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# The Performance of Self-curing Concrete Cast using Seawater

**Enas A. Emam [1] and Alaa A. Bashandy [2*]**
*(1) Civil Engineering Department, Menoufia Higher Technology Institute, Menoufia, Egypt*
*(2) Civil Engineering Department, Faculty of Engineering, Menoufia University, Egypt*
*(Corresponding author: Dr.Alaa.Bashandy@sh-eng.menofia.edu.eg)*

**ABSTRACT**

Construction engineering in coastal areas is facing the challenge of a shortage of fresh water for mixing and curing. The quality of water places an important role in the setting and strength development of concrete structures. This research aims to study the feasibility of using seawater to cast and curing plain concrete for non-structural uses. Samples were cast using tap water or seawater and then cured using tap water or seawater up to testing ages. Concrete properties were studied in terms of compressive, tensile, flexure, and bond strengths at 7, 28, and 56 days of age. Test results showed that the self-curing concrete with Polyethylene Glycol 400 performed better in its main mechanical properties compared to conventional concrete. The compressive strength and subsequently the other related strengths of concrete were shown to increase for specimens mixed and cured with seawater at early ages up to 7 days, while a definite decrease in the respective strengths was observed for ages more than 28 days and up to 56 days. The reduction in strength increases with an increase in exposure time, which may be due to salt crystallization formation affecting the strength gain.

***Keywords:*** *Seawater; Cast; Curing; Self-curing Concrete; Polyethylene Glycol "PEG 400"; Strength.*

## 1. INTRODUCTION

The curing of concrete is an essential stage in concrete manufacturing. Curing is the procedure by which hydraulic cement concrete develops hardened properties over time [1]. Water is essential to the hydration reaction of the cement, which led the cement powder to convert into the binding cement paste, which gives concrete its strength [1, 2]. The hardening of concrete is a result of the sustained hydration of the cement in the presence of sufficient water and heat [1]. An appropriate curing period for concrete is vital at an early age to enable the concrete to gain strength, reduce shrinkage, and develop a structure that will make the concrete adequately durable [3]. Excessive evaporation of water (internal or external) from fresh concrete led to insufficient properties if it is not avoided. Curing regimes should guarantee the accessibility of an adequate amount of water for cement hydration. In cases of lake curing, self-curing "SC" concrete is a good alternative [3-8].

The main idea of self-curing concrete is to cure the concrete from inside to outside while satisfying the characteristics of strength and durability [9]. In addition, Self-curing concrete behaves well in a fire and under sulfate and chloride attack [14, 15, 10]. There are two main curing regimes [16]. One is conducted by using porous materials (lightweight aggregate, wood powder) to act as internal reservoirs [2, 17, 18]. The other is obtained by using chemical curing agents (super-absorbent polymers "SAP" and Shrinkage Reducing Admixture"SRA" such as polyethylene-glycol"PEG", polyacrylamide "PAM" and propylene glycol) [19, 20, 21, 22]. There are several types of SRAs. Each type of SRA has a different effect on the behavior of the obtained "SC" concrete [23, 20, 5, 19]. Self-curing can be used effectively with recycled aggregates to produce self-curing recycled aggregate concrete [24, 25] with sufficient durability [26].

Using pure drinkable water for cast and curing of concrete is essential. In some cases, especially for offshore constructions, the validity of seawater may lead to trying to use it, particularly for plain concrete. Concrete exposed to seawater subjected to wetting by an aqueous solution containing principally dissolved sodium chloride and magnesium sulfate [27, 28, 29]. Several researchers discussed the feasibility of using seawater for mixing and curing concrete [31-40].

The primary chemical constituents of seawater are the ions of chloride "CL" and sodium "$Na^{+}$". The order of the other cations is magnesium "$Mg^{2+}$" > calcium "$Ca^{2+}$" > > potassium "$K^{+}$" > "$Sr^{2+}$". The major anions include $CL^{-}$, which is also not strongly complex, and $HCO_3^{-}$, $SO_4^{-}$, $Br^{-}$, and $F^{-}$ which are expressed as milligrams per liter of seawater with less significance in the charge balance of seawater [31, 40].

The concentrations of major salt constituents of seawater are given in weight as a percentage of salt as about 78% NaCl, 10.5% MgCl, 5% $MgSO_4$, 3.9% $CaSO_4$, 2.3% $K_2SO_4$, and 0.3% KBr [30]. On average, seawater has total salinity of about 3.5% per liter of seawater. Water containing large quantities of chlorides (seawater) tends to cause persistent dampness and surface efflorescence. While the concentration of dissolved solids varied from one place to other, the ratio of any one of the major constituents to the total dissolved solids is nearly constant everywhere.

Following standards such as ASTM C1602 [41], ECP 203/2018 [42], or EN 1008 [43], the use of seawater for the production of reinforced or prestressed concrete is not permitted because sea water does not meet the chloride limit, resulting in a high risk of steel corrosion. Recently, researchers have been interested in searching for cement capable of mixing with salt water. One of these products is blended cement, obtained by partial replacement of OPC clinker with industrial by-products, such as ground-granulated blast furnace slag (GGBFS), fly ash (FA), silica fume (SF), or natural pozzolans and fillers like trass or limestone [44, 45].

The compressive strength of plain concrete cast using seawater strength improves as using seawater [46, 47, 48]. The long-term behavior of concrete cast using seawater was studied [49, 50]. The properties of concrete cast using seawater can be improved [51]. The use of seawater in reinforced concrete by using corrosion-free reinforcements such as fiber-reinforced polymers (FRP) is suggested [52]. In addition, reinforcement-free ductile composites containing polypropylene (PP) fibers were investigated by Li et al. [53, 54] and Jiangtao et al. [55]. Moreover, the corrosion of reinforcing steel can be mitigated by creating a proper mixture design, which incorporates supplementary cementitious materials (SCMs) or corrosion inhibitors such as sodium nitrite [50-54]. [56, 57, 58, 59, 60]

However, recent technological improvements, in some cases, have made it possible to overcome the use of seawater in plain concrete, by using Nano-materials such as nano-silica ($SiO_2$) which contributes to a significant acceleration of the cement hydration process. Various studies have confirmed the accelerating effects of nano-silica in OPC and blended cementitious systems [61]. In the case of reinforced or prestressed members, corrosion of embedded steel can be prevented by painting or coating the steel with cement slurry made with fresh water. In addition, a higher concrete cover can be provided when designing the member [62].

Although the existing literature and codes of practice reveal the effect of mixing and curing seawater on the durability of concrete, it remains an area requiring further study and research.

In the present study, the effect of using seawater to mix and cure conventional plain concrete compared to using it to cast self-curing concrete will be studied. The effects of saltwater on the compressive strength, flexural strength, and splitting tensile strength of both concrete types are determined.

## 2. RESEARCH SIGNIFICANCE

This research aims to investigate the feasibility of using seawater to mix and cure conventional plain concrete compared to using it to cast self-curing concrete. The main variables are the aggregate type, water type for mixing, and water type for curing.

The importance of this research is to address the behavior of "SC" concrete cast using seawater compared to conventional concrete cast and cured using seawater for the researchers and engineers due to the possible problems due to insufficient pure water for cast or curing.

## 3. MATERIALS AND TEST SPECIMENS

All tests in this research were carried out in the construction materials laboratory in Civil Eng. Dep. at the Faculty of Engineering Science, Sinai University, Al Arish city, Egypt.

The materials used, the design of test specimens, and the testing procedures are discussed in the following sections.

### 3.1. Materials

Ordinary Portland cement CEM I 42.5 N obtained from Lafarge factory, Egypt satisfied the Egyptian Standard Specification (E.S.S. 4756-1/2009) [63] was used. A naturally clean and nearly free from impurities siliceous sand as a fine aggregate satisfied the Egyptian standards (E.S.S.1109/2008) [64] was used. Its specific gravity is 2.64 t/$m^3$ and its fineness modulus is 2.05. The coarse aggregate used, dolomite with a maximum nominal size of 10 mm, satisfies the (E.S.S 1109/2008) [64]. Its mechanical and physical properties are shown in Table (3).

Two types of water were used for mixing and curing, fresh drinkable clean water and seawater from the Al-Arish Mediterranean Sea. The chemical analysis of fresh water and seawater is shown in Table (4).

**Table (1):** Typical properties of Ordinary Portland cement used.

| Property | | Value |
|---|---|---|
| Surface area | *($m^2$/kg)* | 310.0 |
| Setting time initial | *(minutes* | 150.0 |
| Specific Weight | *(t/$m^3$)* | 3.12 |
| Compressive | | |
| 2 day | *(N/$mm^2$)* | 20.0 |
| 28 day | *(N/$mm^2$)* | 49.0 |
| Sulfate | $SO_3$ *(%)* | 2.9 |
| Chloride | CL *(%)* | 0.06 |
| Alkali Eq. | $Na_2O$ % | 0.50 |
| Tri-calcium silicate | C3S *(%)* | 55.0 : 65.0 |
| Di-calcium silicate | C2S | 15.0 to |
| Tri-calcium | C3A | 7.0 |
| Tetra-calcium | C4AF | 11.0 |

**Table (2):** Characteristics of Polyethylene-glycol 400 *(as provided by manufacturer)*

| properties | Value |
|---|---|
| Range of Avg. Molecular Weight | 380 - 420 |
| Solubility in water at 20°C, % by WT. | complete |
| Range of Average Hydroxy1 Number, mg KOH/g | 264 - 300 |
| Density, g/$cm^3$ at 20°C | 1.1255 |
| pH at 25oC, 5% Aqueous solution | 4.5 – 7.5 |
| Average Number of Repeating Oxyethylene units | 8.7 |
| Melting or Freezing Range, C | 4 to 8 |
| Viscosity at 100°C, cst | 7.3 |

**Table (2):** Mechanical and physical properties of sand **used** *(as obtained from tests)*.

| Sieve Size *(mm)* | 4.75 | 2.00 | 1.18 | 0.60 | 0.25 | 0.15 |
|---|---|---|---|---|---|---|
| Pass *(%)* | 98.18 | 81.14 | 61.61 | 39.07 | 13.79 | 0.66 |
| Fineness modulus | 3.05 | | | | | |
| Specific Gravity | 2.64 | | | | | |
| Volume Weight | 1675 | | | | | |
| Dust by weight | 0.01 | | | | | |

**Table (3):** Main mechanical and physical properties of crushed dolomite used *(as obtained from tests)*.

| Sieve Size *( mm)* | 4.75 | 2.0 | 1.18 | 0.6 | 0.3 | 0.16 |
|---|---|---|---|---|---|---|
| Pass *( %)* | 98.2 | 81.1 | 61.6 | 39.1 | 13.8 | 0.7 |
| MNS* *(mm)* | 10 | | | | | |
| Specific Gravity | 2.58 | | | | | |
| Volume Weight *(Kg/$m^3$)* | 1610 | | | | | |
| Absorption percentage ( *%)* | 1.0 | | | | | |

**MNS = Maximum nominal size*

**Table (4):** Chemical analysis of fresh water and seawater. *(as obtained from laboratory tests)*

| Test | **Fresh Water** "W" | **Sea Water** "S" |
|---|---|---|
| PH | 7.1 | 8.1 |
| Total dissolve solid "TDS" | 1485 *(mg/L)* | 35900 *(mg/L)* |
| Electrical Conductivity "E.C." | 1055 *(micro S/cm)* | 58 *(micro S/cm)* |
| Odor | -- | -- |
| Color | pure | Light blue |
| Chloride "$CL^-$" | 210 *(mg/L)* | 19800 *(mg/L)* |
| Sodium "$Na^+$" | | 10800 *(mg/L)* |
| Magnesium "$Mg^{2+}$" | 30 *(mg/L)* | 1350 *(mg/L)* |
| Calcium "$Ca^{2+}$" | 60 *(mg/L)* | 390 *(mg/L)* |
| Nitrate "$NO_3^-$" | -- | 4.1 *(mg/L)* |
| Iron "Fe" | -- | 0.31 *(mg/L)* |
| Potassium "K" | -- | 470 *(mg/L)* |
| Sulfate "$SO_4^{2-}$" | 105 *(mg/L)* | 2800 *(mg/L)* |
| Bicarbonate "$HCO_3$" | -- | 156 *(mg/L)* |
| Phosphate "$PO_4^{3-}$" | -- | 1.0 *(mg/L)* |
| Total Hardness | | 6.3 *(mg/L)* |
| Acidity | -- | -- |
| Alkalinity | -- | 120 *(mg/L)* |

Deformed high tensile steel bars of grade 360/520 with a nominal diameter of 16 mm and length of 170 mm were used as embedded reinforcement with proof stress of 360 MPa. Its mechanical characteristics are shown in Table (5). It satisfies the Egyptian Standard Specification (E.S.S. 262) [65].

To obtain a self-curing "SC" concrete, the self-curing agent used in this study is Polyethylene glycol PEG400 produced by Morgan Chemicals Pvt. Ltd in Egypt, as a chemical agent in a liquid form for internal curing of concrete. It is free of chlorides and produces an internal membrane, which protects and prevents fresh concrete from over-rapid water evaporation. Its dosage was chosen based on previous research [10, 15].

**Table (5):** Test results of reinforcing bars (rebars). *(as obtained from laboratory tests)*

| Steel type | Yield Stress (Kg/cm$^2$) | Tensile Strength (Kg/cm$^2$) | Elongatio n (%) | Modulus of Elasticity (t/cm$^2$) |
|---|---|---|---|---|
| Mild Steel | 2950 | 4090 | 22 | 2010 |
| High Tensile Steel | 3650 | 5300 | 13 | 2010 |

**Table (6):** Proportions of concrete mixes used.

| **Mix Code** | **Cement** *(Kg/m$^3$)* | **Water** *(Kg/m$^3$)* | **Fine Aggregate** *(Kg/m$^3$)* | **Course Aggregate** *(Kg/m$^3$)* | **Curing agent PEG400** *(Kg/m$^3$)* |
|---|---|---|---|---|---|
| **CC** Conventional concrete | 350 | 140 | 665.47 | 1330.93 | -- |
| **SC** Self-curing concrete | 350 | 140 | 665.47 | 1330.93 | 7 (2%) |

### 3.2. Concrete Manufacturing

Two mixes were used. The first is a conventional concrete mix "CC" while the second is a self-curing concrete mix "SC". Concrete mixes in this research are shown in Table (6). A target slump of 50–70 mm was selected for all mixes.

For each mix, four cases were considered as shown in Fig. (1). In the first two cases, concrete materials were mixed with fresh water and then cured with fresh water or seawater. In the third and fourth cases, concrete materials are mixed with seawater and then cured with fresh water or seawater. The strength of concrete mixes cast with seawater and cured with fresh water was also observed to have increased even at 28 days.

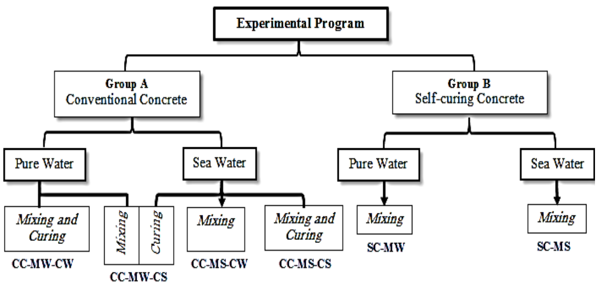


**Fig.1:** Flow chart of the experimental program.

In practice, the fresh-fresh water situations occur in building constructed on interior lands far from salt water. The freshwater for cast and seawater for curing situations is mainly in structures or buildings close to the sea. The using of seawater for cast and freshwater for curing situations are very rare in practice but are well noticeable in areas where the available surface water is salty or there is a shortage of freshwater. The seawater for cast and curing situations is visible mostly in offshore structures or those built in the ocean or sea.

Samples were cast after preparing concrete molds and formworks. A mixer with a capacity of 30 liters was used to mix concrete components. After the completion of sample casting, they were left at the lab temperature of 25ºC for 24 hours then, removed from their formworks. Self-curing concrete "SC" samples left in a laboratory environment without curing. Conventional concrete mix "CC" kept in curing water (freshwater or seawater) up to the testing ages of 7, 28, and 56 days for. They tested for compression, splitting tensile, flexure, and bond strengths.

During this test, both temperature and relative humidity were measured once a week with a temperature varied in the range of 22-32 ºC with an average of 27 ºC, while the relative humidity varied in the range of 62-76 % with an average of 69 %.

### 3.3. Concrete Samples

For all groups, fresh concrete properties are obtained in terms of slump value while main mechanical properties are obtained in terms of compressive, tensile, and flexure strengths. The specimens were cubes (100×100×100 mm) for testing compressive strength, cylinder (100mm diameter, 200 mm height) for testing indirect tensile strength, and prism (100×100×500mm) for testing flexural strength. Standard cubes of dimensions 150x150x150 mm with embedded steel rebars (160mm length and 10mm diameter) to evaluate the relative bond strength between the reinforcing bars and concrete [66]. The concrete-steel bond strength is formulated according to ECP 203/2007 [33] as $F_{bu}= f_s .\varphi /(4.L_d)$ where $L_d$ (mm) is the bond length of steel; φ (mm) is the diameter of the steel, and $f_s$ ($N/mm^2$) is the tensile stress in steel. If in the previous equation $f_s= F / (\pi.\varphi^2 /4)$, where F (N) is the applied force on the rebar, it then comes out as $F_{bu}= F / (L_d .\pi. \varphi)$.

Tests were performed at 7, 28, and 56 days. The samples were cast and then cured. They were tested according to the Egyptian Code for Design and Implementation of Concrete (E.C.P. 203/2020) [42].

## 4. TEST RESULTS AND DISCUSSIONS

The results in this study are derived in terms of compressive strength, indirect tensile (splitting) strength, flexure strength, and bond strength for hardened concrete.

### 4.1. Conventional Concrete

Figures (2) and (3) clearly show the effect of mixing concrete with seawater, the effect of curing concrete in seawater, and the mutual effect of mixing and curing concrete in seawater on the compressive strength of concrete. It was noticed that using pure fresh water for mixing the conventional concrete produced better-recorded values for different concrete strengths.

An appreciable increase and early compressive strengths were gained for "SC" and "CC" mixes as compared with the control mixes "MW-CW" up to an age of 7 days. The rate of strength gain in the "CC" specimens was faster than in the "SC" specimens. At 28 days, all concrete mixes recorded a slight increase in compressive strength but the rates of increase in "CC" mixes were higher than in "SC" mixes. However, at 56 days, the rate of strength gained decreased, especially for "CC" and "SC" mixes.

For compressive strength values, when mixed and then cured with pure water "MW-CW" the obtained values are 32.8 MPa, 36.5 MPa, and 38.76 MPa at 7, 28, and 56 days, respectively. As mixing using pure water and then cured with seawater "MW-CS", the compressive strength values decreased by about 23.9%, 22.9%, and 12.3% at 7, 28, and 56 days, respectively compared to "MW-CW", as a control sample. When mixing using seawater and then cured with pure water "MS-CW", the compressive strength values decreased by about 23 %, 19.4%, and 9.2% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. In the case of mixed and cured using seawater "MS-CS", the compressive strength values decreased by about 35 %, 29.4%, and 17.5% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. That result may be due to the crystallization of salt in seawater. The results show that mixing concrete with fresh water before curing it in seawater improves the compressive strength of concrete. The rate of the strength gain in cubes cast using fresh water is nearly slow as compared with that cast using salt water in accordance with Preeti et al. [48]. The higher compressive strength of concrete specimens with seawater curing may be referred to as the formation of salt crystals and the existence of calcium chloride in seawater, which satisfied Susilorini et al. [38].

Cylinder specimens were tested for splitting tensile, and the average splitting tensile strength was determined from the failure tensile load. The obtained values of average splitting tensile strengths are shown in Figs. (4) and (5). In the case of mixed and then cured with pure water "MW-CW", the obtained values are 3 MPa, 3.2 MPa, and 3.7 MPa at 7, 28, and 56 days, respectively. As mixing using pure water and then cured with seawater "MW-CS", the compressive strength values decreased by about 20.4%, 12.1%, and 9.5% at 7, 28, and 56 days, respectively compared to "MW-CW", as a control sample. When mixing using seawater and then cured with pure water "MS-CW", the splitting tensile strength values decreased by about 18.3 %, 10.9%, and 8.1% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. In the case of mixed and cured using seawater "MS-CS", the compressive strength values decreased by about 23.3 %, 18.8%, and 16.2% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. The results satisfy the behavior under the compression test.

The flexural strength values are shown in figures (6) and (7). When mixed and then cured with pure water "MW-CW" the obtained values are 6.7 MPa, 7.5 MPa, and 8.5 MPa at 7, 28, and 56 days, respectively. As mixing using pure water and then cured with seawater "MW-CS", the flexural strength values decreased by about 10.5%, 11.1%, and 8.7% at 7, 28, and 56 days, respectively compared to "MW-CW", as a control sample. When mixing using seawater and then cured with pure water "MS-CW", the flexural strength values decreased by about 6.4 %, 9.8%, and 7.1% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. In the case of mixed and cured using seawater "MS-CS", the flexural strength values decreased by about 15.4 %, 16.4%, and

11.8% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. The results satisfy the behavior under the compression test.

Cube specimens were pulled out from their embedded bar and the average ultimate pull-out bond strength was determined from the failure pull-out bond load. The obtained values of average bond strengths for concrete mixed and cured in seawater concerning the corresponding ones mixed and cured in freshwater are shown in Figs. (8) and (9) for all mixes and concrete ages. As mixed and then cured with pure water "MW-CW" the obtained values are 1.79 MPa, 2.05 MPa, and 2.37 MPa at 7, 28, and 56 days, respectively. As mixing using pure water and then cured with seawater "MW-CS", the bond strength values decreased by about 16.2%, 10.7%, and 10.7% at 7, 28, and 56 days, respectively compared to "MW-CW", as a control sample. When mixing using seawater and then cured with pure water "MS-CW", the bond strength values decreased by about 13.4 %, 8.9%, and 8% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. In the case of mixed and cured using seawater "MS-CS", the bond strength values decreased by about 24.6 %, 14.6%, and 18% at 7, 28, and 56 days, respectively compared to "MW-CW" as a control sample. The bond strength increased for mixes cured in fresh and seawater with the use of "SC" concrete rather than conventional concrete mixes. The results may be referred to the lower voids in "SC" compared to "CC", which protects reinforcement in concrete.

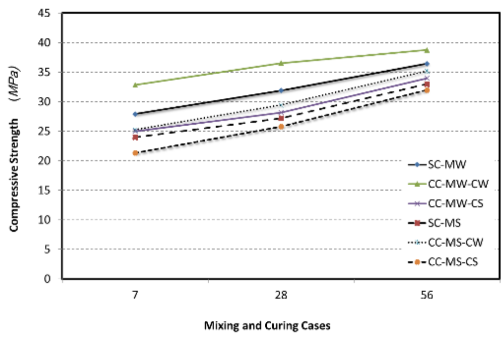


**Fig.2:** Compressive strength values of samples along the time considering different mixing and curing cases.

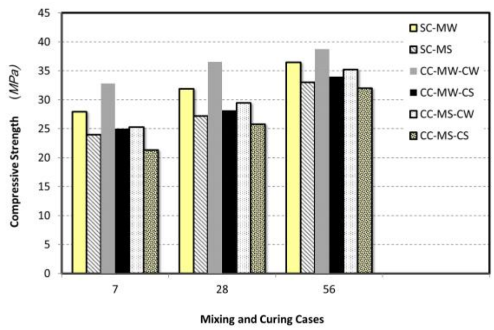


**Fig.3:** Comparison between compressive strength values of samples for different mixing and curing cases.

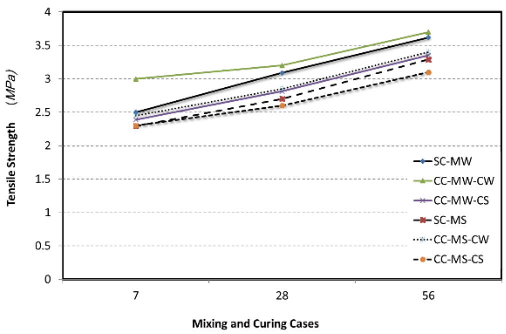


**Fig.4:** Tensile strength values of samples along the time considering different mixing and curing cases.

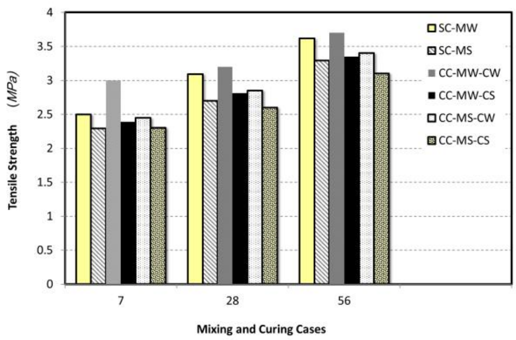


**Fig.5:** Comparison between tensile strength values of samples for different mixing and curing cases.

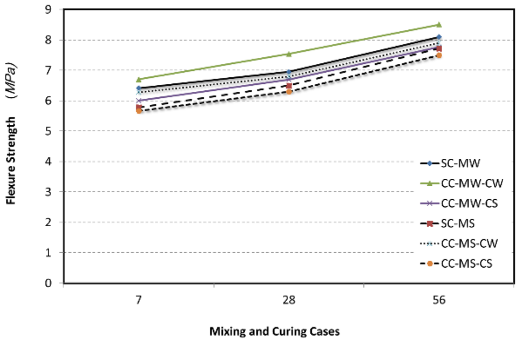


**Fig.6:** Flexure strength values of samples along the time considering different mixing and curing cases.

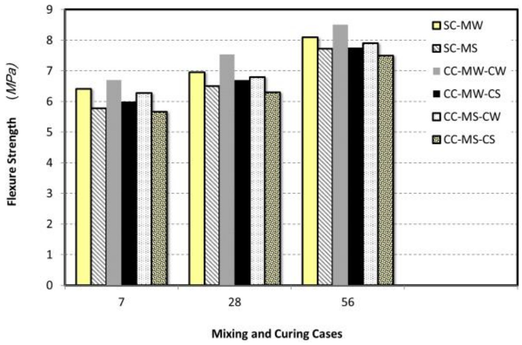


**Fig.7:** Comparison between flexure strength values of samples for different mixing and curing cases.

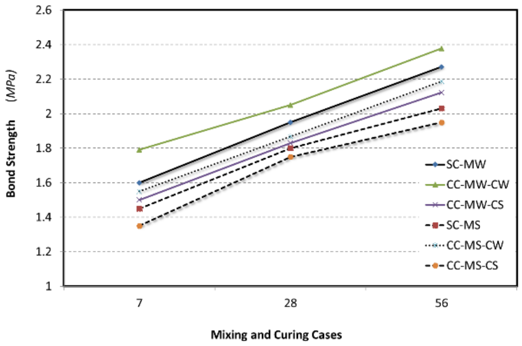


**Fig.8:** Bond strength values of samples along the time considering different mixing and curing cases.

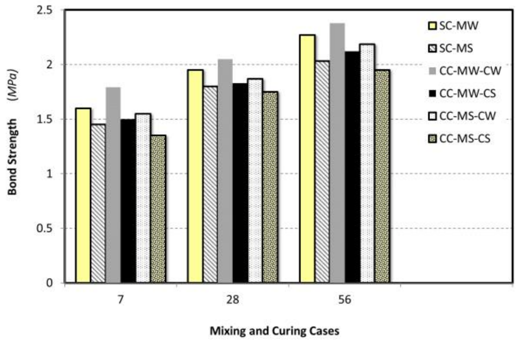


**Fig. 9:** Comparison between bond strength values of samples for different mixing and curing cases.

### 4.2. Self-curing Concrete

Using self-curing "SC" concrete provides a type of concrete that does not need a conventional curing process. Based on obtained results in figures (2) to (9), it was noticed that using pure water for mixing the self-curing concrete produced better-recorded values for different concrete strengths.

For compressive strength values, when mixed with pure water "SC-MW" the obtained values are 27.93 MPa, 31.9 MPa, and 36.47 MPa at 7, 28, and 56 days, respectively. However, when mixed with seawater "SC-MS", the compressive strength values decreased by about 14.1%, 14.7%, and 9.5% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. That may be because of the presence of organic impurities, also high chlorine, and sulfate amount that may interact with the curing agent, which led to reduce the strength compared to those cast using pure water.

The splitting tensile strength values when mixed with pure water "SC-MW" are 2.5 MPa, 3.1 MPa, and 3.6 MPa at 7, 28, and 56 days, respectively. Once, the mixture was mixed using seawater "SC-MS", the splitting tensile strength values decreased by about 8.3%, 12.6%, and 9.1% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. For flexural strength values, when mixed with pure water "SC-MW" the obtained values are 6.4 MPa, 6.9 MPa, and 8.1 MPa at 7, 28, and 56 days, respectively. But when mixed with seawater "SC-MS", the flexural strength values decreased by about 9.8%, 6.5%, and 4.7% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. The bond strength values when mixed with pure water "SC-MW" are 1.6 MPa, 1.95 MPa, and 2.27 MPa at 7, 28, and 56 days, respectively. On the other hand, when mixed with seawater "SC-MS", the bond strength values decreased by about 9.4%, 7.7%, and 10.6% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. The behavior of self-curing concrete cast using seawater is nearly the same for its compressive, splitting tensile, flexure, and bond strengths. Cast "SC" concrete using seawater led to a loss in its strength compared to those cast using pure water. That mainly depends on seawater components and the concentration of its salts.

### 4.3. Comparison between Conventional Concrete and Self-Curing Concrete

The slump test values increased when the dosage of (PEG400) increased. In this research, conventional concrete was compared to self-curing concrete.

The compressive strength values of the samples mixed and then cured with fresh water "MW-CW" increased by about 17.5 %, 14.5%, and 6.3% at 7, 28, and 56 days, respectively compared to self-curing mixed using pure water "SC-MW" as a control sample. The splitting tensile strength values of the samples mixed and then cured with fresh water "MW-CW" increased by about 20 %, 3.6%, and 3.2% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. The flexural strength values increased by about 4.6 %, 8.4%, and 5% at 7, 28, and 56 days, respectively compared to self-curing mixed using pure water "SC-MW" as a control sample. The loss of strength may refer to the non-cured case of "SC" concrete.

In the case of mixed with pure water and then cured using seawater "MW-CS", the compressive strength values decreased by about 10.5 %, 11.7%, and 6.8% at 7, 28, and 56 days, respectively compared to "SC-MW". The splitting tensile strength values decreased by about 4.5 %, 8.9%, and 7.5% at 7, 28, and 56 days, respectively compared to "SC-MW". The flexural strength values decreased by about 4.5 %, 8.9%, and 7.5% at 7, 28, and 56 days, respectively compared to "SC-MW". The bond strength values decreased by about 8 %, 15.8%, and 14.4% at 7, 28, and 56 days, respectively compared to "SC-MW".

Once mixed and cured using seawater "MS-CS", the compressive strength values decreased by about 23.6 %, 19.1%, and 12.2% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. The splitting tensile strength values decreased by about 8 %, 15.8%, and 14.4% at 7, 28, and 56 days, respectively compared to "SC-MW". The flexural strength values decreased by about 11.6 %, 9.4%, and 7.4% at 7, 28, and 56 days, respectively compared to "SC-MW". The bond strength values increased by about 20 %, 3.6%, and 3.2% at 7, 28, and 56 days, respectively compared to "SC-MW". That may suggest using "SC" concrete cast using pure water "SC-MW" in the salt area with no curing, as it is self-curing, than cast and curing using seawater.

In the case of mixed with seawater and then cured with pure water "MS-CW," the compressive strength values decreased by about 9.5 %, 7.7%, and 3.5% at 7, 28, and 56 days, respectively compared to "SC-MW" as a control sample. The splitting tensile strength values decreased by about 2 %, 7.7%, and 6.1% at 7, 28, and 56 days, respectively compared to "SC-MW". The flexural strength values decreased by about 2 %, 7.7%, and 6.1% at 7, 28, and 56 days, respectively compared to "SC-MW". the bond strength values decreased by about 4.5 %, 8.9%, and 7.5% at 7, 28, and 56 days, respectively compared to "SC-MW". The bond strength values decreased by about 2 %, 7.7%, and 6.1% at 7, 28, and 56 days, respectively compared to "SC-MW". The results may be referred to as the presence of salt crystals.

Based on obtained results, using "SC" concrete mixed with water is effective without the need to be cured. It is suggested to be used in offshore structures than using a conventional concrete cast or cured with seawater in case of missing pure water, especially in case of using steel reinforcement.

## 5. CONCLUSIONS

In this study, a series of experiments have been performed to investigate the behavior and properties of plain concrete samples cast and cured by seawater. Based on the experimental results presented in this paper, the conclusions could be drawn as follow:

**1.** Seawater can be used to cast or cure or cast and cure plain concrete with satisfied properties *(in the range of this study)*.

**2.** Self-curing plain concrete can be cast using seawater with sufficient strength.

**3.** Using pure water is more efficient than using seawater. But, in case of missing the pure water, seawater can be used with considered loss of strength and with plain concrete or concrete reinforced with non-metallic reinforcement.

**4.** Using seawater to mix "SC" concrete led to a decrease in strength in the range of 5-20% compared to control samples using pure water *(cast and then cured using pure water)*.

Generally, seawater can be used to cast and cure conventional plain concrete. Long-term behavior in this case should be studied. It may be applied for non-structural applications such as concrete blocks, and plain concrete applications in offshore areas with little drinkable pure water for mixing and curing. Further study should be made on the prevention of reinforcement from chloride attack to avoid the reinforcement corroding and on the effect of salt water on other significant characteristics of concrete.

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