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RESEARCH ARTICLE

Study of the Mechanical Properties of Underwater Concrete in Seawater Environments

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Abstract

Anti-washout concrete (AWC) is a specialized cement-based material designed to be applied directly in underwater environments, maintain mix integrity, and prevent material washout. AWC can. This research aims to evaluate the performance of anti-washout concrete in seawater environments containing chemical compounds aggressive to concrete, by examining the ability of concrete to withstand loads, resistance to washout, and structural stability when exposed to seawater environments. The test methods used included aggregate characteristics, slump flow, compressive strength, split tensile strength, and flexural strength at 7, 14, 28, and 56 days of concrete age. The results showed that concrete with fresh water (AB) had higher compressive, split tensile, and flexural strengths than concrete using artificial seawater (AL), with a decrease in compressive strength in AL against AB of 7.29% at 14 days, 11.20% at 28 days, and 12.69% at 56 days. AWC met the minimum compressive strength requirement of 70% of the Japan Society of Civil Engineers (JSCE) standard, indicating that AWC with artificial seawater remains viable for underwater construction applications. This study's results are expected to guide the use of anti-washout concrete for various underwater applications, particularly to improve durability and reduce long-term maintenance costs for underwater infrastructure.

Keywords: Anti-washout Concrete, Anti-washout Agent, Seawater, Mechanical Properties

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1. Introduction

Underwater construction encounters significant challenges in civil engineering, particularly with regard to the durability of concrete materials that must be able to withstand aggressive environmental conditions, such as atmospheric pollution, seawater attack, and sulfates (Lawrence, 1990; Mahindrakar, 2017; Simanjuntak, 2016).

Underwater concrete is also vulnerable to segregation, which is the separation of mix components, so the concrete must have the ability to settle and compact itself in water without the need for an additional external compaction process (Mihiretu, 2009; Schulze & Schulze, 2021).

To overcome this problem, additives such as Anti-washout Agent (AWA) are required. AWA are specifically created to maintain the integrity of concrete mixes when cast underwater, preventing leaching of materials that can reduce concrete quality. According to (Chen et al., 2024; Song et al., 2024) anti-washout additives, such as polymers and superplasticizers, play an important role in stabilizing concrete during contact with water, by increasing the viscosity of the mixture and reducing the rate of material washout. Thus anti-washout can be used in any type of casting method.

This study was conducted to evaluate the performance of anti-washout concrete with synthetic seawater in terms of compressive strength, resistance to washout, and structural stability under sea-like conditions. The results of this study are expected to guide the use of anti-washout concrete for underwater applications, in order to improve durability and reduce long-term maintenance costs of underwater infrastructure.

2. Literature Review

2.1 Underwater Concrete

Underwater concrete is concrete that is directly cast in water (underwater concreting). This type of concrete is often used in the construction of harbors, docks, bridge piers, and other underwater constructions. Aspects that need to be considered in underwater concreting are aggregate segregation, washout, and filling (Bartos et al., n.d.; A. M. Heniegal, 2016; Nasr et al., 2022). Heniegal, 2016 states that washout of materials from concrete mixtures due to water flow can cause a reduction in the quality and strength of the material, which can affect the long-term durability of the structure. Water intrusion can damage the bonding of the concrete mix so that segregation can occur between the constituent materials of the concrete (segregation), the strength or quality of the concrete can be reduced due to flushing by water. (Mihiretu, 2009; Schulze & Schulze, 2021; Wu et al., 2021).

Underwater concrete casting is usually done by dewatering method or by special equipment method (Khayat & Hester, 1991). The dewatering method starts by draining the water at the casting site such as by constructing a temporary dam (cofferdam), after which the casting can be carried out. The special equipment method uses tools such as tremie pipes, hydraulic pumps, and toggle bags to help place the concrete mix into the water. When these methods are ineffective, the use of concrete with added AWA can be considered.

2.2 Anti-washout Agent

Anti-washout agent (AWA) is an additive used to reduce the flushing of concrete mix during the casting process in water. According to Nasr et al., 2022, concrete treated with

AWA can withstand washout longer, allowing sufficient time for the concrete to cure and harden before water can degrade its quality (Lu et al., 2022; Nasr et al., 2022). The main mechanisms of AWA include the formation of a protective layer that reduces the effect of water on concrete, changes in the surface properties of concrete that decrease water absorption, and accelerated hardening of concrete by reducing water evaporation, which in turn increases the stability of concrete before it is affected by water (Ali Sikandar et al., 2020; Atash Beik et al., 2024; A. Heniegal et al., 2016; Lu et al., 2022; Park et al., 2014). In addition, Lange et al. (2014) stated that increasing the dosage of AWA can reduce the amount of solid particles suspended in concrete, due to the increase in concrete viscosity as the dosage of AWA is increased. Overall, the use of anti-washout agents in underwater construction provides a number of advantages, including increased concrete strength by preventing leaching of constituent materials, extended working time to ensure more precise casting, and improved construction quality by producing structures that are more resistant to corrosion and erosion..

2.3 Self-compacting Concrete

Self-Compacting Concrete (SCC) is a type of concrete designed to self-compact without the need for mechanical compaction, which is particularly useful in casting concrete underwater or in areas with limited space. The advantage of SCC lies in its ability to flow and fill molds using only the weight of the concrete itself (Bartos, 2005; Rich et al., 2017).

To achieve this, SCC usually contains superplasticizers (SP) that can maintain slump flow and improve workability. The addition of SP can also lower the water to cement ratio (FAS), which contributes to increased concrete strength (Lange et al., 2014b). In addition to SP, additives such as viscosity modifying agents (VMA) are often used to control mix viscosity and prevent segregation (Bessaies-Bey et al., 2022; Palacios & Flatt, 2016).

SCC has several key characteristics, such as high flowability that allows the concrete to flow freely, as well as high stability to prevent segregation of material components during casting (Hosseinpoor et al., 2021; Rasekh et al., 2020; Z. Zhang et al., 2021). The advantages of using Self-Compacting Concrete (SCC) include cost and time efficiency in the construction process, improved structural quality through smoother finishes, and increased safety due to reduced reliance on the use of mechanical vibration (Rich et al., 2017). SCC is widely applied.

2.4 Seawater

Seawater has different chemical properties than groundwater or freshwater, one of which is Magnesium Sulfate (MgSO4) and chloride compounds that will inhibit the development of concrete, these compounds contribute to concrete damage by reducing its strength and durability (Saxena & Baghban, 2023; Yi et al., 2020; C. Zhang et al., 2024). Another study by (Yahya et al., 2021) found that Cl- ions in seawater trigger the formation of calcium chloride ($CaCl_2$), which serves as an accelerator to speed up the initial bonding time and strength development of concrete.

Table 1. Chemicals composition in fresh water and seawater

Type	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	S (mg/L)	Cl (mg/L)
Fresh water	12,70	2,51	29,70	3,87	4,49	8,29
Sea-water	21700	417	579	1040	3840	33400

(Li et al., 2019)

Table 1 presents the composition of fresh water and seawater, and the concentration of various chemical elements in each type of water.

3. Methods

The methods applied in this research include literature study, material selection, mix design, workability testing, and mechanical properties evaluation of underwater concrete, which will be further explained below. Fig. 1 presents a sketch of the underwater concrete casting process.

This research focused on evaluating the effectiveness of anti-washout concrete using synthetic seawater as a mixing agent, which has a similar ionic composition to natural seawater. The selection of synthetic seawater aims to provide better experimental control and allow the creation of more stable artificial marine environment conditions.

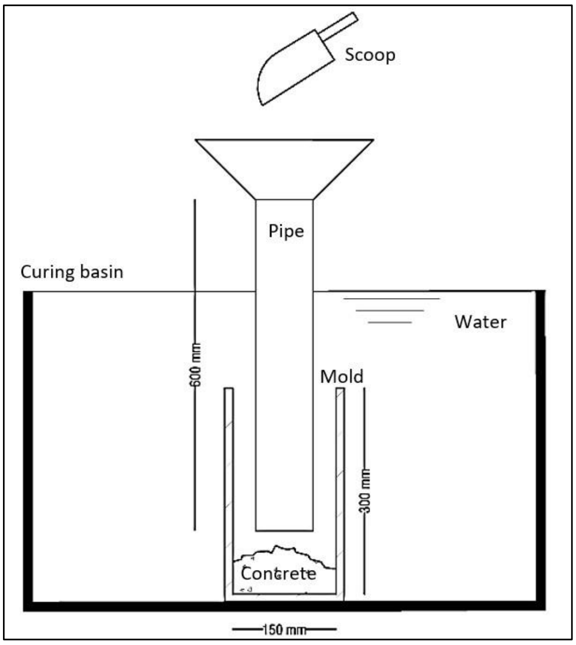

Fig. 1 Underwater concrete casting method

3.1 Inspection of Aggregate

Inspection of aggregate properties is an important step to ensure the quality of the mix. Coarse and fine aggregates play a major role in the strength and stability of concrete. This includes the size, shape, surface texture, silt content, density and water absorption of the aggregate, all of which affect the strength, durability and workability of the concrete (Harmiyati et al., 2024; Mildawati et al., 2022; Yogafanny et al., 2024).

3.2 Speciments Preparation

The concrete mix variation in this study used artificial seawater and fresh water as concrete curing water. The grouping of test specimens is shown in **Error! Reference source not found.**.

The concrete mix design includes 506.67 kg/m³ of cement (21.94%), 231.72 kg/m³ of air (10.03%), 838.24 kg/m³ of coarse aggregate (36.29%), 733.10 kg/m³ of fine aggregate (31.74%), 25.33 kg/m³ of anti-washout admixture (5%), and 4.17 kg/m³ of superplasticizer (1.8%), with a total mix weight of 2309.72 kg/m³ and a W/C ratio of 0.45.

Synthetic seawater was prepared by mixing aquarium sea salt and fresh water. The solution mixed until the specific gravity 1.024-1.026. Concrete curing water was made in the curing basin, while continuously monitoring the salinity using a salinity hydrometer.

Table 2. Classification of test specimens

Variation			Test Speciments		
Curing	Code	Age	Compressive	Tensile	Flexure
			3	-	-
Fresh water	AB	4	3	3	3
		8	3	3	3
		6	3	3	3
			3	-	-
Seawater	AL	4	3	3	3
		8	3	3	3
		6	3	3	3
TOTAL			60		

3.3 Slump Flow Test

The slump flow test is conducted to determine the level of workability when making SCC concrete. The amount of workability value can be seen when fresh SCC concrete is able to flow and fill all parts of the mold through its own weight (filling ability).

The slump flow test was conducted using an inverted Abram cone. The filling of fresh concrete into the abram cone is done before pouring into the mold in water. The fresh concrete is added little by little in one layer until it is completely filled without compaction under flat, level and moist conditions without stagnant water. Japan Society of Civil Engineer (JSCE) (1992) recommends a slump flow range between 450-500 mm for underwater concrete cast into molds with simple forms.

3.4 Speciments Manufacturing

After the slump flow test, fresh concrete was poured slowly into a tremie pipe connected to a water-soaked cylinder mold, without compaction.

After the slump flow test is carried out on fresh concrete and concrete is molded in a cylindrical and cuboid mold, then the test object is allowed to harden for approximately (±) 24 hours. The curing water can be seen in Fig. 2.

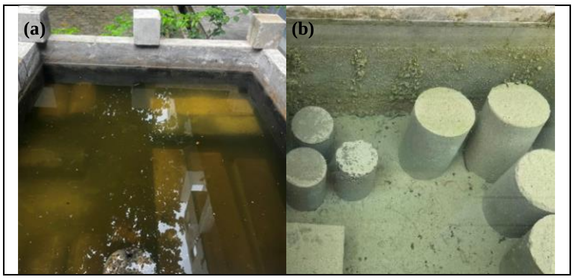

Fig. 2 Speciment curing (a) Artificial seawater (b) Fresh water

3.5 Mechanical Properties Test

Concrete compressive strength testing is carried out after the test specimens are removed from the curing tub. Concrete compressive strength testing refers to SNI 1974-2011. The purpose of testing the compressive strength of concrete is to determine the compressive strength value of concrete. To carry out concrete compressive strength testing, equipment such as a compressive testing machine, scales and a set of concrete capping tools are needed. The compressive strength of concrete is calculated based on the amount of load per unit area, according to Eqn 1.

$$f'c=\frac{P}{A} \qquad (1)$$

Where:

f'c = *compressive strength of concrete (MPa)*
P = *maximum load (N)*
A = *surface area of specimen (mm^2)*

According to SNI 2419:2014 split tensile strength testing is used to evaluate the shear resistance of structural components made of concrete with dimensions of 150 x 300 mm at the age of 28 days. After the test specimens are removed for 24 hours from the curing tub, the test specimens must be dry before testing the split tensile strength. The top of the test specimen is given a pressing steel in a straight line. Then the test specimen is given a load until the test specimen is split. The split tensile strength of concrete can be calculated using Eqn. 2.

$$fct=\frac{P}{A} \qquad (2)$$

Where:

fct = *tensile strength of concrete (MPa)*
P = *maximum load (N)*
L = *length of specimen (mm)*
D = *diameter of specimen (mm)*

The flexural strength of concrete is the ability of a concrete block placed on two supports to withstand a force in the direction perpendicular to the axis of the specimen, which is applied to it, expressed in Mega Pascal (MPa) force per unit area (SNI 4431-2011, 2011). Testing the flexural strength of concrete uses a beam shaped test object with a height of 15 cm, a width of 15 cm and a length of 60 cm. The tested concrete block will experience a fracture in its stem. Fractures can occur in three parts of the concrete flexural strength test. The fracture that occurs in the area 1/3 distance from the center of the placement point, then the flexural strength of the concrete is calculated in Eqn. 3.

$$fs=\frac{PL}{bh} \qquad (3)$$

Where:

fs = *flexural strength of concrete (Mpa)*
P = *maximum load (N)*
L = *span length between supports (mm)*
b = *width of the horizontal fracture (mm)*
h = *width of the vertical fracture (mm)*

4. Result and Discussion

4.1 Coarse Aggregate Properties

The test results of the characteristics of coarse aggregates from Pangkalan, West Sumatra, showed that most parameters met the requirements.

The fineness modulus was recorded at 6.05, which is within the specification range of 5-8, indicating that the aggregate grain size is quite uniform and suitable for construction needs. The specific gravity of the aggregates also met the specifications, with Apparent Specific Gravity (2.80), Bulk Specific Gravity on Dry (2.65), and (Bulk Specific Gravity on SSD) of 2.70, indicating good density and consistency of physical properties according to SNI 03 1969-2008. The aggregate volume weight in solid condition of 1518.76 kg/m^3 is within the specification range (1400-1900 kg/m^3), but the volume weight in loose condition is only 1288.10 kg/m^3, which does not meet the minimum specification.

The aggregate moisture content of 1.27% also met the specification range (0-5%), indicating a controlled natural moisture content, as per SNI 1971-2011 standards. However, there were two parameters that did not meet the standard, namely the water absorption percentage of 1.68%, which was lower than the specification of 2-7%, and the wear resistance value of 48.86%, which exceeded the maximum limit of 40%.

The low water absorption value may indicate that the aggregates are less able to absorb water, potentially affecting adhesion with the cement paste, while the high wear value indicates that the aggregates have low resistance to abrasion and impact, making them less ideal for use in structures with high dynamic loads, such as highways or runways.

Overall, these coarse aggregates have characteristics that are good enough for most construction needs. However, for certain structural applications that require high durability, it is advisable to consider using alternative materials or improving the quality of the aggregate through modification processes or blending with aggregates that are more resistant to wear and tear.

Table 3. Coarse agregate inspection

Inspection	Standard	Result
Fineness modulus	5–8	6.05
Specific gravity		
a. *Apparent specific gravity*	2.58–2.83	2.80
b. *Bulk specific gravity on dry*	2.58–2.83	2.65
c. *Bulk specific gravity on SSD*	2.58–2.83	2.70
d. Water absorption percentage (%)	2–7	1.68
Unit weight (Kg/m^3)		
a. Compacted	1400–1900	1518.76
b. Loose	1400–1900	1288.10
Water content (%)	0–5	1.27
Abrasion resistance (%)	<40	48.86

4.2 Fine Aggregate Properties

The results of testing the characteristics of fine aggregates from Bingkuang River, Kampar showed that most parameters met the set standards, although there were some exceptions.

The fineness modulus was recorded at 2.85, slightly above the specification range of 1.5-2.83, but still considered to meet the standard based on SNI 03-1968-1990. This indicates that the fineness of the aggregate is suitable for application in concrete mixes. The aggregate specific gravity in the Apparent Specific Gravity (2.64) and Bulk Specific Gravity on SSD (2.58) parameters also meet the specification range of 2.58-2.83 as per SNI 1070 (2016), which reflects good material density. However, the Bulk Specific Gravity on Dry value of 2.55 does not meet the minimum specification (2.58), which indicates this material has higher porosity in dry conditions. In addition, the water absorption percentage of 1.32% was below the specification range (2-7%), which indicates the resistance of the aggregate to water penetration, but the low value may reduce the adhesion of the aggregate to the cement paste.

In the organic content parameter, the test results show a value of No. 5, which exceeds the maximum permissible limit (Max. No. 3) according to SNI 2816 2014. This high organic content has the potential to affect the strength and durability of the concrete, thus requiring more attention. On the other hand, the mud content of 4.29% is still below the maximum threshold (<5%) as per SNI 03-4142-1996, indicating a relatively low level of material impurities. The volume weight of the fine aggregate, both in the solid state (1733.69 kg/m³) and loose state (1514.03 kg/m³), is within the specification range of 1400-1900 kg/m³ as per SNI 03 4804 (1998), thus supporting the stability of the material in use. In addition, the moisture content of 1.63% is within the specification range (0-5%) as per SNI 1971 (2011), indicating that the aggregates have a controlled natural moisture content and are safe for use in concrete mixtures.

Overall, the fine aggregate from Danau Bingkuang met most of the standard specifications. However, there were two parameters that did not comply, namely organic content that exceeded the threshold and Bulk Specific Gravity on Dry that was below the minimum value. This could affect the durability and final quality of the concrete, hence the need for corrective measures such as washing or purifying the material to reduce the organic content, as well as considering blending with other materials of better quality.

Table 4. Fine aggregate inspection

Inspection	Standard	Result
Fineness modulus	1.5–3.8	2.85
Specific gravity		
e. *Apparent specific gravity*	2.58–2.83	2.64
f. *Bulk specific gravity on Dry*	2.58–2.83	2.55
g. *Bulk specific gravity on SSD*	2.58–2.83	2.58
h. Water absorption percentage (%)	2–7	1.32
Organic content	Max. No. 3	No. 5
Mud content (%)	<5	4.29
Unit weight (Kg/m^3)		
c. Compacted	1400–1900	1733.69
d. Loose	1400–1900	1514.03
Water content (%)	0–5	1.63

4.3 Trial Mix Result

The trial mix results indicate that the water-cement ratio (W/C), anti-washout agent (AWA), and superplasticizer (SP) significantly influence concrete performance, including workability, compressive strength, and resistance to washout. At a W/C ratio of 0.54, mixtures with low doses of AWA and SP exhibited poor water resistance, with the concrete experiencing segregation and honey comb as shown as in Fig. 3.

Fig. 3. Low AWA% effect on underwater-cast concrete

Increasing the AWA dosage to 4% and SP to 1.6% improved washout resistance and enhanced workability. A mix with 4.5% AWA and 1.8% SP achieved a compressive strength of 18 MPa at 7 days and 21 MPa at 28 days, with a slump flow of 400 mm. At a W/C ratio of 0.45, normal concrete following the ACI method achieved a compressive strength of 29.4 MPa at 28 days with a slump of 12 cm. Variations incorporating AWA and SP at this W/C ratio showed a slump flow of up to 450 mm. However, high dosages (AWA 10% and SP 3.6%) resulted in very low porosity but required higher amounts of admixtures and extended setting times.

Based on the trial mix results, the optimal mix variation selected consists of a W/C ratio of 0.45, 5% AWA, and 1.8% SP. This variation provides optimal performance with a compressive strength of 19 MPa at 28 days, a slump flow of 450 mm, and excellent washout resistance, making it suitable for underwater applications. Additionally, this mix exhibits low porosity, ensuring durability for underwater structures. The selection of this variation is based on a balance between admixture efficiency and concrete performance, meeting the technical requirements for anti-washout underwater concrete.

4.4 Slump Flow Test Result

The slump flow result of 450 mm satisfied the JSCE requirement for anti-washout concrete (450-500 mm), achieved through an optimal balance of AWA and SP to maintain flowability and cohesion underwater. Fig. 4 illustrates the relationship between AWA percentage and slump flow under a constant SP dosage, highlighting the impact of AWA on workability. As the AWA dosage increases, slump flow decreases due to higher viscosity, while washout resistance improves by reducing cement dispersion in water (Efiandi et al., 2020). Fig. 5 compares water-cement ratios (w/c) of 0.45 and 0.54, showing that the 0.54 mix experienced segregation, indicating that a higher w/c ratio compromises the stability of underwater concrete.

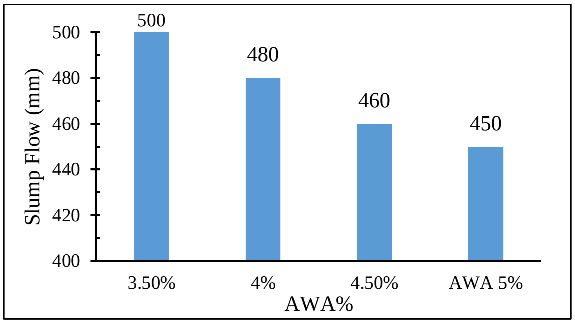

Fig. 4 AWA% vs slump flow relationship

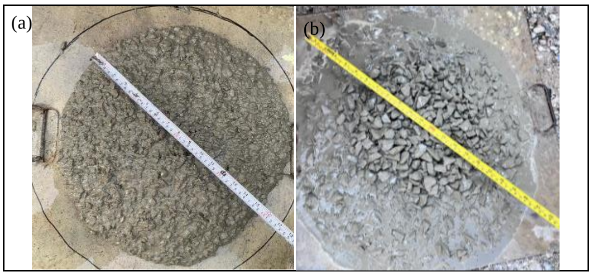

Fig. 5. Slump flow test (a) W/C 0.45 (b) W/C 0.54

4.5 Compressive Strength Test Result

The results of testing the compressive strength of concrete in the variation of AB and AL test specimens show significant differences at various testing ages, namely 7, 14, 28, and 56 days. At 7 days, the compressive strength of AL concrete reached 15.18 MPa, slightly higher than AB which had a compressive strength of 14.81 Mpa. Other studies have shown similar results, which are attributed to ions, indicating that the increase in salt concentration in seawater is influenced by the combined effect of chloride (Cl^-) and sodium (Na^+) ions (Wang et al., 2020). This is likely due to the salt ion reaction in AL concrete which accelerated the hydration process in the early stages. However, as the concrete aged, the compressive strength pattern showed that AB performed better than AL.

At 14 days, the compressive strength of AB concrete increased to 19.33 MPa, while AL only reached 17.92 MPa, with a relative decrease of 7.29% compared to AB. Furthermore, at 28 days, the compressive strength of AB was recorded at 21.88 MPa, higher than AL which only reached 19.43 MPa, with a relative decrease of 11.20%. At 56 days, the compressive strength of AB concrete decreased slightly to 21.60 MPa, but remained higher than AL which experienced a further decrease to 18.86 MPa, resulting in a relative decrease of 12.69%.

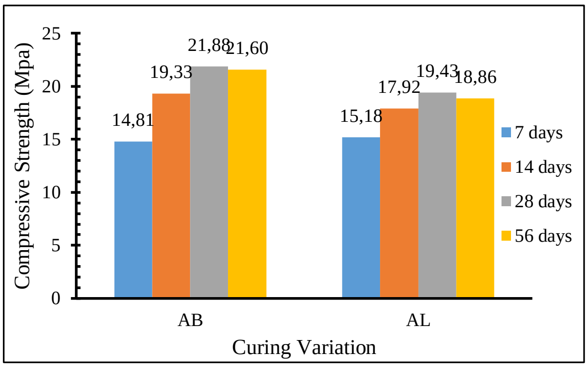

Fig. 6 Compressive strength test result

In general, AB concrete showed a more steady increase in compressive strength than AL, especially at 14 to 56 days of age. The decrease in performance of AL concrete at older ages due to the impact of salt ions that could potentially disrupt the formation of a mature cement paste structure, thereby reducing long-term strength (Wang et al., 2023). AB concrete, which is unaffected by salt ions, showed more consistent and robust results, making it superior for construction applications that require long-term concrete strength. Concrete that expands after exposure to seawater will leave voids in the concrete. So that when the concrete is applied by load it will be more easily failed at the age of concrete after the initial 7 days. (Wedhanto, 2017).

4.6 Tensile Strength Test Result

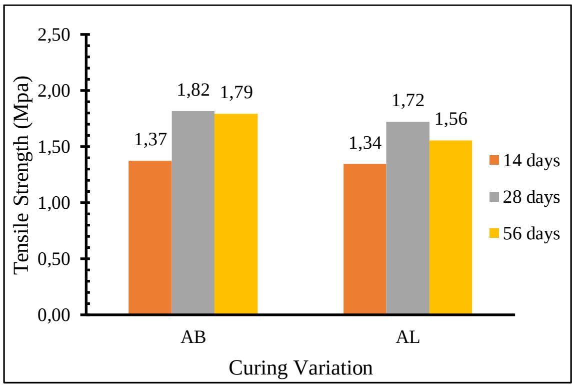

Fig. 7. Tensile Strength Result

Split tensile strength tests at 14, 28, and 56 days resulted: AB 1.37 MPa (14 days), 1.82 MPa (28 days), 1.79 MPa (56 days), AL 1.34 MPa (14 days), 1.72 MPa (28 days), 1.56 MPa (56 days). The split tensile strength of AB concrete is higher than AL, with a decrease in AL of 2.19%, 5.49%, and 12.85% at each age.

The relationship between compressive strength and split tensile strength of UWC concrete at the age of 28 days for each variation of test specimens can be seen in Figure 8 where from the figure it can be seen that the value of R2 based on compressive strength data and split tensile strength is equal to 0.9923 AB variation. 0.9925 for AL variation which shows a strong relationship between compressive strength and split tensile strength.

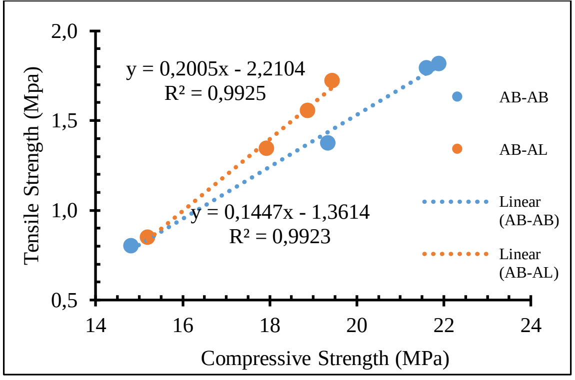

Fig 8. Compressive strength vs tensile strength relationship

4.7 Flexural Strength Test Result

Flexural strength tests at 14, 28, and 56 days resulted: AB 4.18 MPa (14 days), 4.67 MPa (28 days), 4.47 MPa (56 days), AL 3.91 MPa (14 days), 4.49 MPa (28 days), 4.22 MPa (56 days). AB concrete had higher flexural strength than AB AL at all ages, with decreases in AL of 6.46%, 3.85%, and 5.59%.

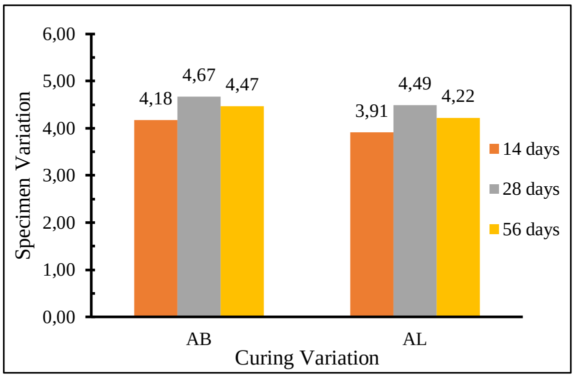

Fig. 9. Flexural Test Result

The relationship between compressive strength and flexural strength of UWC concrete at the age of 28 days for each variation of specimens can be seen in Fig. 10. From the figure it can be seen that the R2 value based on the data of compressive strength and split tensile strength is equal to 0.9821 for AB variation. 0.9884 for AL variation which shows a strong relationship between compressive strength and flexural strength. The study by Lu et al. (2022) also reported similar findings, indicating that in all tested concrete mixtures (W/C 0.45, with curing ages of 7, 28, and 56 days), the relative compressive and flexural strengths remained below 100%.

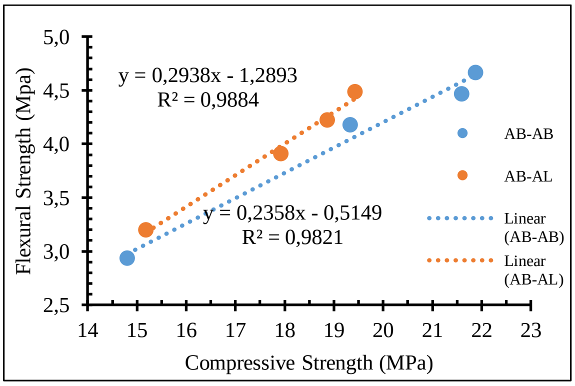

Fig. 10. Compressive strength vs flexural strength relationship

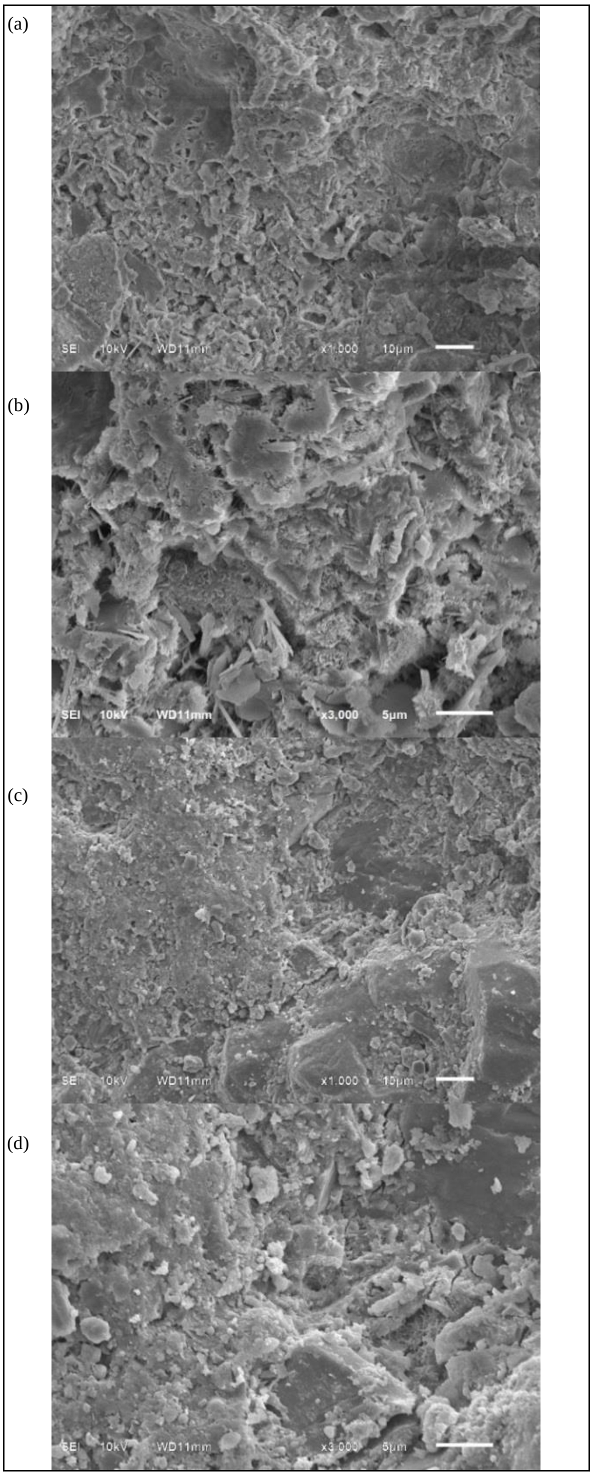

Fig. 11 SEM result of (a) & (b) 28 days AL speciment (c) & (d) 28 days AB speciment

4.8 Scanning Electron Microscopic (SEM) Result

Fig. 11 presents scanning electron microscope (SEM) images of underwater concrete specimens at 28 days, illustrating differences in their microstructures. Figures a and b show specimens with artificial seawater (AL) at magnifications of 1000× and 3000×, while Figures c and d display specimens with freshwater (AB) at the same magnifications. In the AL specimen, the initial expansion of salts during early hydration (around 7 days) is followed by their reaction and subsequent disappearance, leaving voids within the concrete matrix (Yahya et al., 2021). This increased porosity weakens the microstructure, leading to a reduction in compressive strength and a higher permeability coefficient (Wedhanto, 2017). In contrast, the AB specimen remains dense, indicating better structural integrity, which helps maintain its mechanical properties and durability.

Strong bonding between cement and other materials after casting resulted in robust particle connections and a high unit weight. For the fresh water mix with fresh water curing (variation AB), the surface similarly appears dense with few pores. The acidic nature of seawater enhances initial chemical reactions with cement, improving bonding; however, these reactions diminish over time, leading to weathering and seawater-induced corrosion. Despite this, the admixtures remained effective, with bulk density and porosity values of AL variation showing no significant difference from AB variation. This suggests that both curing methods provide sufficient durability in the short term, although long-term exposure to seawater may present additional challenges, such as chloride ingress and reduced structural integrity over time.

5. Conclussion

Underwater anti-washout concrete exposed to seawater experiences a decline in mechanical properties. The compressive strength of concrete cured in seawater decreased from 21.88 MPa (in fresh water) to 19.43 MPa at 28 days. A similar reduction was observed in flexural and splitting tensile strengths. This phenomenon is attributed to complex chemical reactions between salt ions, such as chloride and sodium, and the concrete mix, forming microscopic voids that weaken the concrete structure. Interestingly, at the early stage (7 days), concrete mixed with seawater showed slightly higher strength due to accelerated hydration, but it underwent significant strength degradation over the long term.

Although the compressive strength of underwater concrete is lower than that of normal concrete, both variations still meet the JSCE requirements, with a residual compressive strength of at least 70% of the design compressive strength. For example, at 14 days, normal concrete achieved a compressive strength of 27.31 MPa, while underwater concrete reached 19.33 MPa for the fresh water variation (AB) and 17.92 MPa for the seawater variation (AL). These results demonstrate that underwater concrete maintains reliable mechanical performance despite facing extreme environmental challenge.

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