a consistent monotonic trend, while water absorption was higher

under seawater exposure than under freshwater exposure at every investigated fiber content. The highest mean water absorption occurred at 0.5% fiber under seawater exposure, whereas the lowest was observed at the same fiber content under freshwater exposure. These contrasting patterns indicate that improved relative compressive strength does not necessarily correspond to reduced water absorption or systematic changes in bulk density. Accordingly, the mechanical and physical characteristics of coconut coir fiber-reinforced concrete should be considered complementary but distinct indicators of material performance.

The principal contribution of this study is the identification of exposure-dependent differences in the relative mechanical and physical performance of coconut coir fiber-reinforced concrete. The findings indicate that the suitability of fiber incorporation depends on both the environmental exposure condition and the performance characteristic being considered. Within the investigated fiber range and exposure period, a 1.0% coconut coir fiber content provided the highest mean compressive strength under seawater exposure, whereas plain concrete retained the highest mean strength under freshwater exposure. These findings provide an empirical basis for evaluating coconut coir reinforcement in relation to specific material performance requirements rather than assuming that increasing fiber content produces uniform improvements across different exposure environments.

RECOMMENDATION

Future research should extend the evaluation of coconut coir fiber-reinforced concrete by examining broader fiber contents, different fiber lengths, and alternative fiber preparation or surface-treatment procedures to identify combinations that provide a favorable balance between mechanical and physical performance. Particular attention should be given to prolonged freshwater and seawater exposure, including different immersion durations and wetting–drying cycles, to characterize changes in material behavior over time. Additional measurements of flexural strength, splitting tensile strength, porosity, sorptivity, chloride penetration, and microstructural characteristics would help clarify the relationships among fiber–matrix interactions, moisture transport, and mechanical response. Furthermore, increasing the number of specimens and incorporating appropriate statistical analyses would strengthen the evaluation of fiber-content and exposure-related effects. These investigations would support the development of performance-based recommendations for coconut coir fiber-reinforced concrete in construction environments where moisture exposure and mechanical requirements must be considered simultaneously.

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