Journal of Advanced Sciences and Mathematics Education
Volume 6, Issue 3, 487-514.
e_ISSN: 2798-1606
DOI: 10.58524/jasme.v6i3.1451

Engineering performance assessment of sustainable coconut coir fiber-reinforced pervious concrete for perforated breakwater design

Susi Hariyani
Politeknik Negeri Pontianak, INDONESIA

Randy Setiawan*
Politeknik Negeri Pontianak, INDONESIA

Elza Naila Edi Priyoto
Politeknik Negeri Pontianak, INDONESIA

Riska Amelia Putri Permatasya
Politeknik Negeri Pontianak, INDONESIA

Article Info

Article history:

Received: May 15, 2026
Revised: June 25, 2026
Accepted: Augst 08, 2026

Keywords:

Coconut Coir Fiber; Engineering Performance; Perforated Breakwater; Pervious Concrete; Sustainable Concrete.

Abstract

Background: Coastal erosion has increased the demand for sustainable construction materials capable of reducing wave energy while minimizing environmental impacts. Pervious concrete is considered a promising alternative for perforated breakwaters because of its interconnected pore structure; however, its relatively low mechanical strength remains a major limitation.
Aims: This study assesses the engineering performance of coconut coir fiber-reinforced pervious concrete for perforated breakwater applications by evaluating its mechanical and hydraulic properties.
Method: An experimental study was conducted using coconut coir fiber contents of 0%, 1%, 3%, 5%, and 7% by weight of coarse aggregate. Concrete specimens (150 × 150 × 150 mm) were cured for 28 days under freshwater and seawater conditions. Compressive strength, porosity, water absorption, and infiltration rate were measured to determine the optimum fiber content.
Results: Increasing the fiber content enhanced porosity, water absorption, and infiltration capacity but reduced compressive strength. The 5% fiber mixture exhibited the most balanced performance, with porosity values of 14.84% in freshwater and 15.35% in seawater while maintaining acceptable mechanical properties for porous concrete.
Conclusion: Coconut coir fiber can improve the hydraulic performance of pervious concrete and represents a sustainable alternative for perforated breakwater design. However, further optimization is required to achieve the compressive strength required for primary coastal protection structures.

To cite this article: Hariyani, S., Setiawan, R., Priyoto, E. N. E. & Permatasya, R. A. P. (2026). Engineering performance assessment of sustainable coconut coir fiber-reinforced pervious concrete for perforated breakwater design. *Journal of Advanced Sciences and Mathematics Education, 6*(3), 487-514.

INTRODUCTION

Coastal erosion has become an increasingly critical environmental and engineering challenge because continuous wave action, tidal fluctuations, extreme coastal processes, and anthropogenic activities can accelerate shoreline retreat and threaten infrastructure located in vulnerable coastal zones. Conventional coastal protection systems, including rubble mound and solid concrete breakwaters, have been widely constructed to reduce incoming wave energy and protect shorelines from progressive degradation. However, relatively impermeable structures can reflect substantial wave energy toward the surrounding environment, potentially intensifying local scour, altering sediment distribution, and generating undesirable interactions between coastal structures and natural processes (Duan et al., 2025; Hussein et al., 2025; Romão et al., 2024; Saengsupavanich et al., 2022; Wright & Thom, 2023). These limitations have encouraged the development of coastal protection systems that provide sufficient structural resistance while offering improved hydraulic

***Corresponding author:**
Randy Setiawan, Politeknik Negeri Lampung, Indonesia
raindiwawan90@gmail.com

functionality and greater environmental compatibility. Previous engineering studies have demonstrated that modifications to construction materials can substantially influence their performance characteristics, highlighting the importance of evaluating material composition in relation to the functional requirements of infrastructure applications (Karami et al., 2020). Pervious concrete represents a promising material for this purpose because its interconnected pore structure permits water transmission through the concrete body and provides opportunities for dissipating incoming hydraulic energy (Debnath & Sarkar, 2020; Elizondo-Martínez et al., 2020; Shan et al., 2022). The porous configuration distinguishes pervious concrete from conventional dense concrete and creates functional characteristics that can potentially support its application in permeable and perforated coastal protection structures. Nevertheless, the void network responsible for permeability simultaneously reduces the effective load-bearing area within the material and may consequently decrease its compressive strength. This inverse relationship between mechanical resistance and hydraulic functionality represents one of the fundamental engineering challenges associated with the broader structural application of pervious concrete. The challenge becomes particularly relevant for perforated breakwaters because the material must provide adequate resistance to structural loading while maintaining sufficient interconnected pores to facilitate water movement and energy dissipation. Sustainable infrastructure development increasingly requires engineering solutions that integrate functional performance with efficient water management and environmental considerations (Ha & Ardianti, 2025). Therefore, developing pervious concrete capable of achieving an appropriate balance between mechanical performance, hydraulic functionality, and environmental sustainability is essential for advancing its application in coastal protection infrastructure.

The incorporation of natural fibers has emerged as a potential strategy for modifying concrete performance while simultaneously promoting the utilization of renewable and locally available materials. Coconut coir fiber is particularly attractive because it is an agricultural by-product with favorable toughness, flexibility, and potential resistance to humid and marine environments. Previous studies have increasingly investigated coconut and coir fibers as renewable reinforcement materials and examined their effects on the mechanical properties, durability, porosity, and sustainability of conventional and recycled aggregate concrete . In cement-based composites, coconut coir fiber can contribute to structural continuity by bridging microcracks and modifying post-cracking behavior, although its effectiveness depends substantially on fiber content and fiber–matrix interaction. Parallel research on pervious concrete has investigated basalt, carbon, steel, polypropylene, recycled synthetic, and other fibers as reinforcement strategies for improving strength, ductility, pore characteristics, permeability, and durability (Abeer et al., 2024; Bilal et al., 2024; Bright Singh & Madasamy, 2022; Furkan Ozel et al., 2022; Oni et al., 2020; Tang et al., 2022; Tran et al., 2024; Wu et al., 2022; Yuan et al., 2024). These studies indicate that fiber type, aggregate characteristics, mixture composition, and pore configuration can collectively determine the mechanical–hydraulic behavior of pervious concrete (Furkan Ozel et al., 2022; Wu et al., 2022). More recent developments have also focused on high-performance and low-carbon pervious concrete by modifying cementitious matrices and aggregate systems to increase mechanical resistance without eliminating the permeability required for its intended functionality (Cui et al., 2024; Tran et al., 2024). Nevertheless, increasing fiber content does not necessarily result in improved overall engineering performance because excessive fiber incorporation may generate additional voids and weaker interfacial transition zones within the concrete matrix. Consequently, the suitability of coconut coir fiber for pervious concrete should be evaluated through multiple complementary performance indicators rather than through compressive strength or permeability considered independently. An integrated assessment of compressive strength, porosity, water absorption, and infiltration characteristics is therefore required to determine whether natural fiber incorporation can provide an appropriate balance between structural and hydraulic requirements.

Beyond conventional pavement and drainage applications, recent research has begun to extend pervious concrete into marine and coastal engineering because its interconnected pore structure offers functional opportunities for water transmission and wave-energy dissipation (He et al., 2023; Qian et al., 2026; Uddin et al., 2021). Research involving coral aggregate and seawater has demonstrated the feasibility of developing pervious concrete under marine-related material conditions while considering both mechanical strength and water permeability (He et al., 2023). Porous and pervious structural concepts have also been introduced into breakwater engineering, where structural permeability can influence wave transmission, reflection, hydrodynamic forces, and energy attenuation (Sukcharoen et al., 2024; Vijay et al., 2022). Investigated pervious concrete as a permeable breakwater and demonstrated its potential for attenuating wave energy, establishing an important foundation for further material development in coastal protection systems. Research has additionally examined the mechanical deterioration and damage evolution of fiber-reinforced pervious concrete following seawater erosion, emphasizing that marine exposure must be considered when assessing its engineering suitability (Yan et al., 2025). Despite these developments, existing research remains fragmented because studies on coconut coir fiber have predominantly focused on conventional concrete, whereas fiber-reinforced pervious concrete studies have largely employed mineral or synthetic fibers (Ahmad et al., 2022; Bilal et al., 2024; Furkan Ozel et al., 2022; Wu et al., 2022). Similarly, coastal applications of pervious concrete have primarily addressed seawater-based materials, durability, hydrodynamic behavior, or wave attenuation without specifically integrating renewable coconut coir fiber and simultaneous mechanical–hydraulic optimization (He et al., 2023; Sukcharoen et al., 2024; Yan et al., 2025). Consequently, limited experimental evidence explains how different coconut coir fiber dosages simultaneously affect compressive strength, porosity, water absorption, and infiltration performance of pervious concrete specifically intended for perforated breakwater applications. Comparative evidence under freshwater and seawater curing conditions is also needed because the intended coastal application requires an understanding of material behavior under environments representative of marine infrastructure. Addressing this intersection is important because improving interconnected porosity and hydraulic functionality may simultaneously compromise mechanical resistance, making the determination of an optimum fiber dosage an engineering optimization problem rather than an effort to maximize a single property.

Recent research has increasingly explored the incorporation of fibers and sustainable materials into concrete to improve engineering performance while reducing environmental impacts. Coconut and coir fibers have received particular attention as renewable reinforcement materials, with previous studies examining their effects on the mechanical properties, durability, porosity, and sustainability of conventional concrete and recycled aggregate concrete (Ahmad et al., 2022; Ali et al., 2022; Bediako et al., 2025; Huang et al., 2025; Mutnbak, 2026). Parallel developments in pervious concrete have demonstrated that fiber incorporation can substantially modify its mechanical and physical characteristics, with basalt, carbon, steel, polypropylene, recycled synthetic, and other fibers being investigated to improve strength, ductility, pore characteristics, permeability, and durability (Abeer et al., 2024; Bilal et al., 2024; Bright Singh & Madasamy, 2022; Furkan Ozel et al., 2022; Oni et al., 2020; Tang et al., 2022; Tran et al., 2024; Wu et al., 2022; Yuan et al., 2024). Previous studies further indicate that aggregate characteristics and fiber type influence the mechanical–hydraulic balance of pervious concrete, emphasizing the importance of simultaneously considering strength and permeability rather than optimizing either property independently (Furkan Ozel et al., 2022; Wu et al., 2022). Research has also progressed toward high-performance and low-carbon pervious concrete through modifications to cementitious matrices, aggregates, and reinforcing materials to improve compressive strength while maintaining permeability and sustainability (Cui et al., 2024; Tran et al., 2024). Beyond conventional pavement and drainage applications, pervious concrete has increasingly attracted attention in marine and coastal engineering, including reef restoration, living shorelines, seawater-based concrete, and coastal infrastructure (He et al., 2023; Qian et al., 2026; Uddin et al., 2021). More specifically, porous and pervious structural concepts have been introduced into breakwater engineering, where structural permeability has been associated with wave transmission, reflection, and energy attenuation (Sukcharoen et al., 2024; Vijay et al., 2022). Recent research has additionally examined the mechanical deterioration and damage life of fiber-reinforced pervious concrete following seawater erosion, further highlighting the importance of material performance under marine exposure (Yan et al., 2025).

Despite these developments, existing research remains fragmented across several distinct domains. Studies on coconut coir fiber have predominantly focused on conventional or recycled aggregate concrete, whereas fiber-reinforced pervious concrete research has largely employed mineral or synthetic fibers rather than renewable coconut coir fiber (Ahmad et al., 2022; Ali et al., 2022; Bilal et al., 2024; Furkan Ozel et al., 2022; Wu et al., 2022). Meanwhile, studies extending pervious concrete to marine and coastal environments have primarily addressed seawater-based materials, durability, wave interaction, or hydrodynamic performance, rather than simultaneously optimizing natural-fiber reinforcement and mechanical–hydraulic properties for breakwater applications (He et al., 2023; Sukcharoen et al., 2024; Yan et al., 2025). Consequently, limited evidence is available regarding the incorporation of coconut coir fiber into pervious concrete specifically for perforated breakwater applications, particularly concerning how variations in fiber dosage simultaneously influence compressive strength, porosity, water absorption, and infiltration performance under freshwater and seawater curing conditions. This gap is important because increasing fiber content and interconnected porosity may improve hydraulic functionality while simultaneously reducing mechanical resistance, meaning that an optimum fiber dosage must be determined rather than simply maximizing fiber incorporation or permeability. Therefore, the present study bridges these previously separated research domains by integrating renewable coconut coir fiber reinforcement, pervious concrete technology, mechanical–hydraulic performance assessment, freshwater and seawater curing conditions, and perforated breakwater applications within a single experimental framework. Through this approach, the study seeks to identify an optimum coconut coir fiber content capable of providing a balanced combination of structural resistance, hydraulic functionality, and material sustainability for perforated breakwater design.

This study aims to assess the engineering performance of sustainable coconut coir fiber-reinforced pervious concrete for perforated breakwater design through an integrated evaluation of its mechanical and hydraulic characteristics. The investigation specifically examines coconut coir fiber contents of 0%, 1%, 3%, 5%, and 7% by weight of coarse aggregate to determine the influence of fiber dosage on concrete performance. Specimens are evaluated after 28 days of curing under freshwater and seawater conditions to provide comparative evidence relevant to coastal infrastructure environments. Mechanical performance is assessed through compressive strength as an indicator of the material's capacity to maintain structural resistance. Hydraulic performance is evaluated through porosity, water absorption, and infiltration rate to characterize the capacity of the interconnected pore network to accommodate water movement. The simultaneous assessment of these parameters is intended to clarify the trade-off between structural resistance and hydraulic functionality associated with increasing coconut coir fiber content. Furthermore, the study seeks to determine whether moderate fiber incorporation can enhance hydraulic characteristics without producing an excessive reduction in mechanical performance. The comparative curing conditions are incorporated to provide additional understanding of the engineering behavior of the proposed material under freshwater and seawater environments. Based on these evaluations, the study seeks to identify the optimum coconut coir fiber content that provides the most appropriate balance between compressive strength, porosity, water absorption, and infiltration capacity. Ultimately, this research is expected to provide experimental evidence for the development of renewable fiber-reinforced pervious concrete as a sustainable and functionally balanced material for perforated breakwater and coastal protection applications.

LITERATURE REVIEW

Pervious concrete has emerged as an important material in sustainable infrastructure because its interconnected pore network provides hydraulic characteristics that differ substantially from those of conventional dense concrete. The intentionally developed void structure allows water to move through the concrete matrix and makes permeability one of its principal functional properties (Abdel Rahman & Dincer, 2020; Lavagna & Nisticò, 2022; Mitrosz et al., 2025). This characteristic has traditionally supported its application in pavements and drainage systems, but recent developments have expanded its potential toward environmental and coastal engineering applications (Cui et al., 2024). The engineering performance of pervious concrete is strongly governed by interactions among aggregate characteristics, cementitious matrix composition, pore connectivity, and mixture proportions (Cui et al., 2024; Furkan Ozel et al., 2022). Increasing porosity generally enhances water transmission but simultaneously reduces the effective load-bearing area and can consequently decrease mechanical strength. This relationship creates a fundamental trade-off between mechanical resistance and hydraulic functionality that must be considered when designing pervious concrete for structural applications (Furkan Ozel et al., 2022; Wu et al., 2022). Recent approaches have therefore focused on modifying mixture compositions and cementitious systems to achieve higher compressive strength without eliminating the interconnected pores responsible for permeability (Cui et al., 2024; Tran et al., 2024). Such developments demonstrate that optimum pervious concrete performance cannot be defined solely by maximizing either strength or permeability. Instead, mechanical and hydraulic properties need to be evaluated simultaneously according to the functional requirements of the intended infrastructure. This performance-based perspective becomes particularly important when pervious concrete is proposed for coastal protection structures that require both structural resistance and controlled water transmission.

Fiber reinforcement represents one approach for modifying the structural behavior of pervious concrete while maintaining its characteristic porous configuration. Different fiber materials have been investigated because fibers can interact with the cementitious matrix, aggregate skeleton, and pore network in ways that influence both mechanical and hydraulic properties. Previous research has incorporated basalt, carbon, steel, polypropylene, recycled synthetic, and other fibers into pervious concrete to examine improvements in strength, ductility, crack resistance, permeability, and durability (Bright Singh & Madasamy, 2022; Oni et al., 2020; Tang et al., 2022; Tran et al., 2024; Wu et al., 2022). Basalt fiber-reinforced pervious concrete, for example, demonstrates that fiber incorporation can modify mechanical performance while simultaneously influencing pore-related characteristics (Wu et al., 2022). Aggregate properties and fiber characteristics have also been identified as influential factors in determining the relationship between mechanical performance and permeability (Furkan Ozel et al., 2022). Nevertheless, fiber reinforcement does not necessarily produce proportional improvements as fiber dosage increases because excessive incorporation can interfere with cement paste continuity and aggregate bonding. High fiber contents may also alter void distribution and generate additional fiber–matrix interfaces that affect load transfer within the hardened composite (Chen et al., 2021; Goda et al., 2024; Noman et al., 2026). Consequently, identifying an appropriate fiber content is more important than simply maximizing the quantity of reinforcement incorporated into pervious concrete. Evaluation of fiber-reinforced pervious concrete should therefore integrate compressive strength with pore- and water-related indicators to establish its overall engineering suitability. This approach provides the conceptual basis for determining whether a particular fiber material can improve functional performance without creating unacceptable reductions in structural capacity.

Natural fibers provide an additional sustainability dimension because they offer opportunities to replace or complement manufactured reinforcement while utilizing renewable or agricultural resources. Coconut coir fiber is particularly relevant because coconut processing generates fibrous residues that can potentially be converted into value-added construction materials rather than remaining underutilized agricultural by-products. Existing studies have investigated coconut and coir fibers in concrete and reported their potential contributions to mechanical behavior, durability, pore characteristics, and sustainable material development (Ahmad et al., 2022; Ali et al., 2022; Bediako et al., 2025; Huang et al., 2025; Mutnbak, 2026). The fibrous morphology and toughness of coconut coir enable it to interact with the cementitious matrix and potentially bridge microcracks that develop under loading. However, coconut coir is a lignocellulosic and hydrophilic material, meaning that its interaction with water and cement paste can also affect the internal structure of the composite. These characteristics are particularly significant in pervious concrete because its engineering functionality depends directly on the configuration and connectivity of internal voids. Incorporating coconut coir fiber may therefore influence compressive resistance, pore formation, water absorption, and infiltration simultaneously rather than affecting only one material property (Alenezi et al., 2025; Nissar et al., 2025; Rodríguez-Robalino et al., 2025). An insufficient fiber dosage may provide limited modification, whereas excessive fiber incorporation may disrupt matrix continuity and increase void formation beyond the level desirable for mechanical resistance. Accordingly, coconut coir fiber content should be treated as an optimization parameter whose engineering suitability depends on the balance achieved among multiple performance indicators. Integrating coconut coir fiber into pervious concrete thus offers a potentially valuable pathway for combining agricultural resource utilization with the development of multifunctional and sustainable construction materials.

The application of pervious concrete in marine and coastal environments introduces engineering requirements beyond those typically encountered in pavement and drainage applications. Coastal structures are subjected to water movement and environmental exposure while being expected to maintain sufficient mechanical integrity throughout their intended service conditions. Recent investigations have consequently explored pervious concrete using marine-related materials and conditions, including seawater, coral aggregates, reef restoration systems, and living shoreline applications (He et al., 2023; Qian et al., 2026; Uddin et al., 2021). Research using coral aggregate and seawater indicates that mechanical strength and water permeability can be considered simultaneously when developing pervious concrete for marine-related environments (He et al., 2023). Marine exposure also creates potential deterioration mechanisms, making the response of fiber-reinforced pervious concrete to seawater an important consideration for coastal applications. Examined mechanical performance and damage development following seawater erosion, illustrating the relevance of environmental exposure to the long-term engineering behavior of fiber-reinforced pervious concrete. These findings suggest that material performance observed under conventional freshwater conditions cannot automatically represent behavior relevant to marine infrastructure. Comparative assessment under freshwater and seawater conditions can therefore provide useful evidence regarding changes in the mechanical and hydraulic responses of the material. Such comparisons are especially relevant for coconut coir fiber because both the natural fiber and interconnected pore network facilitate interactions between the composite and surrounding water. Evaluating curing environments alongside fiber dosage consequently provides a more comprehensive framework for assessing pervious concrete intended for coastal engineering.

Breakwaters represent a particularly relevant coastal application for pervious concrete because their effectiveness is closely associated with interactions between structural geometry, incoming water, and wave energy. Conventional impermeable structures primarily resist and reflect incoming waves, whereas porous structures can permit partial water transmission and promote energy dissipation through interconnected void spaces. Previous research on porous and permeable breakwater concepts has demonstrated that structural porosity can influence wave reflection, transmission, hydrodynamic forces, and energy attenuation (Sukcharoen et al., 2024; Vijay et al., 2022). More specifically, investigated solitary-wave attenuation through a pervious concrete breakwater, providing evidence that pervious concrete can serve a functional role beyond conventional pavement applications. These findings establish an important relationship between material porosity and the hydraulic function expected from permeable coastal protection structures. However, a material suitable for breakwater construction must also retain sufficient mechanical resistance, meaning that enhanced permeability cannot be considered independently from compressive performance. For perforated breakwater design, this requirement creates a multidimensional optimization problem involving strength, porosity, water absorption, infiltration, and environmental exposure. Coconut coir fiber-reinforced pervious concrete provides a potentially sustainable solution because it combines a permeable cementitious matrix with renewable fiber reinforcement and agricultural resource utilization. Nevertheless, its engineering suitability depends on identifying a fiber dosage that enhances or preserves hydraulic functionality without causing an excessive loss of compressive resistance under relevant curing conditions. Therefore, evaluating different coconut coir fiber contents through compressive strength, porosity, water absorption, and infiltration rate under freshwater and seawater conditions provides an integrated theoretical and engineering foundation for sustainable perforated breakwater material design.

METHOD

Research Design and Experimental Setting

This study employed a quantitative experimental design to investigate the effect of coconut coir fiber incorporation on the mechanical and hydraulic performance of pervious concrete intended for perforated breakwater applications. The experimental work was conducted under controlled laboratory conditions at the Civil Engineering Laboratory, Politeknik Negeri Pontianak, Indonesia, from November 3 to December 26, 2025. Coconut coir fiber content was treated as the primary independent variable, whereas compressive strength, porosity, infiltration, and water absorption were evaluated as dependent variables. Five coconut coir fiber contents were investigated, namely 0%, 1%, 3%, 5%, and 7% by weight of coarse aggregate. The 0% mixture was used as the control, while the remaining four mixtures represented increasing levels of natural fiber incorporation. All specimens were prepared as 150 × 150 × 150 mm concrete cubes and tested at the age of 28 days. To examine the effect of environmental exposure relevant to coastal applications, the specimens were divided into freshwater- and seawater-curing groups. Four specimens were prepared for each combination of fiber dosage and curing condition, resulting in a total of 40 specimens. The overall experimental design is summarized in Table 1.

This factorial arrangement enabled a systematic comparison of the effects of increasing coconut coir fiber content under freshwater and seawater curing conditions. Consistent specimen dimensions, curing duration, and preparation procedures were maintained across all experimental groups to minimize uncontrolled variations in the measured responses. The experimental framework therefore provided a basis for evaluating the mechanical–hydraulic trade-off and identifying the fiber dosage that achieved the most balanced performance for the intended perforated breakwater application.

Table 1. Experimental design and specimen distribution

Coconut coir fiber content	Freshwater curing	Seawater curing	Total specimens
0%	4	4	8
1%	4	4	8
3%	4	4	8
5%	4	4	8
7%	4	4	8
Total	**20**	**20**	**40**

The overall experimental sequence consisted of material characterization, mixture proportioning, concrete production, fresh-concrete testing, specimen casting, curing, physical-property testing, mechanical testing, and comparative analysis. For the article, the existing laboratory documentation can be consolidated into a single research procedure diagram as shown in Figure 1.

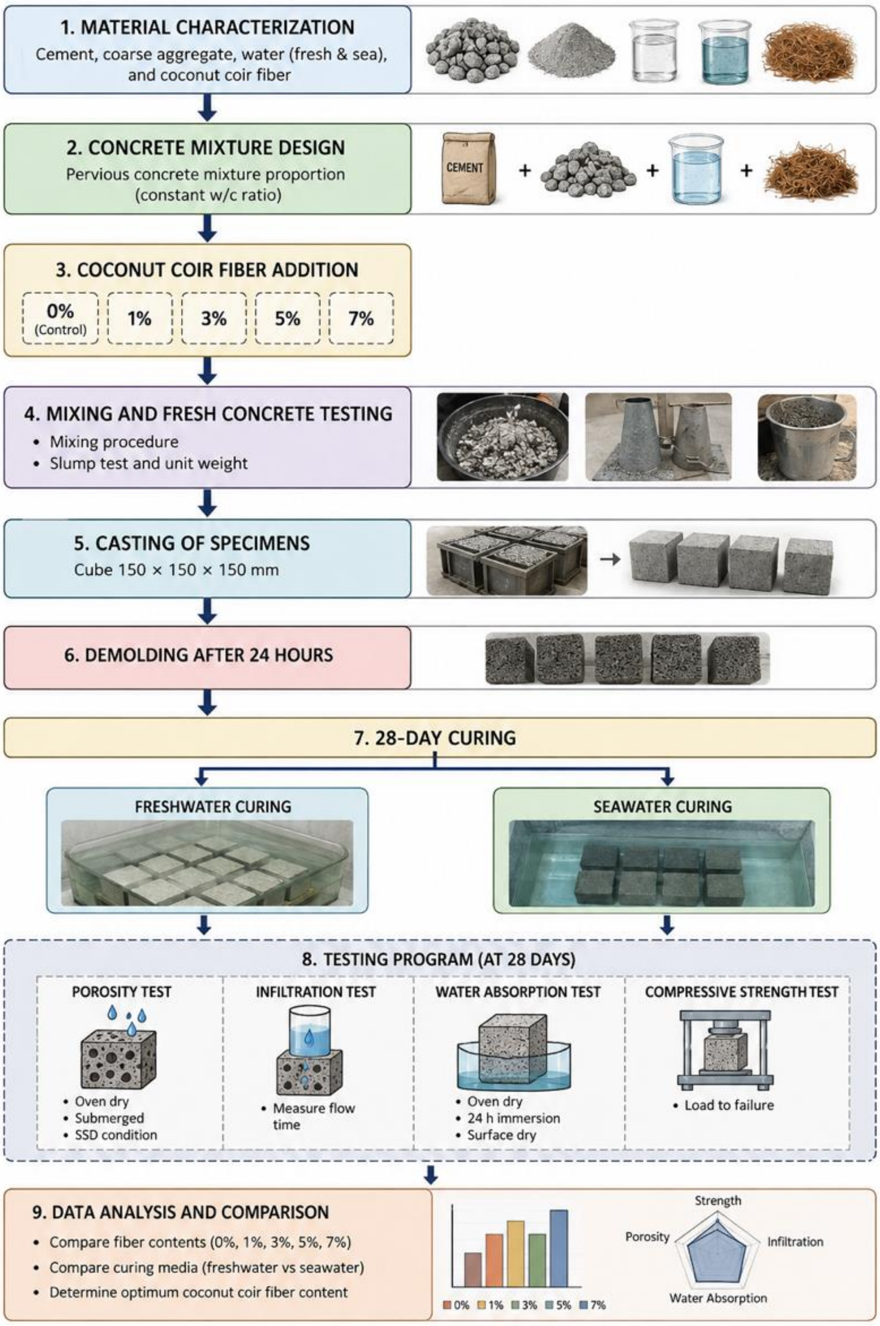

Figure 1. Experimental research procedure for coconut coir fiber-reinforced pervious concrete.

Figure 1. Experimental research procedure for coconut coir fiber-reinforced pervious concrete

Materials

The constituent materials consisted of Portland cement, crushed coarse aggregate, freshwater, seawater, and untreated coconut coir fiber. Portland cement served as the primary binder, whereas crushed coarse aggregate provided the skeletal structure required to form interconnected pores within the pervious concrete. Freshwater supplied by the local water utility was used during concrete production and as one of the curing media. Seawater was used as an alternative curing medium to provide an initial representation of exposure conditions associated with coastal infrastructure. Coconut coir fiber was incorporated as a natural reinforcing material at predetermined percentages relative to the weight of coarse aggregate. Before mixing, the fibers were cut into smaller pieces to facilitate more uniform distribution throughout the concrete matrix. The materials and their functions are summarized in Table 2.

Table 2. Materials used in the experimental program

Material	Function
Portland cement	Primary binder for the concrete constituents
Crushed coarse aggregate	Main structural skeleton and pore-forming aggregate
Freshwater	Mixing water and freshwater curing medium
Seawater	Marine-representative curing medium
Coconut coir fiber	Natural fiber reinforcement/additional material

Material Characterization

Prior to specimen production, coarse aggregate was characterized to determine its suitability for pervious concrete preparation. The characterization included moisture content, specific gravity and absorption, bulk density, particle-size distribution, and abrasion resistance. Moisture content was measured according to SNI 03-1971-1990 by oven-drying the aggregate at 110 ± 5°C until a constant mass was achieved. Specific gravity and absorption were determined following SNI 1969:2016 using oven-dry and saturated-surface-dry conditions. Loose and compacted bulk densities were evaluated according to SNI 03-4804-1998. Particle-size distribution was determined through sieve analysis following SNI 03-1968-1990. Aggregate resistance to abrasion and mechanical degradation was examined using the Los Angeles abrasion test according to SNI 2417:2008. During this test, the prepared aggregate and steel spheres were subjected to 500 revolutions at approximately 30–33 rpm before the percentage of material loss was calculated. The existing photographs of aggregate characterization can be combined into a representative composite image rather than presented individually.

The results of these preliminary tests were used to verify the consistency and suitability of the coarse aggregate before its incorporation into the concrete mixtures. Particular attention was given to particle-size distribution because aggregate gradation directly influences the formation and continuity of voids within pervious concrete. The bulk-density measurements were also used to support the determination of aggregate quantities required in the subsequent mixture design. Meanwhile, specific gravity and water absorption provided essential information for adjusting aggregate conditions and maintaining the intended water content during concrete preparation. The Los Angeles abrasion test complemented the physical characterization by assessing the resistance of the aggregate to mechanical degradation during handling and loading. Collectively, these characterization procedures established a consistent material basis for preparing all fiber variations and enabled subsequent differences in concrete performance to be evaluated primarily in relation to coconut coir fiber content and curing conditions.

Figure 2. Material characterization procedures: (a) oven drying for moisture-content determination; (b) saturated-surface-dry aggregate preparation; (c) bulk-density measurement; (d) sieve analysis; and (e) Los Angeles abrasion testing.

Concrete Mixture and Specimen Preparation

Concrete preparation began by weighing Portland cement, coarse aggregate, water, and coconut coir fiber according to the predetermined mixture proportions. Coconut coir fiber was incorporated at 0%, 1%, 3%, 5%, and 7% by weight of coarse aggregate. Before mixing, the mixing surface was moistened to minimize unintended loss of mixing water. Cement and coarse aggregate were initially combined, followed by gradual incorporation of coconut coir fiber while the mixture was continuously mixed to minimize fiber agglomeration. Water was subsequently introduced in stages until the required consistency of the pervious concrete was obtained. Particular attention was given to maintaining relatively uniform fiber dispersion because fiber clustering could affect both cement-matrix continuity and interconnected pore formation. The fresh mixture was then placed into pre-oiled 150 × 150 × 150 mm cube molds. Compaction was applied sufficiently to fill the molds while avoiding excessive consolidation that could reduce the characteristic void structure of pervious concrete. The upper surfaces were leveled, and the specimens were stored under laboratory conditions for approximately 24 hours before demolding.

After demolding, each specimen was visually inspected to ensure that no major defects or damage had occurred during casting and removal from the molds. The specimens were subsequently classified according to fiber content and assigned to either freshwater or seawater curing conditions. Four specimens from each fiber variation were allocated to each curing medium, resulting in eight specimens for every mixture and 40 specimens in total. All specimens were immersed for 28 days under their designated curing conditions to maintain consistent curing duration across the experimental groups. This preparation protocol was applied uniformly to minimize variations associated with casting, compaction, specimen dimensions, and curing time. Consequently, differences observed in the subsequent physical and mechanical tests could be systematically evaluated according to coconut coir fiber dosage and curing environment.

Figure 3. Preparation of coconut coir fiber-reinforced pervious concrete: (a) weighing constituent materials; (b) mixing cement, coarse aggregate, and coconut coir fiber; (c) controlling fresh-mixture consistency; (d) casting into cube molds; (e) compaction; and (f) demolding after 24 h.

Fresh Concrete Test

The properties of fresh concrete were assessed through slump and unit-weight measurements. The slump test was conducted according to SNI 1972:2008 to evaluate the consistency and workability of the mixtures. The slump mold was filled in three approximately equal layers, with each layer subjected to 25 uniformly distributed strokes using a tamping rod. After the final layer was compacted and leveled, the mold was lifted vertically, and the reduction in specimen height was recorded as the slump value. Fresh concrete unit weight was evaluated according to SNI 03-1973-1990. The measuring container was filled in three layers, each compacted with 25 rod penetrations, followed by light tapping of the container to eliminate visible entrapped air. The surface was subsequently leveled and the total mass was recorded.

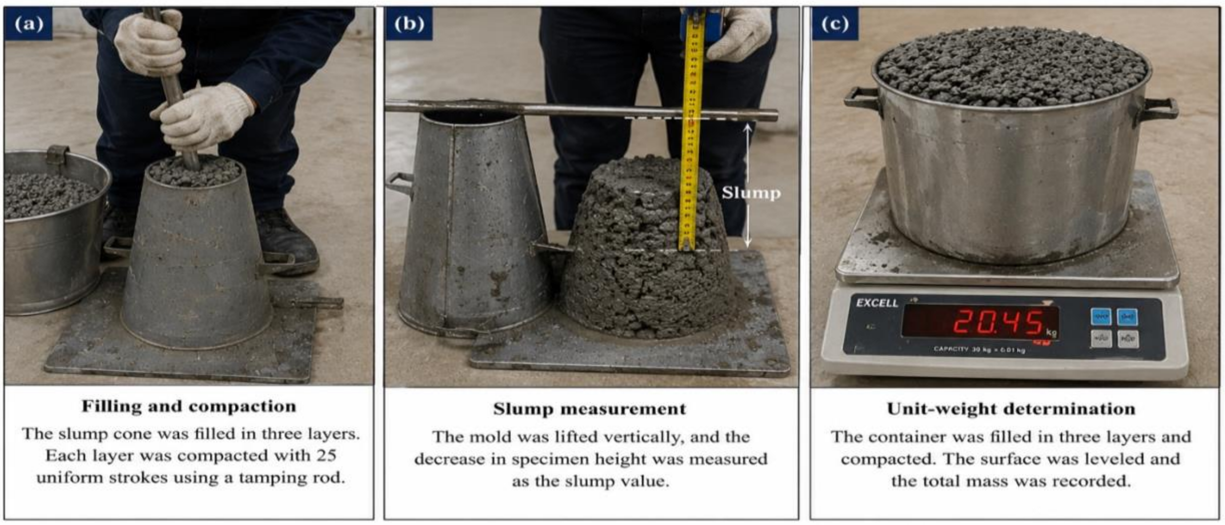

Figure 4. Fresh pervious concrete testing: (a) filling and compacting the slump cone; (b) slump measurement after mold removal; and (c) fresh concrete unit-weight determination.

Curing Procedure

After demolding, specimens from each fiber-content group were divided equally into freshwater and seawater curing conditions. Twenty specimens were immersed in freshwater and another twenty specimens were immersed in seawater for 28 days. Freshwater curing provided a conventional reference condition for cement hydration, whereas seawater curing represented an initial simulation of environmental exposure associated with coastal infrastructure. The same curing duration was maintained for all mixtures to enable direct comparisons among fiber contents and between curing conditions. At 28 days, the specimens were removed from the curing media and prepared for physical and mechanical testing.

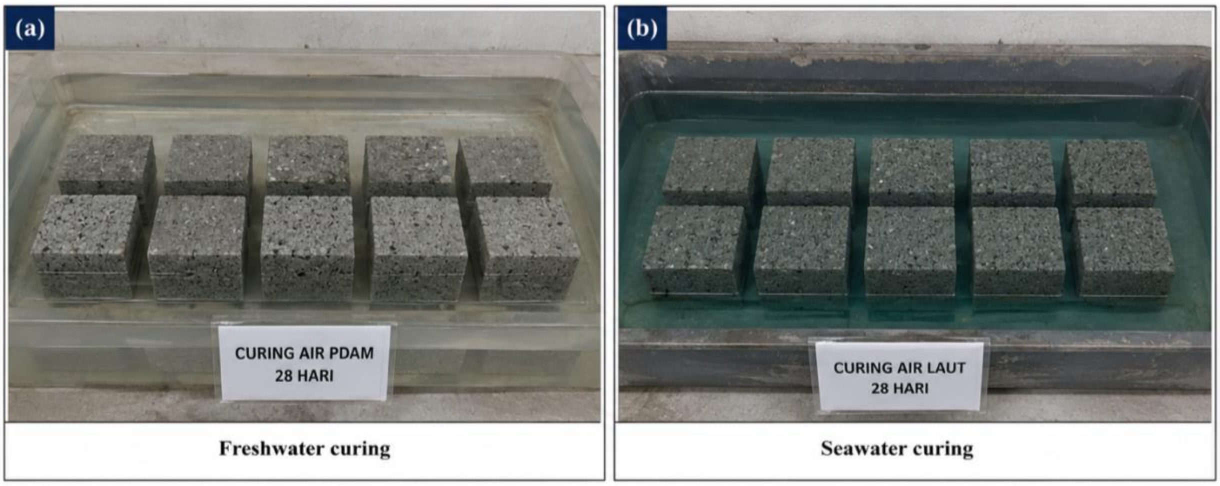

Figure 5. Curing conditions of pervious concrete specimens: (a) freshwater curing and (b) seawater curing.

Porosity Test

Porosity was determined using the procedure adopted from ASTM C642-90 to quantify the internal void characteristics of the hardened pervious concrete. After the designated curing period, the specimens were removed and allowed to drain before being dried in an oven at approximately 100°C for 24 hours. After cooling at room temperature, the oven-dry mass was recorded. The specimens were subsequently immersed in water for 24 hours, after which their submerged mass was determined. Each specimen was then removed from the water and surface-dried to obtain the saturated-surface-dry condition before being weighed again. The oven-dry, submerged, and saturated-surface-dry masses were used to calculate the corresponding porosity. Measurements were performed for all fiber variations under both curing conditions to identify changes associated with fiber incorporation and curing environment.

The calculated porosity values were subsequently compared across the five coconut coir fiber contents to determine the influence of fiber dosage on the internal void structure of the concrete. Comparisons were also performed between freshwater- and seawater-cured specimens at identical fiber contents to evaluate variations associated with the curing environment. Particular attention was given to changes in porosity because the interconnected void system represents a fundamental characteristic governing the hydraulic functionality of pervious concrete. The porosity results were further interpreted together with infiltration and water absorption measurements to provide a more comprehensive assessment of pore-related performance. This integrated evaluation allowed differences between total void characteristics and actual water-transport behavior to be identified across the experimental mixtures. Accordingly, the porosity assessment provided an important basis for evaluating the balance between pore development, hydraulic functionality, and mechanical performance required for the intended perforated breakwater application.

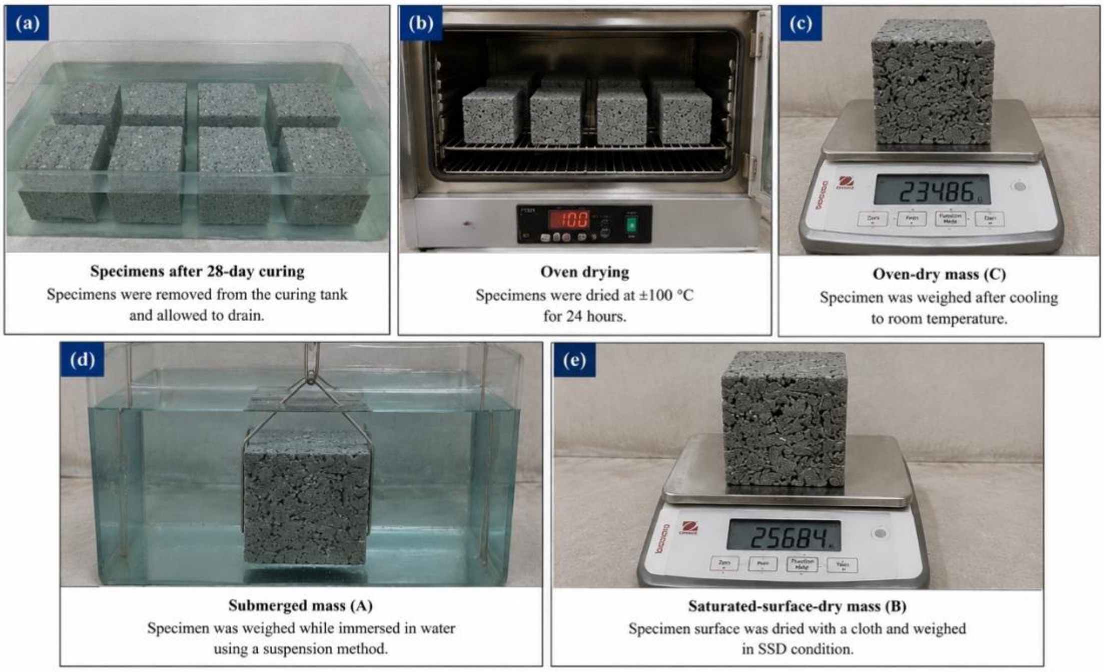

Figure 6. Porosity testing procedure: (a) specimen curing; (b) oven drying; (c) determination of oven-dry mass; (d) submerged weighing; and (e) saturated-surface-dry weighing.

Infiltration Test

The infiltration test was conducted at 28 days to evaluate the ability of water to pass through the interconnected pore system. Before testing, the surface of each cube specimen was cleaned and the specimen was positioned on a flat and impermeable surface. A cylindrical pipe was installed vertically on the specimen surface and sealed around its perimeter using plasticine to minimize lateral leakage. A predetermined quantity of water was introduced into the cylinder to a specified initial level. A stopwatch was used to measure the time required for the water to pass completely through the concrete specimen. The recorded flow time was subsequently used to evaluate infiltration performance. Comparisons were performed across the five fiber contents and between freshwater- and seawater-cured specimens.

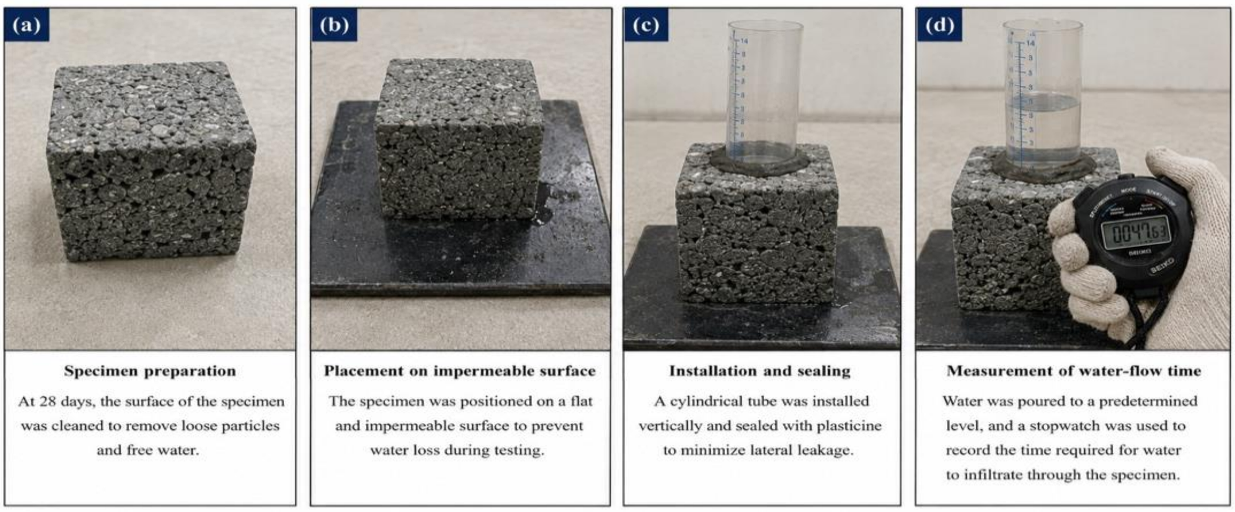

Figure 7. Infiltration testing of pervious concrete: (a) specimen preparation; (b) placement on an impermeable surface; (c) installation and sealing of the infiltration cylinder; and (d) measurement of water-flow time.

Water Absorption Test

Water absorption was evaluated according to SNI 03-6433-2000 to quantify water uptake through the pore system. Specimens were initially dried in an oven at 105 ± 5°C for approximately 24 hours or until a constant mass was obtained. After cooling to room temperature, the dry mass of each specimen was recorded. The specimens were then fully immersed in water for 24 hours. After immersion, excess surface water was removed using a cloth before the saturated mass was determined. Water absorption was calculated from the difference between saturated and oven-dry masses and expressed as a percentage of the dry mass. This parameter was compared across fiber contents and curing conditions to evaluate changes in the water-retention characteristics of the concrete pore network.

$$WA=\frac{Ws-Wd}{Wd}\ x\ 100\%$$

where WA is water absorption (%), W_s is the saturated specimen mass, and W_d is the oven-dry specimen mass.

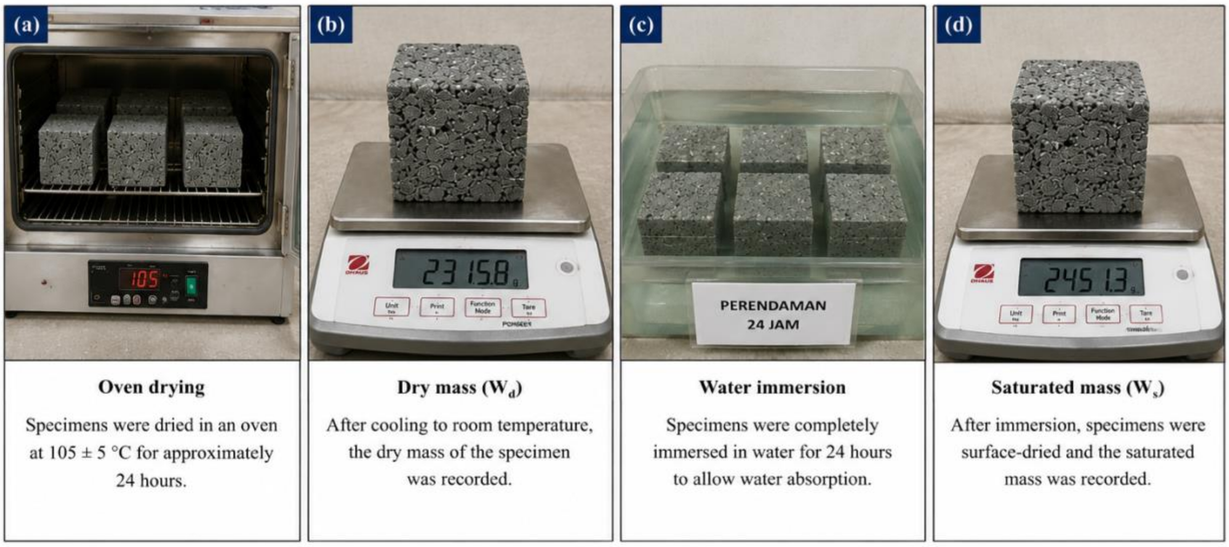

Figure 8. Water absorption testing: (a) oven drying; (b) dry-mass measurement; (c) 24-h water immersion; and (d) saturated-mass measurement.

Compressive Strength Test

Compressive strength was evaluated at 28 days according to SNI 03-1974-1990 using a compression testing machine. Prior to testing, each specimen was weighed and visually inspected. The cube was positioned centrally on the loading platform to ensure that the applied compressive force was distributed uniformly over the loaded surface. A continuous compressive load was then applied until the specimen reached failure. The maximum load sustained by the specimen was recorded and used to determine compressive strength. Failure patterns and visible cracking characteristics were also documented to support the interpretation of mechanical behavior. Compressive strength was calculated as:

$$Fc = \frac{P}{A}$$

where f_c is compressive strength, P is the maximum failure load, and A is the loaded cross-sectional area. The calculated strengths were compared among specimens containing 0%, 1%, 3%, 5%, and 7% coconut coir fiber under freshwater and seawater curing conditions.

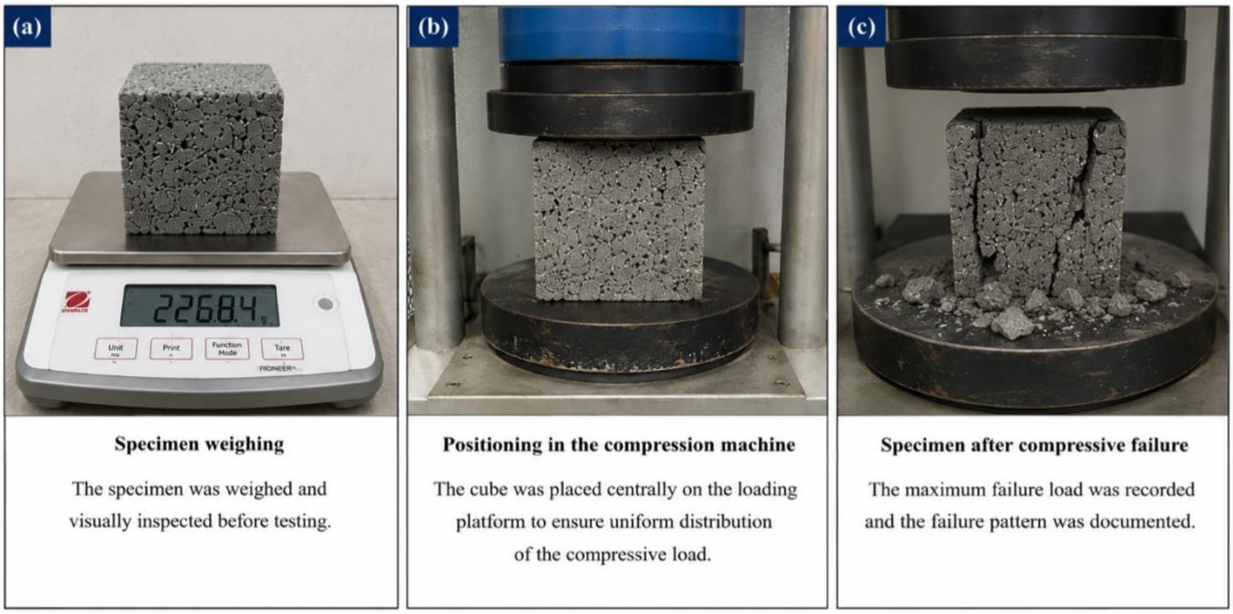

Figure 9. Compressive strength testing: (a) specimen weighing; (b) positioning of the cube in the compression testing machine; and (c) specimen after compressive failure.

Data Analysis

Experimental data were analyzed using descriptive and comparative procedures to identify changes in mechanical and hydraulic performance associated with coconut coir fiber dosage and curing environment. The principal response variables were compressive strength, porosity, infiltration, and water absorption, as summarized in Table 3. Results for the fiber-reinforced mixtures were compared with those of the 0% control mixture to determine the direction and magnitude of changes associated with fiber incorporation. Comparisons were also performed between freshwater- and seawater-cured specimens at identical fiber contents. Compressive strength represented mechanical performance, whereas porosity, infiltration, and water absorption were interpreted collectively as indicators of physical and hydraulic functionality. Particular attention was given to the potential trade-off between the development of interconnected voids and the corresponding reduction in load-bearing capacity. Consequently, optimum performance was not defined solely by the highest value of an individual parameter. Instead, the optimum coconut coir fiber content was identified from the mixture providing the most balanced combination of mechanical resistance and hydraulic functionality. This analytical framework was adopted to assess the suitability of coconut coir fiber-reinforced pervious concrete as a sustainable material for perforated breakwater applications.

Table 3. Experimental variables and performance indicators

Variable category	Variable	Levels/indicator
Independent	Coconut coir fiber content	0%, 1%, 3%, 5%, 7%
Experimental condition	Curing medium	Freshwater; seawater
Dependent	Compressive strength	Mechanical performance
Dependent	Porosity	Internal void characteristics
Dependent	Infiltration	Hydraulic conductivity/pervious performance
Dependent	Water absorption	Water uptake characteristics
Controlled	Specimen dimensions	150 × 150 × 150 mm
Controlled	Testing age	28 days
Controlled	Basic mixture and preparation	Maintained consistently

RESULTS AND DISCUSSION

Results

Coarse Aggregate Properties

The preliminary characterization confirmed that the coarse aggregate used in the mixtures exhibited physical and mechanical properties appropriate for pervious concrete production. The average moisture content was 0.786%, which was within the specified range of 0.5–3.0%. The bulk, saturated surface-dry (SSD), and apparent specific gravities were 2.640, 2.654, and 2.677, respectively, while water absorption was 0.532%. The measured bulk density was 1.501 kg/dm^3, indicating an adequate aggregate packing condition for subsequent mixture preparation. Sieve analysis showed that the coarse aggregate corresponded to a maximum aggregate size of 40 mm. In addition, the Los Angeles abrasion value was 20.07%, remaining below the maximum allowable value of 40%. These results indicate that the coarse aggregate satisfied the material requirements adopted in the experimental program. The aggregate characterization results were subsequently incorporated into the mixture proportioning process. Based on ACI 522R-10, the pervious concrete mixture was designed with a target void content of 18% and a nominal compressive strength of 20 MPa. The resulting reference mixture consisted of 410.26 kg/m^3 cement, 110.77 kg/m^3 water, and 1511.73 kg/m^3 coarse aggregate, corresponding to a water-to-cement ratio of 0.27.

Table 4. Physical and mechanical characteristics of coarse aggregate

Property	Experimental value	Reference/criterion
Moisture content	0.786%	0.5–3.0%
Bulk specific gravity	2.640	—
SSD specific gravity	2.654	≥ 2.50
Apparent specific gravity	2.677	—
Water absorption	0.532%	< 3%
Bulk density	1.501 kg/dm^3	1.4–1.9 kg/dm^3
Maximum aggregate size	40 mm	Sieve analysis
Los Angeles abrasion	20.07%	≤ 40%

Mixture Proportions

Five concrete mixtures were produced by varying coconut coir fiber content from 0% to 7%. The control mixture contained no coconut coir fiber, whereas the remaining mixtures incorporated 1%, 3%, 5%, and 7% fiber relative to the coarse aggregate component. Cement and water quantities were maintained at 11.08 and 2.99 kg, respectively, for each batch of eight specimens. As fiber content increased, the amount of coarse aggregate was progressively reduced from 41.03 kg in the control mixture to 38.16 kg in the 7% mixture. Coconut coir fiber quantities consequently increased from 0.41 kg at 1% to 2.87 kg at 7%. This mixture configuration allowed the effects of progressive fiber incorporation to be evaluated while maintaining the primary cement and water quantities. The detailed mixture proportions are summarized in Table 5.

Table 5. Mixture proportions for coconut coir fiber-reinforced pervious concrete

Mixture	Fiber content	Cement (kg)	Coarse aggregate (kg)	Water (kg)	Coconut coir fiber (kg)	Specimens
B.N	0%	11.08	41.03	2.99	—	8
B.S-1	1%	11.08	40.62	2.99	0.41	8
B.S-3	3%	11.08	39.81	2.99	1.22	8
B.S-5	5%	11.08	38.98	2.99	2.05	8
B.S-7	7%	11.08	38.16	2.99	2.87	8

Fresh Concrete Properties

The slump results revealed a progressive reduction in fresh-mixture consistency as coconut coir fiber content increased. The control mixture exhibited the highest slump of 0.6 cm, followed by 0.5 cm for the 1% fiber mixture. Increasing fiber content to 3% and 5% resulted in an identical slump value of 0.3 cm, whereas the lowest value of 0.1 cm was obtained at 7% fiber content. Thus, the slump decreased by approximately 83.3% between the control and 7% fiber mixtures. Despite this reduction, all mixtures retained the very low-slump characteristics expected for pervious concrete. The fresh unit-weight measurements similarly demonstrated an overall reduction following fiber incorporation. The control concrete recorded the highest fresh unit weight of 1.774 kg/dm^3, whereas the 7% mixture exhibited the lowest value of 1.371 kg/dm^3. A gradual reduction occurred up to 3% fiber content, followed by a slight increase at 5% and another decrease at 7%. Overall, the fresh concrete results indicate that increasing coconut coir fiber content substantially altered mixture consistency and density.

Table 6. Slump of fresh pervious concrete mixtures

Mixture	Coconut coir fiber (%)	Slump (cm)
B.N	0	0.6
B.S-1	1	0.5
B.S-3	3	0.3
B.S-5	5	0.3
B.S-7	7	0.1

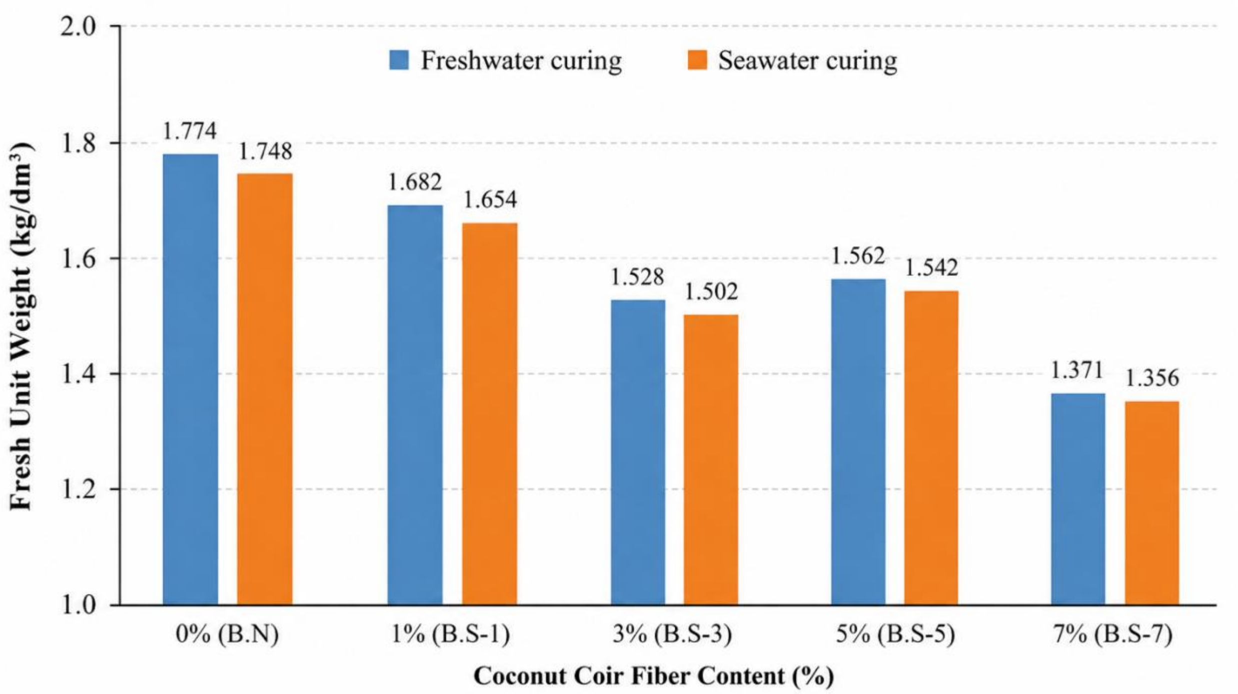

Figure 10. Fresh unit weight of pervious concrete at different coconut coir fiber contents.

Porosity

The porosity results showed a nonlinear response to coconut coir fiber incorporation and curing medium. In general, porosity increased with increasing fiber content up to 5% and subsequently decreased at 7% under both curing conditions. At 5% fiber content, the porosity reached 14.84% for freshwater-cured concrete and 15.35% for seawater-cured concrete. These values represented the highest reported porosity levels and were closest to the lower limit of the 15–35% range adopted for pervious concrete. At 7% fiber content, the porosity decreased under both curing conditions, demonstrating that additional fiber beyond 5% did not produce a corresponding increase in total pore volume. A comparison of the curing environments further showed that seawater-cured specimens generally exhibited higher porosity than their freshwater-cured counterparts. The difference was evident at the 5% fiber level, where seawater curing increased porosity from 14.84% to 15.35%. Most other mixtures, however, remained below the targeted porosity range. Therefore, among the investigated mixtures, the 5% coconut coir fiber mixture exhibited the most favorable porosity response, particularly under seawater curing.

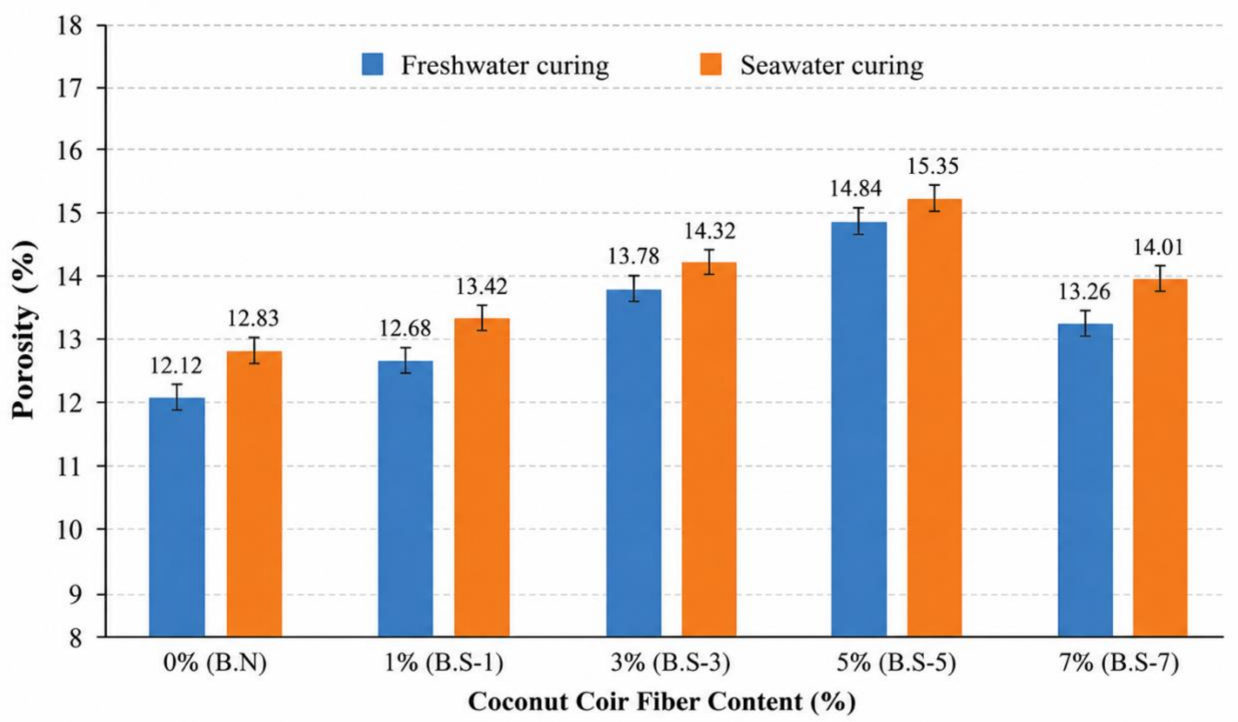

Figure 11. Effect of coconut coir fiber content and curing medium on the porosity of pervious concrete.

Infiltration Performance

The infiltration results demonstrated that the hydraulic response of the concrete varied considerably with coconut coir fiber content. The control mixture exhibited infiltration rates of 0.081 L/s under freshwater curing and 0.080 L/s under seawater curing. Incorporating 1% fiber slightly reduced these values to 0.080 and 0.078 L/s, respectively. A substantial increase was subsequently observed at 3% fiber content, reaching 0.099 L/s for freshwater-cured specimens and 0.101 L/s for seawater-cured specimens. At 5% fiber content, the infiltration rates were 0.097 and 0.103 L/s under freshwater and seawater curing, respectively. The highest infiltration performance was obtained with the 7% fiber mixture, which reached 0.101 L/s under freshwater curing and 0.114 L/s under seawater curing. Relative to the corresponding control, the 7% mixture increased infiltration by approximately 24.7% under freshwater curing and 42.5% under seawater curing. The effect of curing medium became more apparent at higher fiber contents, with seawater-cured specimens exhibiting higher infiltration at 3%, 5%, and 7% fiber levels. Overall, the results demonstrate that moderate-to-high coconut coir fiber incorporation enhanced water transmission through the pervious concrete, although the response was not strictly linear across all fiber contents.

Table 7. Infiltration rate according to coconut coir fiber content and curing condition

Fiber content	Freshwater (L/s)	Seawater (L/s)
0%	0.081	0.080
1%	0.080	0.078
3%	0.099	0.101
5%	0.097	0.103
7%	0.101	0.114

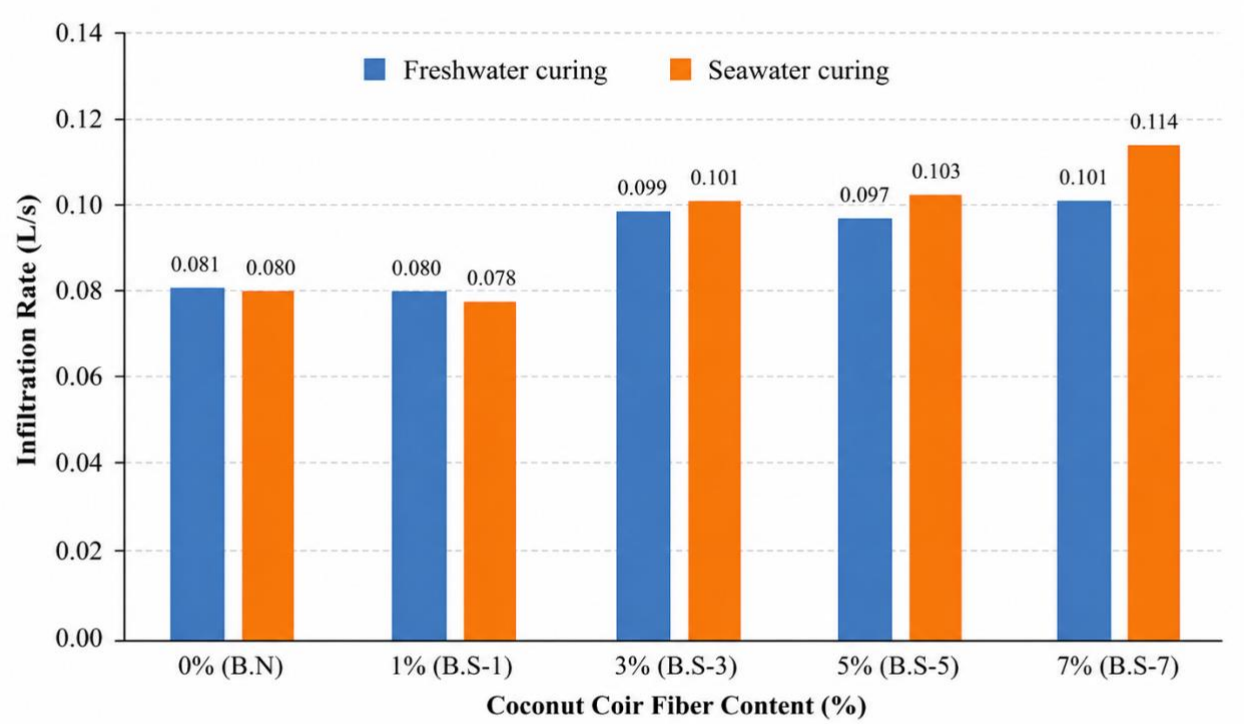

Figure 12. Infiltration rate of coconut coir fiber-reinforced pervious concrete under freshwater and seawater curing conditions.

Water Absorption

Water absorption generally increased with coconut coir fiber incorporation under both curing conditions. The control specimens exhibited the lowest absorption values, corresponding to 4.38% after freshwater curing and 4.69% after seawater curing. The absorption response subsequently increased as the proportion of coconut coir fiber was raised. The highest values occurred at 7% fiber content, reaching 6.34% for freshwater-cured specimens and 6.47% for seawater-cured specimens. Relative to the control mixture, these values corresponded to increases of approximately 44.7% and 38.0% under freshwater and seawater conditions, respectively. Seawater-cured specimens generally exhibited greater water absorption than specimens cured in freshwater. At 0% fiber content, the difference between the two curing conditions was 0.31 percentage points, whereas at 7% fiber content it was 0.13 percentage points. The overall trend indicates an increase in the capacity of the concrete to retain water as coconut coir fiber content increased. This result also demonstrates that the incorporation of coconut coir fiber altered the water-accessible pore characteristics of the hardened composite. The maximum absorption observed at 7% fiber content was consistent with the high infiltration performance recorded for this mixture.

Table 8. Selected water absorption results

Fiber content	Freshwater (%)	Seawater (%)
0%	4.38	4.69
7%	6.34	6.47

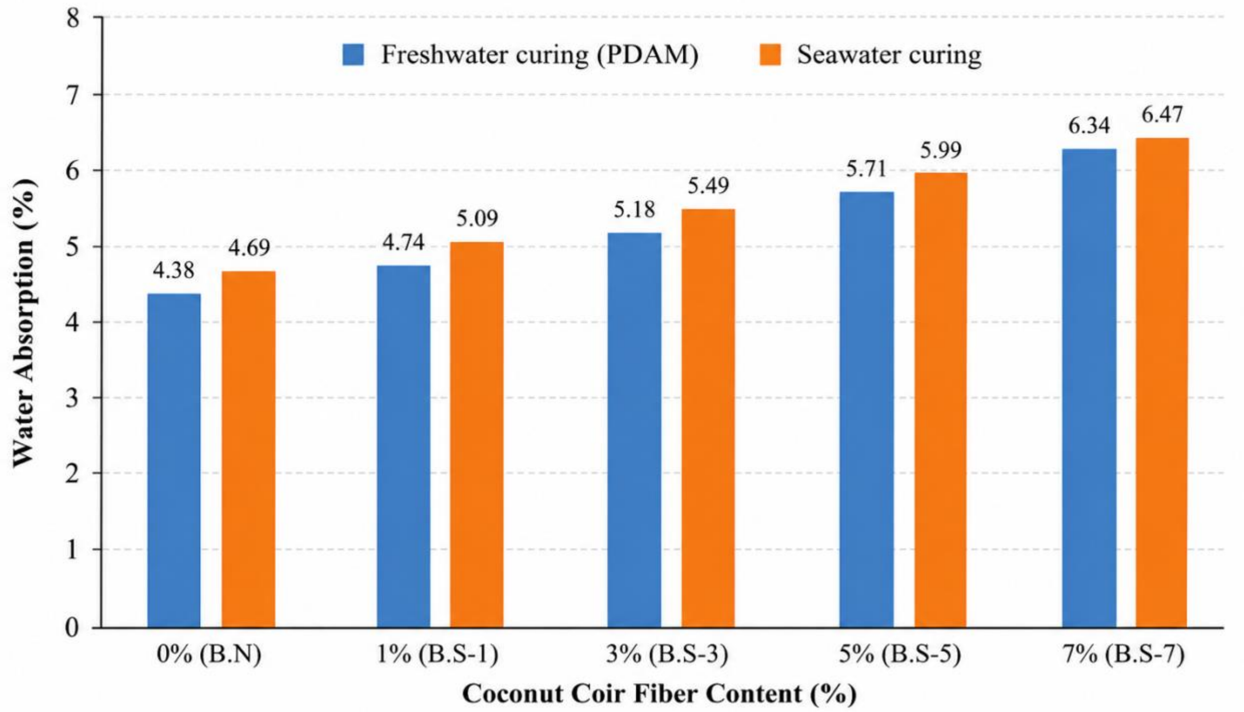

Figure 13. Water absorption of pervious concrete as a function of coconut coir fiber content and curing medium.

Compressive Strength

Compressive strength decreased as coconut coir fiber content increased, demonstrating an inverse trend relative to the improvement observed in infiltration performance at higher fiber contents. For specimens cured in freshwater, the control mixture achieved a compressive strength of 5.122 MPa, whereas the 7% fiber mixture recorded 3.754 MPa. This represents a reduction of approximately 26.7% between the control and highest fiber content. The seawater-cured control specimens exhibited a lower compressive strength of 4.077 MPa. The supplied experimental description indicates a further reduction at 7% fiber content, corresponding to an approximately 8.5% decrease relative to the seawater-cured control. Across the investigated mixtures, seawater-cured specimens generally exhibited lower compressive strength than corresponding freshwater-cured specimens. The measured compressive strengths were reported to range approximately from 3.7 to 5.1 MPa. Although these values remained within the general 2.8–28 MPa compressive-strength range referenced for pervious concrete, they were concentrated near the lower end of that range. The results therefore demonstrate that increased coconut coir fiber incorporation did not improve compressive strength under the investigated mixture conditions. Instead, the mechanical response declined as the fiber content increased, highlighting a clear trade-off between compressive resistance and the hydraulic benefits observed at higher fiber dosages.

Table 9. Selected compressive strength results at 28 days

Fiber content	Freshwater (MPa)	Seawater (MPa)
0%	5.122	4.077
7%	3.754	*Value not completely reported in the supplied text*

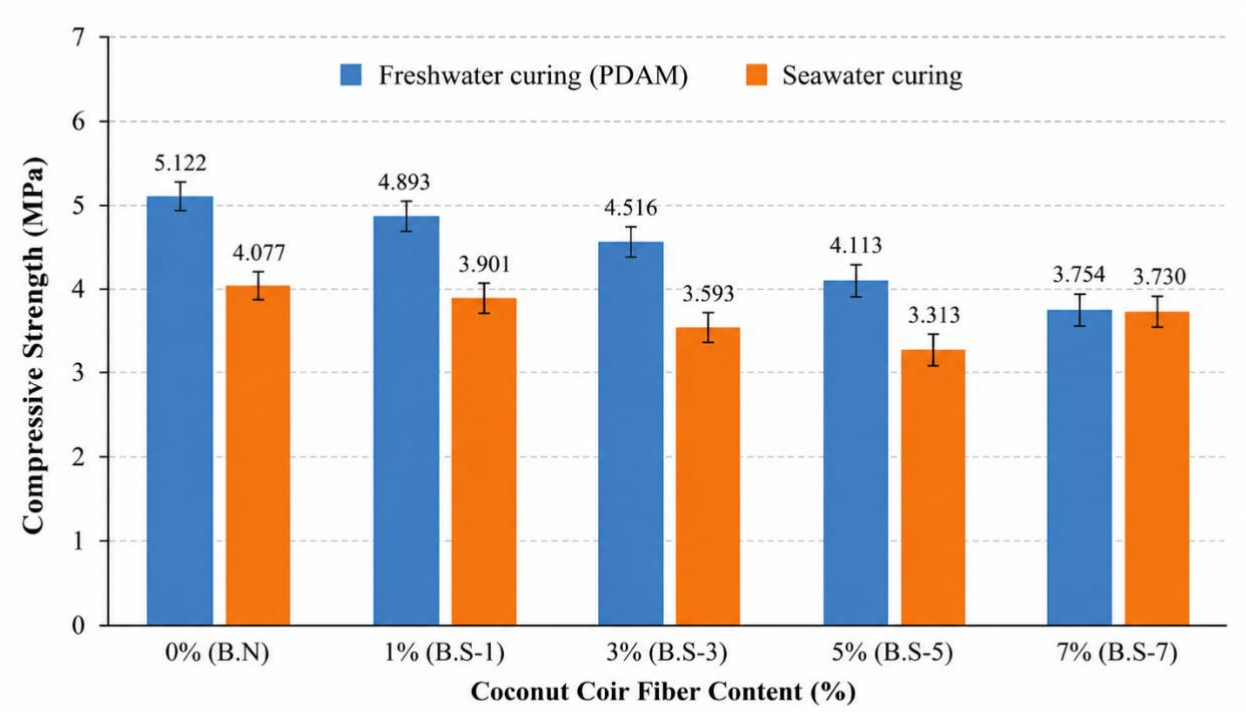

Figure 14. Effect of coconut coir fiber content and curing medium on 28-day compressive strength.

The combined results reveal a distinct trade-off between the mechanical and hydraulic characteristics of coconut coir fiber-reinforced pervious concrete. Increasing fiber content substantially reduced slump and generally lowered fresh concrete density, indicating changes in the consistency and packing characteristics of the mixtures. Porosity increased up to 5% fiber content, where maximum reported values of 14.84% and 15.35% were obtained under freshwater and seawater curing, respectively, before decreasing at 7%. In contrast, infiltration reached its highest values at 7% fiber content, corresponding to 0.101 L/s in freshwater-cured specimens and 0.114 L/s in seawater-cured specimens. Water absorption also reached its maximum at 7% fiber content, with values of 6.34% and 6.47%, respectively. These hydraulic improvements were accompanied by a reduction in compressive strength, particularly under freshwater curing, where strength decreased from 5.122 MPa at 0% fiber to 3.754 MPa at 7%. Seawater curing generally resulted in higher porosity, infiltration, and water absorption but lower compressive strength than freshwater curing. Therefore, no single fiber dosage simultaneously maximized both mechanical and hydraulic performance. The 5% mixture exhibited the porosity closest to the target characteristics of pervious concrete, whereas the 7% mixture provided the greatest infiltration capacity but lower mechanical resistance. Taken together, the results indicate that coconut coir fiber modifies the mechanical–hydraulic balance of pervious concrete, and its suitability for perforated breakwater applications should therefore be determined by the required compromise between water-transmission capacity and structural resistance rather than by maximizing either response independently.

Discussion

The experimental results demonstrate that coconut coir fiber substantially modifies the fresh-state behavior of pervious concrete, particularly its workability and unit weight. Slump decreased progressively from 0.6 cm in the control mixture to only 0.1 cm at 7% fiber content, indicating that increasing fiber dosage produced a considerably stiffer mixture. This tendency is consistent with previous research indicating that coconut fiber generally decreases concrete flowability because its morphology and water affinity reduce the amount of free water available for mixture mobility (Ahmad et al., 2022). The pronounced reduction observed in the present study is particularly relevant because pervious concrete already contains relatively little paste and is intentionally produced with low workability to preserve interconnected voids. The fresh unit weight similarly decreased from 1.774 kg/dm^3 for the control concrete to 1.371 kg/dm^3 at 7% fiber content, although a minor intermediate increase occurred at 5%. Such behavior indicates that the effect of coir is not restricted to water demand but also extends to particle packing and consolidation efficiency. Previous investigations of fiber-reinforced pervious concrete have likewise demonstrated that aggregate and fiber characteristics jointly control rheological behavior, unit weight, pore development, and hardened performance (Furkan Ozel et al., 2022). The relatively low density of coir, combined with increasingly difficult compaction at high dosages, provides a plausible explanation for the declining fresh unit weight observed here, while localized fiber redistribution may account for the non-monotonic response at 5%. Importantly, the extremely low slump values should not automatically be interpreted as poor mixture performance because low-slump consistency is intrinsic to pervious concrete; rather, the critical issue is whether the mixture remains sufficiently workable to achieve homogeneous fiber dispersion and stable interconnected pores. Collectively, these findings indicate that increasing coir content changes the fresh-state architecture of the mixture before hardening, which subsequently influences the mechanical and hydraulic responses observed at 28 days.

The porosity results further reveal that the influence of coconut coir fiber on pore structure is nonlinear and dependent on both fiber dosage and curing environment. Porosity increased with fiber addition up to 5%, reaching 14.84% under freshwater curing and 15.35% under seawater curing, before decreasing at 7% fiber content. This response suggests that moderate fiber incorporation facilitated void development, whereas excessive fiber addition did not continuously increase measurable porosity and may instead have altered pore geometry, connectivity, or local packing. Previous studies have established that fiber characteristics can significantly modify the pore structure of pervious concrete, although the direction of this effect depends strongly on fiber type, dosage, aggregate characteristics, and compaction conditions (Furkan Ozel et al., 2022). The present trend is also important when compared with conventional coconut-fiber concrete, because reductions in porosity and water absorption following fiber incorporation, illustrating that the response of dense fiber-reinforced concrete cannot be directly transferred to an intentionally porous matrix. This difference can reasonably be attributed to the fundamentally different design objectives of the two materials: conventional concrete seeks to minimize voids, whereas pervious concrete requires a stable interconnected pore system to maintain hydraulic functionality. The higher porosity generally observed after seawater curing further indicates that curing environment contributed to the evolution of the pore structure, although the present experiment alone cannot establish the specific chemical mechanism responsible for this difference. This finding is nevertheless relevant to marine applications because previous research has emphasized that seawater exposure and fiber–matrix interactions can affect microstructural deterioration and transport behavior (Yan et al., 2025). Although the 5% seawater-cured mixture reached approximately 15.35% porosity, several other mixtures remained below the commonly reported ranges for conventional pervious concrete, suggesting that the experimental material possessed a relatively compact pore structure. Therefore, the porosity results should be interpreted together with infiltration and water absorption rather than as an isolated indicator of whether the mixtures can function effectively as permeable coastal materials.

The infiltration and absorption results provide stronger evidence that coconut coir fiber altered the water-transport characteristics of the concrete, although the responses of these two indicators were not identical to the total-porosity trend. Infiltration initially decreased slightly from 0.081 to 0.080 L/s under freshwater curing and from 0.080 to 0.078 L/s under seawater curing when fiber content increased from 0% to 1%, but subsequently increased substantially at higher fiber contents. The highest infiltration rates occurred at 7% fiber, reaching 0.101 L/s under freshwater curing and 0.114 L/s under seawater curing, equivalent to increases of approximately 24.7% and 42.5% relative to the corresponding control mixtures. Interestingly, this maximum infiltration occurred even though porosity decreased from its 5% peak, indicating that total pore volume and hydraulic connectivity did not evolve proportionally. This distinction is consistent with the broader understanding of pervious concrete, in which permeability is governed not only by the quantity of voids but also by pore continuity, tortuosity, constriction, and spatial distribution. Fiber type can consequently modify hydraulic transport without necessarily maximizing total porosity, as previous fiber-reinforced pervious concrete research has demonstrated different strength–permeability responses depending on fiber characteristics and dosage (Furkan Ozel et al., 2022). Water absorption exhibited a clearer upward tendency, increasing from 4.38% to 6.34% under freshwater conditions and from 4.69% to 6.47% under seawater conditions between 0% and 7% fiber content. The hydrophilic and porous morphology of coconut coir provides a credible explanation for this increase because coconut fiber has a relatively high capacity to interact with and absorb water (Bediako et al., 2025). The combination of increasing absorption and enhanced infiltration at high fiber contents therefore suggests that coir influenced both water storage within the material and pathways for water transmission, rather than simply increasing the total volume of pores. From a coastal-engineering perspective, this hydraulic modification is potentially beneficial because experimental work on pervious concrete breakwaters has shown that material permeability and porosity can influence wave reflection, transmission, and attenuation (Sukcharoen et al., 2024).

The principal limitation identified from the mechanical results is the systematic reduction in compressive strength associated with increasing coconut coir fiber content. Under freshwater curing, compressive strength decreased from 5.122 MPa in the control mixture to 3.754 MPa at 7% fiber content, corresponding to a reduction of approximately 26.7%, while seawater-cured specimens also exhibited lower strength than their freshwater counterparts across the experimental series. This finding demonstrates that the hydraulic advantages produced at higher fiber dosages were obtained at the expense of load-bearing resistance. A comparable tendency has been reported in coconut-fiber concrete research, where coir-fiber incorporation may reduce compressive performance despite providing benefits for other mechanical, physical, or durability characteristics (Bediako et al., 2025). Similarly, previous reviews have indicated that coconut fiber can contribute more effectively to crack control and tensile or flexural behavior than to compressive-strength enhancement, with its effectiveness strongly dependent on fiber dosage and mixture characteristics (Ahmad et al., 2022). Research using coconut-derived materials at relatively high proportions has also reported deterioration in compressive performance, reinforcing the importance of optimizing the amount of lignocellulosic material incorporated into cementitious composites. In the present pervious concrete, reduced workability, lower fresh density, possible fiber agglomeration at higher dosage, increased water interaction, and disruption of aggregate–paste contact are plausible contributors to the observed strength loss, although microstructural testing would be required to distinguish their individual contributions. The effect is particularly important because pervious concrete inherently faces a strength–permeability trade-off: increasing the connected void network required for hydraulic functionality can reduce the effective load-bearing area of the cementitious skeleton. Previous fiber-reinforced pervious concrete research similarly indicates that fiber type, physical characteristics, and dosage determine whether reinforcement improves mechanical performance while maintaining permeability or shifts the overall balance toward hydraulic performance. Consequently, the present 7% mixture cannot be regarded as the optimum formulation merely because it achieved the highest infiltration rate, since its reduced compressive strength represents a critical constraint for structural breakwater use.

When all performance indicators are considered together, the results establish that coconut coir fiber-reinforced pervious concrete presents a clear mechanical–hydraulic trade-off rather than a single monotonically improving response. The 5% mixture produced the highest reported porosity, reaching 14.84% under freshwater and 15.35% under seawater curing, whereas the 7% mixture achieved the greatest infiltration and water absorption but simultaneously exhibited lower compressive resistance. This distinction is critical for perforated breakwater applications because a highly impermeable material may maintain structural resistance but limit water passage and energy dissipation, while excessive permeability accompanied by insufficient strength may compromise structural integrity. Experimentally that pervious concrete breakwaters can attenuate solitary waves and that variations in material porosity influence wave reflection and transmission, supporting the functional relevance of maintaining an interconnected pore system in coastal-defense elements. Nevertheless, favorable hydraulic performance alone is insufficient to establish structural suitability, making the comparatively low compressive strengths measured in the present investigation particularly important (Abousnina et al., 2025; Ammar et al., 2024; Bouabdallah et al., 2025; Öz et al., 2026). The results therefore suggest that coconut coir fiber should be viewed primarily as a modifier of the mechanical–hydraulic balance rather than as a straightforward strength-enhancing reinforcement for this pervious concrete system. This interpretation also explains why an intermediate fiber dosage may be more technically meaningful than the maximum dosage, since the broader coconut-fiber literature identifies dosage optimization as essential for preventing deterioration of workability, particle packing, and mechanical properties (Ahmad et al., 2022; Huang et al., 2025). Furthermore, seawater curing generally shifted the response toward higher porosity, infiltration, and absorption while reducing compressive performance, indicating that material optimization for coastal use should be conducted under environmental conditions representative of the intended application. On the basis of the present evidence, the material shows promising hydraulic characteristics relevant to porous coastal elements, but its relatively low compressive strength prevents an unqualified recommendation as the primary load-bearing material for a breakwater without further mixture optimization and structural validation. Future optimization should therefore investigate intermediate coir dosages around the observed transition region, fiber pretreatment, controlled fiber length and dispersion, paste modification, and longer-term seawater exposure while integrating mechanical, microstructural, durability, and hydrodynamic evaluations.

Implications

The findings demonstrate that coconut coir fiber significantly influences the mechanical–hydraulic balance of pervious concrete for coastal applications. Increasing fiber content generally improved hydraulic performance but reduced compressive strength, indicating that fiber dosage requires careful optimization. The 5% mixture produced the highest porosity, whereas the 7% mixture achieved the greatest infiltration capacity but showed lower mechanical resistance. These results indicate that optimum performance cannot be determined from a single property but should integrate strength, porosity, infiltration, and water absorption. Differences between freshwater and seawater curing further emphasize the importance of considering marine exposure when designing pervious concrete for coastal infrastructure. From a sustainability perspective, coconut coir also provides an opportunity to utilize agricultural waste as a functional construction material. However, the relatively low compressive strength limits the current mixtures for primary load-bearing breakwater components. Further mixture optimization and structural validation are therefore required before practical implementation. Overall, this study provides a basis for developing sustainable pervious concrete that balances hydraulic functionality, mechanical performance, and resource efficiency for coastal engineering applications.

Limitations and Suggestions for Future Research

This study is limited by the use of five coconut coir fiber contents and a single testing age of 28 days. The seawater curing condition also provides only an initial simulation of marine exposure and does not fully represent waves, tidal cycles, or long-term salt exposure. Moreover, the evaluation was limited to compressive strength, porosity, infiltration, and water absorption without examining tensile, flexural, and long-term durability properties. Microstructural characteristics and fiber–matrix interactions were also not investigated. The relatively low compressive strength further limits the direct application of the developed concrete as a primary load-bearing breakwater material. Future studies should investigate narrower fiber intervals to identify a more precise optimum dosage. Fiber pretreatment, length, orientation, and dispersion should also be optimized to improve mechanical performance while maintaining permeability. Longer exposure periods incorporating seawater, wet–dry cycles, and aggressive-ion penetration are recommended to evaluate durability. Wave-flume and structural-scale experiments are also required to assess wave attenuation, transmission, reflection, and structural stability. These investigations would provide stronger evidence for the practical application of coconut coir fiber-reinforced pervious concrete in sustainable coastal infrastructure.

CONCLUSION

This study evaluated the mechanical and hydraulic performance of coconut coir fiber-reinforced pervious concrete for potential application in perforated breakwater systems. The results demonstrate that coconut coir fiber content significantly modifies the fresh and hardened characteristics of pervious concrete. Increasing fiber content reduced slump from 0.6 cm in the control mixture to 0.1 cm at 7% fiber, indicating progressively lower workability. Porosity increased to its highest values at 5% fiber content, reaching 14.84% under freshwater curing and 15.35% under seawater curing. Infiltration performance generally improved at higher fiber contents, with the 7% mixture achieving the highest rates of 0.101 L/s and 0.114 L/s under freshwater and seawater curing, respectively. Water absorption similarly increased, reaching 6.34% under freshwater and 6.47% under seawater conditions at 7% fiber content. In contrast, increasing coconut coir fiber reduced compressive strength, with freshwater-cured concrete decreasing from 5.122 MPa at 0% fiber to 3.754 MPa at 7% fiber. Seawater curing generally resulted in higher porosity, infiltration, and water absorption but lower compressive performance than freshwater curing. These findings confirm a clear trade-off between hydraulic functionality and mechanical resistance as coconut coir fiber content increases. The 5% mixture provided the most favorable porosity response, whereas the 7% mixture maximized infiltration but sacrificed mechanical performance. Consequently, the developed material cannot yet be recommended as the primary load-bearing component of breakwater structures without further mixture optimization and structural validation. Overall, this study demonstrates the potential of coconut coir as a sustainable functional modifier for pervious concrete and provides an experimental foundation for developing environmentally responsible porous materials with a more balanced mechanical–hydraulic performance for coastal engineering applications.

AUTHOR CONTRIBUTIONS STATEMENT

Susi Hariyani contributed to the conceptualization of the study, experimental investigation, methodology development, data curation, formal analysis, and preparation of the original manuscript draft. Randy Setiawan supervised the overall research process, contributed to the study conceptualization and methodology, validated the experimental findings, critically reviewed and edited the manuscript, managed the project administration, and served as the corresponding author. Elza Naila Edi Privoto participated in the experimental investigation, laboratory testing, data curation, visualization of the research findings, and manuscript revision. Riska Amelia Putri

Permatasya contributed to the experimental investigation, data validation, literature review, visualization, resource management, and manuscript editing. All authors discussed the results, contributed to the interpretation of the findings, critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, and agreed to be accountable for all aspects of the work, ensuring the accuracy and integrity of the reported research.

REFERENCES

Abdel Rahman, A., & Dincer, I. (2020). Analysis and assessment of a geothermal based cogeneration system and lithium extraction. *International Journal of Energy Research, 44*(12), 9586–9597. https://doi.org/10.1002/er.5356

Abeer, S. Z., Abdulridha, S. Q., Nasr, M. S., Hasan, Z. A., & Shubbar, A. (2024). Improving the mechanical behavior of pervious concrete using polypropylene and waste rope fibers. *Al-Qadisiyah Journal for Engineering Sciences, 17*(1), 38–46. https://doi.org/10.30772/qjes.2024.146598.1114

Abousnina, R., Aljuaydi, F., Benabed, B., Almabrok, M. H., & Vimonsatit, V. (2025). A State-of-the-Art review on the influence of porosity on the compressive strength of porous concrete for infrastructure applications. *Buildings, 15*(13). https://doi.org/10.3390/buildings15132311

Ahmad, J., Majdi, A., Al-Fakih, A., Deifalla, A. F., Althoey, F., Ouni, M. H. E., & El-Shorbagy, M. A. (2022). Mechanical and durability performance of coconut fiber reinforced concrete: A State-of-the-Art review. *Materials, 15*(10). https://doi.org/10.3390/ma15103601

Alenezi, D., Mohammad, D., Alfoudari, F., Saeedi, M., Alajmi, R., & Mustafaraj, E. (2025). Strength and water absorption behavior of untreated coconut Fiber-Reinforced mortars: Experimental evaluation and mix optimization. *Construction Materials, 5*(3). https://doi.org/10.3390/constrmater5030069

Ali, B., Farooq, M. A., El Ouni, M. H., Azab, M., & Elhag, A. B. (2022). The combined effect of coir and superplasticizer on the fresh, mechanical, and long-term durability properties of recycled aggregate concrete. *Journal of Building Engineering, 59*, 105009. https://doi.org/10.1016/j.jobe.2022.105009

Ammar, M. A., Chegenizadeh, A., Budihardjo, M. A., & Nikraz, H. (2024). The effects of crystalline admixtures on concrete permeability and compressive strength: A review. *Buildings, 14*(9). https://doi.org/10.3390/buildings14093000

Bediako, M., Ametefe, T. K., Asante, N., & Adumatta, S. (2025). Incorporation of natural coconut fibers in concrete for sustainable construction: Mechanical and durability behavior. *Case Studies in Construction Materials, 22*, e04867. https://doi.org/10.1016/j.cscm.2025.e04867

Bilal, H., Gao, X., Cavaleri, L., Khan, A., & Ren, M. (2024). Mechanical, durability, and microstructure characterization of pervious concrete incorporating polypropylene fibers and fly Ash/Silica fume. *Journal of Composites Science, 8*(11). https://doi.org/10.3390/jcs8110456

Bouabdallah, A., Benaissa, A., Bouabdallah, M. A., Malab, S., & Khatir, A. (2025). Development and performance evaluation of self-leveling sand concrete: Enhanced fluidity, mechanical strength, durability, and non-destructive analysis. *Construction and Building Materials, 468*, 140463. https://doi.org/10.1016/j.conbuildmat.2025.140463

Bright Singh, S., & Madasamy, M. (2022). Investigation of aggregate size effects on properties of basalt and carbon fibre-reinforced pervious concrete. *Road Materials and Pavement Design, 23*(6), 1305–1328. https://doi.org/10.1080/14680629.2021.1886158

Chen, R. S., Muhammad, Y. H., & Ahmad, S. (2021). Physical, mechanical and environmental stress cracking characteristics of epoxy/glass fiber composites: Effect of matrix/fiber modification and fiber loading. *Polymer Testing, 96*, 107088. https://doi.org/10.1016/j.polymertesting.2021.107088

Cui, B., Luo, A., Zhang, X., & Huang, P. (2024). Research development and key issues of pervious concrete: A review. *Buildings, 14*(11). https://doi.org/10.3390/buildings14113419

Debnath, B., & Sarkar, P. P. (2020). Pervious concrete as an alternative pavement strategy: A state-of-the-art review. *International Journal of Pavement Engineering, 21*(12), 1516–1531. https://doi.org/10.1080/10298436.2018.1554217

Duan, B., Wang, D., Qin, C., & Duan, L. (2025). Local scour around marine structures: A comprehensive review of influencing factors, prediction methods, and future directions. *Buildings, 15*(12). https://doi.org/10.3390/buildings15122125

Elizondo-Martínez, E.-J., Andrés-Valeri, V.-C., Jato-Espino, D., & Rodriguez-Hernandez, J. (2020). Review of porous concrete as multifunctional and sustainable pavement. *Journal of Building Engineering, 27*, 100967. https://doi.org/10.1016/j.jobe.2019.100967

Furkan Ozel, B., Sakallı, Ş., & Şahin, Y. (2022). The effects of aggregate and fiber characteristics on the properties of pervious concrete. *Construction and Building Materials, 356*, 129294. https://doi.org/10.1016/j.conbuildmat.2022.129294

Goda, I., Padayodi, E., & Raoelison, R. N. (2024). Enhancing fiber/matrix interface adhesion in polymer composites: Mechanical characterization methods and progress in interface modification. *Journal of Composite Materials, 58*(29), 3077–3110. https://doi.org/10.1177/00219983241283958

Ha, P. E., & Ardianti, I. M. (2025). Comparative study of household-scale rainwater harvesting systems in Indonesia and South Korea: A case study of Mojoagung and Jeju. *Journal of Engineering Innovation and Management Science, 1*(2), 64–77. https://doi.org/10.64780/jeims.v1i2.6

He, S., Jiao, C., & Li, S. (2023). Investigation of mechanical strength and permeability characteristics of pervious concrete mixed with coral aggregate and seawater. *Construction and Building Materials, 363*, 129508. https://doi.org/10.1016/j.conbuildmat.2022.129508

Huang, F., He, J., Peng, D., & Fu, S. (2025). An experimental investigation on the mechanical and thermal characteristics of eco-friendly concrete with coconut shell aggregate and coir fiber as reinforcement. *Construction and Building Materials, 498*, 144012. https://doi.org/10.1016/j.conbuildmat.2025.144012

Hussein, I. H., Jamel, A. A. J., & Irzooki, R. H. (2025). Environmental and hydraulic considerations in scour reduction around spur dikes: A comprehensive review. Sustainable Marine Structures, 117-135. https://doi.org/10.36956/sms.v7i3.2125

Karami, M., Sulistyorini, R., & Ardianti, I. M. (2020). Resilient modulus master curve for BRA-modified asphalt mixtures. *Roads and Bridges – Drogi i Mosty, 19*(4), 315–331. https://doi.org/10.7409/rabdim.020.020

Lavagna, L., & Nisticò, R. (2022). An insight into the chemistry of Cement-A review. *Applied Sciences, 13*(1). https://doi.org/10.3390/app13010203

Mitrosz, O., Kurpińska, M., Miśkiewicz, M., & Brzozowski, T. (2025). Effect of vibration duration on strength and permeability of pervious concrete with recycled aggregate and low-carbon cements. *Scientific Reports, 15*(1), 35905. https://doi.org/10.1038/s41598-025-19842-6

Mutnbak, M. (2026). Coconut shell aggregate and coir fiber in cement concrete: A review of mechanical performance, durability, and sustainability under functional equivalency. *Polymers, 18*(11). https://doi.org/10.3390/polym18111383

Nissar, M., N, C. K., Birjerane, Y. A., Patil, S., Shetty, S., & Das, A. (2025). Coconut coir fiber composites for sustainable architecture: A comprehensive review of properties, processing, and applications. *Journal of Composites Science, 9*(10). https://doi.org/10.3390/jcs9100516

Noman, M. T., Amor, N., Azeem, M., & Hussain, F. (2026). Fiber-Matrix interface engineering in polymer composites: Linking surface chemistry to multiscale mechanical performance. *Polymers, 18*(15). https://doi.org/10.3390/polym18151842

Oni, B., Xia, J., & Liu, M. (2020). Mechanical properties of pressure moulded fibre reinforced pervious concrete pavement brick. *Case Studies in Construction Materials, 13*, e00431. https://doi.org/10.1016/j.cscm.2020.e00431

Öz, A., Korkulu, G., Benli, A., & Kaplan, G. (2026). Synergistic enhancement of mechanical, thermal, and durability properties in expanded perlite-based lightweight alkali-activated composites with basalt fiber and natural zeolite. *Structural Concrete, 27*(3), 4634–4667. https://doi.org/10.1002/suco.70409

Qian, Q., Selvaratnam, T., Haselbach, L. M., Sriram, K., Shuster, W., Zhang, Y., & Fountain, M. B. (2026). Field and laboratory evaluation of conjunctive pervious concrete and bioretention systems in challenging soil ecosystems of southeast coastal Texas. *Sustainability, 18*(15). https://doi.org/10.3390/su18157797

Rodríguez-Robalino, M. F., Ferrández, D., Verdú-Vázquez, A., & Zaragoza-Benzal, A. (2025). Development and performance of coconut fibre gypsum composites for sustainable building materials. *Buildings, 15*(11). https://doi.org/10.3390/buildings15111899

Romão, F., Lima, M., & Coelho, C. (2024). A State-of-the-Art review on storm events, overtopping and morphological changes in front of coastal structures. *Journal of Marine Science and Engineering, 13*(1). https://doi.org/10.3390/jmse13010040

Saengsupavanich, C., Ariffin, E. H., Yun, L. S., & Pereira, D. A. (2022). Environmental impact of submerged and emerged breakwaters. *Heliyon, 8*(12). https://doi.org/10.1016/j.heliyon.2022.e12626

Shan, J., Zhang, Y., Wu, S., Lin, Z., Li, L., & Wu, Q. (2022). Pore characteristics of pervious concrete and their influence on permeability attributes. *Construction and Building Materials, 327*, 126874. https://doi.org/10.1016/j.conbuildmat.2022.126874

Sukcharoen, T., Kositgittiwong, D., Ekkawatpanit, C., Tran, T. N. H., & Tangchirapat, W. (2024). Assessment of the solitary wave attenuation through pervious concrete breakwater. *Construction and Building Materials, 411*, 134457. https://doi.org/10.1016/j.conbuildmat.2023.134457

Tang, C.-W., Cheng, C.-K., & Ean, L.-W. (2022). Mix design and engineering properties of Fiber-Reinforced pervious concrete using lightweight aggregates. *Applied Sciences, 12*(1). https://doi.org/10.3390/app12010524

Tran, T. N. H., Kaur, H., Sukcharoen, T., Pulngern, T., Sata, V., Jaturapitakkul, C., Ban, C. C., & Tangchirapat, W. (2024). Application of ultra high-performance mortar for producing high-performance pervious concrete with low carbon emissions and cost. *Journal of Building Engineering, 86*, 108847. https://doi.org/10.1016/j.jobe.2024.108847

Uddin, M. J., Smith, K. J., & Hargis, C. W. (2021). Development of pervious oyster shell habitat (POSH) concrete for reef restoration and living shorelines. *Construction and Building Materials, 295*, 123685. https://doi.org/10.1016/j.conbuildmat.2021.123685

Vijay, K. G., Neelamani, S., Sahoo, T., Al-Salem, K., & Nishad, C. S. (2022). Scattering of gravity waves by a pontoon type breakwater with a series of pervious and impervious skirt walls. *Ships and Offshore Structures, 17*(1), 130–142. https://doi.org/10.1080/17445302.2020.1827630

Wright, L. D., & Thom, B. G. (2023). Coastal morphodynamics and climate change: A review of recent advances. *Journal of Marine Science and Engineering, 11*(10). https://doi.org/10.3390/jmse11101997

Wu, J., Pang, Q., Lv, Y., Zhang, J., & Gao, S. (2022). Research on the mechanical and physical properties of basalt Fiber-Reinforced pervious concrete. *Materials, 15*(19). https://doi.org/10.3390/ma15196527

Yan, X., Wang, X., Sun, C., Xin, M., & He, J. (2025). Analysis of the mechanical properties and prediction of damage life for GBFS-HPMC/fibre pervious concrete after seawater erosion. *Road Materials and Pavement Design, 26*(1), 103–132. https://doi.org/10.1080/14680629.2024.2338762

Yuan, S., Li, K., Luo, J., Yin, W., Chen, P., Dong, J., Liang, W., Zhu, Z., & Tang, Z. (2024). Research on the frost resistance performance of fully recycled pervious concrete reinforced with fly ash and basalt fiber. *Journal of Building Engineering, 86*, 108792. https://doi.org/10.1016/j.jobe.2024.108792