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Concrete Durability Performance Against Seawater as Curing and Mixing Water

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Abstract

The durability of concrete is its ability to withstand and function well over a long period without experiencing significant damage due to environmental conditions, whether physical or chemical. The durability of concrete in a seawater environment naturally affects its compressive strength. The salt content of 3.5% in seawater can deplete the energy of the concrete. Due to its high chloride (Cl) content, seawater has a coarse salt characteristic that can penetrate the concrete along with other compounds within it, accelerating the weathering reaction and causing a loss of strength and rigidity. This research aims to determine the effect of seawater on concrete durability and to assess the compressive strength of concrete based on variations in concrete mixtures and curing methods. The tests conducted include testing the characteristics of coarse and fine aggregate materials to obtain accurate concrete mix planning, followed by compressive strength testing after curing for 3, 7, 14, 21, and 28 days with four different mix and curing variations. The results show that in variation 1, the compressive strength of concrete cured with seawater for 14 days was 9.81% higher than that cured with freshwater. In variation 2, the compressive strength of concrete mixed with seawater and freshwater cured for 3 days was 43.91% higher compared to seawater curing. In variation 3, the compressive strength of concrete with a freshwater-seawater mix cured for 14 days was 44.65% higher than that of the seawater-only mix. In variation 4, the compressive strength of concrete with a seawater-freshwater mix cured for 3 days was 15.54% higher than that of the freshwater-only mix.

Keywords: *Concrete; Sea Water; Compressive Strength*

INTRODUCTION

Infrastructure development projects are closely related to the use of concrete. Many factors influence the strength and durability of the resulting concrete, one of which is the curing process. Concrete processing is typically done with clean water without using chemicals that affect the strength of the concrete itself. However, when concrete construction is on the coast or offshore, contact with seawater is unavoidable. This contact naturally impacts the compressive strength of the concrete produced [1]. In offshore projects, the supply of clean water is also an issue, but contact with seawater during curing is very risky, as concrete absorbs seawater and salts through its pores. The compounds in seawater reduce the quality of concrete, preventing it from achieving the intended grade [2].

The compressive strength of concrete refers to its ability to withstand compressive loads. In concrete production and curing, water is a vital component for producing strong, high-quality concrete [3]. According to existing concrete standards, the water used for mixing should be potable (with a pH = 7) and free from other substances [4]. However, the issue is that construction projects in Indonesia are not always located in areas with sufficient freshwater availability, making seawater an economical alternative for mixing or curing.

Therefore, using seawater in the curing and mixing of concrete aims to understand the durability of concrete against seawater. The purpose of this study is to determine the visual and density effects of concrete cured in seawater and normal water at the ages of 3, 7, 14, 21, and 28 days, and to determine the average compressive strength of concrete cured with seawater and normal water at 28 days.

RESEARCH METHODS

The method used in this research is the experimental method, which aims to determine the cause-and-effect relationship between variables and compare the results. This study was conducted to investigate the effect of seawater on the strength of concrete for bridge pillars. In this research, there are four variations: Concrete mixture using freshwater and curing with freshwater (V1), concrete mixture using freshwater and curing with seawater (V2), concrete mixture using seawater and curing with seawater (V3), and concrete mixture using seawater and curing with freshwater (V4). Based on these variations, the required number of test specimens for concrete compressive strength testing can be determined, as shown in Table 1.

Table 1 Number of test object variations

Variations	Compressive Strength of Concrete Age					Number of Test Objects
	3	**7**	**14**	**21**	**28**	
Variation 1	3	3	3	3	3	15
Variation 2	3	3	3	3	3	15
Variation 3	3	3	3	3	3	15
Variation 4	3	3	3	3	3	15

a. Concrete

Concrete is one of the building materials commonly used for buildings, roads, bridges, and more. Concrete is a mixture of Portland cement or other hydraulic cement, fine aggregate, coarse aggregate, and water, with or without additional admixtures, forming a solid mass. The standard quality of concrete for bridge pillars is specified in the Indonesian National Standard (SNI) 2451:2008, which includes certain quality requirements for materials used in simple bridge pillars and heads spanning 10 to 25 meters for Class A bridges. The structure of simple bridge heads and pillars must use concrete with a minimum compressive strength of fc' = 25 MPa. This value is based on cylinder compressive testing at 28 days.

b. Seawater

Chemically, the properties of seawater are influenced by 80 chemical elements, with a pH value between 7.5 and 8.5. Seawater has an average salt content of 3.5%, meaning that in 1 liter (1000 mL) of seawater, there are 35 grams of salt (primarily, though not entirely, sodium chloride ($NaCl$), magnesium sulfate ($MgSO_4$), magnesium chloride ($MgCl_2$), potassium chloride (KCl), gypsum ($CaSO_4 \cdot H_2O$), calcium chloride ($CaCl_2$), and calcium carbonate ($CaCO_3$)). According to SNI 2847:2013, seawater is not permitted for use in concrete mixtures because it contains compounds that, in excessive amounts, can harm concrete structures, such as causing corrosion to concrete reinforcement and reducing concrete strength.

c. Cement

According to SNI 15-2049-2004, Portland cement is a hydraulic cement produced by grinding Portland cement clinker, primarily composed of hydraulic calcium silicate, and ground with additives in the form of one or more crystalline forms of calcium sulfate compounds and possibly other additives. When mixed with water, cement forms a paste. The chemical reaction between cement and water generates heat and hardens the cement. Cement is generally divided into two types: hydraulic cement, which hardens when it reacts with water (waterproof and stable in water after hardening), and non-hydraulic cement, which can harden but is not stable in water. Portland cement has the advantages of being easy to shape, strong, resistant to high temperatures, and relatively low maintenance cost; however, once set, it is difficult to alter without causing damage.

d. **Concrete Curing**
Concrete curing aims to prevent concrete from losing water too quickly or to maintain the moisture and temperature of the concrete immediately after the finishing process and once the total setting time is reached. Concrete curing should begin as soon as concrete enters the hardening phase (for open concrete surfaces) or after the mold/formwork is removed, for a specific duration intended to ensure that the conditions required for the chemical reaction process in the concrete mixture remain intact. The method and duration of curing depend on the type of cement and concrete used, including additional or substitute materials, the type and extent of structural elements being constructed, weather conditions, temperature, and humidity at the project location, as well as the designated compressive strength value and timeframe for the characteristic strength of concrete (28 days or other periods, as specified by the design consultant).

According to the technical specifications listed in SNI 03-2847-2002, curing should be carried out for 7 days for normal concrete and 3 days for high-early-strength concrete. ACI 318 recommends curing until at least 70% of the required concrete compressive strength (fc') is achieved. ASTM C-150 requires a minimum curing time of 7 days for Type I cement, 10 days for Type II cement, 3 days for Type III cement, and 14 days for Type IV or V cement.

RESULTS AND DISCUSSION.

The results of concrete compressive strength testing with curing durations of 3 days, 7 days, 14 days, 21 days, and 28 days for concrete mixture using freshwater with Freshwater Curing can be seen in **Table 2.**

Table 2. Compressive Strength Results of Concrete Mixture Using Freshwater with Freshwater Curing (V1)

Water	Compressive Strength of Concrete (Mpa)					
	Test Object	3	7	14	21	28
Seawater	1	10.98	14.99	16.07	18.64	18.32
	2	13.94	24.93	20.93	13.22	17.45
	3	13.64	17.60	13.00	15.63	14.17

The results of concrete compressive strength testing with curing durations of 3 days, 7 days, 14 days, 21 days, and 28 days for concrete mixture using freshwater with Seawater Treatment can be seen in **Table 3.**

Table 3. Compressive Strength Results of Concrete Mixture Using Freshwater with Seawater Treatment (V2)

Water	Test Object	Compressive Strength (MPa)				
		3	7	14	21	28
Seawater	1	19.0	25.7	26.8	24.6	18.7
	2	18.5	26.3	26.2	33.3	17.8
	3	15.9	19.1	26.0	21.8	14.4

The results of concret4 compressive strength testing with curing durations of 3 days, 7 days, 14 days, 21 days, and 28 days for concrete mixture using Seawater with Seawater Treatment can be seen in **Table 4.**

Table 4. Compressive Strength Results of Concrete Mixture Using Seawater with Seawater Treatment (V3)

Water	Compressive Strength of Concrete (Mpa)					
	Test Object	3	7	14	21	28
Seawater	1	10.98	14.99	16.07	18.64	18.32
	2	13.94	24.93	20.93	13.22	17.45
	3	13.64	17.60	13.00	15.63	14.17

The results of concret 4 compressive strength testing with curing durations of 3 days, 7 days, 14 days, 21 days, and 28 days for concrete mixture using seawater with freshwater treatment can be seen in **Table 5.**

Table 5. Compressive Strength of Concrete Mixture Using Seawater with Freshwater Treatment(V4)

Water	Compressive Strength of Concrete (Mpa)					
	Test Object	3	7	14	21	28
Fresh water	1	21.60	22.40	9.71	13.24	12.90
	2	19.68	18.97	16.10	11.63	14.72
	3	18.98	21.43	17.75	14.05	13.84

Fig 1. shows that the compressive strength of concrete mixed with freshwater and cured with either freshwater or seawater is initially low during the early stages of immersion (1-3 days) because the cement hydration process has just begun. Cement and water react to form hydration products that bind the aggregate. At 14 days of immersion, the compressive strength of the concrete significantly increases as most of the hydration process has taken place, resulting in a denser and stronger concrete structure. However, after reaching its peak, the compressive strength declines due to over-curing. Prolonged immersion can cause the concrete to become saturated with water, hindering cement hydration, softening the concrete surface, and reducing its resistance to abrasion and wear.

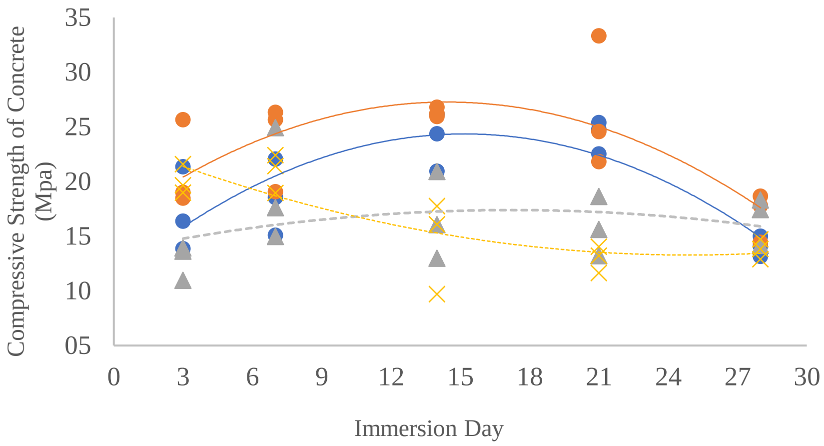

Fig 1. Compressive strength results of concrete

Comparing the concrete mix with freshwater and curing in freshwater to the concrete mix with freshwater but cured with seawater, as shown in Figure 1, the compressive strength of the concrete mix with seawater curing is higher. This increase is due to calcium chloride ($CaCl_2$) in seawater, which forms crystals that fill the pores in the concrete, resulting in higher compressive strength than freshwater curing. The hydration reaction due to seawater can accelerate the cement hydration process due to its salt content and the slightly warmer temperature of seawater compared to freshwater, which also accelerates concrete hardening. For the concrete mix with seawater and freshwater curing, the compressive strength was 43.91% higher after 3 days of immersion. However, at 7, 14, 21, and 28 days, the compressive strength decreased. The significant increase after 3 days is due to calcium chloride ($CaCl_2$) in seawater, forming crystals that fill the concrete pores. Over time, however, these compounds dissolve in freshwater curing, leaving the concrete pores unfilled and causing a reduction in compressive strength. In contrast, the concrete mix with seawater and seawater curing showed continuous improvement in compressive strength up to 14 and 21 days before a decline at 28 days. This increase in compressive strength is due to Friedel's salt, formed from calcium chloride ($CaCl_2$) in seawater, enhancing the concrete's water absorption capacity.

The compressive strength of the concrete is used in designing bridge pillars to assess its load-bearing capacity. Based on the compressive strength results for each variation in the study and the generated graphs, Variation 2 (V2)—a mix with freshwater and seawater curing—was selected due to its higher compressive strength than the other variations. In Variation 2 (V2), the compressive strength results were as follows: an average of 17.8 MPa at 3 days, 23.7 MPa at 7 days, 26.3 MPa at 14 days, 26.6 MPa at 21 days, and 17.0 MPa at 28 days. For bridge pillar planning, the 14-day compressive strength result of 26.3 MPa is used. This result meets the specifications of ASTM C-150, which requires Type I cement with a minimum curing time of 7 days.

CONCLUSIONS.

Based on the research findings and discussion on the compressive strength of concrete exposed to seawater for bridge pillars, it can be concluded that the compressive strength of concrete using freshwater as the mix and seawater for curing increased compared to other variables. The compressive strength of concrete cured with seawater at 14 days was 9.81% higher than that cured with freshwater. The compressive strength of concrete with seawater mix and freshwater curing at 3 days was 43.91% higher. The compressive strength of concrete with a freshwater mix and seawater curing at 14 days was 44.65% higher than that of the seawater mix with seawater curing. Additionally, the compressive strength of concrete with a seawater mix and freshwater curing at 3 days was 15.54% higher.

This study requires further research examining the effects of prolonged immersion to more specifically understand the impact of seawater on concrete compressive strength. This study was conducted without reinforcement; therefore, research involving reinforcement is also necessary.

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