EXPLORING THE EFFECTS OF SALINITY ON CONCRETE BASED ON COSOLIDATION METHOD

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ABSTRACT

Salinity poses a significant challenge in coastal areas, impacting various aspects of the environment and infrastructure. In these regions, groundwater serves as a vital source of drinking water due to the presence of salinity. However, the ingress of seawater can infiltrate coastal structures, leading to detrimental effects. Water can permeate through the concrete structure via its pores, eventually reaching the reinforcement and causing its deterioration. The utilization of groundwater in numerous construction activities further exacerbates the scarcity of fresh water. The intrusion of salinity, intensified by rising sea levels and climate fluctuations, poses a growing menace to the availability of potable water sources in coastal areas. Consequently, the coastal regions of Bangladesh face a pressing issue of limited access to safe drinking water. Opting to use fresh water sources for construction purposes will only contribute to the exacerbation of this problem. This study provides an analysis of the effect of salinity if it replaces fresh water in both casting and curing. The study mainly discusses the effect of manual mixing and consolidation and compares it with the mechanical process.

Keywords: *Salinity, Concrete, Chlorine attack, Cylinder, Compression Test, Sieve Analysis, Consolidation*

1. INTRODUCTION

One of the major issues in coastal region is salinity. Due to the presence of salinity the major source for drinking water is groundwater. The sea water can also seep in and affect the coastal structures. Through pores water can leach in the concrete structure and make its way to the reinforcement and deteriorate it. Salinity in concrete refers to the presence of salt, typically in the form of chloride ions, within the concrete matrix. When salt enters the concrete, it can have various detrimental effects on its properties and durability. Salinity can occur in coastal regions due to the proximity to seawater or in environments where salt is used for de-icing or where saline water is present. The presence of salinity can lead to corrosion of the reinforcement steel, increased permeability and porosity of the concrete, alkali-silica reaction, efflorescence, and scaling of the concrete surface. It is important to address and mitigate the effects of salinity in concrete to ensure the long-term performance and structural integrity of the concrete structures.

The presence of salinity can have significant effects on concrete structures. Salinity, particularly in the form of chloride ions, can penetrate concrete and reach the reinforcement, leading to corrosion and deterioration of the steel. Additionally, saline water can increase the porosity and permeability of concrete, making it more susceptible to water absorption and damage. This can accelerate the corrosion process and weaken the structure. Salinity can also cause the appearance of efflorescence, white crystalline deposits on the concrete surface, which affects the aesthetics and may indicate moisture-related issues. The chemical reactions between salts and cementitious materials can deteriorate the concrete matrix, resulting in reduced strength, cracking, and overall degradation. Salinity can exacerbate the occurrence of alkali-silica reaction, leading to expansion, cracking, and reduced durability. Moreover, the combination of salinity and the freeze-thaw cycle can cause scaling and spalling of concrete surfaces. To mitigate these effects, measures such as using low-permeability concrete mixes, corrosion-resistant reinforcement, proper surface protection, and drainage systems are employed, along with regular maintenance and monitoring in salinity-prone areas.

The formation of efflorescence can also be scene on concrete surfaces due to presence of salt in curing water or atmosphere. Efflorescence is "a deposit of salts, usually white, formed on a surface, the substance having emerged in solution from within either concrete or masonry and subsequently precipitated by evaporation. It occurs most readily in porous concrete near the surface. Efflorescence is not normally damaging, but it is aesthetically undesirable(Bai, 2009).

Also, in coastal areas there is scarcity of fresh water and thus using saline water which is present in abundant can also be a solution. The presence of sulphate salts at high rates negatively affects the hardened cement paste due to the formation of additional quantities of Ettrengite where a large volume increase in the hardened cement paste leads to internal stresses causing cracks in the concrete mass affecting the resistance(Moore & Taylor, 1970). While chlorine can attack the reinforcement causing it to deteriorate and destroy structural framework(Verma et al., 2013).

The objective of this study is to determine the effect of salinity on concrete based on the method of mixing. The objective was obtained by comparing machine mixed with consolidated samples and hand mixed with hand tamping samples.

2. METHODOLOGY

An experimentation to understand the effect of salinity on concrete for a specific mix design was conducted. A model of 1:1.5:3 was taken as the ratio for the concrete mix. Two types of method of consolidation was used i.e, tamping and vibrator. Cylinders were made inorder to test compressive strength of the mix. Pure NaCl was mixed with the water for the mix to create a lab synthesized version of saline water found in the coastal region. The salt concentration used were 33gm/l and 66gm/l. The compressing strenght was determined and then compared among fresh water mixed concrete and saline water mixed concrete between two different consolidation method.

2.1 Materials

The materials used and their composition are given below:

2.1.1 Cement:

For this project Shah Cement is selected as the only cement to be used for all the samples.

Table 1 Physical properties of cement

SL.No	Test Conducted	Test Results
1	Normal Consistency	25 %
2	Initial Setting Time	135 min
3	Final Setting Time	185 min
4	Compressive Strength	3 days – 13.69 MPa 7 days-20.62 MPa 28 days- 28.56 MPa
5	Specific Gravity	3.14

2.1.2 Fine Aggregate:

Table 2 and Figure 1 contains the properties and gradation of fine aggregate.

Table 2 Properties of sand

SL.No	Test Conducted	Test Results
1	Fineness Modulus (FM)	3.36
2	Specific Gravity	2.75
3	Bulk Density (SSD)	1675 kg/m3
4	Water Absorption (SSD)	3.9%

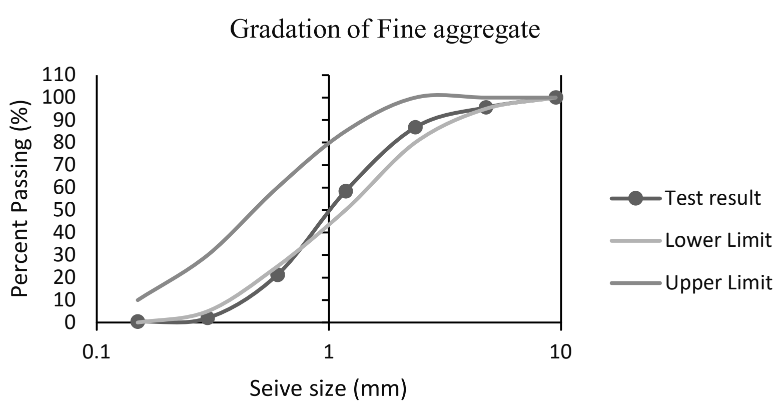


Figure 1 FM (Fine Aggregate)

2.1.3 Coarse Aggregate:

Table 3 and Figure 2 contains the properties and gradation of coarse aggregate.

Table 3 Properties of Coarse Aggregate

SL.No	Test Conducted	Test Results
1	Fineness Modulus (FM)	6.70
2	Specific Gravity	2.41
3	Bulk Density (SSD)	1578 kg/m^3
4	Water Absorption (SSD)	1.01%

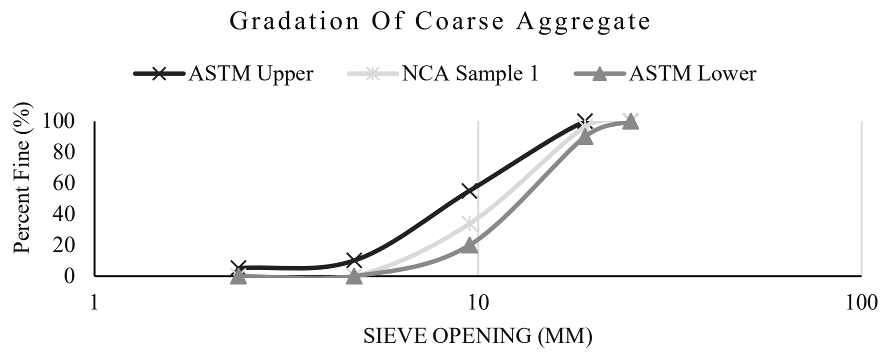


Figure 2 FM (Coarse Aggregate)

2.1.4 Water:

The samples are mixed with three variations of water i.e., Fresh water, Saline water (33gm/l & 66gm/l). Table 4 contains test results of collected water samples from coastal regions, fresh water at HBRI and synthesized saline water. The synthesized saline water sample was collected during sample curing due to which the salt quantity is 32.8 which is less than the 33 gm/l of applied salt. Figure 4 shows the CTR lab where lab test for chemical analysis of materials is performed and the water samples being tested. Table 5 represents a range of salt concentration in saline water.

Table 4 Water test result

Parameters	Fresh water (HBRI)	Saline water (Chittagong Dry Dock)	Saline water (HBRI synthesized)	Mongla, Sonatola, Ulubinia	Poddopukur, Pashchimpatakhali, Shyamnagar
DO (mg/l)	3.15	2.97	3.67	-	-
O_2 (%)	40.6	38.4	49.2	-	-
pH	8.53	7.69	11.45	-	-
Conductivity (mS)	4.93	29.5	45.7	-	-
TDS (ppt)	3.24	19.4	29.8	-	-
Salt (mg/l)	0	14.7	32.8	30	35
Temperature (°C)	28.6	28.6	28.6	-	-

Figure 3 Sieve Analysis

Figure 4 Water Sample testing

Table 5 Salinity Standard (USGS, 2018)

	Salinity condition in ppm
Fresh water	Less that 1,000 ppm
Slightly Saline water	From 1,000 ppm to 3,000 ppm
Moderately Saline water	From 3,000 ppm to 10,000 ppm
Highly Saline water	From 10,000 ppm to 35,000 ppm
Ocean water	35,000 ppm

2.1.5 Water- Cement ratio:

The water cement ratio is taken as 0.50.

2.2 Mixing Procedure

Two trial batch and three main batch of cylinders have been casted. The 1st trial batch contains 30 cylinders and is made out of fresh water and is cured in both fresh water and salt water containing 33gm/l of salt concentration. The mix had a slump of 50mm.

The 2nd trial batch contains 15 cylinders and was casted using 33gm/l NaCl added with water. These samples are cured in Salt water only as curing of saline water samples with fresh water is not practical and economical. The mix had a slump of 100mm.

The 1st main batch contains 30 cylinders and is made out of fresh water and is cured in both fresh water 'FF' and saltwater 'FS' containing 33 gm/l of salt concentration. The mix had a slump of 75mm.

The 2nd main batch 'SS1' contains 15 cylinders and is made out of saltwater containing 33 gm/l of salt concentration and is cured in saltwater containing 33 gm/l of salt concentration. The mix had a slump of 50mm.
The 3rd main batch 'SS2' contains 15 cylinders and is made out of saltwater containing 66 gm/l of salt concentration and is cured in saltwater containing 33 gm/l of salt concentration. The mix had a slump of 100mm.
We did similar tests using hand mixed and manual consolidation of cylinders according to ASTM C31(C31, 2011) using the information from Table 6 and Table 7.
All the concrete cylinders are made using the ratio 1:1.5:3.

Table 6 Method of Consolidation Requirements (International, 2020)

Slump, mm [in.]	Method of Consolidation
=25 [1]	rodding or vibration
< 25 [1]	Vibration

Table 7 Molding Requirements by Rodding (International, 2020)

Specimen Type and Size	Number of Layers of Approximately Equal Depth	Number of Roddings per Layer
Cylinders:		
Diameter, mm [in.]		
100 [4]	2	25
150 [6]	3	25
225 [9]	4	50

3. RESULT AND DISCUSSION

Table 8 contains the compressive test data for all batches and Figure 5 and Figure 6 are comparison between machine mixed batch and hand mixed batch respectively. Figure 7 compares between all batch. Figure 8 shows the compressive strength test being performed on the cylinders.

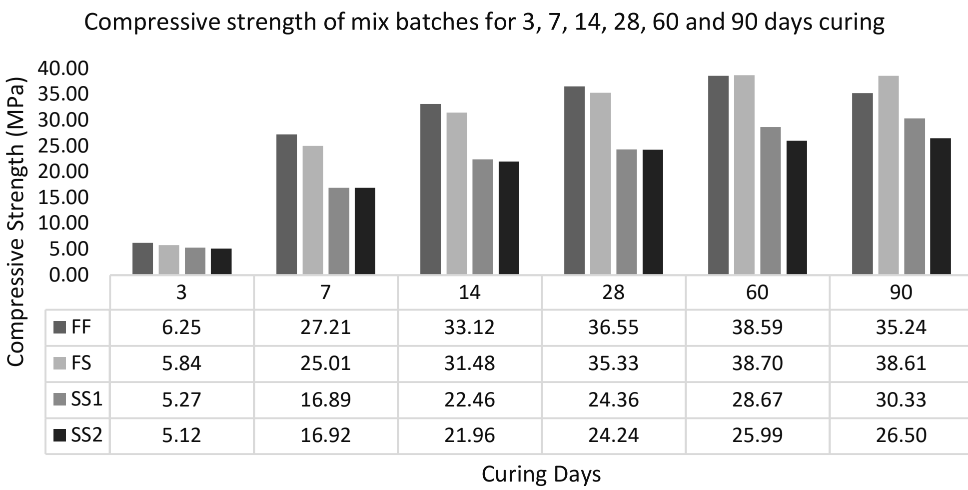
- The data obtained from the trial batch contains some inconsistencies due to external issues related to labour and equipment. The trial batches are conducted before proper setup to maintain sample consistency throughout the project keeping changes in the quantity of salt used and understanding how it may affect the concrete.
- The Freshwater samples showed strength higher than what we get for the used mix ratio. This may simply be the result of using a vibrator, as the compression is much better.
- The data obtained from the trial batch contains some inconsistencies due to external issues related to labour and equipment. The trial batches are conducted before proper setup to maintain sample consistency throughout the project keeping changes in the quantity of salt used and understanding how it may affect the concrete.
- Compared to FF all other batches were more brittle and weaker by a large margin. The tamping batches are different as no machineries were utilized. The strength is lower than the main batch and the gap of strength due to salinity is very small as shown in Figure 7.
- We can see salt deposits on cylinders in Figure 9.
- For 3 days the **FS** sample vary by 6.56%, the **SS1** by 15.68 and **SS2** by 18.08%.
- For **7 days** the **FS** samples varied by **8 %** when compared with **FF** samples i.e., the salt water cured samples were weaker by **8%** but after **28 days** curing the gap decreased to **3%**. The data

after **60 days** showed **0%** variation. At 90 days it goes down to 9.56%. this may be due to bad samples.

- For 7 days the saltwater sample **SS1** batch was weak by approximately **37%** and after 28 days it was approximately **33%**. For 60 days the strength gap decreases to **25%** and for 90 days it further decreases to 13.93%. It is expected for the saline water cured batch to become weak with long term exposure but may gain strength faster before losing strength due to long term exposure.
- For **7 days** the saltwater sample **SS2** batch was weak by approximately **37%** and after **28 days** it was approximately **33%**. For **60 days** the strength gap decreases to **32%** and at 90 days it falls to 24.80%. It is expected for the saline water cured batch to become weak with long term exposure.
- For the $\mathbf{T_{FS}}$ Batch the strength is less than 0.19% when compared to $\mathbf{T_{FF}}$ batch after 3 days curing. For 7, 14 and 28 days the strength varies by 0.52%, 0.17%, 4.06% respectively.
- For $\mathbf{T_{SS1}}$ Batch when compared with $\mathbf{T_{FF}}$ Batch, for 3, 7, 14 and 28 days the strength varies by 3.4%, 4.93%, 3.4% and 0.97% respectively.
- For $\mathbf{T_{SS2}}$ Batch when compared with $\mathbf{T_{FF}}$ Batch, for 3, 7, 14 and 28 days the strength varies by 16.45%, 3.42%, 16.43% and 10.26% respectively.
- The values are slightly inconsistent in the hand mix and rodded samples though the data shows that the behavior of presence of salt in water decreases the strength in a similar way to the machine mixed and vibrator consolidated samples.
- Consistency of saltwater impact: The data suggests that the presence of salt in water consistently decreases the strength of the concrete, whether it is hand-mixed, rodded, machine mixed, or vibrator consolidated samples.

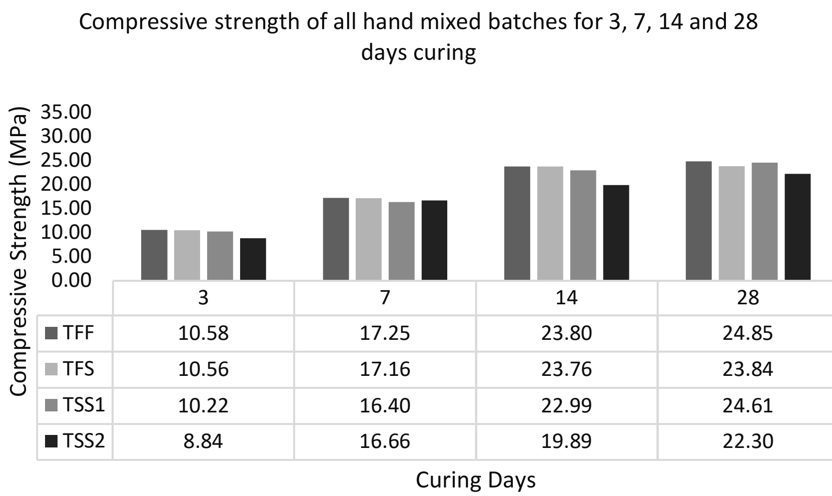
Table 8 Compression test Data

Sl. No	Description	Cured for 3 days	Cured for 7 days	Cured for 14 days	Cured for 28 days	Cured for 60 days	Cured for 90 days
		Average strength (MPa)	Average strength (MPa)	Average strength (MPa)	Average strength (MPa)	Average strength (MPa)	Average strength (MPa)
1	Curing and Casting with fresh water (FF)	6.25	27.21	33.12	36.55	38.59	35.24
2	Curing with salt water and Casting with fresh water (FS)	5.84	25.01	31.48	35.33	38.7	38.61
3	Curing with salt water(33g/l) and Casting with salt water (33g/l) (SS1)	5.27	16.89	22.46	24.36	28.67	30.33
4	Curing with salt water (33g/l) and Casting with salt water (66g/l) (SS2)	5.12	16.92	21.96	24.24	25.99	26.50
5	Curing and Casting with fresh water (Hand mixed and Tamping) (T_{FF})	10.58	17.25	23.80	24.85	-	-
6	Curing with salt water and Casting with fresh water (Hand mixed and Tamping) (T_{FS})	10.56	17.16	23.76	23.84	-	-
7	Curing with salt water(33g/l) and Casting with salt water (33g/l) (Hand mixed and Tamping) (T_{SS1})	10.22	16.40	22.99	24.61	-	-
8	Curing with salt water (33g/l) and Casting with salt water (66g/l) (Hand mixed and Tamping) (T_{SS2})	8.84	16.66	19.89	22.30	-	-



	3	7	14	28	60	90
FF	6.25	27.21	33.12	36.55	38.59	35.24
FS	5.84	25.01	31.48	35.33	38.70	38.61
SS1	5.27	16.89	22.46	24.36	28.67	30.33
SS2	5.12	16.92	21.96	24.24	25.99	26.50

Figure 6 Compressive strength of machine mixed batches



	3	7	14	28
TFF	10.58	17.25	23.80	24.85
TFS	10.56	17.16	23.76	23.84
TSS1	10.22	16.40	22.99	24.61
TSS2	8.84	16.66	19.89	22.30

Figure 7 Compressive strength of all hand mixed batch

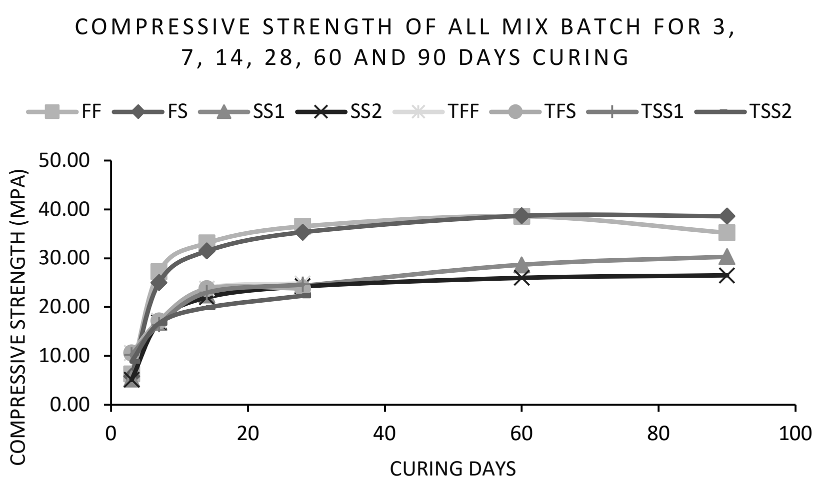


Figure 5 Compressive strength of all mixed batches

Figure 8 Compression Test of SS1 Batch for 7 days curing

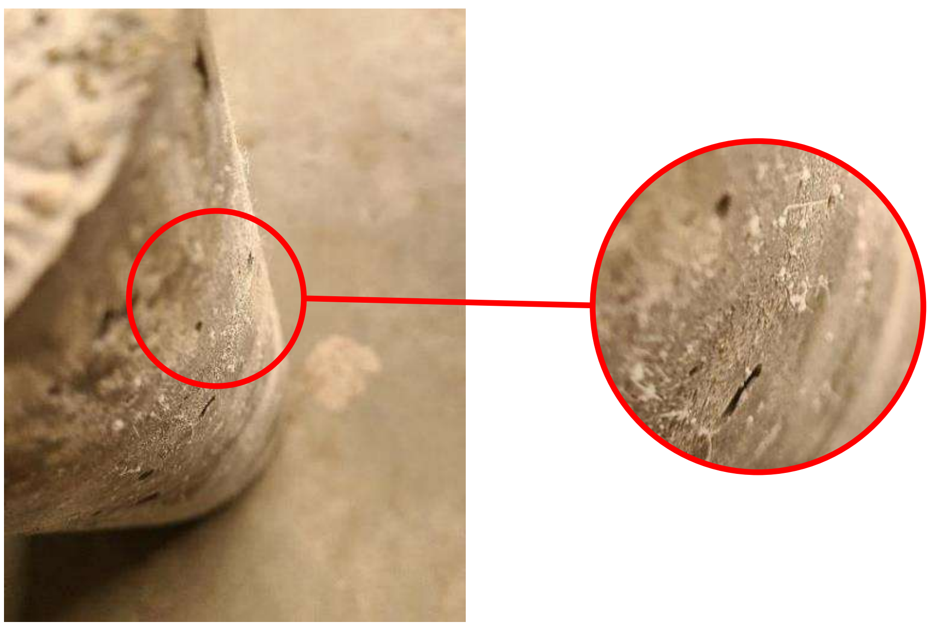


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Figure 9 Salt deposit on SS1 Batch at 28 days curing

4. CONCLUSIONS

Based on the information provided, several conclusions can be drawn regarding the effects of saltwater on concrete strength.

The freshwater samples displayed higher strength compared to the expected mix ratio, which was attributed to the use of a vibrator during testing, resulting in better compression. However, when it came to saltwater curing, both SS1 and SS2 batches exhibited weaker strength compared to the freshwater (FF) batch. The difference in strength was smaller for the tamping batches, where no machinery was utilized. Over time, the saline water cured batches demonstrated further weakening, indicating that long-term exposure to saltwater has a detrimental effect on concrete strength.

It was observed that the strength variation between the saltwater cured samples and the freshwater cured samples decreased over time. After 60 days, the strength gap between the saline and freshwater batches diminished. However, even after 90 days, the saltwater cured batches still showed a notable difference in strength, suggesting that they continued to be weaker compared to their freshwater counterparts.

Additional findings were noted in the T_{FS}, T_{SS1}, and T_{SS2} batches. The T_{FS} batch displayed slightly lower strength compared to the T_{FF} batch, with the difference increasing slightly over 7, 14, and 28 days of curing. Similarly, the T_{SS1} and T_{SS2} batches exhibited varying strength compared to the T_{FF} batch, with T_{SS2} showing the most significant variations.

Overall, the data consistently indicated that the presence of salt in water decreases the strength of concrete, regardless of whether the samples were hand-mixed, rodded, machine mixed, or vibrator consolidated. Saltwater curing resulted in weaker concrete compared to freshwater curing, with a reduction in strength observed over time. However, even with a decrease in the strength gap, long-term exposure to saltwater still resulted in a noticeable weakness in the concrete. These conclusions highlight the importance of carefully considering the effects of saltwater when using concrete in projects exposed to such conditions.

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