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EXPERIMENTAL INVESTIGATION OF SELF PROTECTED UNDER WATER ANTIWASH OUT RESISTANCE CONCRETE IN MARINE AND FRESH WATER

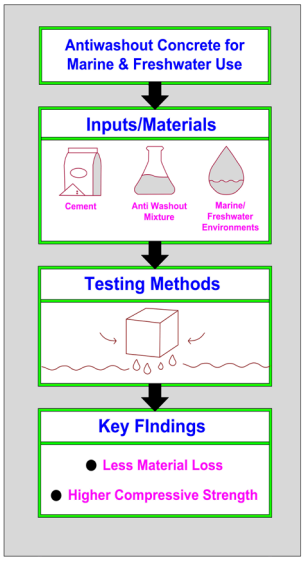
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Graphical abstract



Abstract

Underwater construction projects such as man-made islands, piers, and bridge foundations often face the challenge of washout, especially in marine environments where tidal forces and direct exposure to seawater can deteriorate freshly placed concrete. Washout not only reduces material efficiency but also affects the durability and strength of the structure. To mitigate these issues, this study introduces a self-protected underwater concrete incorporating an anti-washout admixture (AWA), specifically VITCON 2014 AWA, to improve washout resistance in both marine and freshwater environments. The experimental program evaluated the effect of AWA on the concrete's rheological and durability properties. Key tests included non-dispersion testing (Plunge Test, CRD C61), workability measurements (slump test, flow table, L-box, and U-box), and pH assessments in both marine and freshwater. Parameters such as varying water-to-cement ratios and AWA dosages were examined. Results indicate a significant reduction in mass loss and improved cohesion in the mixes containing AWA, with enhanced viscosity contributing to superior washout resistance. The modified concrete showed stable behavior in underwater placement conditions, demonstrating improved performance against segregation and loss of cement paste. The study concludes that anti-washout admixtures are effective in producing durable underwater concrete suitable for marine applications, with enhanced workability and stability under turbulent conditions.

***Keywords*:** Underwater Concrete, Anti-Washout Admixture (AWA), VITCON 2014 AWA, Workability Tests, Rheological Properties, Marine Structures

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1.0 INTRODUCTION

Underwater Concrete (UWC) is specially designed to enhance performance during placement in aquatic environments. It is characterized by its resistance to washout, segregation, and bleeding—challenges commonly faced in underwater construction. The behavior of UWC is influenced by mix proportioning, aggregate shape and gradation, admixture type, and placement techniques. Recent advancements in UWC technology have enabled high fluidity mixes with improved resistance to washout and segregation.

Despite these developments, underwater placement still presents issues such as cold joints, low workability, and cement washout, all of which impact the strength and durability of the structure. To overcome these, viscosity-modifying admixtures are used to reduce fluidity while increasing the cohesion of concrete. These admixtures improve anti-dispersive properties and support self-compacting and self-leveling behavior, essential for quality underwater placement.

Various anti-washout admixtures (AWAs), such as wellan gum and hydroxypropyl methylcellulose (HPMC), are commonly used, although they require higher dosages of superplasticizers (SP), which can delay setting time. In this study, VITCON 2014 was employed as the AWA, and Sikament 100 SC as the SP, both of which improved rheological performance. Compressive strength increased significantly, with some cases reporting improvements up to 93%.

Assessment of UWC's washout resistance was conducted using two standard methods: the CRD C61 plunge test and the MC-1 test. Parameters analyzed included AWA and SP dosages, water-to-cement (W/C) ratio, and workability measured through slump and slump flow tests. For UWC, slump values typically range between 100–180 mm, and the W/C ratio should not exceed 0.6, depending on the concrete grade and environmental conditions.

This study confirms that using VITCON 2014 as an AWA enhances the anti-washout characteristics and rheological behavior of UWC, making it suitable for durable marine and freshwater applications.

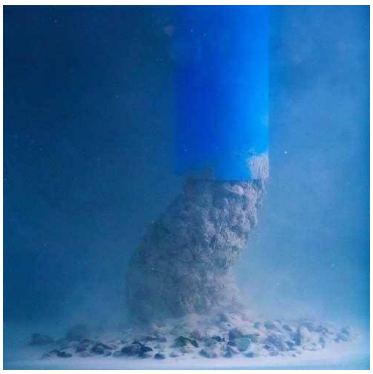


Figure 1 Under Water Concrete

Much work, however, has been accomplished on improving workability, durability and resistance to washout of an underwater concrete. Two stage (preplaced aggregate) concrete is viable for underwater applications in Libya, as Abdelgader et al. [1] showed cause by demonstrating the reduction of segregation to increased strength. That being said, Heniegal et al. [4] also carried out simulation of pressurized underwater concrete, while Heniegal [11] and Heniegal and Agwa [24] extended the study of self-compacting underwater concrete considering the effects of coarse aggregate types and anti-washout admixtures on fresh properties and self-flowing capabilities.

In recent studies of self protected underwater concretes to resist different current water velocity by Nasr et al. [2], [3] and Wang et al. [7]. Both in freshwater and seawater environments, these studies found considerable reduction in strength loss and washout rates. Similar to Megahed et al. [6], they also reported that mixture composition significantly affects washout resistance, relative strength, and fresh properties for which earlier work performed by Khayat and co-workers [8]–[10] had relate washout resistance and flowability to rheological properties and admixture dosage.Several researchers have looked into the effectiveness of Anti Washout admixtures (AWAs) to increase the weld out resistance in underwater concrete. According to Khayat [9] and Imam [13], AWAs can greatly enhance cohesion and significantly diminish bleeding in fresh concrete. Sonebi et al. [18] further modeled variations in flow characteristics, slump retention, and washout resistance in combination with superplasticizers and AWAs and calculations.

Geopolymer concrete is becoming a possible substitution to the traditional underwater concrete with a low carbon footprint and better durability. Zaidi et al. [5] and Yaswanth et al. [14], [15] have reviewed about geopolymer concretes with incorporation of ground granulated blast furnace slag (GGBS), rice husk ash (RHA) and copper slag and found out more superior results under submerged conditions. Anti-washout concretes as discussed in [19] were summarized by Lu et al. [wherein the keynote aspects including binder type, admixtures as well as the mix design were reiterated as the means to produce stable underwater concretes.Furthermore, Guo et al. [21] investigated the application of super water absorbing polymers in cement pastes that are mixed with seawater and have discovered that super water absorbing polymers are effective for dispersion mitigation. Sikandar et al. [17] investigated different AWAs and confirmed their emphasis on improving the non dispersive and mechanical strength of underwater concrete.You and He [12] also addressed durability concerns under submerged environments by studying long term deterioration mechanisms of the concrete submerged under coupled underwater environments. This is of particular interest with regards to concretes for

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marine or aggressive environments. Despite focusing on solar cell applications, Venkatesh et al. [16] give material insights that are applicable for the development of advanced sol – gel processes for underwater concrete surface coatings.

Studies such as [23][24] have shown that concrete containing micro-silica and limestone powder exhibits reduced durability under acidic exposure, including acid rain and industrial wastewater. These environmental effects underscore the importance of designing underwater concretes with high cohesion and chemical resistance, particularly when exposed to aggressive aqueous environments.

In combination, these studies show that low permeability, mix design minimization, admixtures of structural integrity, binders designed for geopolymer production – all of which are essential for the development of high performance underwater concrete that does not wash out and maintains structural integrity under aquatic conditions.

2.0 METHODOLOGY



Figure 2 Methodology flow Chart

Cement is a fundamental material in civil engineering construction, commonly referred to as hydraulic cement or Ordinary Portland Cement (OPC). In this project, OPC 53 grade cement has been selected for use in underwater concrete due to its high strength characteristics. The composition of OPC includes Lime (62%), Silica (22%), Alumina (5%), Calcium Sulphate (4%), Iron Oxide (3–7%), Magnesium Oxide (2%), Sulphur Trioxide (1%), and Alkaline materials (1%). Fine aggregates used in this study consist of locally available river sand with a particle size of 300 microns. This sand enhances the cohesive properties of underwater concrete, which is critical to minimizing washout and segregation. For coarse aggregates, rounded particles with a nominal size of 20mm (passing through a 20mm sieve and retained on a 16mm sieve) were utilized. Rounded aggregates are preferred in underwater concrete as they improve cohesion and reduce bleeding and segregation tendencies.

Water is another crucial component in concrete, required for mixing and curing. The quality of water significantly influences the concrete's final strength. For optimal results, potable water with a pH not less than 7 is considered suitable for concrete production. In this study, VITCON 2014 AWA, a cellulose-based anti-washout admixture, is used to improve underwater performance. This liquid admixture is specially developed to reduce the washout of cement and fines while resisting water bleeding into plastic concrete. VITCON 2014 AWA complies with CRD-C-61 standards for anti-washout admixtures and is typically recommended in the dosage range of 250–1300 ml/kg of cementitious material. In this project, a dosage of 500 ml/kg was used.

According to ACI 304R guidelines for underwater concrete placement, concrete should contain 356 kg/m³ of total cementitious material with around 15% pozzolan replacement, a water-cement ratio of 0.45 or less, fine aggregate content between 45–55% of total aggregate volume, slump range of 150–300 mm, and air content up to 5%. When VITCON 2014 AWA is added to achieve washout resistance, a decrease in slump is observed, which may require additional high-range water-reducing admixtures to meet placement workability. The washout resistance is evaluated using the CRD-C 61 test method, ensuring the concrete retains its integrity when placed in underwater environments.

Table 1 Materials used

No.	Material	Type
1	Cement	OPC 53 Grade
2	Fine Aggregate	River Sand
3	Coarse Aggregate	20mm Crushed Stone
4	Water	Tap and marine water
5	Admixture	Vitcon 2014 AWA

2.1 TESTS CONDUCTED

Various tests were conducted on Water such as PH test, Fresh Concrete tests such as Slump flow test , L - Box Test, U - Box Test and Plunge test. Compressive Strength test was done for Hardened Concrete. The dosage of VITCON 2014 AWA was selected based on manufacturer recommendations and trial batch performance. Marsh cone testing was not used in this study since the AWA functions as a viscosity-enhancing agent, and its effect was instead validated using plunge tests to assess anti-washout behavior

2.1.1 TESTS ON WATER:

A. PH test on fresh and marine water

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The pH test for both fresh and marine water samples was conducted using a calibrated digital pH meter. Prior to testing, the electrode was immersed in standard buffer solutions with known pH values of 4.0 and 9.8 to ensure accurate calibration. Simultaneously, the temperature of the water sample was measured and input into the meter to apply temperature correction, ensuring precise readings. The electrode was then thoroughly rinsed with distilled water and gently dried using tissue paper to prevent contamination. Subsequently, the electrode was immersed in the water sample, and the reading was recorded once the meter displayed a stable value, typically after approximately one minute. The pH value recorded for the freshwater sample was 8.89, while the marine water sample showed a pH of 8.70.

The quality of curing water was further evaluated by measuring its Total Dissolved Solids (TDS) and Electrical Conductivity (EC) using a calibrated digital TDS/EC meter. The freshwater used in the study had a TDS of 152 mg/L and an EC of 290 µS/cm, confirming its low mineral content. In contrast, the marine water sample exhibited a TDS of 34,000 mg/L and an EC of 51,000 µS/cm, indicating a high salt concentration typical of seawater. These values are critical, as the higher ionic presence in marine water may affect the cement hydration process and early-age strength development of underwater concrete.

2.1.2 TESTS ON FRESH CONCRETE:

A. Slump flow test

The slump test was conducted to assess the workability of the concrete mixes prepared with varying dosages of chemical admixture (0%, 0.50%, 0.75%, and 1.0%). The test was performed using a standard slump cone mould, shaped as a frustum of a cone with a height of 300 mm, a bottom diameter of 200 mm, and a top diameter of 100 mm. The mould was placed on a smooth, non-absorbent surface and filled in three equal layers with freshly prepared concrete. Each layer was compacted by tamping 25 times using a 16 mm diameter steel rod with a rounded end to ensure uniform compaction. After filling the mould, the top surface was levelled using a screening and rolling motion with the tamping rod. The mould was held firmly in place throughout the process using its built-in handles or footrests to prevent movement. Immediately upon finishing, the mould was lifted vertically in a steady manner to allow the concrete to slump freely. The slump was determined as the vertical difference between the height of the mould and the highest point of the slumped concrete. This measurement was taken by placing the empty mould adjacent to the concrete and using the tamping rod and a ruler to measure the vertical drop, providing a reliable indication of the concrete's workability.

B. L-box test

The L-box test was conducted to evaluate the flowability and passing ability of the M30 grade concrete mix prepared as per the designed proportions. The apparatus was placed on a firm and level surface, ensuring the sliding gate operated smoothly and was initially kept closed. Prior to filling, the internal surfaces of the apparatus were moistened, and any excess water was removed to prevent any interference with the flow characteristics. The freshly mixed concrete was then poured into the vertical section of the apparatus and allowed to settle for one minute. Following this, the sliding gate was lifted to allow the concrete to flow into the horizontal section, simulating movement through reinforcement. A stopwatch was started simultaneously, and the time taken for the concrete front to reach the 200 mm and 400 mm marks on the horizontal section was recorded. Once the concrete came to rest, the vertical heights of the concrete at the end of the horizontal section (H2) and at the starting point (H1) were measured. The ratio H2/H1, known as the blocking ratio, was then calculated to assess the ability of the concrete to flow without obstruction. A blocking ratio of 1.0 indicates that concrete has excellent flow characteristics with no blockage, like the behavior of water. All measurements and observations were completed within five minutes of mixing to ensure accuracy.

C. U-box test.

The U-box test was carried out to evaluate the filling and passing ability of the M30 grade concrete mix. The apparatus was positioned on a horizontal surface and leveled using a spirit level to ensure accuracy. The internal surfaces were dampened prior to testing to minimize friction and avoid water absorption. Freshly prepared concrete, as per the specified mix design, was poured into the right compartment of the U-box without compaction, and excess material was removed to level the surface. The apparatus consists of two chambers separated by a vertical wall, with an opening at the bottom controlled by a sliding gate. At this opening, deformed steel reinforcement bars of 13 mm diameter were installed with a center-to-center spacing of 50 mm, providing a clear gap of 35 mm to simulate reinforcement congestion. During the test, a slight pressure of approximately 2400 Pa was applied to help initiate flow. The sliding gate was then lifted, allowing the concrete to pass through the narrow reinforcement gaps into the left chamber. Once the flow stopped, the concrete heights in both compartments were measured—H1 in the left limb and H2 in the right limb. The difference in heights was used to calculate the filling ability of the concrete, with a lower difference indicating better flow and passing ability. The test was repeated three times, and the average of the readings was reported to ensure reliability of the workability assessment.

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D. Plunge test (CRD-C 61)

The washout test was conducted to assess the resistance of the M30 grade concrete mix to segregation under water exposure. The test began by leveling the base of the washout tube and filling it with water up to a height of 1700 ± 5 mm. A fresh concrete sample was prepared according to the M30 mix design. A quantity of freshly mixed concrete slightly exceeding 2000 grams was placed into a cylindrical container, and the mass of the filled container was recorded as the initial mass (Mi). The container was securely covered, attached to a rope, and gently lowered into the washout tube until it reached the bottom. After allowing the container to rest at the bottom for 15 seconds, it was retrieved to the surface within 5 ± 1 seconds. The container was then allowed to drain for 2 minutes, with a slight tilt to facilitate water runoff. The mass of the concrete remaining in the container was measured and recorded as the final mass (Mf). The difference between the initial and final mass (Mi - Mf) represented mass loss due to washout. This procedure was repeated three times on the same sample, and the final value of Mf was considered as the cumulative mass remaining. The washout or mass loss percentage was calculated using the following formula:

D = (Mi-Mf)/Mi*100
Where;
D = washout %
Mi. = mass of sample before initial test
Mf = mass of sample after each test

2.1.3. TESTS ON HARDENED CONCRETE:

A. Compressive strength test

The compressive strength test for concrete specimens was carried out following standard procedures. After the designated curing period, the cube specimens were removed from the curing tank and surface water was wiped off. The bearing surfaces of the compression testing machine were cleaned to ensure proper contact. Each cube specimen, measuring 150 mm × 150 mm × 150 mm, was centrally placed on the base plate of the machine to ensure uniform load distribution. The movable portion of the machine was gently rotated by hand until it contacted the top surface of the specimen. The load was then applied gradually and continuously at a uniform rate of 140 kg/cm² per minute, without shock, until the specimen failed. The maximum load at failure was recorded along with any notable failure characteristics. All compressive strength tests were performed on standard cube specimens measuring 150 mm × 150 mm × 150 mm, in accordance with IS 516 and ASTM C39 procedures



Figure 3 Compressive strength test

3.0 RESULTS & DISCUSSIONS

The performance of underwater concrete (UWC) mixed with VITCON 2014 AWA was evaluated through various workability and washout resistance tests.

3.1 PH TEST ON FRESH AND MARINE WATER

To study the chemical interaction between the concrete mixture and its environment of curing, the pH behavior of the adjacent medium was monitored. Prior and after immersion of concrete samples in freshwater and marine water, the pH measurements were taken and presented in Table

Table 2 Readings

No.	Water	PH value
1	Fresh water	8.88
2	Marine water	8.70

Specimen immersion results in marginal increases in recorded pH values and not the leaching of alkaline constituents into the curing environment. The enhanced cohesiveness from the VITCON 2014 AWA resulted in enhanced stability of this product (stable pH behavior) as the loss of fine particles and unhydrated cement was minimized due to submersion. Additionally, the relatively constant alkaline range observed (pH 8.7–8.9) also implies that the surrounding water chemistry is not greatly disrupted an important consideration for eco-sensitive marine applications. The modified underwater concrete is confirmed to be environmentally compatible and suitable for use in both offshore and freshwater infrastructure without negative environmental effects as previously mentioned.

Unlike acid rain–affected concrete discussed in previous studies [24], the underwater concrete in this study maintained a stable pH in both marine and freshwater, indicating minimal chemical interaction and strong anti-leaching characteristics due to the AWA-enhanced cohesion.

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Figure 4 PH value for fresh water



Figure 5 PH value for marine water

3.2 SLUMP FLOW TEST

Such as the standard slump cone test in accordance with ASTM C143/C143M, the workability of the fresh concrete mixes was assessed. The test was performed on four different mix batches with 0%, 0.5%, 0.75 and 1.0% dosages by weight of cement given of VITCON 2014 AWA. According to Figure 4, the true slump of the control mix (0% AWA) showed high workability and low cohesion, indicated by the observation of signs of segregation. At 0.5% AWA, the slump decreased slightly to 270 mm but kept a true slump shape which indicates increased viscosity without loss of flowability.There were types of shear slump with recorded slump values of 190 mm and 180 mm when admixture dosage increased further to 0.75% and 1.0%, respectively. The reduction in the flowability and the rise in the internal friction in the shear slump phase reflects the rheology-modifying action of the anti-washout admixture imparted towards a more true slump form of concrete. There is a need for this type of behavior in the case of underwater concrete, where higher cohesion and viscosity are necessary to prevent washout and maintain the integrity of the mix during placement. The reduction in slump observed with increasing AWA dosage is due to enhanced cohesion and viscosity. However, the inclusion of Sikament 100 SC superplasticizer was crucial in maintaining acceptable workability by reducing water demand and facilitating better flow. This helped counteract excessive slump loss, especially at 0.75% and 1.0% AWA dosages. In accordance with these results, it is demonstrated that the VITCON 2014 AWA addition modifies the rheological behavior of concrete by increasing its cohesiveness and decreasing slump in a dosage dependent fashion. Increased AWA content has a negative effect on slump, however, and increases stability, making it a suitable material in underwater environments. figures contain the summary of observed slump value.



Figure 6: True slump
% of Admixture : 0 %
Slump value: 280mm



Figure 7 : True slump
% of Admixture : 0.5 %
Slump value : 270mm

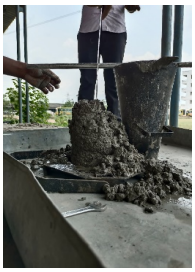


Figure 8 – Shear slump
% of Admixture : 0.75 %
Slump value : 190 mm

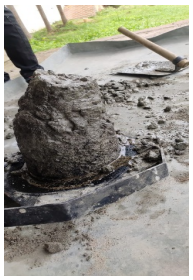


Figure 9 - Shear slump
% of Admixture : 1 %
Slump value : 180 mm

3.3 L- BOX TEST

Passing ability of self-compacting underwater concrete mixes was tested by employing L-Box test and varying dosages of VITCON 2014 AWA. H_2/H_1 ratio is used as the indicator of relative flow depth in the test, which quantifies the capacity of concrete to flow through the gaps simulating the reinforcement congestion. The higher the H_2/H_1 ratio, the better the passing ability and the reduction of segregation.

Table 3 has shown that the control mix without AWA had the H_2/H_1 ratio of 0.60, and thereby exhibited insufficient cohesiveness, high internal friction and blocking tendency due to poor viscosity control. Such improvement of flowability is clearly attributed to the viscosity enhancing effect of the admixture that mitigated aggregate blocking.

The AWA dosage further increased to bring on a more favorable response. Excellent passing ability with minimal segregation was indicated by the H_2/H_1 ratio reaching 0.86 at 0.75 and 0.89 at 1.0 percent AWA at ±0.01 mm passing presence. Consistent with the trend, flow performance increases at higher AWA contents, and no further gains beyond 0.75% do not appear to occur.

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Results confirm that the VITCON 2014 AWA will substantially improve the rheological behavior of underwater concrete by increasing cohesive forces to resist flow obstruction. The technique is also validated for use in confined placements where it may be challenged by reinforcement density, and its results are consistent with earlier work in a 2D model.

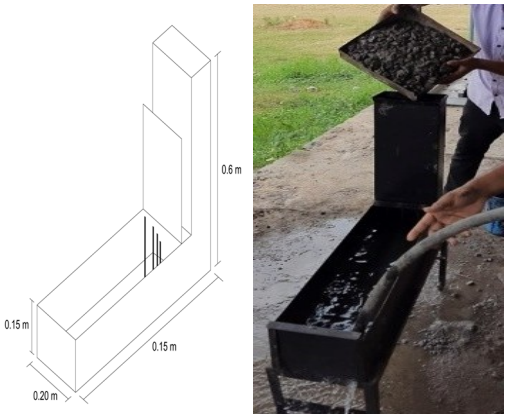


Figure 10 L- Box Test

The passing ability of the underwater concrete:
H2/H1
= 13 /15
= 0.86.

Table 3 L- Box test Readings

AWADosage (%)	H_1 (cm)	H_2 (cm)	H_2/H_1 Ratio	Flow Behavior
0.0	15.0	9.0	0.60	Poor(High blocking risk)
0.5	15.0	12.3	0.82	Moderate flow
0.75	15.0	12.9	0.86	Good passing ability
1.0	15.0	13.4	0.89	Excellent flow

3.4 U – BOX TEST

To determine the degree of self-compaction ability and the ability to pass the filler of self-compacted underwater concrete modified with VITCON 2014 AWA, the U-Box test was carried out. The test is a flow in congested reinforcement through the voids, and it provides a measure of concrete's capacity of filling voids under self-weight and gravitational flow. The measure of flowability is defined as the difference in height between the concrete levels in both chambers and will have a lower difference being indicative of better performance

AWA lowered the height difference of the control mix greatly, but this reflected limited filling ability and thus poor cohesion and high internal friction. When AWA doses are increased on concrete, concrete becomes more suitable for flow and less height differentiated, thus confirming admixture's role on improving the mix rheological properties.

The values recorded for height difference in Table 5 indicate that the mix with 0.5% AWA has reduced the height difference to 45mm and 0.75% AWA further improves the value to 35mm. At 1.0 % AWA, the height difference of 20 mm represents nearly complete filling and good flow past reinforcement congestion, giving the best result.

From the present study, a good filling was observed in a representative test result with H_1 = 20 cm and H_2 = 16 cm (40 mm height difference). Table 6 U Box Test Results for Varying AWA Dosages

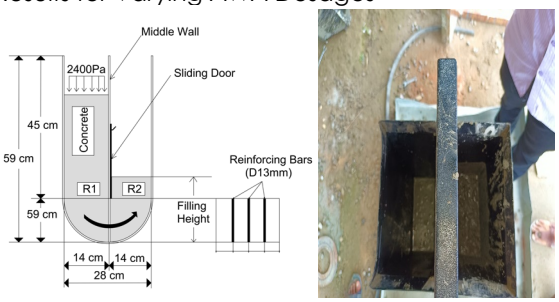


Figure 11 U - Box Test

Table 4 U Box Test Readings

AWA Dosage (%)	H_1 (cm)	H_2 (cm)	H_1–H_2 (cm)	Flowability Evaluation
0.0	20	13	7	Poor (Low filling ability)
0.5	20	15.5	4.5	Moderate
0.75	20	16	4	Good
1.0	20	18	2	Excellent

3.5 PLUNGE TEST (CRD-C 61)

To evaluate the washout resistance of M30 grade underwater mixes of concrete with varying dosages of VITCON 2014 AWA, the CRD-C 61 plunge test was carried out. The underwater placement condition is simulated by measuring the mass loss percentage after the fresh concrete is immersed and withdrawn by water. If the mass loss percentage is lower, then it demonstrates better resistance to washout, very important to retaining cohesion and limiting segregation when casting underwater.

It was tested under freshwater and marine water environments and Concrete mixes were tested. Tables 5 and 6 show that the AWA free control mix could lose most mass (we lost 6.8 % mass in freshwater and 6.5 mass in marine water). Such a performance is attributable to lack of viscosity control and poor cohesion of conventional concrete when submerged. The 6.1% washout loss in freshwater (with 0.5% AWA) and 5.9% loss in marine water (using 0.5% AWA) was obtained with the addition of 0.5% AWA. Values were reduced to 5.6 and 5.3% at the 0.75% dosage. In freshwater and marine water, minimum washout loss was achieved at 1.0% AWA with a value of 5.6% and 5.0%, respectively, and performance here was best. This points out that submerged VITCON 2014 AWA is

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effective for improving the mix's resistance to the dispersion of cement paste and aggregate separation.

As the AWA dosage increases, the data bears out that the washout resistance of underwater concrete increases progressively, yet the marine water provides slightly better enhancements because of the higher salinity and water density that further strengthens particle cohesion.



Figure 12 Plunge test

Table 5 Plunge test readings for fresh water

S. No	% Of admixture added	Washout %
1	0	6.8
2	0.5	6.1
3	0.75	5.6
4	1.0	5.6

Table 6 Plunge test readings for marine water

S. NO.	% Of admixture added	Washout %
1	0	6.5
2	0.5	5.9
3	0.75	5.3
4	1.0	5.0

Results conclusively demonstrate that VITCON 2014 AWA substantially reduces the washout sensitivity of underwater concrete and thus its stability. A dosage of ~~0.75 to 1.0 %~~ 0.5 % is optimal for providing satisfactory workability while maintaining washout resistance for underwater use, including marine foundations, piers, and coastal repairs.

3.6 COMPRESSIVE STRENGTH OF UNDERWATER CONCRETE

Early age strength development of mixes containing various dosages of VITCON 2014 AWA were tested at 7 and 14 days of age and the compressive strength of concrete specimens was evaluated at 7 and 14 days. Compression testing on the standard 150 mm cube specimens has been carried out according to IS: 516 and ASTM C39 procedures on a calibrated compression testing machine by a uniform loading rate of 140 kgcm²/min.

Concrete cubes were cured in both freshwater and marine environments representative of submersed structure conditions. Tables 7 and 8 showing the results indicate a pronounced increase in strength with the AWA, as well as an optimal dosage of 0.5%.

The compressive strength results in this study represent early-age performance at 7 and 14 days. To gain a more comprehensive understanding of long-term strength gain and durability, further studies incorporating 28-day and 90-day curing periods are recommended.

It is important to consider the effect of specimen size on compressive strength. As reported in recent literature[22], larger specimens generally exhibit reduced strength values due to internal flaw distribution and stress propagation effects. Our use of 150 mm cubes aligns with standard practice, but strength variations may occur with different geometries or dimensions in field conditions. Further studies could evaluate this aspect in underwater environments

3.6.1 FRESHWATER CURING RESULTS

The strength of 19.42 MPa at 7 days was obtained with the control mix (i.e. 0% AWA). It is found that strength at 22.22 MPa, increased 14.4% compared to the AWA strength at 0.5%, attributed to increased cohesion, reduced washout and improved paste aggregate bonding. Strengths remained stable at higher dosages (0.75% and 1.0%) indicating that above some point, viscosity has little effect on early strength gain.

Table 7 7-Day Compressive Strength – Freshwater Curing

AWA Dosage (%)	Strength (MPa)
0.0	19.42 ± 0.19
0.5	22.22 ± 0.11
0.75	21.85 ± 0.17
1.0	21.66 ± 0.20

3.6.2 MARINE WATER CURING RESULTS

Similar trends were obtained for specimens cured in marine water. The strength of the mix (21.33 MPa) at 14 days reached 26.13 MPa i.e., more than 22.5% more than the mix with 0.5% AWA. Underwater stability can be bettered, leaching is reduced, and the microstructural integrity is bettered thanks to the AWA.

Table 8 14-Day Compressive Strength – Marine Water Curing

AWA Dosage (%)	Strength (MPa)
0.0	21.33 ± 0.13
0.5	26.13 ± 0.13
0.75	25.10 ± 0.23
1.0	24.85 ± 0.15

Based on these findings it seems that 0.5% AWA dosage strikes the right balance between workability, wash out resistance, and early age development. At

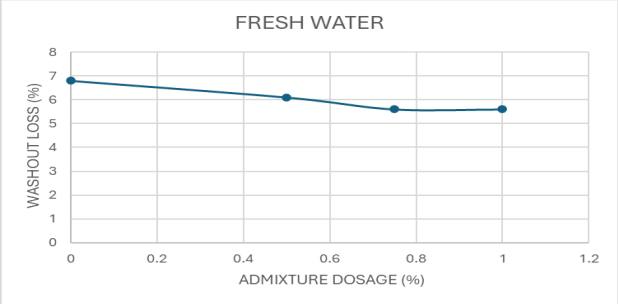
DOI: https://doi.org/10.11113/jurnalteknologi.v88.24860

higher dosages, there is no proportionate strength gain and may deteriorate workability if not compensated with a superplasticizer.

The values presented above include the mean and standard deviation (±) based on three replicate cube tests per mix. To validate the performance improvement, an independent-sample t-test was conducted between the control mix (0% AWA) and the optimal mix (0.5% AWA). The result showed a highly significant difference in compressive strength with a t-statistic of -46.72 and a p-value < 0.00001, confirming that the enhancement in strength with 0.5% AWA is statistically significant at the 95% confidence level.

Comparing the different % of anti-washout admixtures with loss of weight in fresh water and marine water, pH value in fresh water and marine water and compressive strength of the concrete after curing periods of 7& 14 days. As mentioned above the graphs and their results are shown below

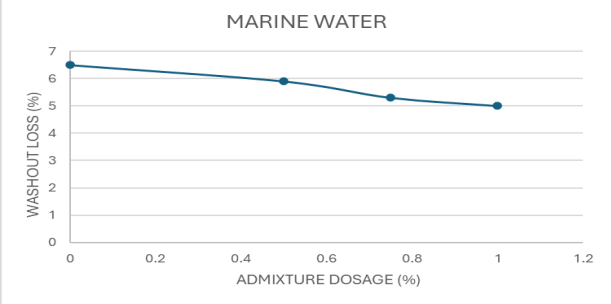
Comparison Between Percentage of Anti-Washout Admixture and Loss Of % Of Weight in Fresh Water



Graph -1 % of admixture Vs loss of weight in fresh water

In the above graph based upon the % of admixture the minimum loss of % of fresh water is noted as 5% at 1% of admixture.

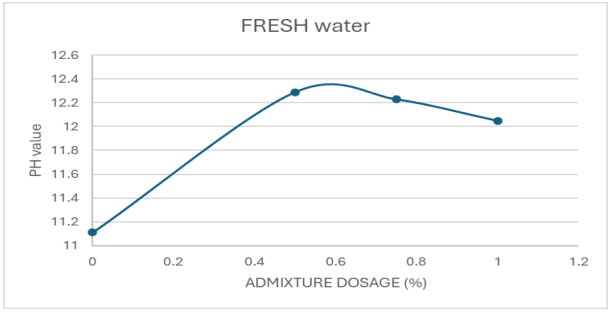
Comparison between percentage of anti-washout admixture and loss of % of weight in marine water



Graph -2 % of admixture Vs loss of weight in marine water

In the above graph based upon the % of admixture the minimum loss of % of fresh water is noted as 5% at 1% of admixture

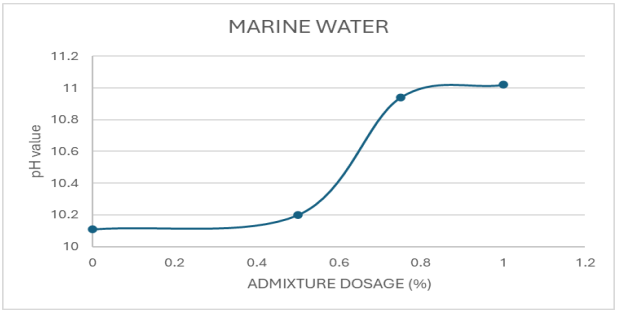
Comparison between percentage of anti-washout admixture and pH value in fresh water



Graph -3 % of AWA Vs pH value in fresh water

In the above graph based upon the % of admixture (AWA) the maximum PH value is noted as 12.29 at 0.5% of admixture in fresh water.

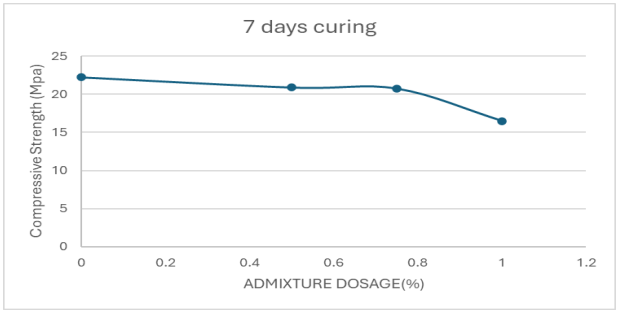
Comparison between percentage of anti-washout admixture and pH value in marine water



Graph -4 % of AWA Vs pH value in marine water

In the above graph based upon the % of admixture (AWA) the maximum PH value is noted as 11.04 at 1.0% of admixture in fresh water.

Comparison between percentage of anti-washout admixture and compressive strength in fresh water

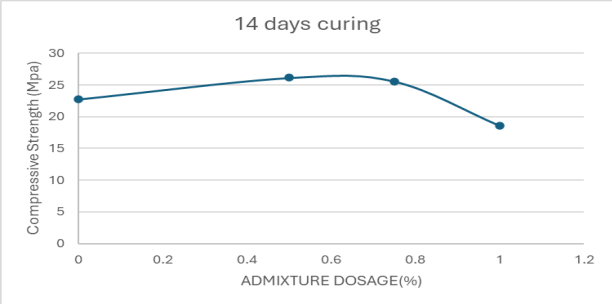


Graph -5 % of AWA Vs compressive strength of concrete

In the above graph based upon the % of admixture the maximum compressive strength value for 7 days curing in fresh water as 22.22 kn/m^2, at 0.5% of admixture (AWA).

Comparison between percentage of anti-washout admixture and compressive strength in marine water.

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Graph -6 % of AWA Vs compressive strength of concrete

In the above graph based upon the % of admixture the maximum compressive strength value for 7 days curing in fresh water as 26.13 kn/m^2, at 0.5% of admixture (AWA)

4.0 CONCLUSION

Based on the experimental results, it was found that according to the requirements and specifications of the CRD-C 61 test, self-protected underwater anti-washout resistance concrete (SPUAR) has good efficiency in the washout resistance in both fresh and marine water. In addition, high concentrations of AWA such as 1% had a mass loss lower than 0.5%, which is less than the traditional methods of pouring concrete underwater. The results of the CRD-C 61 were consistent with the pH value test. As in both tests, sea water had a lower mass loss than fresh water. The proportions of the concrete mix shall be well adjusted, taking into consideration the slump cone value will be decreased by increasing the % of admixture content, and the flowability requirements in the water medium as increasing the viscosity of the concrete and increasing W/C ratio leads to high slump. As the compressive strength of SPUAR concrete gives good results in 0.5% of admixture (AWA) compared to the 1.0% of admixture (AWA). And the pH values after performing the plunge test will be more compared to before dipping the concrete in fresh and marine water. Finally, SPUAR is an eco-friendly innovative concrete they can be used in various engineering applications such as pouring concrete underwater, repair, and strengthening on/offshore structures.

Statistical analysis using a t-test further confirmed the significant improvement in compressive strength at 0.5% AWA dosage ($p < 0.00001$), establishing the reliability of this dosage for practical underwater applications.

Limitations and Future Scope :

The present study was conducted under controlled laboratory conditions using freshwater and marine water to evaluate early-age compressive strength. However, several limitations must be acknowledged. Firstly, the curing period was limited to 14 days due to time constraints; longer-term evaluations at 28 and 90 days are recommended for more comprehensive strength and durability analysis. Secondly, the underwater environment simulated did not account for actual field turbulence or tidal movement. Therefore, future research should consider turbulent flow simulations using wave tanks or current flumes. Additionally, the study only focused on compressive strength, leaving out other important durability parameters such as permeability, chloride ion penetration, and abrasion resistance. Only one commercial anti-washout admixture (VITCON 2014 AWA) was studied, and results may not generalize to other products. Lastly, the mix design was tailored to specific material sources, which may vary geographically. Expanding the study to include flexural and split tensile strength, different admixtures, and region-specific materials is recommended for broader applicability.

Water absorption, permeability, and sorptivity tests were not included in the current study. These are essential indicators of durability for underwater concrete and should be explored in future investigations

The study was limited to M30 grade concrete. Future work should consider multiple strength grades to understand the behavior of AWA in both lower and higher performance mixes.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics declaration

Formal ethical approval was not obtained for this study. However, the authors confirm that the research

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was conducted in accordance with established ethical principles and good research practices, with due consideration given to participant rights, informed consent, confidentiality, and responsible data handling.

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