Protection of the Coastal Shores by Adequate Concrete Wave Breakers

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Abstract. Climate change is a pertinent pervasive phenomenon that has been under increasing scrutiny and regulation across the world. The coastal prolonged shorelines are susceptible to the intensifying rise in sea levels and its chemical composition. This work pursued the production of concrete mix adequate for seawater wave breakers subjected to an aggressive environment. To meet this goal, conventional and environmentally friendly concrete mixtures were evaluated. Cement was partially replaced, with different percentages, by various admixtures; sugarcane bagasse ashes, nano clay, quartz, fly ash, and silica fumes with an air-entraining agent, superplasticizer, and water acting as the binding agent in each mix. compressive strength and flexural strength were tested on all mixtures to shed light on the potentially augmented mechanical properties of the mixtures. Moreover, abrasion, chemical soundness, and rapid chloride permeability tests were conducted to determine the prospective improvement in durability. Results reveal that the adjustment of concrete mixtures plays an integral role in enhancing the performance of wave breakers. In addition, the use of supplementary cementitious materials, as well as the use of chemical admixtures, need to be amended to meet both environmental as well as performance criteria.

Keywords: climate change, concrete, sugarcane bagasse ashes, supplementary cementitious, wave breakers

1 Introduction

The escalating impact of climate change, environmental degradation, and carbon emissions originating from the construction sector has galvanized global attention. The Earth's climate is undergoing discernible warming trends, precipitating a consequential rise in sea levels due to the melting of polar ice caps. This surge in sea level poses imminent threats such as coastal erosion, wetland inundation, and salinization of agricultural soils.

Wave breakers, crucial for coastal protection, have exhibited conspicuous signs of premature failure, attributable to prolonged exposure to seawater and environmental factors. The deleterious effects of climate change have long been disregarded, endangering coastal communities with rising sea levels and intensified wave impacts (Leopoldo, 2000).

The construction industry is endeavoring to mitigate its reliance on cement, seeking alternative or supplementary materials to enhance concrete properties. Previous studies have shown promising results in the mechanical and durability aspects of concrete by incorporating various waste materials, thereby addressing pollution concerns (Deepika, 2017). Materials such as Sugarcane Bagasse Ashes, possessing pozzolanic characteristics, and Nano Clay and Nano Silica Fume have demonstrated efficacy in improving concrete durability and reducing permeability, potentially suitable for wave breaker compositions.

Additionally, regions experiencing freezing temperatures necessitate the incorporation of air-entraining agents to mitigate freeze-thaw-induced cracking (Nasir, 2020).

Critical factors influencing wave breaker performance include design loads and seawater composition, notably the presence of sulphates and other salts. Seawater exhibits significantly higher levels of total dissolved solids, conductivity, and salinity compared to freshwater, exerting unique challenges on concrete durability (Nasir, 2020).
This research endeavors to develop concrete formulations resilient to the aggressive marine environment encountered by wave breakers. Through systematic experimentation, environmentally friendly concrete mixes will be evaluated to identify optimal compositions capable of withstanding diverse environmental stresses. Key criteria for selection include enhanced mechanical properties, heightened durability, and minimal porosity and permeability.

2 Materials and Experimental Work

The experimental work commenced by entailing the development of 7 unique mixes, 6 of which are based on the partial replacement of cement with different pozzolanic materials. The pozzolanic materials have different percent replacement of cement and together form multiple combinations to compare their properties against the control. The last mixture introduces a new type of cement that is currently being used in the offshore construction field. The major variable in the mixtures is the percent replacement of cement. Air entraining agent has been added to all mixtures to increase workability and freeze thaw resistance. 2 samples mixes have been prepared to provide an indication about the potential and adverse effects of its addition. A high range water reducing superplasticizer (type F) have been added to all mixtures to boost the mixtures' strength.

2.1 Material Properties

The materials included in the 2 sample mixes and 7 mixes are: cement where two types of cements were tested type I - Ordinary Portland Cement (OPC) – with 3.15 specific gravity, and CEM III - Blast Furnace Cement – with specific gravity 2.95; Fine Aggregates well graded sand, 2.53 specific gravity, 0.44% absorption, and 2.82 fineness modulus; coarse aggregates well graded crushed dolomite, with 2.64 specific gravity and 1.9% absorption; ordinary municipal tap water was used in producing and curing process of the concrete mixtures; Sugarcane Bagasse Ashes (SCBA) were used and grinded to values of D80 (80% passing size) below 60 µm and blain fineness above 3000 cm^2/gm; Nano Clay (NC) of specific gravity 1.66*;* Quartz (QZ) powder with particle size less than 125 µm*;* Fly Ash (FA) with 2.2 specific gravity; Silica Fume (SF); Admixtures were used as follow a super plasticizer, type A, in accordance with ASTM C-

494, was used; it had 1.2 specific gravity, and an air-entraining agent complies with ASTM C 260-81 and C-494.

2.2 Concrete Mix Design

The following were used in the mix design for all the concrete mixes with the following specified weights per meter cube sand 680 kg/m^3, 20 mm gravel 510 kg/m^3, 15 mm gravel 512 kg/m^3, and super placticizer type A 4 kg/m^3.

Table 1. Mix Design

Mix No.	Water kg/m^3	OPC kg/m^3	CEM III kg/m^3	SF kg/m^3	FA kg/m^3	SCBA kg/m^3	NC kg/m^3	QZ kg/m^3	AE kg/m^3
SM 3	164	356.7	-	-	-	-	32.8	20.5	-
SM 7		-	410	-	-	-	-	-	-
M1		410	-	-	-	-	-	-	1.03
M2		389.5	-	-	-	20.5	-	-	1.03
M3		356.7	-	-	-	-	32.8	20.5	1.03
M4		328	-	20.5	61.5	-	-	-	1.03
M5		307.5	-	20.5	61.5	20.5	-	-	1.03
M6		274.7	-	20.5	61.5	0	32.8	20.5	1.03
M7		-	410	-	-	-	-	-	1.03

2.3 Tests Performed

Seawater Analysis Tests, total dissolved solids test was conducted on an obtained Mediterranean seawater sample from Alexandria to determine the dissolved solids concentration per litre. Conductivity test was conducted on an obtained Mediterranean seawater sample from Alexandria to determine the conductivity. Salinity test was conducted on an obtained Mediterranean seawater sample from Alexandria to determine the dissolved salts concentration per litre. Sulfate test was conducted on an obtained Mediterranean seawater sample from Alexandria - according to Method 8051 - to determine the sulfate concentration. Chloride test was conducted on an obtained Mediterranean seawater sample from Alexandria - according to Method 8113 - to determine the chloride concentration (Nasir, 2020).

Fresh concrete tests, air content test was conducted on the freshly poured concrete mixtures - according to ASTM C231 - to determine the air content. Slump test was conducted on the freshly poured concrete mixtures - according to ASTM C143 - to determine the consistency. Temperature, This test was conducted on the freshly poured concrete mixtures to determine the temperature. Unit weight test was conducted on the freshly poured concrete mixtures - according to ASTM C138 - to determine the density (Leopoldo, 2000).

Hardened Concrete Tests, Compressive Strength test was conducted on the hardened concrete mixtures after 3, 7, and 28 days - according to ASTM C39 - to determine the properties of the mix on a cube specimen by measuring its ability to withstand loads. The test was performed on 3 cubes for each testing age per mix; their dimensions were 150x150x150 mm. Flexural strength test was conducted on the hardened concrete mixtures after 28 days - according to ASTM C293 - to determine the properties of the mix on a beam specimen by measuring its ability to withstand loads through center-point loading. The test was performed on 2 beams for each testing age per mix; their dimensions were 150x150x750 mm. Abrasion resistance of concrete test was conducted on the hardened concrete mixtures after 28 days to determine the abrasion resistance by calculating the loss in mass. The test was done on 3 cubes for each mix; their dimensions were 75x75x75 mm. Rapid chloride permeability test was conducted on the hardened concrete mixtures after 28 days - according to ASTM C1202 - to determine the resistance of concrete mix to chloride ion penetration by evaluating the charge passed, the test was performed on 3 discs for each mix; their diameters were 100 mm, and their thickness were 50 mm. Chemical soundness tests were conducted on the hardened concrete mixtures for 20 days to determine the aggregate resistance to weathering by calculating the change in cubes' compressive strength and loss in mass, each mixture had 6 cubes immersed in sulfate solution and another 6 submerged in chloride solution; the 6 cubes of each mix were used as follows, 3 cubes were used to determine the change in the cubes' mass and 3 cubes used to determine the compressive strength of the mix's cubes after being immersed in the solution, the solutions have been prepared by using a calculated concentrations and adding them to distilled unionized water, the concentration for sulfate and chloride solution have been acquired from the water testing done on the obtained seawater sample (Leopoldo, 2000). The cube dimensions were 50x50x50 mm.

3 Test Results and Discussion

3.1 Seawater Analysis Tests Results

Table 3. Seawater Analysis Tests Results

Test	Seawater	Freshwater
Total Dissolved Solids	14.65 g/L	0.3 – 0.9 g/L
Conductivity	29.3 mS/cm	0.6 – 2.7 mS/cm
Salinity	20.76 g/L	0.001 – 0.5 g/L
Sulfate	3.8 g/L	0.003 – 0.03 g/L
Chloride	11.5 g/L	0.001 – 0.25 g/L

These results prove the exceptional environmental conditions wave breakers are continuously exposed to because of the sea water properties. In addition, it is clear that the seawater samples significantly surpass the typical freshwater ranges.

3.2 Fresh Test Results

Table 4. Fresh Tests Results

Mix Number	Slump (cm)	Unit Weight (kg/m^2)	Air Content (%)	Temperature (°C)
SM3	2.1	2345	2.2	29.4
SM7	2.33	2349	2.5	26.5
M1	2	2353	3	28.5
M2	2.2	2368	3.1	28.3
M3	4	2350	2.5	29
M4	2	2328	2	28.9
M5	4	2382	3.5	30.6
M6	2	2342	2.1	28.3
M7	3	2249	2.7	26.6

All the mixes showed adequate results needed to be used in wave breakers given the environmental and atmospheric exposure requirements (Marlog, 2021).

The slump test results show that the concrete all the concrete mixes above have low workability except for both concrete mixes 3 and 5 which show medium workability.

The unit weight of all mixes are close in value except for mix 7 which has the lowest value of 2249 kg/m^3.

The air content results show that mix 5 has the highest air content and mix 4 has the lowest.

The temperature of all the mixes is of adequate values ranging between 26.6 to 30.6 °C.

3.3 Compressive Strength Results

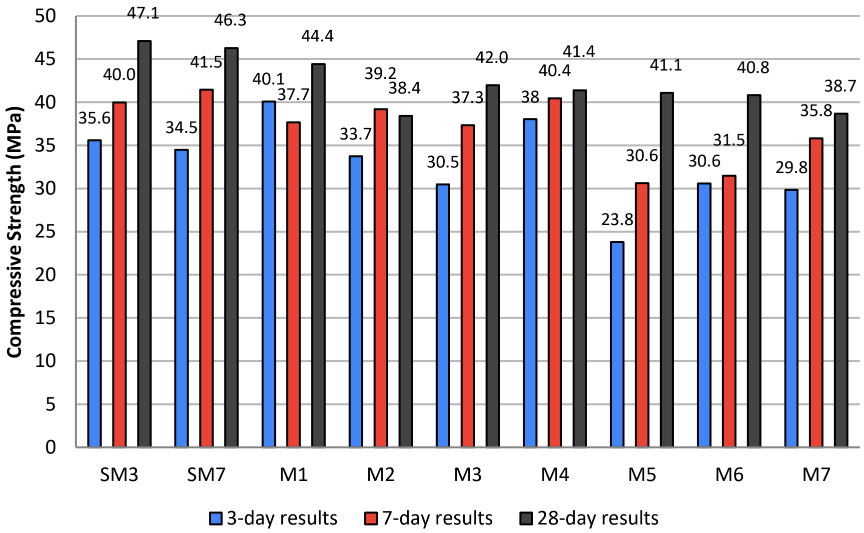

Fig. 2. Average compressive strength of each 3 cubes per mix

The results of the compressive test are presented in figure 2 for the different concrete mixes after 3 days, 7 days, and 28 days. The results were used to compare the concrete mixes' compressive strength to that of the control mix's (mix 1). The compressive strength test was also conducted to study the effect of the addition of air-entraining agent to the mixes.

The results proved that the concrete mixes are of high quality as their compressive strengths exceeded 30 MPa after 28 days. In addition, the results proved that the replacement of OPC with various percentages with SCBA, silica fume, fly ash, nano clay or quartz does not affect the structural integrity, safety, and serviceability of concrete mixtures. The compressive of the mixtures met the minimum requirements for wave breakers, only mix 2 and mix 7 compressive strength results were inadequate as they did not achieve the required 40 MPa, which is the required compressive strength after 28 days for the wave breakers. This means the irrelevancy of the usage of CEM III instead of OPC or the replacement of OPC with only 5 % SCBA.

3.4 Flexural Strength Results

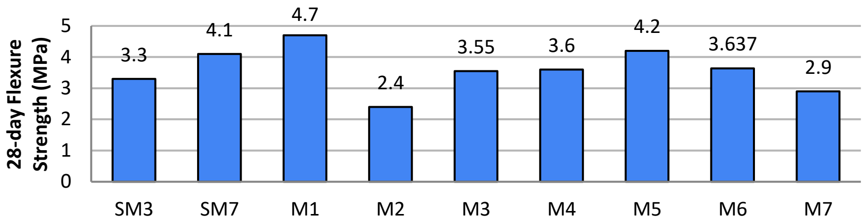

Fig. 3. Average compressive strength of each 2 beams per mix

The results of this test give a clear insight into the effect of replacements of concrete and the usage of air entraining agent in the mixes.

The flexural strength results are presented in figure 3 for all the concrete mixes after 28 days. The flexural strengths results are used to compare concrete mixes' flexural strength to that of the control mix. Also, the results are used to study the effect of the addition of the air-entraining agent.

As shown in figure the control mix has the highest flexural strength value. By comparing concrete sample mixes 3 and 7 to concrete mixes 3 and 7, the results do not show a clear effect for using air entraining agent. The results show that all the concrete mixes' flexural strengths exceeded 3.5 MPa, which is the required flexural strength for the wave breakers, except for mixes 2, 7, and sample mix 3. These results are consistent with the compressive strength results.

3.5 Abrasion Resistance of Concrete Results

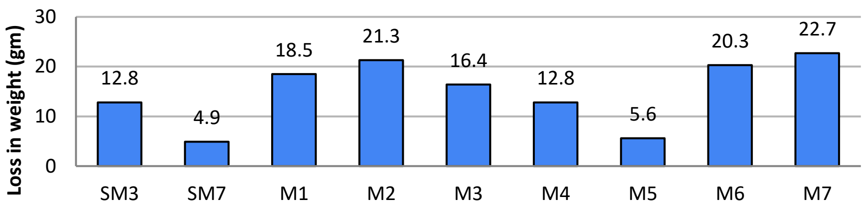

Fig. 4. Average change in mass that each 2 cubes per mix

The results of the abrasion resistance of the concrete cubes tested show that all mixes have different abrasion resistance represented in the loss in weight after the test. The presence of SCBA with silica fume and fly ash in mix 5 gave a high abrasion resistance to the concrete mixture which is required for wave brakers comparing to mix 1 the currently used concrete mixture for wave breakers that has very low abrasion resistance according to the results.

In comparison between sample mix 3 and sample mix 7 with mix 3 and mix 7 respectively; it shows that the usage of the air-entraining agent in the concrete mix decreases the abrasion resistance of the concrete.

3.6 Rapid Chloride Permeability Test (RCPT) Results

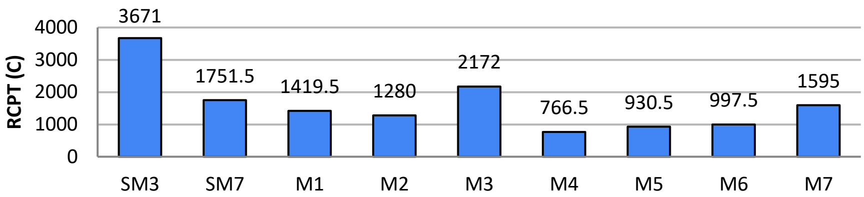

Fig. 5. Average charge passed through each 2 discs per mix to obtain the rapid chloride permeability test result

The RCPT results are shown in figure 5. The results show that the addition of air-entraining agent to the concrete mixes increase its permeability. Also, the results demonstrate that concrete mixes 4, 5, and 6 have very low permeability; and demonstrates that concrete mixes 1, 2, 7 and sample mix 7 have Low Permeability; it also shows that concrete mix 3, and sample mix 3 have moderate permeability. The results show that mixes 2, 4, 5, and 6 have lower permeability than that of the control mix. The lower permeability of the wave breaker's concrete mix the more durable it is.

The presence of SCBA, fly ash, and silica fume within the concrete mixtures showed high resistance of concrete to chloride penetration, which is crucial for ensuring the long-term integrity and performance of concrete in the sea water. However, the usage of CEM III and the presence of quartz and nano clay showed low resistance to chloride penetration which is inadequate for wave breakers.

4 Conclusion and Recommendations

4.1 Conclusion

Numerous tests have been conducted to determine the impact of the listed materials and their respective combinations on the mechanical properties and durability of the concrete mixtures. The mechanical properties did not encounter significant improvement compared to that of the control mixture, however, the durability had substantial development which fits the purpose of the study.

After investigating the mechanical properties, the materials incorporated, and tests implemented, it was concluded that no indication about whether the percent replacement of cement deteriorates the strength of the concrete. No significant improvement in compressive and flexural strength compared to the control mixtures. All mixes surpassed compressive strength of 30 MPa, nevertheless, mixtures that did not achieve minimum compressive strength of 40 MPa should be neglected.

After investigating the durability and permeability, the materials integrated, and tests executed, it was concluded that partial replacement of cement has higher resistance to abrasion. No specific trend that correlates permeability with partial replacement, however mixtures with high air content demonstrated lower permeability values. Sulfate attack shows a drastic effect on all concrete mixtures with significant declination in compressive strength and weight. Chloride attack does not support a conclusive overview, yet they had an overall increase in weight.

4.2 Recommendations

The recommendations for our study are classified according to the purpose deemed necessary by the study reviewer.

For future work and investigations, it is highly recommended to introduce more concrete mixes with various conventional materials, further relevant tests shall be conducted, such as creep and exposure to more marine-life conditions, consider additional environmentally friendly materials in studies, conduct a pilot trial at a designated location as a case study, conduct Accelerated Corrosion Potential Test for 40 days.

For forthcoming operations and application, it is highly recommended to use various percentage of SCBA as a replacement for cement to enhance mechanical properties, excessive replacement of cement is not recommended for trial mixtures. Concrete mixture shall maintain a good balance between mechanical properties, durability and permeability, and performance in sea water.

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