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Performance analysis of ordinary portland cement and portland pozzolan cement cement in improving sea sand and sea water concrete with zeolite powder

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ABSTRACT

This study examines the performance of concrete made with sea sand sea water using two types of cement: ordinary portland cement (OPC) and portland pozzolan cement (PPC), with the incorporation of zeolite powder. Variations in zeolite content (0%, 7.5%, and 10%) were tested to evaluate compressive strength at 14, 28, and 56 days, as well as durability after immersion in a 5% Na_2SO_4 solution for 30, 60, and 90 days. The results indicate that OPC-based concrete generally achieves higher compressive strength compared to PPC. The addition of 7.5% zeolite to OPC yielded optimal compressive strength at 56 days, while PPC with 10% zeolite demonstrated significant improvements, despite lower overall strength. Durability testing revealed that PPC concrete exhibited superior resistance to aggressive environments, particularly sulfate attack. The addition of 10% zeolite significantly enhanced durability up to 90 days of immersion. For OPC concrete, 7.5% zeolite effectively reduced porosity and improved durability, although a slight decline was observed at 90 days. These findings highlight that while OPC provides better compressive strength, PPC with zeolite offers superior durability under harsh environmental conditions, making it a recommended choice for concrete construction in coastal regions.

Keywords: sea sand, sea water, concrete, OPC, PPC, zeolite, durability, compressive strength.

INTRODUCTION

The growing demand for construction materials in Indonesia has led to excessive exploitation of river sand, resulting in environmental damage such as erosion and sedimentation [1]. To mitigate these effects, the abundant availability of sea sand has become a focus of research, with studies indicating that it can be utilized in concrete production through composition adjustments and the addition of specific admixtures [2]. Additionally, seawater can be used as a mixing agent, reducing dependency on freshwater resources. However, the high chloride content in seawater poses a risk of corrosion to steel reinforcement. To address this challenge, supplementary materials such as zeolite, fly ash, and volcanic ash can be used to decrease concrete porosity and inhibit chloride ion penetration [3]. Zeolite, a naturally occurring porous aluminosilicate mineral, offers a unique crystalline structure with excellent water and ion absorption properties, as well as ion exchange capabilities. These characteristics make zeolite an ideal additive for concrete mixtures [4]. Its high silica and alumina content provides pozzolanic properties, zeolite exhibits pozzolanic properties, allowing it to react with calcium hydroxide in cement to form calcium silicate hydrate (C-S-H), the primary binding compound in concrete [5]. This reaction enhances concrete strength through additional C-S-H formation, reduces porosity, and improves durability against external attacks [6]. Furthermore, zeolite enhances concrete's workability and elastic modulus [7].

However, the optimal dosage of zeolite must be carefully determined, as excessive amounts can impact setting time and viscosity [8]. Moreover, the effectiveness of zeolite depends on the type of cement used [9].

Cement plays a critical role in global infrastructure development due to its ability to bind aggregates into a solid and durable mass, its widespread availability, and cost-effectiveness [10]. For aggressive environments, such as those involving seawater, Type V cement is often recommended for its excellent sulfate resistance [11]. However, its limited availability in the market necessitates the use of alternatives. portland pozzolan cement (PPC), classified as Type II cement, is a suitable substitute for coastal and sulfate-rich environments due to its moderate sulfate resistance and heat of hydration [12]. Additionally, PPC outperforms Ordinary Portland Cement (OPC) in seawater environments because its pozzolanic components form stable, sulfate-resistant compounds, providing long-term structural durability [13, 14].

This study explores the use of concrete made with sea sand seawater, utilizing OPC and PPC as binders, combined with the addition of zeolite powder at varying concentrations (5%, 7.5%, and 10%). The primary objective is to reduce the overexploitation of river sand in concrete construction by introducing sea sand as a sustainable alternative, while also leveraging the natural zeolite resources abundant in Aceh Province. Specifically, the study investigates the effects of zeolite addition on the compressive strength and durability of concrete produced with OPC and PPC, identifying the optimal zeolite content from the tested variations.

MATERIALS AND METHODS

Materials

This study used ordinary portland cement (OPC) and portland pozzolan cement (PPC), or Type II cement, produced by PT solusi bangun andalas (SBA) operating in Lhoknga, Aceh Besar. These cements were chosen for their resistance to sulfate, chloride, and alkali, making them suitable for aggressive environments. Sea sand, obtained from the Pasir Putih Lhok Mee beach in Aceh Besar, was used as fine aggregate and tested according to ASTM C1585-13 (2013) and ASTM C20 (2017). Coarse aggregate, in the form of crushed stone, was sourced from a stone crusher in Indrapuri, Aceh Besar. The chemical composition of the sea sand was analyzed using XRF. Seawater, which aids in the binding process of the concrete mixture, was collected from the same location as the sea sand. Natural zeolite from the Aceh Besar mountains was used as an additive. The chemical composition of the zeolite was analyzed using XRF, while the mineralogical characteristics of the OPC and PPC were determined based on SNI 15-2049-2004.

Concrete mixture methodology

In this study, the concrete mix was prepared using sea sand seawater, comparing two types of cement (OPC and PPC) with the addition of zeolite powder. The aggregates consisted of fine aggregate (sea sand) and coarse aggregate (crushed stone), both of which met the required specifications for concrete based on physical property tests. The fine aggregate had a fineness modulus ranging from 1.5 to 3.8, while the coarse aggregate had a size distribution between 5.0 and 8.0 mm. The particle gradation of the aggregates was determined using sieves ranging from No. 25 to No. 0.15 mm, with the results shown in Figure 1. The physical properties of the aggregates and the XRF analysis of the sea sand are presented in Tables 1 and 2. XRF characterization revealed that the sea sand contains silica (SiO_2) and calcium oxide (CaO), which are key components in cement production and confirm its suitability for use in concrete mixtures. The chemical composition of the seawater indicated a pH of 7.96, which falls within the acceptable range for concrete mixes (7–8), as outlined in Table 3. Natural zeolite powder was incorporated into the concrete mix in varying proportions of 0%, 5%, 7.5%, and 10% by weight of cement. The zeolite was processed into a 200-mesh powder through grinding and heating at 200 °C for 6 hours. The particle size distribution of the zeolite powder was analyzed using Particle Size Analysis (PSA), yielding favorable results. The SiO_2 and Al_2O_3 content in the zeolite powder was particularly high. A comparison of the chemical composition of the zeolite powder, OPC, and PPC, as determined by XRF, is presented in Table 4. The complete process for preparing the zeolite powder is illustrated in Figure 1.

Mix design

This study used the concrete mix design method according to the american concrete institute

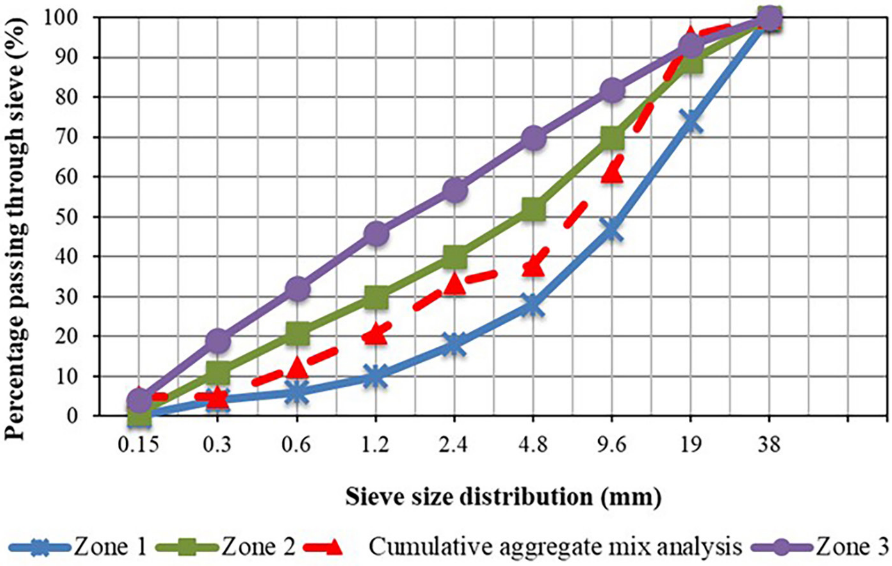

Figure 1. Particle gradation of the aggregates determined using sieves ranging from No. 25 to No. 0.15 mm

Table 1. Physical properties of aggregates

Physical property	Coarse aggregate (Gravel)	Fine aggregate (Sand)
Maximum size	25.4 mm	Fine sea sand
Specific gravity (saturated surface dry - SSD)	2.717	2.716
Specific gravity (oven-dry - OD)	2.695	2.668
Absorption	0.825%	1.798%
Bulk density	1.554 kg/m³	1.637 kg/m³
Fineness modulus (FM)	6.842	2.285

Table 2. XRF Analysis of the chemical composition of sea sand

Composition	Wt. (%)											
	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	Mn_2O_3
Sea sand	6.47	41.49	1.24	0.47	47.62	4.15	0.81	0.26	0.06	0.03	0.01	0.02

Table 3. River water and seawater data

Indicator	Sample
	Sea water (Lhok Mee)
pH	7.96
Conductivity (ms/cm)	57.7
Fe (ppm)	0.04
Ca-hardness (ppm)	trace
Total hardness (ppm)	trace

(ACI) standards. Two types of cement were used: ordinary portland cement (OPC) and portland pozzolan cement (PPC). Zeolite powder was added as a cement substitute at varying proportions of 0%, 5%, 7.5%, and 10% by weight of cement. Each cement variation consisted of four groups for compressive strength testing and four groups for concrete durability testing. The mix design process included determining the water-cement ratio, selecting aggregates, and adjusting the slump to achieve optimal concrete performance (Figure 2).

Preparation of specimens

The test specimens for compressive strength and durability were cubic, with dimensions of 150 × 150 × 150 mm, in accordance with ASTM C109-17 standards. After 24 hours, the specimens were removed from the molds and immersed in seawater for curing periods of 14, 28, and 56 days to assess compressive strength. Additionally, the specimens

Table 4. Chemical composition of OPC and PPC cement in weight percentage

Composition	Zeolite (%wt.)	OPC cement (%wt.)	PPC cement (%wt.)
LOI	13.51	–	–
SiO_2	69.55	21.3	22.3
Al_2O_3	9.93	6.0	4.7
Fe_2O_3	0.75	2.7	4.3
CaO	2.95	63.2	63.1
MgO	0.73	2.9	2.5
SO_3	0.05	1.8	1.7
Na_2O	0.96	–	–
K_2O	2.31	–	–
TiO_2	0.09	–	–
P_2O_5	0.02	–	–
Mn_2O_3	0.02	–	–

Figure 2. Preparation process of zeolite from natural form to powder

were exposed to a Na_2SO_4 solution for 30, 60, and 90 days, with the solution being replaced every 30 days to maintain consistent concentration and evaluate the concrete's durability. Absorption tests were conducted on the specimens after 56 days of immersion to measure their absorption rate.

Compressive strength test

The compressive strength test was conducted in accordance with ASTM C39/C39M standards using a compressive strength testing machine (Ton Industri model No. 2547/14/1970) with a capacity of 1500 KN. The cube specimens were placed horizontally on the testing machine, and load was applied gradually until the specimen failed. Compressive strength testing was performed on cube specimens with dimensions of 150 × 150 × 150 mm, divided into eight groups based on cement type. The variations in test specimens for compressive strength testing are presented in Table 5. The corresponding pressure changes were recorded and used to calculate the compressive strength using the formula:

$$f'c = \frac{P}{A} \tag{1}$$

where: P – maximum load from the testing machine (tons), A – cross-sectional area under pressure (mm²), $f'c$ – compressive strength (Mpa).

Durability strength test

Durability test of concrete specimens immersed in a 5% Na_2SO_4 sulfate solution for 30, 60, and 90 days aimed to assess the concrete's resistance to sulfate ions, which can potentially damage the concrete structure. The test involved monitoring the changes in strength of concrete

Table 5. Compressive strength concrete samples and corresponding codes

Variation of sample	Code
Compressive strength - OPC cement, normal sand normal water, no zeolite (control variable)	CO_N
Compressive strength - OPC cement, sea sand sea water, no zeolite	CO_Z0
Compressive strength - OPC cement, sea sand sea water, 5% zeolite	CO_Z5
Compressive strength - OPC cement, sea sand sea water, 7.5% zeolite	CO_Z7.5
Compressive strength - OPC cement, sea sand sea water, 10% zeolite	CO_Z10
Compressive strength - PPC cement, sea sand sea water, no zeolite	CP_Z0
Compressive strength - PPC cement, sea sand sea water, 5% zeolite	CP_Z5
Compressive strength - PPC cement, sea sand sea water, 7.5% zeolite	CP_Z7.5
Compressive strength - PPC cement, sea sand sea water, 10% zeolite	CP_Z10

incorporating zeolite powder, using the same specimen dimensions and compressive strength testing machine as in the compressive strength test. After the test periods were completed, an SEM-EDS analysis was performed to evaluate the chemical composition of the concrete affected by immersion in the sulfate solution. The durability testing was also divided into eight groups of specimens, with variations presented in Table 6.

Absorption test

The absorption test was conducted on concrete specimens in the form of 150×150×150 mm cubes to measure the water absorption rate of the concrete, which can indicate the quality and durability of the concrete against moisture. The specimens were immersed in seawater for 56 days. The procedure for calculating water absorption, based on ASTM C642, is as follows:

$$Absorbtion = \frac{W-D}{D} \times 100\% \quad (2)$$

where: D is the dry weight of the specimen (kg), W is the weight of the specimen after immersion (kg).

RESULT AND DISCUSSION

Compressive strength of concrete with OPC and PPC cement

The data analysis in Figure 3 shows that concrete with OPC generally exhibits higher initial strength compared to concrete made with PPC cement [15]. he addition of zeolite to OPC concrete results in a significant strength improvement, particularly at 28 days of curing. This indicates that zeolite plays a crucial role in enhancing the bond between concrete particles [16]. However, the decrease in strength at later ages is likely attributed to factors such as microcracking and the influence of aggressive environmental conditions [17]. At a 10% zeolite concentration, the concrete strength actually increased at 56 days [18]. This can be attributed to the denser pore filling at higher concentrations, which enhances resistance to seawater penetration and slows the degradation process [19, 20].

For PPC-based concrete, there is a consistent trend of strength improvement with increasing zeolite concentration and curing age [21]. This can be explained by the ongoing pozzolanic reaction

Table 6. Sample of durability strenght concrete and code

Variation of sample	Code
Durability - OPC cement, normal sand normal water, no zeolite (control variable)	DO_N
Durability - OPC cement, sea sand sea water, no zeolite	DO_Z0
Durability - OPC cement, sea sand sea water, 5% zeolite	DO_Z5
Durability - OPC cement, sea sand sea water, 7.5% zeolite	DO_Z7.5
Durability - OPC cement, sea sand sea water, 10% zeolite	DO_Z10
Durability - PPC cement, sea sand sea water, no zeolite	DP_Z0
Durability - PPC cement, sea sand sea water, 5% zeolite	DP_Z5
Durability - PPC cement, sea sand sea water, 7.5% zeolite	DP_Z7.5
Durability - PPC cement, sea sand sea water, 10% zeolite	DP_Z10

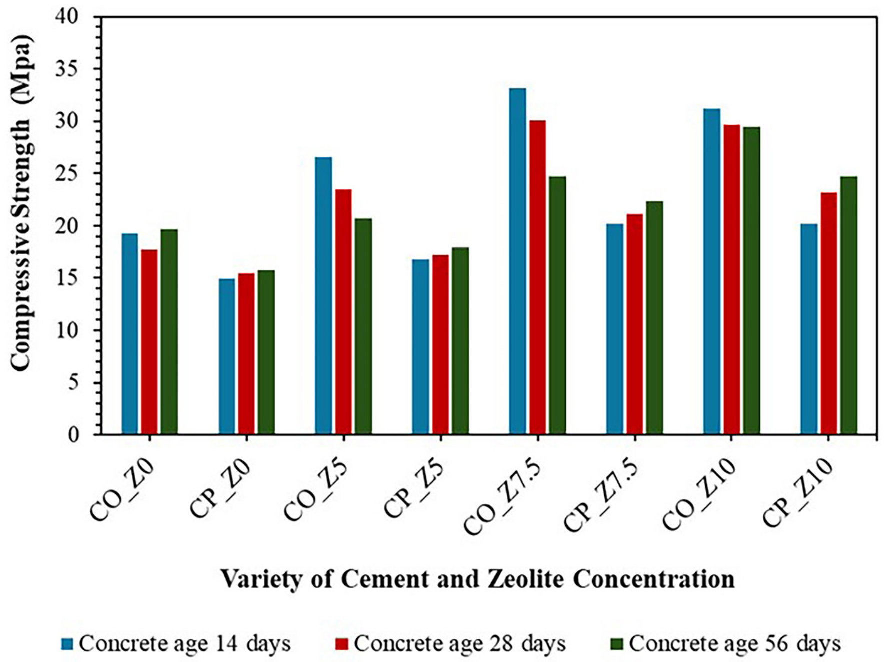

Figure 3. Comparison of compressive strength of OPC and PPC cement concrete with sea sand seawater

mechanism. As the zeolite concentration increases, more material is available to react with calcium hydroxide, resulting in the formation of additional calcium silicate hydrate (C-S-H) gel [22, 23]. Over time, the pozzolanic reaction continues, producing more C-S-H gel and gradually enhancing the concrete's strength. The combination of PPC cement and zeolite provides a synergistic effect that significantly improves both the strength and durability of concrete, especially in aggressive environments such as seawater [13, 24].

Compressive strength of normal concrete with OPC and PPC cements at optimal zeolite content

The compressive strength values of the concrete were measured at 56 days of immersion to represent the long-term effects on sea sand concrete exposed to seawater, using OPC and PPC cements with optimal zeolite content. Figure 4 shows that the compressive strength of sea sand concrete with seawater and PPC cement

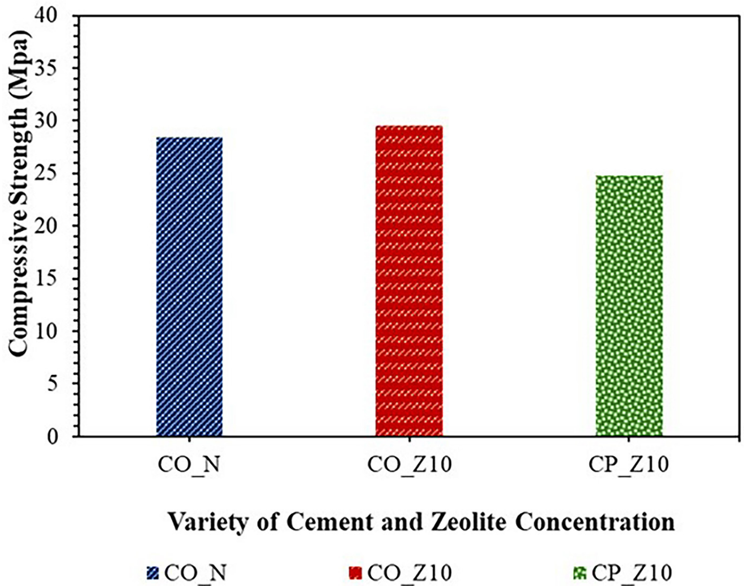

Figure 4. Comparison of compressive strength of normal concrete, OPC, and PPC at optimal zeolite content

increased with the addition of zeolite (5%, 7.5%, and 10%) and longer curing times (14, 28, and 56 days) [25]. The addition of zeolite helps improve the bond between the cement paste and the sea sand aggregates, which have high salt content and irregular particles [19].

For comparison, concrete specimens were tested at 56 days of immersion using both OPC and PPC cements with optimal zeolite content. The use of two different types of cement in concrete made with sea sand seawater demonstrated varying effects on the compressive strength. Figure 4 shows that for concrete with OPC, the addition of 10% zeolite (SOPC_Z10%) resulted in a 3.62% increase in compressive strength compared to normal concrete, indicating that this combination effectively enhances the concrete's strength [26]. In contrast, for PPC-based concrete with 10% zeolite (CP_Z10), the compressive strength decreased by 13.01% [27]. These performance differences suggest that OPC is more effective than PPC in improving the strength of sea sand concrete exposed to seawater. This can be attributed to the superior hydration characteristics of OPC, while the higher pozzolanic content of PPC may alter the chemical properties of the mixture, such as increasing the risk of alkali-silica reactions or reducing optimal hydration [13]. Overall, the type of cement used has a significant impact on the performance of concrete, particularly when using sea sand and seawater as the primary materials.

Durability of OPC and PPC concrete in sulfate-exposure environments

PPC cement concrete with sea sand and seawater exhibits better long-term durability compared to OPC, especially in aggressive environments such as sulfate exposure [13, 28]. The addition of zeolite to both OPC and PPC concrete significantly improves durability, with the best results observed at 7.5% zeolite for OPC and 10% for PPC as depict in Figure 5. In the case of OPC, the addition of 7.5% zeolite optimally reduces the porosity of the concrete through a reaction with calcium hydroxide, although durability slightly decreases after 90 days of immersion [4]. Conversely, PPC concrete with 10% zeolite demonstrates improved durability even after 90 days of immersion, making it an excellent choice for concrete applications in sulfate-rich environments.

Compressive strength of normal concrete with OPC and PPC cements at optimal zeolite content

A comparison of the durability of normal concrete, OPC, and PPC at optimal zeolite content is illustrated in Figure 6. The addition of 10% zeolite powder to PCC concrete mixed with sea sand and seawater significantly enhanced durability. The impact of zeolite in sea sand and seawater concrete varies depending on the type of cement

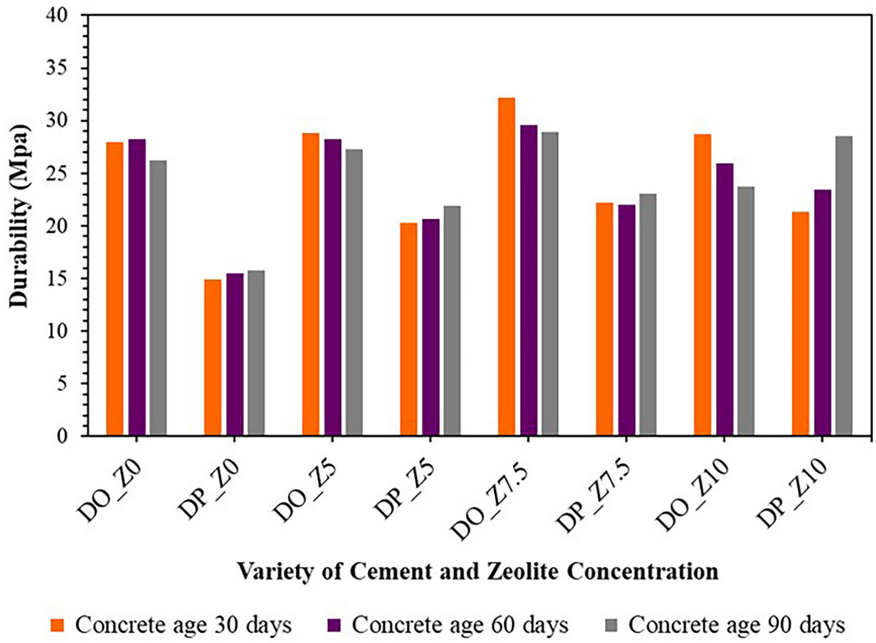

Figure 5. Comparison of durability of OPC and PPC cement concrete with sea sand seawater

used. Concrete made with OPC and 7.5% zeolite (DO_Z7.5) showed a slight durability increase of 0.84%, indicating that the combination of OPC cement and zeolite can enhance the concrete's resistance to sulfate solutions, though the impact is not substantially significant [20]. This improvement is likely due to the high reactivity of OPC cement, which responds effectively to additives like zeolite, helping reduce the negative effects of sulfate content in sea sand and seawater [29].

However, concrete made with PCC and 10% zeolite (DP_Z10) exhibited a durability decrease of -0.59%. This reduction may result from the mismatch between the high proportion of zeolite and the characteristics of PCC cement or the less-than-optimal interaction between zeolite and the pozzolanic materials in PCC. Additionally, the adverse impact of sea sand and seawater, containing chlorides and sulfates, could compromise the quality of the concrete, especially when the added zeolite amount is not optimal. Nevertheless, PCC cement still demonstrated superiority in long-term durability, with improved resistance over extended immersion periods, although the negative effects of sea sand and seawater remain evident [30].

Absorption in aggressive environments

The addition of zeolite significantly reduced the sea water absorption values of concrete, for both OPC and PPC cement types [31] as shown in Figure 7. Zeolite functions by filling the pores within the concrete, thereby decreasing void spaces that could absorb water. Concrete made with PPC

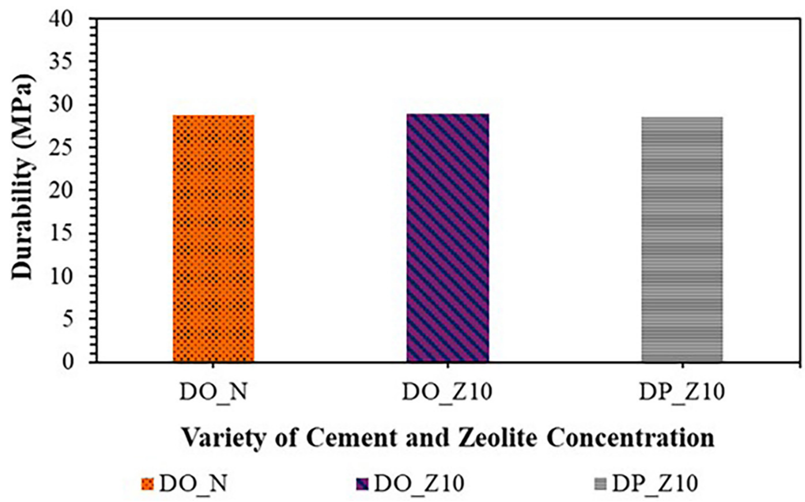

Figure 6. Comparison of durability of normal concrete, OPC, and PPC at optimal zeolite content

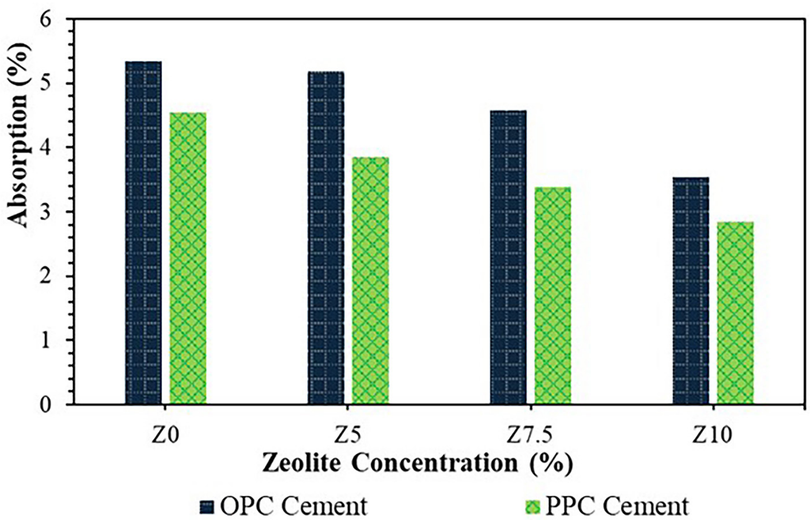

Figure 7. Comparison of water absorption values for OPC and PPC concrete with varying zeolite concentrations

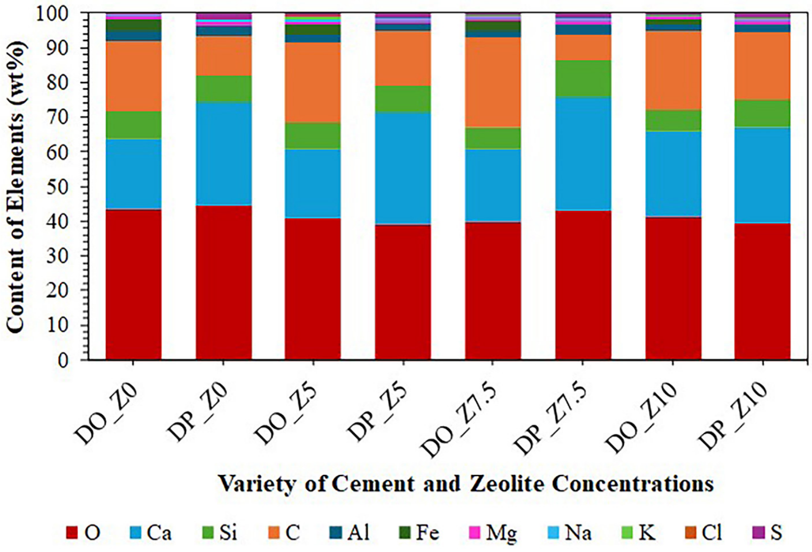

Figure 8. SEM-EDS results for durability of sea sand sea water concrete with OPC and PPC cement

cement exhibited lower absorption rates compared to OPC, with a significant difference of 19.54% at a 10% zeolite concentration. This is attributed to the hydration characteristics of PPC cement, which produces a denser cement paste, thereby reducing the porosity of the concrete. Consequently, PPC cement is more suitable for concrete applications requiring resistance to aggressive environments, such as seawater exposure [25].

SEM-EDS analysis

The chemical composition comparison of the durability of sea sand seawater concrete using OPC and PPC cement after 90 days of immersion in sulfate solution is shown in Figure 8. SEM-EDS analysis of OPC concrete with sea sand and seawater revealed fluctuations in the contents of O, Ca, and Si across different zeolite concentrations. The higher carbon content in concrete with 7.5% zeolite contributes to enhanced durability through the formation of calcium carbonate [32, 33]. However, a decrease in durability was observed in concrete with 10% zeolite, likely due to a reduction in carbon content and an increase in chloride levels [34]. For PPC concrete, similar fluctuations in elemental content were observed. Concrete with 10% zeolite exhibited the highest durability, despite lower levels of O, Ca, and Si. The significant increase in carbon content indicates the formation of carbonates, which improves resistance to acids. The denser C-S-H structure and better pore filling in this concrete effectively inhibit sulfate ion penetration, thereby enhancing durability [35].

CONCLUSIONS

This study investigated the strength of concrete made with seawater-sea sand using PPC and OPC cement with varying levels of zeolite powder. Durability was tested by immersing the concrete in a 5% Na_2SO_4 solution. The results indicate the following:

1. Concrete made with sea sand seawater showed a significant increase in compressive strength at 10% zeolite, particularly at 56 days, contributing to long-term strength.
2. Type II cement (PPC) with 10% zeolite improved the durability and strength of the concrete, as observed at 30, 60, and 90 days.
3. OPC with 10% zeolite enhanced concrete resistance to water and chloride ion penetration, thus strengthening its durability.
4. SEM-EDS analysis showed that zeolite increased carbon content in the concrete, improving durability through calcium carbonate formation.
5. The use of sea sand and zeolite as alternative concrete materials has potential to reduce the environmental impact of river sand exploitation.

Acknowledments

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