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# EFFECTS OF USING SEAWATER IN THE MIXING AND CURING OF CONCRETE

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The U.N. evaluates that in 2050 the world population will increase about three point five billion, mostly in evolving countries that have underwent potable water crises. Furthermore, over half of the world population will unable to provide sufficient amounts of drinking water. Consequently, it is absolutely crucial to study ways to save freshwater. The use of seawater, which accounts for 97 percent of all the water present on Earth, is very essential. This thesis studies the use of seawater instead of freshwater in the mixing and curing of structural concrete in order to reduce future water shortage and aid in the evolution of concrete technology. Concrete mixed and cured with seawater is studied in terms of fresh and hardened properties. Results include an expected early accelerated rate of gain in compressive strength and presumably no direct effect on the rate of corrosion of reinforcement when compared to concrete mixed and cured with freshwater. Also, the type of concrete's effect was studied by using ordinary Portland cement (OPC) and by partial replacement of OPC with Blast-Furnace Slag Cement (BFSC).

*Keywords:* Water scarcity, Water shortage, Compressive strength, Tensile strength, Flexural strength.

## 1 INTRODUCTION

Fresh water resources across the globe are facing continuing stress due to the increase in population density, water used for each person, development and increased manufacturing activities (Contruction Products Association 2015). These pressures also bring forth the dangers and risks of future water scarcity and shortage worldwide. Water shortage already infects every continent in the world and, according to the United Nations, water usage has grown so rapidly at a rate that exceeds almost two times the rate of population increase within the last era. Water shortage will grow worse as developing urban areas place heavy stress on nearby water resources (United Nations 2019). Climate change and bio-energy needs are also projected to increase the already complicated connection between world progress and water demand. Water strain starts when amount of water in a country becomes below 1700 $m^3$/year or 4600 liters/day for each person. And when they go below 1000 $m^3$/year or about 2700 liters/day per person, it is then called water scarcity. Add to that, when a country goes below 500 $m^3$/year or 1400 liters/day per person, this is defined as absolute water scarcity (United Nations 2019). According to this definition, 49 nations are considered water stressed, nine of them face water scarcity and 21 are near absolute water scarcity level. More than two billion persons live in countries facing extreme water stress, and about four billion people face ultimate water scarcity for at least one month every year (United Nations Water 2019).

Hence, this thesis considers the subject of implementing the use of seawater, instead of freshwater, in the mixing and curing of concrete in order to reduce water consumption in the near future and hopefully prevent water shortage worldwide. The use of seawater in this work includes substituting freshwater with seawater in the mixing and curing of concrete to study its effects on the hardened properties of concrete, such as the compressive, tensile and flexural strengths.

## 2 DESIGN AND METHODOLOGY

### 2.1 Concrete Mix Design

This part of the thesis focuses on the experimental procedure required to study the effects of replacing freshwater with seawater in the mixing and curing of concrete.

This procedure included concreting of different mixes with varying water type (i.e. seawater and fresh water) with the addition the varying cement type (Ordinary Portland cement vs. Blast-Furnace Slag cement).

In terms of material, Ordinary Portland Cement (OPC) plus Blast-Furnace Slag Cement (BFSC) were used as cementitious binding material along with fresh water and seawater (from the Mediterranean Sea) for mixing/curing water. River sand and gravel from Baldet Al Mazera'a, Akkar were also obtained and used in the concreting process. The nominal aggregate size for coarse aggregate used was 25 mm. The designed mixes' proportions that were used in the experimentation can be seen in Table 1.

Table 1. Mix design proportions.

| ***Variable*** | ***Quantity/Value*** |
|---|---|
| *Ordinary Portland Cement (kg/m$^3$)* | 231.5 |
| *Blast-Furnace Slag Cement (kg/m$^3$)* | 231.5 |
| *River Gravel (kg/m$^3$)* | 1,136 |
| *River Sand (kg/m$^3$)* | 772 |
| *Sea Water/ Fresh water (kg/m$^3$)* | 200 |
| *Req. Avg. Compressive Strength, $f_c'$ (MPa)* | 40 |
| *Water-to-cement Ratio (w/c)* | 0.43 |

It is essential to mention that the mix design set was only for experimental purposes, with an initial mindset of creating concrete that was going to be subject to severe marine environment as described by the ACI; but, with the course of the experiment itself it was drawn out that for whichever designed mix, the effect of seawater was the same.

Each concrete mix was tested in four different ways depending on the mixing and curing of the concrete cylinders after setting: PP, PS, SP and SS. Therefore, PP means mixed and cured in potable water; (2) PS concrete mixed with potable water and cured in seawater; (3) SP concrete mixed with seawater and cured in potable water; (4) SS concrete mixed and cured in seawater. The latter mixes included the type of cement as a variable; which means that the four types of mixes were analyzed using Ordinary Portland Cement (OPC) and Ordinary Portland Cement with 50% replacement by Blast-Furnace Slag (OPC + 50% BFS) in order to analyze the relation between the cement type and mixing water. This resulted in eight different concrete mixes that were made, cured and tested at CityU Construction Materials Laboratory.

The specimens were de-molded one day after casting and then cured in either potable water or seawater for up to 7 days before the first testing. Concrete cylinders were tested for hardened properties at 7 and 28 days. In addition, properties of fresh concrete such as slump and workability were accounted for as well.

## 2.2 Concrete Mix Methodology

The procedure for preparing the concrete cylinders and beams with respect to their testing dates was a setup of seven cylinders and one beam per mix. That meaning three cylinders for compressive testing at seven days, and then three cylinders were tested at 28 days; leaving one for tensile testing at 28 days as well while the beam was sent for flexural tests at ACTS, Central Laboratory in Beirut. A sample group mix design for 100% OPC mixed with fresh water as shown in Table 2.

Table 2. Group mix design for seven cylinders and one beam.

| ***Material*** | ***Quantity (kg)*** |
|---|---|
| *Ordinary Portland Cement (OPC)* | 17.15 |
| *River Gravel* | 42.14 |
| *River Sand* | 28.63 |
| *Water* | 7.39 |

It should be mentioned also that during the concreting of these mixes, a certain amount (approximately 120 mL) of superplasticizer was needed to reach the required workability and slump without altering the water-to-cement ratio. To ensure that the concrete process was code-standard, the coarse and fine aggregates were sieved and then compared according to the upper and lower limit set by the ACI to see its grading. Thus, according to ACI E1-16, under Chapter 3: "Aggregate Properties and Test Methods" – section 3.1 Grading, Fig. 3.1.1b sets the limits specified in ASTM C33/C33M for fine aggregates and for 25.0 mm (1 in.) coarse aggregates.

Figure *1* and Figure *2* show the results obtained from the sieve analysis.

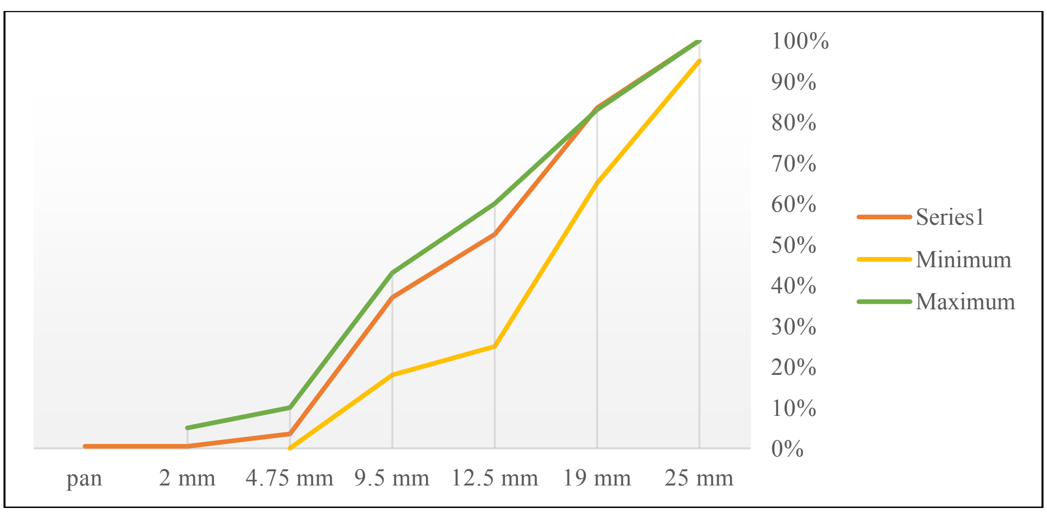


Figure 1. Sieve analysis results for coarse river aggregates.

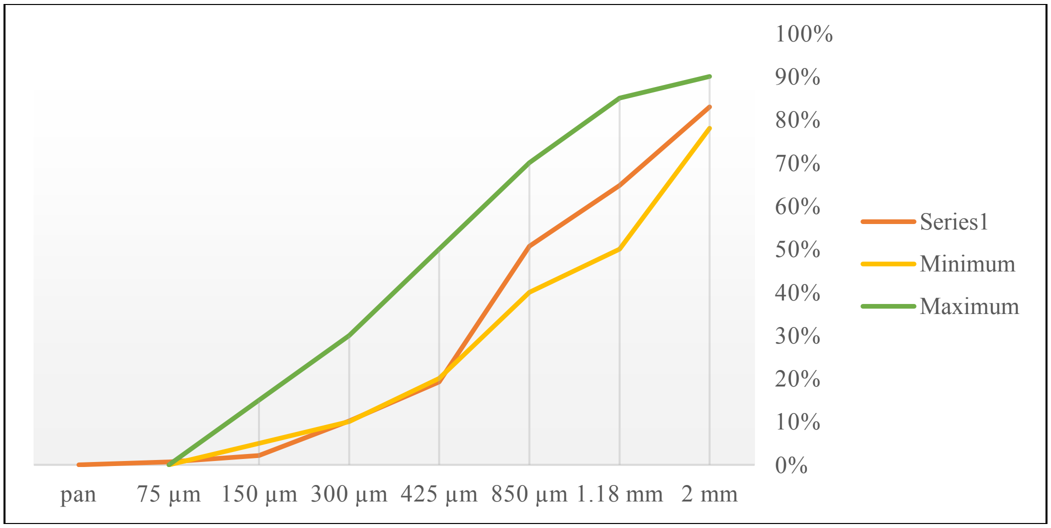


Figure 2. Sieve analysis results for fine river aggregates.

## 3 HARDENED CONCRETE TESTING

For the compressive strength test, the average of 3 cylinders for each group mix was taken for the ones test at 7 and 28 days in the BESMAK dual compression machine at City University, Tripoli. The results for the compressive strengths of the cylinder for 100% Ordinary Portland cement and for the partial replacement of 50% Blast-Furnace Slag cement are summarized in Figure 3 and Figure 4.

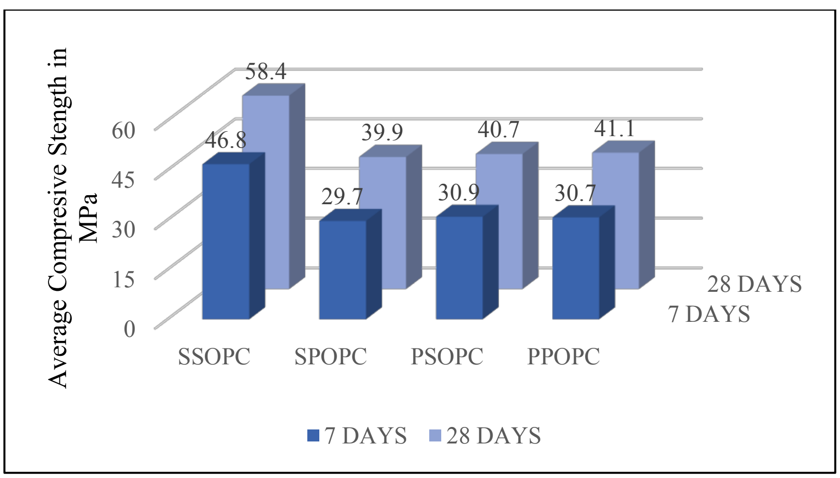


Figure 3. Chart summarizing the compressive strengths at seven and 28 days for OPC.

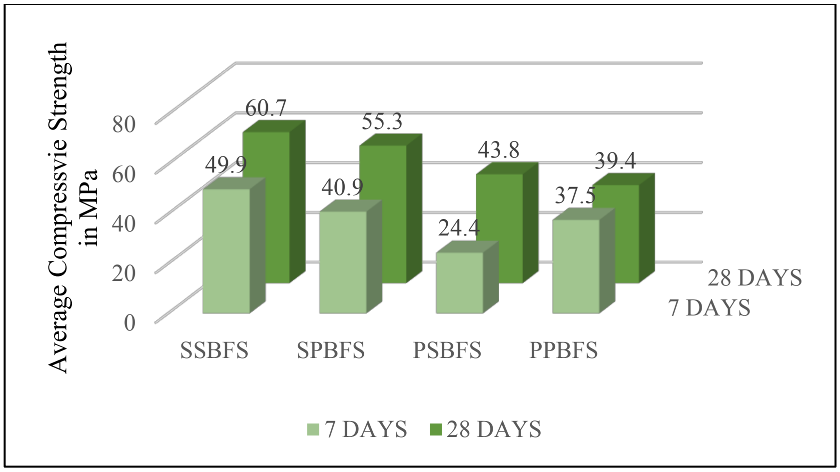


Figure 4. Chart summarizing the compressive strength at seven and 28 days for BFSC.

At 7 days, the process of mixing and curing in the seawater increased the compressive strength at about 51% when compared to PPOPC, and 42% at 28 days when compared to PPOPC as well. Same for the BFS, at 7 days, the process of mixing and curing in seawater increased the compressive strength at about 33.3% when compared to PPBFS, and about 55% at 28 days when compared to PPBFS as well.

As for the indirect tensile strength test, the concrete cylinders were also tested in the BESMAK dual compression machine at 28 days for each group mix resulting in eight different values for tensile strength. The values of the tensile strength for each cylinder at 28 days for both Ordinary Portland Cement (OPC) and Blast-Furnace Slag Cement (BFSC) are summarized in Figure 5.

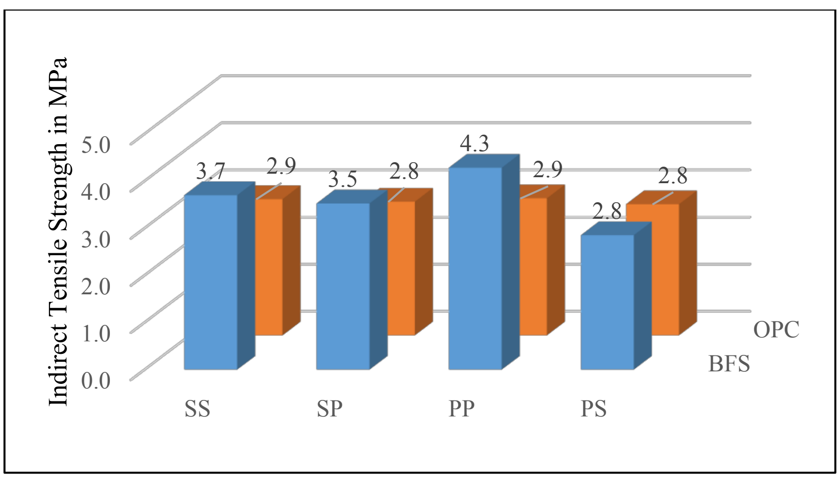


Figure 5. Chart summarizing the indirect tensile strength at 28 days for OPC and BFSC.

The final test for hardened properties of concrete is the flexural test for transverse strength. The machine required for testing beams in flexure was not available at City University; therefore, the beams were taken to ACTS, Beirut for testing.

The results for the transverse strength at 28 days for the Ordinary Portland cement (OPC) and Blast-Furnace Slag cement (BFSC) are summarized in Figure 6.

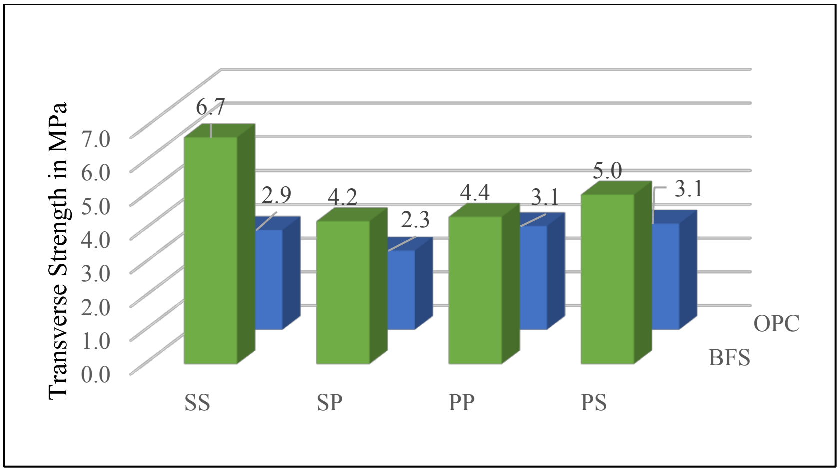


Figure 6. Chart summarizing the transverse strength at 28 days for OPC and BFSC.

## 4 CONCLUSION

The compressive strength of the concrete batches that were both mixed and cured in seawater showed an impressive acceleration in the rate of gain in compressive strength to a point where it actually exceeded the target compressive strength set by the mix design. Whereas, those that were mixed and cured in a conventional way reacted as any concrete mix would and only reached the target strength on the concrete age of 28 days. Those that were mixed and cured with seawater exceeded the target compressive strength at 28 days, and seemed to become denser and harder as it cured in the seawater.

The compressive strength with BFSC reached at 28 days exceeded the target compressive strength even higher than that which was mixed and cured in seawater but had 100% OPC. It was apparent that the type of mixing and curing water had an immense effect on the percentage gain of compressive strength when compared to those that were mixed and cured in potable water.

The only aspect of this thesis that may cast doubt is the reinforcement, therefore more studies on reinforced concrete must be conducted to further validate the hypothesis.

In regards to corrosion of rebar, a study is currently being conducted with the use of an Accelerated Corrosion Test (ACT) to test the rate of corrosion of rebar embedded in concrete mixed and cured in seawater in comparison to conventional concrete. This is to be pursued in another paper with a hypothesis that the mixing/curing water does not accelerate the rate of corrosion when compared to potable mixing/curing water.

### References

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