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Evaluation of the application potential of coral concrete for marine infrastructures

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KEYWORDS

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Elastic modulus

ABSTRACT

The growing demand for sustainable and cost-effective marine infrastructure in remote island regions has stimulated interest in locally sourced construction materials. This study investigates the feasibility of producing coral concrete using on-site marine resources, specifically coral coarse aggregates, coral sand, and seawater that are collected from offshore islands. A coral concrete mix was experimentally developed by optimizing the water-to-cement ratio and aggregate proportions, resulting in a compressive strength of 35.7 MPa after 28 days of curing, which corresponds to the strength grade B25. Physical and mechanical properties of the coral-derived aggregates were thoroughly characterized, and the estimated elastic modulus was computed using several empirical models to evaluate strength characteristics. In addition to mix development and material testing, the study explores potential applications of coral concrete in marine infrastructure. The study identifies key technical challenges, including dynamic resistance performance, limited long-term durability data under marine exposure, and a lack of design codes. The findings of this research contribute to expanding the application potential of coral concrete in Vietnam's marine and coastal infrastructure systems.

1. Introduction

As a maritime nation, the rapid expansion of marine infrastructure and the growing demand for the development of offshore structures on islands in Vietnam have led to a significant increase in construction activities in these regions. However, one of the primary challenges faced in the implementation of offshore construction projects, particularly on remote islands, lies in the severe scarcity of conventional construction materials such as fresh water, river sand, and natural crushed stone. Due to geographical isolation, the transportation of these materials from mainland areas is not only logistically complex and time-consuming but also economically inefficient, contributing to significantly higher construction costs and increased carbon emissions associated with transport. Furthermore, environmental regulations and concerns about resource depletion have imposed additional constraints on the large-scale exploitation of river sand and freshwater for concrete production.

In light of these challenges, the development and utilization of alternative construction materials sourced from the local marine environment have become an area of increasing academic and practical interest. Among these, coral concrete produced from coral sand, coral coarse aggregate, and seawater, collectively referred to as coral concrete has emerged as a promising solution. Coral debris and coral sand are abundantly available on many offshore islands of Vietnam, originating from natural processes of coral weathering and erosion. Their use as concrete aggregates not only mitigates the demand for mainland materials but also contributes to more sustainable and environmentally compatible construction practices. Seawater, readily available in the marine environment, can replace freshwater in both mixing and curing processes, further enhancing the self-sufficiency of construction operations on remote islands. The adoption of coral concrete aligns with the strategic objectives of promoting low-carbon, low-cost, and resilient infrastructure development in marine and island territories. While coral concrete holds considerable potential, its widespread application in structural engineering remains limited, primarily due to concerns regarding its mechanical performance, long-term durability, and alignment with conventional design standards. Moreover, although both international and domestic studies have explored the performance of coral concrete in diverse contexts, experimental investigations specifically targeting the behavior of coral concrete made with locally sourced marine materials in Vietnam and its practical applicability in construction remains relatively limited.

This study aims to further enhance the understanding of coral concrete by experimentally designing a coral concrete mixture to achieve a compressive strength corresponding to grade B25, an appropriate strength level for general-purpose structural applications in marine environments. All constituent materials, including coral coarse aggregate, coral sand, and seawater, were locally sourced on-site from the islands of Vietnam. Only the cement was supplied from a conventional manufacturing facility. In parallel, the research evaluates the practical applicability of this material for offshore structures such as breakwaters, retaining walls, and utility infrastructure on islands. The obtained results demonstrate the feasibility of producing coral concrete using available marine resources and provide recommendations for its potential integration into offshore construction practices in Vietnam.

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2. Review of domestic and international research on coral concrete

2.1. International research

Zhang [1] explored the enhancement of coral aggregate concrete (CAC) performance through the use of alkali-activated materials (AAMs) derived from slag, in place of traditional Portland cement. By incorporating AAMs into coral concrete with varying alkali contents, the study evaluated stress–strain behavior, compressive strength, elastic modulus, and Poisson's ratio under uniaxial loading. The findings indicated that while failure modes were consistent across mixes. AAMs contributed to improved interfacial microstructures and mechanical performance, suggesting a viable approach for enhancing weak coral aggregates in offshore construction.

Rao [2] conducted experimental studies to examine the mechanical behavior of coral concrete incorporating polyvinyl alcohol (PVA) fibers. The inclusion of PVA fibers significantly improved post-cracking performance, particularly in terms of toughness and crack resistance. This research emphasized the effectiveness of PVA fibers in enhancing mechanical resilience and proposed critical parameters for predictive modeling.

Shi [3] investigated the triaxial compression behavior of coral seawater concrete reinforced with polypropylene fibers. A total of 36 specimens with varying fiber content (1–3 kg/m^3) and confining pressures (0–18 MPa) were tested. The study demonstrated that increasing fiber dosage, particularly at 3 kg/m^3, led to substantial improvements in peak stress, ductility, and energy dissipation. Moreover, confinement delayed damage onset and mitigated its progression. These results highlight the potential of fiber reinforcement to counteract the brittle nature of coral concrete under multiaxial stress conditions.

Chen [4] evaluated the cyclic compressive behavior of coral seawater concrete reinforced with sisal fibers (SiF-CSC). The study revealed that the addition of 0.10 % sisal fiber volume content yielded the greatest enhancements in peak stress and strain, with values increasing by 2.34 % and 10.11 %, respectively. Sisal fibers were also effective in reducing stiffness degradation and energy loss under repeated loading, achieving up to a 51.36 % increase in total energy dissipation. Constitutive and damage models were proposed to predict the cyclic response of SiF-CSC, offering useful tools for design in marine environments subjected to dynamic loading.

Fei Wang [5] examined the effects of substituting traditional aggregates with modified coral aggregates in seawater sea-sand concrete. By treating coral particles with superfine cement slurry, the study aimed to reduce their porosity and improve mechanical properties. Although improvements in compressive and tensile strength were limited (<10 %), the modification produced more cohesive failure surfaces and a more predictable failure pattern. The research also proposed a predictive model for compressive stress–strain behavior across different replacement ratios, confirming the limitations and potential of modified coral aggregate systems.

Guo [6] investigated the axial compressive behavior of coral concrete-filled aluminum alloy tube columns. The study showed strong composite action between the coral concrete core and the aluminum tube. Specimens exhibited decreased strength and ductility with increasing section width-to-thickness and aspect ratios. However, even with slender geometries, the system demonstrated reliable load-bearing capacity. These findings suggest that coral concrete, when used within composite systems, can support structural applications under axial loading in offshore environments. Arafat Easin focused on enhancing the durability of coral concrete exposed to chloride-induced corrosion through a novel treatment called Reverse Seepage and Saturation-Based Active Anti-Corrosion Technology (RS-AAT). Over a 120-day exposure period, this method reduced chloride surface concentration by over 15% and total chloride content by more than 40% compared to untreated specimens. The technique also stabilized chloride gradients and delayed ingress under cyclic wet–dry conditions, particularly in high water-to-cement ratio mixes. These results demonstrate the potential of RS-AAT for extending the service life of coral concrete structures in marine environments.

Most recent, Shunquan Zhang [7] proposed a composite modification approach for coral aggregates that involved mild acid-washing followed by coating with sulphoaluminate cement slurry. This dual treatment effectively removed surface impurities, reduced porosity, and enhanced the mechanical properties of coral concrete. Notably, the slump improved by 38.1 %, while compressive and flexural strengths increased by 30.4 % and 24.7 %, respectively. The enhancements were attributed to improved ITZ characteristics and pore refinement, offering a promising strategy for producing high-performance coral aggregate concrete for coastal infrastructure. Other international studies on coral concrete can be found in the existing literature [8-14].

2.2. Domestic research

The study of Xuan Bang Nguyen et al. [15] investigates the mechanical characteristics of coral-based materials including coral sand and coral stone when used as concrete aggregates. The substitution of various constituent materials in concrete, including binders and aggregate blends, is fundamentally justified. While such substitutions may enhance or reduce certain properties, they do not alter the intrinsic mechanical-chemical-physical bonding mechanisms within the concrete structure. As a result, these modifications lead to concrete products with improved characteristics tailored to specific performance requirements. These results affirm the potential for practical application of coral concrete in certain structural types, particularly in marine or remote island environments where access to conventional materials is limited.

Another study [16] focuses on the development and evaluation of coral concrete mix designs corresponding to strength grades B15, B20, and B22.5, utilizing coral sand, coral stone, and seawater as replacement materials for conventional aggregates and freshwater. The findings confirm the viability of substituting these marine-based materials in concrete production. However, to achieve equivalent strength levels compared to conventional concrete mixes, the coral concrete required an increase in cement content ranging from 17.4 % to 22.3 %. This adjustment was necessary to offset the reduced mechanical performance associated with the lower quality of coral aggregates relative to traditional crushed stone.

The study of Van Cuong Tran and Xuan Bang Nguyen [17] investigates the strength development of coral concrete produced with coral sand, coral stone, and seawater at strength grades B15, B20, and B22.5 over a period of 360 days. The experimental findings indicate that the evolution of compressive strength over time generally follows a logarithmic trend. Although the specific formulation of the logarithmic function varies with the target strength grade, the overall relationship between strength and curing time remains consistent. These results suggest that coral concrete incorporating seawater and marine-derived aggregates when mixed according to principles similar to those used for conventional concrete exhibits comparable structural characteristics and strength development behavior to conventional concrete.

Based on the literature review, compared to the domestic research, the international research on coral concrete has progressed in specialized directions, aiming to improve its mechanical properties through advanced materials and reinforcement techniques. Notably, studies have examined the use of alkali-activated binders, such as slag-based materials, to enhance interfacial bonding and compressive strength. Others have incorporated fiber types like PVA, PP, and sisal to improve post-cracking behavior, toughness, ductility, and energy dissipation. These strategies offer promising solutions to overcome the brittleness and low strength of coral aggregates in offshore applications. However, coral concrete is highly region-specific, with its components, coral aggregates and seawater, varying significantly in physical and chemical properties depending on local geographical and hydrological conditions. Consequently, findings from international studies may not directly apply to Vietnam's construction context. This highlights the importance of localized research on coral concrete in Vietnam. Expanding domestic studies is essential to understand mechanical behavior, optimize mix design, and evaluate long-term performance using locally sourced materials. The present study addresses this need by focusing on Vietnamese coral aggregates and marine resources, thereby promoting context-specific solutions for sustainable marine construction.

3. Design of coral concrete mix for strength grade B25

3.1. Raw materials

Table 1 presents the technical specifications of PCB40 cement in accordance with the requirements of Vietnamese standard (TCVN 6260 : 2020) [18]. The compressive strength is specified to be not less than 18 MPa at 3 days and 40 MPa at 28 days. The initial and final setting times are required to be no less than 45 minutes and 420 minutes, respectively. Fineness is assessed by both the residue on a 0.09 mm sieve, which must not exceed 10 %, and the specific surface area by the Blaine method, which should not be less than 2800 cm^2/g. The cement must also meet volume stability requirements, with Le Chatelier expansion limited to 10 mm. Furthermore, the allowable content of anhydrous sulfur trioxide (SO_3) is capped at 3.5 %, and autoclave expansion must not exceed 0.8 %.

Table 2 summarizes the chemical characteristics of seawater sourced from offshore areas for use in coral concrete production. The measured pH is 6.8. The dominant ions include chloride (Cl^-) at 15.3 g/l, sulfate (SO_4^{2-}) at 2.4 g/l, sodium (Na^+) at 8.5 g/l, potassium (K^+) at 0.35 g/l, and magnesium (Mg^{2+}) at 1.1 g/l. The other category includes trace elements not specifically listed. These values are consistent with the typical ionic composition of seawater.

The coral coarse aggregates used in this study was collected from offshore islands, crushed by mechanical means, and then sieved to obtain particles of size 1x2 cm, as shown in Figure 1. The results of the physical and mechanical tests on the aggregate are presented in Table 3. The particle size distribution, determined by sieve analysis, indicates that 98 %, 95 %, and 4 % of the aggregate are retained on the 5 mm, 10 mm, and 20 mm sieves, respectively, suggesting a predominance of smaller particles. The water absorption capacity is relatively high at 3.92 %, which reflects the typical porous characteristic of coral-based materials. The loose bulk density of the aggregate is 980 kg/m^3, reflecting its lightweight nature. The crushing strength, assessed using the test of compression in cylinders, reaches 46 %, indicating moderate strength performance. The flat and elongated particle content is measured at 19.6 %, which may influence the mechanical interlocking behavior within concrete mixtures. Additionally, the fine impurities such as dust, clay, and silt constitute 0.41 % of the total weight, a value that remains within acceptable limits for coarse aggregate use.

Figure 2 and Table 4 show the physical characteristics and gradation of natural coral sand used as fine aggregate in this study. The coral sand was collected from an offshore island, the same location as the coral coarse aggregate. Visual observation reveals that the coral sand possesses a rough surface texture and angular particle shape, which may enhance interfacial bonding in concrete. Table 4 details the cumulative retained percentages corresponding to various sieve sizes, with values increasing progressively from 13.5 % (at 5 mm) to 94.6 % (at 0.14 mm). Additionally, the coral sand shows high water absorption (14.4 %) and a bulk density of 1120 kg/m^3, while the dust and clay content remains low at 1 %. The fineness modulus is calculated as 2.2, placing the sand in the medium-fine range. These properties indicate that while the coral sand is suitable for concrete production, adjustments in mix design may be necessary to accommodate its distinct physical characteristics.

3.2. Composition design and mix process

Due to the irregular shape, rough surface texture, and high porosity of coral aggregates, the mix design of coral concrete follows principles similar to those of reactive powder concrete. Accordingly, a higher cementitious material content, increased sand proportion, and a large-volume approach are adopted during mix proportioning [19, 20]. The coral concrete in this study was designed to achieve a target compressive strength grade of B25, with a water-to-cement ratio of 0.62. To obtain an optimal mix design, the coral concrete incorporating sea water was adjusted through multiple trial batches. The final mix composition is detailed in Table 5. The mix comprises 450 kg of cement, 279 kg of seawater, 754 kg of coral sand, and 745 kg of coral coarse aggregate per cubic meter of concrete, resulting in a water-to-cement (W/C) ratio of 0.62. In terms of percentage by total weight, cement accounts for 20.20 %, water 12.52 %, coral sand 33.84 %, and coral aggregate 33.44 %. This proportioning approach reflects the adaptation of reactive powder concrete principles, characterized by a relatively high binder content and increased fine aggregate ratio, which are essential to offset the strength limitations of coral material.

The procedure for preparing the coral concrete test specimens is illustrated in Figure 3. The mixing process begins with the combination of all dry constituents, including cement, coral sand, and coral aggregate. These materials are blended thoroughly for approximately 3 to 5 minutes. A 250 L capacity concrete mixer is employed for this process to ensure efficient and consistent mixing of the materials. Following this initial dry mixing stage, sea water is gradually added to the mixture in a controlled manner. This step initiates the hydration of cement and facilitates the development of a cohesive. The gradual incorporation of water ensures that the mixture attains a uniform consistency without segregation or the formation of lumps. Once the mixing is complete and the concrete achieves a smooth and homogeneous texture, the fresh mixture is ready for casting. The prepared concrete is poured into standard molds with dimensions of 15 cm × 15 cm × 15 cm, which are used to form the test specimens. During casting, care is taken to ensure proper compaction and surface finishing to eliminate air voids and achieve the desired specimen quality. After casting, the specimens are demolded and subjected to a curing process in accordance with the procedures specified in the relevant technical standards [21, 22]. These guidelines are followed rigorously to ensure the reliability and reproducibility of the mechanical testing results, thereby supporting accurate evaluation of the performance of coral concrete.

The compressive strength of coral concrete was evaluated in accordance with the Vietnamese standard TCVN 3118:2022 [23], which outlines the method for determining the compressive strength of concrete specimens. After the curing period of 28 days, each specimen were carefully verified using a precision ruler to ensure conformity with standard tolerances (Figure 4a). The specimens were then placed centrally and symmetrically between the loading platens of a calibrated compression testing machine with a capacity suitable for concrete testing (Figure 4b). Particular attention was given to aligning the specimen surfaces perpendicular to the loading axis to avoid eccentric loading. The test was conducted using a displacement-controlled loading mode, with a controlled rate of 0.2–0.6 MPa/s applied continuously until failure, in line with TCVN 3118 [23] and relevant international testing protocols. The loading duration until specimen failure exceeded 30 seconds. During the loading process, initial cracks began to appear, primarily at the corners or along the aggregate-matrix interface, and progressively widened as the load increased (Figure 4c). Failure was characterized by diagonal splitting and crushing of the specimen, with a brittle fracture pattern typical of coral concrete due to the porous and angular nature of the aggregates (Figure 4d). The peak compressive load was recorded for each specimen, and compressive strength was calculated based on the loaded area. Table 6 presents the compressive strength test results of three concrete specimens after 28 days of curing. The measured compressive strengths were 36.0 MPa, 35.7 MPa, and 36.2 MPa, respectively, yielding an average value of 35.9 MPa. These value of compressive strength corresponds to strength grade B25 concrete.

3.3. Elastic modulus

Several investigations have introduced approaches for determining the elastic modulus of coral concrete E_c using its compressive strength as a reference. For instance, Li conducted a regression analysis linking the cube compressive strength to the elastic modulus of coral concrete, adapting a model originally developed for conventional concrete [24]. The resulting regression model demonstrated a strong correlation, with a coefficient of determination (R^2) of 0.98. The corresponding equation for estimating the elastic modulus of coral concrete derived from this analysis is presented as follows:

$$E_c = \frac{10^5}{1.1 + \frac{73.7}{f_{cu}}} \quad (1)$$

A study on the elastic modulus of coral concrete was conducted by Wang [25].

$$E_c = \frac{10^5}{3.28 + \frac{21.63}{f_{cu}}} \quad (2)$$

The elastic modulus of coral concrete can be reasonably estimated using empirical equations developed for lightweight concrete. Given the porous structure and lower density of coral aggregates, the mechanical behavior of coral concrete shares similarities with that of lightweight concrete, making these models a suitable reference for preliminary evaluation, such as the study by Ding et al. [26].

$$E_c = \frac{10^5}{2.35 + \frac{47.9}{f_{cu}}} \quad (3)$$

In the above equations, fcu represents the ultimate compressive strength (MPa) of the coral concrete specimen.

Table 7 presents the estimated elastic modulus values of coral concrete corresponding to a compressive strength of 35.7 MPa, calculated using three empirical formulas developed in previous studies by Li et al. [24], Wang [25], and Ding et al. [26], respectively. Each was derived based on regression analysis linking compressive strength and elastic modulus, either specifically for coral concrete or by adapting models for lightweight concrete. The method proposed by Li et al. yields the highest estimated modulus value at 31,601 MPa, which is attributed to the lower denominator in their expression due to the formulation of the strength-based term. In contrast, Wang's method, which adapts a model developed for lightweight concrete, produces the lowest elastic modulus at 25,734 MPa. This relatively conservative estimate may reflect the higher sensitivity of the equation to lower compressive strength ranges, and it provides a safer approximation where material variability is significant. The method of Ding et al. gives an intermediate value of 27,081 MPa, offering a balance between the upper and lower bounds provided by the other two approaches. Their model includes a more moderate correction factor in the denominator, which accounts for both material porosity and strength.

4. Application potential of coral concrete in marine structures and challenges

4.1. Application potential

The use of coral concrete yields substantial benefits in terms of sustainability and logistical efficiency. Environmentally, it mitigates the overexploitation of river sand and freshwater, resources that are increasingly restricted due to regulatory and ecological concerns. By sourcing sand, coarse aggregate, and mixing water from the local environment, the carbon footprint associated with material transport is significantly reduced. This contributes to the development of low-carbon construction practices, particularly critical in climate-sensitive marine zones. Coral concrete demonstrates significant applicability in various forms of marine infrastructure. For instance, the construction of breakwaters and revetments, essential components of coastal protection can benefit from coral concrete due to its sufficient compressive strength and compatibility with marine conditions. Figure 5a shows a concrete floating breakwater, which is designed to reduce wave energy in harbors and coastal zones. Given its exposure to harsh marine conditions and the need for reduced self-weight to ensure buoyancy, coral concrete presents a viable material alternative. Its lower density, when compared to conventional concrete, may enhance the floating capability while maintaining sufficient structural integrity for wave attenuation. Figure 5b depicts a concrete-block revetment, composed of modular precast blocks arranged on a slope to prevent shoreline erosion. This type of structure benefits from the ease of installation and replacement of individual blocks. Coral concrete, with appropriate mix design, could be used for these prefabricated units, offering advantages in remote or island regions where transporting traditional materials is logistically challenging.

Table 1. Technical specifications of PCB40 cement [18].

No.	Indicators	PCB40 Cement
1	Compressive strength, MPa, not less than: - 3 days ± 45 minutes - 28 days ± 8 hours	 18 40
2	Setting time: -Initial setting time, minutes, not less than - Final setting time, minutes, not less than	 45 420
3	Fineness, determined by: - Residue on 0.09 mm sieve, %, not more than - Specific surface area by Blaine method, cm^2/g, not less than	10 2800
4	Volume stability (Le Chatelier method), mm, not more than	10
5	Anhydrous sulfur trioxide content (SO_3), %, not more than	3.5
6	Autoclave expansion, %, not more than	0.8

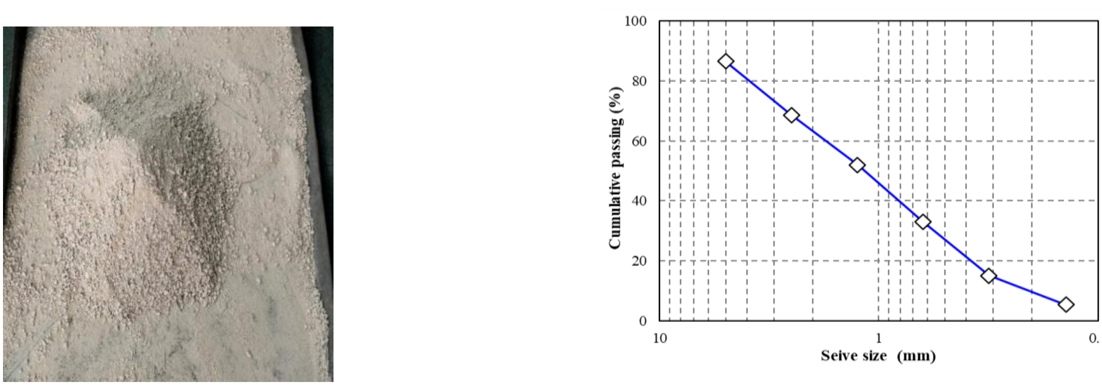
Table 2. Seawater chemical characteristics.

PH	Cl^-	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Other
	(g/l)	(g/l)	(g/l)	(g/l)	(g/l)	(g/l)
6.8	15.3	2.4	8.5	0.35	1.1	//

Figure 1. Sieve for coral coarse aggregate.

Table 3. Mechanical properties of coarse coral aggregate.

Mechanical property	Unit	Coral aggregate		
Sieve size	mm	5	10	20
Cumulative retained on sieve	%	98	95	4
Water absorption	%	3.92		
Loose bulk density	kg/m^3	980		
Test of compression in cylinders	%	46		
Flat and elongated particle content	%	19.6		
Dust, clay, and silt content	%	0.41		



a) b)

Figure 2. Natural coral sand and particle size distribution curve.

Table 4. Physical and mechanical properties of coral sand.

Property	Unit	Coral sand					
Sieve size	mm	5	2.5	1.25	0.63	0.315	0.14
Cumulative retained	%	13.5	31.4	48	66.9	84.4	94.6
Water absorption	%	14.4					
Dust and clay content	%	1					
Loose bulk density	kg/m^3	1120					
Fineness modulus	//	2.2					

Table 5. Coral concrete mix design.

Cement	Water	Coral sand	Coral aggregate	Water to cement ratio (W/C)
kg	kg	kg	kg	0.62
450	279	754	745	
%	%	%	%	
20.20	12.52	33.84	33.44	

a) Preparation of raw materials

b) Mixing of coral concrete

c) Casting of compressive strength test specimens

d) Curing of specimens

Figure 3. Coral concrete fabrication process.

a) Verification of specimen dimensions

b) Specimen placement in testing machine

c) Crack formation during the loading process

d) Failure of the specimen

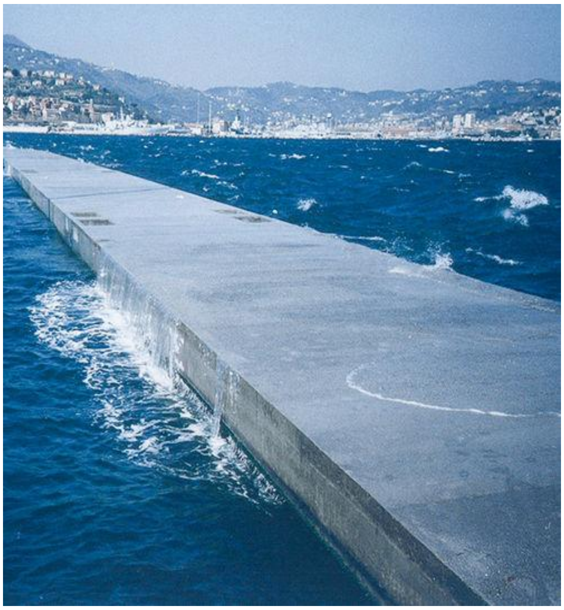
Figure 4. Testing procedure of specimens.

Table 6. Compressive strength test results of specimens.

No.	Water to cement ratio (W/C)	Compressive strength at 28 days (MPa)	Average value (MPa)
1	0.62	36.0	35.9
2		35.7	
3		36.2	

Table 7. Elastic modulus of coral concrete estimated using empirical formulas.

Compressive strength: 35.7 (MPa)		
Method	Equation	Estimated modulus (MPa)
Li et al. [24]	$E_c = \frac{10^5}{1.1 + \frac{73.7}{f_{cu}}}$	31601
Wang [25]	$E_c = \frac{10^5}{3.28 + \frac{21.63}{f_{cu}}}$	25734
Ding et al. [26]	$E_c = \frac{10^5}{2.35 + \frac{47.9}{f_{cu}}}$	27081



a)

b)

Figure 5. Concrete floating breakwater [27] and concrete-block revetment [28].

a)

b)

Figure 6. Concrete box culverts [29] and precast concrete tanks [30].

Additionally, utility and service structures, such as culverts, foundations, storage tanks, and access walkways, which typically require moderate strength and durability, can be effectively realized with coral concrete, particularly when on-site fabrication is prioritized. Figure 6a depicts a concrete box culvert, commonly used for stormwater drainage, underpasses, or utility crossings. These elements require sufficient compressive strength and durability to withstand soil pressure and water flow. Figure 6b shows precast concrete tanks, which are often employed in water treatment systems or as storage units. With the incorporation of supplementary cementitious materials, coral concrete can make it a viable option for manufacturing such tanks, especially in marine or saline environments where conventional aggregate sources may be limited. Figure 7 illustrates a concrete walkway, a typical application in pedestrian infrastructure that requires moderate strength, and good workability. Given its relatively low structural demand compared to load-bearing elements, this type of construction is well-suited for the use of coral concrete.

Figure 7. Concrete walkway [31].

Figure 8. Pier 914 in Con Dao island (Source: Internet).

Figure 9. Precast house constructed with lightweight concrete [31].

Another promising application lies in harbor and pier substructures, where pile caps, footing pads, and precast slab elements are frequently exposed to tidal action, chloride ions, and mechanical loading (Figure 8). Coral concrete may offer sufficient structural reliability while utilizing abundant marine materials, thus enhancing site independence. Figure 9 shows a precast house constructed with lightweight concrete, highlighting a modular construction approach that enables fast assembly and efficient material use. In the offshore islands, such systems typically consist of prefabricated wall panels, floor slabs, and partition elements, which are transported to the site and assembled with minimal labor and equipment. Given the lightweight and non-load-bearing nature of many of these components, coral concrete presents a promising alternative material. By replacing conventional aggregates with coral-derived materials, the panels can achieve further weight reduction.

4.2. Challenges and future research directions

Despite its demonstrated feasibility, several challenges limit the widespread adoption of coral concrete in structural applications. The long-term durability of coral concrete in aggressive marine environments, especially under cyclic wet–dry exposure and chloride-induced corrosion, remains a key concern. Further research is necessary to evaluate the behavior of reinforced coral concrete, particularly with respect to steel–concrete bond strength, corrosion resistance, and crack propagation control. In addition, the absence of standardized design guidelines for coral concrete such as those specifying mechanical performance ranges, mix design procedures, and exposure classifications poses difficulties in engineering practice. Empirical design models and testing protocols must be developed and validated to facilitate regulatory acceptance and engineering adoption. A significant research gap also exists in the evaluation of coral concrete under dynamic loading conditions, particularly in coastal and offshore environments where structures are subjected to wave impact, repeated hydrodynamic pressure, and other forms of transient loading. The structural response of coral concrete to such dynamic effects, including fatigue resistance, energy absorption, and deformation behavior, has not been sufficiently investigated. Understanding these characteristics is crucial for the safe and reliable use of coral concrete in maritime structures such as breakwaters, revetments, and offshore platforms. To enhance the engineering performance of coral concrete, emerging technologies can be integrated. For example, fiber reinforcement using polypropylene, basalt, or natural fibers can improve ductility and energy dissipation. These innovations, combined with advanced modeling and experimental validation, are essential to unlocking the full potential of coral concrete in both static and dynamic marine applications.

5. Conclusions

This research demonstrates the technical feasibility and application potential of coral concrete for marine infrastructure, particularly in Vietnam's island and coastal regions where conventional construction materials are scarce or logistically impractical. The experimental results confirm that coral concrete produced with coral sand, coral coarse aggregate, and seawater can achieve compressive strengths suitable for structural applications, such as grade B25, with the aid of mix design methods. The successful development of a workable concrete mix incorporating porosity coral aggregates underlines the adaptability for site-specific resources. Beyond compressive strength, the study further provides comparative evaluations of the elastic modulus using empirical formulas, reinforcing the mechanical credibility of coral concrete for moderate structural demands. Various application scenarios, including breakwaters, revetments, precast culverts, walkways, and modular housing, illustrate the versatility and practical relevance of coral concrete in island-based construction. These findings position coral concrete as a viable low-carbon alternative that aligns with sustainable development goals in maritime environments. Despite these promising outcomes, several limitations require continued investigation. In particular, the long-term performance of coral concrete under cyclic wet-dry conditions, chloride-induced deterioration, and dynamic wave loading remains poorly understood. Moreover, the absence of codified design frameworks and performance-based specifications hinders broader adoption. Future research should thus prioritize mechanical characterization under repeated and dynamic loads, integration of fiber reinforcements, and the development of region-specific design standards. Addressing these gaps is essential to enable the safe and sustainable implementation of coral concrete in marine and coastal infrastructure systems.

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