STUDY ON THE EFFECT OF SALINITY OVER BUILDING MATERIALS IN THE COASTAL BELT OF BANGLADESH

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ABSTRACT

In the coastal belt, the salinity intrusion into the civil structure, one of the most serious environmental issues in the world, imposes a socio-economic threat to the overall development of Bangladesh. The civil structures around Bangladesh's coastal belt deteriorated early compared to other parts. Avoiding the consequences of salinity is one of the major concerns of the scientific community and the Bangladesh government. In the present study, the effect of salinity and pH of the surrounding groundwater on coastal Bangladesh's building materials was surveyed to identify the major causes of deterioration. It was found that the mortar and brick samples collected from buildings aged over 30 years are rich in sodium, potassium, chloride, and sulfate ions. Moreover, older buildings have a lower pH in their mortar suspension. The water used during mortar preparation also contains a significant number of ions, which stay inside the structure and facilitate its deterioration over time, in addition to the surrounding saline water. For a detailed understanding of salt and pH effects in a comparatively short period, the natural deterioration was mimicked in the laboratory on a small scale using NaCl, K_2SO_4, and pH solutions. Mortar prepared with pure water was aged under saline water, and mortar prepared with salty water was aged under normal conditions. It was found that the lower pH of either soaking or mixing water lowers the strength. For NaCl attack from surrounding groundwater, the kinetics of deterioration is diffusion controlled. Na^+ ions replace the Ca^{2+} ions from C−S−H (calcium−silicon−hydride) bonds and Cl^- forms Ca−Cl clusters causing structural damage. When the ions are inside, diffusion is unnecessary; the deterioration is faster. A similar mechanism is attributed to the K_2SO_4 attack. It was also found that coarse sand is more resistant to ion attack than fine sand. The study will provide a better understanding of the impact of salinity on the building's structural integrity, a better way of handling building materials during construction, and benefit the people of the coastal belt.

Keywords: *Groundwater Salinity, Coastal Bangladesh, Building materials deterioration, Ion Attacks, pH level*

1. INTRODUCTION

The coastal belt of Bangladesh faces significant challenges related to infrastructure sustainability, primarily due to the harsh maritime environment it is exposed to. Such an environment leads to various issues, including spelling plaster, concrete degradation, steel corrosion, and problems with building materials. Notably, salinity intrusion from the Bay of Bengal is a critical concern, impacting agriculture and the construction industry, given that 32% of the country is in the coastal belt. Salinity is progressively affecting land and water due to climate change, posing a serious threat to the construction sector in this region (Dasgupta et al., 2015).

Understanding how coastal structures deteriorate over time in a coastal environment is crucial. For example, consider saline water composition's chemical effects on the cement hydration products and the salt crystallization pressure in mortar and concrete. Cementitious materials must be investigated in various saline water exposure scenarios to assess how saline water affects coastal buildings. Both positive and negative effects of saline water chemicals can be seen on cementitious concrete's coastal performance. Cementitious materials and the chloride and sulfate ions that make up saline water can interact chemically in various ways (Islam et al., 2012; Ragab et al., 2016; Wegian, 2010). The average amount of dissolved salt in saline water is 35 g/L. However, unlike the ions in river water, the concentration of specific salts varies geographically. Saline water ions, as a consequence, attack all cementitious materials. The salts of Friedel and Kuzel can be preserved in pore solutions as calcium chloroaluminate hydrates and are related to calcium silicate hydrate (C−S−H). Structures deteriorate due to sulfate corrosion of cementitious materials in saline water. Brucite ($Mg(OH)_2$) precipitates when saline water is exposed to high pH values, such as those seen in one of the porous solutions of cementitious materials (pH of 12.5-13.5) (Buenfeld et al., 1986).

Research has shown that salt reaction is one of the causes of the fragility of buildings and corrosion of reinforcement in coastal belts. Previous research has examined how salt crystallization affects deformation, hygienic characteristics, and moisture transport in brick. The pattern of sodium chloride intrusion and dispersion is still unknown. Total salinity in saline water is about 35% (78% dissolved solids are NaCl and 15% $MgCl_2$ and $MgSO_4$), giving it a slightly higher starting strength but a shorter life (UNDP, 2011). When it comes to strength, the influence of water on the setting is generally insignificant. A significant amount of chlorinated water is the root cause of perpetual moisture and surface efflorescence. To avoid the consequences of salinity, it is necessary to understand the effects of salt on mortar and concrete.

The interaction of changes in building material's physical properties and chemical reaction mechanisms determines the durability of building structures, particularly brick masonry structures, in the coastal belt (Mahdi Safhi et al., 2019). It is widely known that the durability of building structures under the coastal belt is associated with the coastal conditions and properties of the building materials (Qiao et al., 2017; Zhang et al., 2018). In this chapter the literature on salinity and related issues on coastal belt structure are discussed.

According to Khalaf et al. (2002), moisture has the biggest impact on the durability of a masonry structure. Zsembery (2001) mentioned that soluble salts and the harshness of the environmental conditions exposed are the most crucial elements. According to Binda et al. (1990), structural characteristics, including porosity, mechanical strength, deformability, kinds of salt, and the frequency and length of wetting and drying cycles might affect a material's durability. However, the salt solution can disrupt the wetting and drying phase of the material, leading to alternative dissolution and crystallization (Fassina et al., 2002). Building materials frequently deteriorate when exposed to the environment. Sulfate attack, frost attack, and soluble salt crystallization cause most brick and brickwork complications, according to Hendry et al. (2001) and Surej et al. (1998). Binda et al. (1990)believe salt crystallization is a major cause of brick and stone deterioration, especially in maritime or industrial contexts. Stopping water from entering the brickwork might address all these issues and make the building durable.

Na_2SO_4 and NaCl are the two most prevalent soluble salts in brick masonry; moisture transports them from several sources. Salt crystallization in brick unit pores, which may produce pressure sufficient to disrupt the material microstructure, leads to degradation. The crystallizing salts' chemical makeup regulates these actions. Each of the key elements influencing the salt attack is necessary for the decay to occur, but the decay can be stopped if any one element is missing or insufficient. It is important to be aware of and consider the salts that are included in clay bricks and mortar, particularly sulfate because when it reacts with water during the brick-and-mortar installation process, it can create a crystallization pressure that may be strong enough to harm masonry walls. The presence of salt attack will have an impact on the mortar's chemical expansion, which may therefore cause the masonry wall to expand(Bakar et al., 2009).

Building materials are essential for construction and must be environmentally responsible. They typically take the form of natural resources like water, clay, sand, wood, and stones, or man-made materials like bricks and cement. The performance of a building material is determined by evaluating its compatibility with the environment and its function, durability, and mechanical performance Folorunso et al. (2017). Reddy et al. (2003) have argued that the materials and technologies used for the construction of buildings should satisfy the user's and society's felt demands without damaging the environment. Building materials is vital in the material selection, but the completion of a construction project is impossible without the right selection. Not all salt in moisture will produce damage or even be subject to attack, according to Zsembery (2001). $MgCl_2$ and Na_2SO_4 are the salts that attract and absorb water and cause the most problems. Most salt attacks are caused by sodium sulfate or sodium chloride, however, sulfate attacks are one of the more common and harmful forms (Binda et al., 1990). The amount of salt needed to harm masonry varies depending on its type, but anything over 0.5% by weight is seen as a problem (Binda et al., 1990).

According to AASHTO LRFD Bridge Construction Specifications 2008 (AASHTO, 2008a), for concrete mixing and curing the water needs to be clean, and free of oil, salt, acid, alkali, sugar, vegetable, and other harmful compounds. It must pass testing and adhere to AASHTO T 26 2008's recommended specifications (AASHTO, 2008b). Without testing, water that is recognized to be of drinkable quality may be used. Chloride ion concentrations above 1000 ppm and sulfate above 1300 ppm are prohibited in mixing water for concrete containing steel. When the pH of the water is between 4.5 and 8.5, it is good for construction activities.

Moisture is a persistent threat to every structure. Wind-driven rain, ice, sleet, snow, hail, or water vapor may cause building walls to become permeable, which can lead to corrosion, decomposition, efflorescence, or mold (Christine, 2004). Some reports show that whereas salts alone strengthen the bricks, salts mixed with moisture significantly decrease that strength. The sub-florescence and efflorescence brought on by the crystallization of these salts inside the bricks may eventually decrease the strength of the bricks and the masonry.

Its strength refers to the greatest load or stress that a mortar can withstand. The quality of mortar that is most frequently regarded as valuable is its compressive strength. Nonetheless, the compressive strength of mortar typically provides the most comprehensive picture of its quality. Coastal conditions can have a substantial effect on the compressive strength of cementitious mortar. It is common knowledge that compressive strength is related to the properties of raw materials, such as cement types (Hossain, 2008) and aggregate (Yue et al., 2013).

Cementitious materials must be investigated in various saline water exposure scenarios to assess how saline water affects coastal buildings. Both positive and negative effects of saline water chemicals can be seen on cementitious concrete's coastal performance. Ghorab et al. (1990); Teng et al. (2019) worked on the mechanical characteristics of saline water concrete, particularly its compressive strength. It has been demonstrated that using saline water as the mixing water may boost the concrete's early-age strength, but that the long-term strength of saline water concrete with the same mix proportions is comparable to or lower than that of freshwater concrete (Nishida et al., 2015; Younis et al., 2018).

Based on the literature review, some study questions were raised. For example, how serious is the salinity issue on building materials in Bangladesh's coastal belt, and what is the damage? Another important field to study is finding the root cause of the salinity in building materials and how to properly get rid of this. So far, the optimizations of construction techniques in the coastal area of Bangladesh are still not reported. Hence, field-level and laboratory-level work plans must be proposed to find a beneficial solution to building deterioration in the coastal belt.

In the present study, a field-level survey was done to find the cause and magnitude of the salinity effect in the coastal belt of Bangladesh. A further laboratory-level experiment was done to find the remediation. A weathering test was conducted using the entire immersion method to assess the impact of various salt and pH concentrations on the mortar and to comprehend the variance in salt resistance. It is the first experimental study in Bangladesh to determine where construction materials (water, bricks, sand, and cement) come from, how much people in the area understand how salty water damages structures, and what can be done about it. Moreover, the study finds out how long after a building is completed can usually detect the consequences of salinity, how many RCC/brick-masonry structures are subsequently impacted by salinity, what are the significance of the impact, what type of salt is most commonly used to construct building materials along Bangladesh's coast, and how do chloride and sulfate ions affect the compressive strength of the mortar.

By increasing the understanding of how salinity may affect a building's structural integrity, the findings of this study will benefit construction businesses and people of coastal belt towns who are involved in the construction of buildings. The study systematically investigates the impact of mixed proportions with various salt solutions and pH on the mortar's strength. The study evaluated the impact of coastal salinity on mortar's compressive strength as well as the assessment of coastal salinity's impact on building materials.

2. METHODOLOGY

This study conducted both a field survey and laboratory testing to establish the best course of action for the practical cause and severity of the salinity effect. A preliminary examination was performed on the existing construction structures. A detailed laboratory test was carried out, considering the obtained materials' characteristics testing and determining the influence of NaCl, K_2SO_4, and pH solution concentration in mortar.

The preliminary examination of the existing structures was performed by interviewing the owners using some specific questionnaire. The people living in Bangladesh's coastline region were the study's target demographic. 19 districts of Bangladesh suffer from moderate to severe salinity, according to Kamal et al. (2003). Due to its low-lying coastal regions and extensive network of rivers and canals, the region is particularly vulnerable to tidal surges and sea level rise-induced saline intrusion. Khulna, Bagerhat, and Satkhira, three coastal districts in Bangladesh, were chosen as study districts to ascertain the source, distribution, and damping of construction materials. Consequently, they were selected as sampling zones for this study. A sample of bricks, sand, cement, sand, mortar, and water was collected from 32 damaged buildings in three southern districts. The samples were brought to the laboratory and tested for the composition of salt and pH level. Simultaneously, mortar samples were freshly prepared with and without adding extra salts and acids to mimic the deterioration in the laboratory. All the samples were tested for compressive strength after sequential soaking time in fresh and salty water. The results obtained from natural artificial deterioration were analyzed to find the cause and mechanism of damaging the building structure. Figure 1 shows the key elements of the experimental method used for this study.

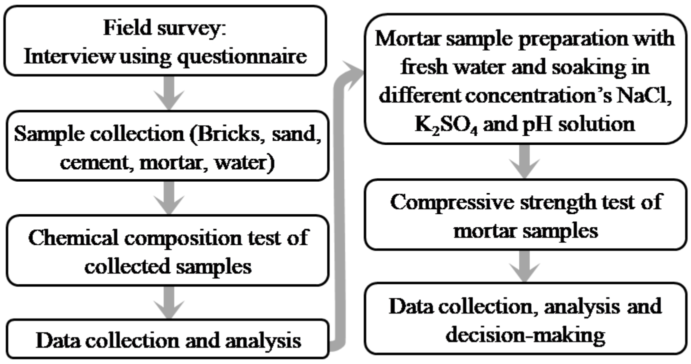

Figure 1: Study flowchart

3. ILLUSTRATION

Through a number of experiments on a range of building materials, the impact of salinity on building materials in coastal Bangladesh was examined in this study. Firstly, the affected coastal buildings were identified and explored.

3.1 Exploration of Affected Coastal Building

According to the research, a noteworthy 80% of Bangladesh's coastal structures are affected by salinity to some extent (Figure 2). Notably, it takes an average of around 6 years for these buildings to start displaying salinity-induced deterioration, with a range spanning from 1 to 13 years. This observation underscores the urgent issue of salinity in the coastal region, highlighting its rapid onset in the degradation of building materials.

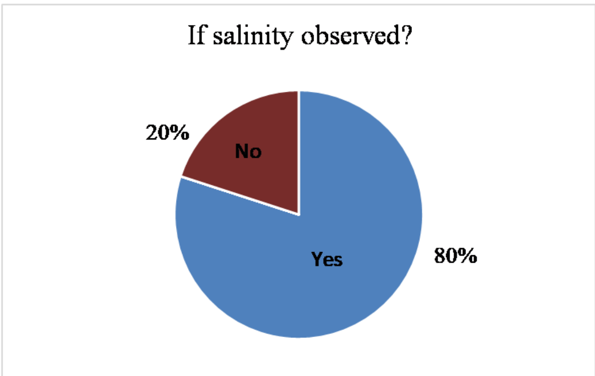

Figure 2: Percentage of buildings affected by salinity.

3.2 Source of Building Materials

This section explores the sources of sand and water utilized in construction within the coastal belt. Remarkably, 60% of the local population relies on the Padma river sand (Kushtia sand) for construction, despite approximately 43% of users reporting salinity-related issues. Furthermore, 70% of residents use pond water for construction, with only 13% unaffected by salinity. These findings raise concerns regarding the suitability of pond water for construction and emphasize the need for a dependable and suitable water supply for sustainable development. Figures 3 and 4 show the sand and water sources used by local people, respectively.

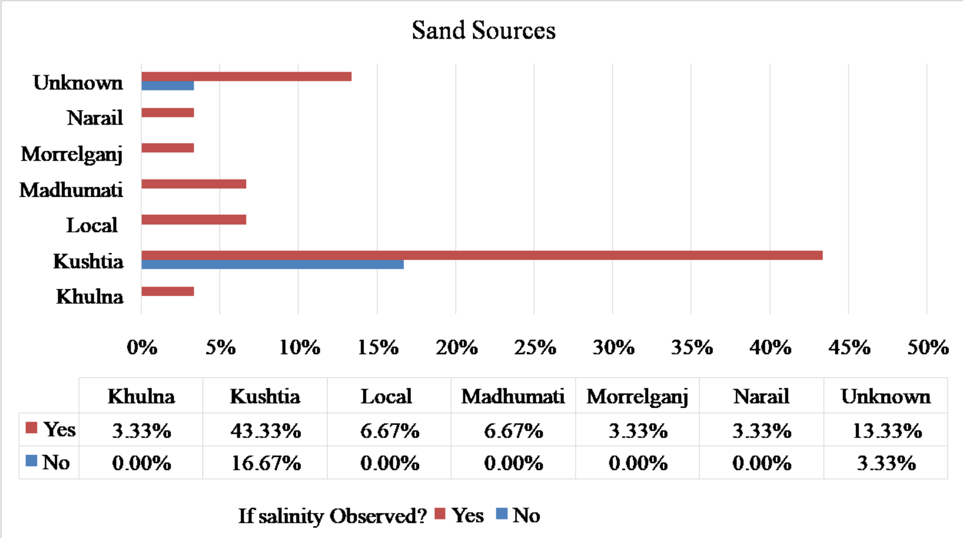

Figure3: Sand sources used by local people.

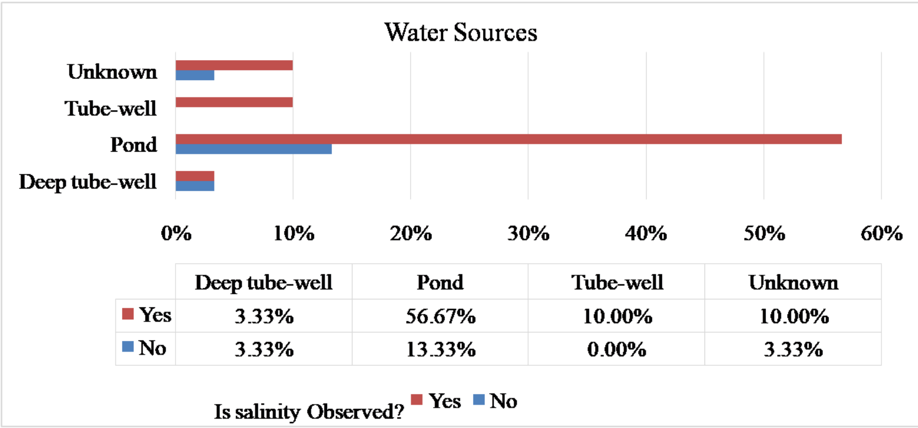

Figure 4: Water sources used by local people.

3.3 Field Survey and Analysis

The collected samples were brought to the laboratory and analyzed for the salinity content. 10g of each sample was taken in 100 mL of distilled water and mixed to form a suspension mixer, which was shaken for 6 hours on a shaker. The mixer was then filtered through the Whatman-42 filter paper. Each of the filtered samples was stored in 100 mL of HDPE bottles as a stock solution for further chemical analysis. pH of the solutions was measured in a 100mL suspension mixture when the pH meter (Inolab, pH-7110 model, WTW, Germany) was calibrated by reference (pH 4, 7 & 10) buffer solution. The conductivity of the stock solutions was measured when the conductivity meter (Sension-156 model, HACH, USA) was calibrated by reference (1000µS/cm) sodium chloride solution. TDS was measured from the measured conductivity. For chloride estimation, 10mL of Stock sample was titrated with 0.1 M silver nitrate solution when 5% potassium dichromate was used as an indicator. For nitrate, sulfate, phosphate, fluoride, and bromide estimation, 10mL samples were taken and respective color-developing agents were mixed. The absorbance of the samples was measured by UV-Vis spectrophotometer (HACH, USA, 3900) at 500, 450, 890, 580, and 530nm, respectively. For the estimation of magnesium, potassium, and sodium, 10g of sample was taken in 100mL of distilled water and mixed with the suspension mixer. The suspension mixer was mixed on a shaker for 12 hours. Then, it was filtered through the Whatman-42 filter paper. The filtered sample was preserved by 2mL of 6M nitric acid and stored in 100mL HDPE bottles for analysis. Mg, Na, and K were measured by the Flam-AAS method (USEPA-3111) at 285.2nm, 589.0nm and 766.5 nm.

The investigation examines the correlation between mortar pH values and building age, revealing a reduction in pH over time. Additionally, the conductivity of mortar, a marker of ion concentration, increases in building age suggesting the infiltration of soluble ions from groundwater into structures. The tendency of ion deposition into the structure is similar for almost all the ions. From the survey, it is inconclusive that the ions are responsible for the deterioration of the structure. From the literature(Wang et al., 2019), it was found that, after NaCl solution immersion, the mortar specimens' deterioration tendency fluctuates, ranging from 0 to 20%wt of NaCl, and the worst case is the intermediate concentration. Therefore, it is worth studying the effect of ions on structural deterioration in the laboratory. For the laboratory study, the natural effects were mimicked in the laboratory scale.

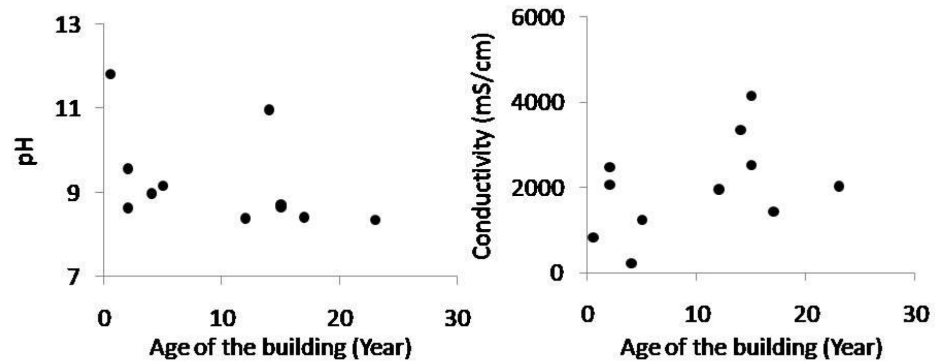

Figure 4: pH and conductivity of the mortar collected from the coastal buildings with various ages.

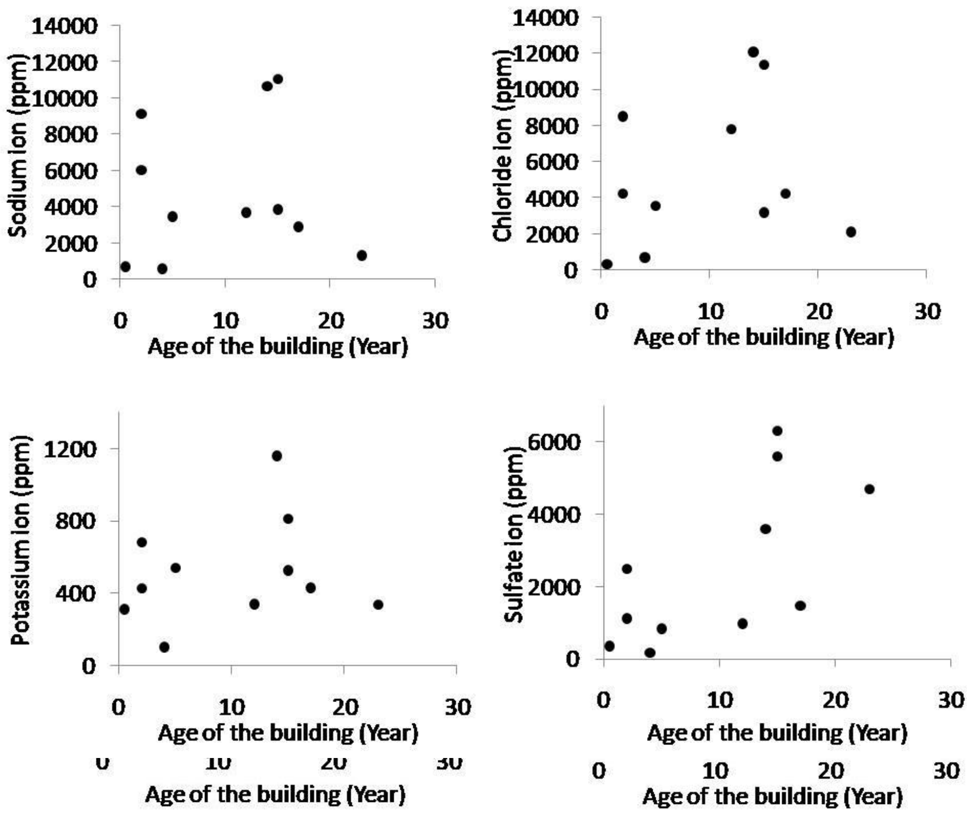

Figure 5: Presence of ions in the mortar collected from the coastal buildings with various ages.

3.4 Mimicking Natural Deterioration in Laboratory

To investigate the ion attack in the laboratory, mortar blocks were soaked in ions of different concentrations for different time duration. The results are shown in Figure 6. The mortar tends to lose its strength at lower pH, which is due to acid corrosion. The observed tendency supports the survey results, where the older buildings have lower pH values and tend to deteriorate easily. After twelve weeks of immersion in salt solutions, it was found that strength increased.

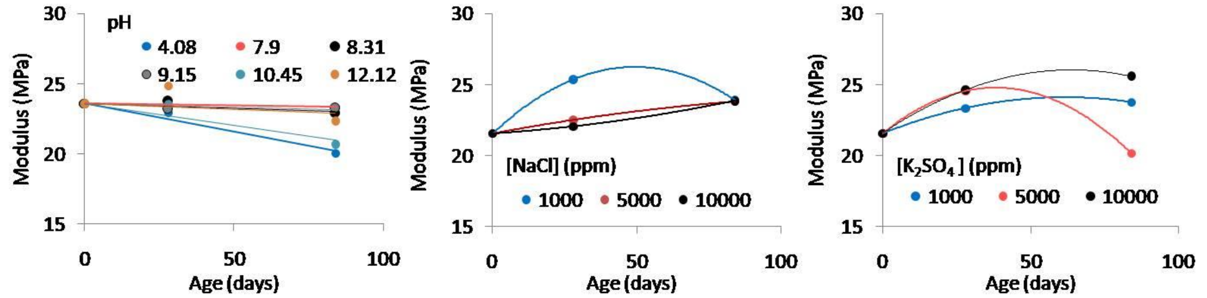

Figure 6: pH and salt effect on mortar prepared from fine sand and deionized water.

Since there is a possibility that ion diffusion is difficult over a short period, the mortar blocks were prepared using different salt and pH solutions so that the targeted ions are initially placed inside the mortar. This time, the blocks were cured with deionized water. When the effect of ion diffusion is eliminated, deterioration of ion attack over time becomes visible. Figure 7 shows the effect of salt and pH on the strength of mortar, excluding ion-diffusion. It is observed that the lower pH of the curing water will lower the strength. If the surrounding groundwater contains a lower pH, diffusion protection is mandatory. Moreover, a lower concentration of NaCl in curing water slightly decreases the strength, whereas higher NaCl strengthens the system. The NaCl in surrounding groundwater in the coastal belt region will diffuse into the building over time and make a moderately concentrated deposition of Na^+ and Cl^- ions. Na^+ ions will replace the Ca^{2+} ions from C−S−H bonds, and Cl^- will form Ca−Cl clusters, causing structural damage. The kinetics of the ion attack and, hence, the mortar deterioration is mainly diffusion controlled.

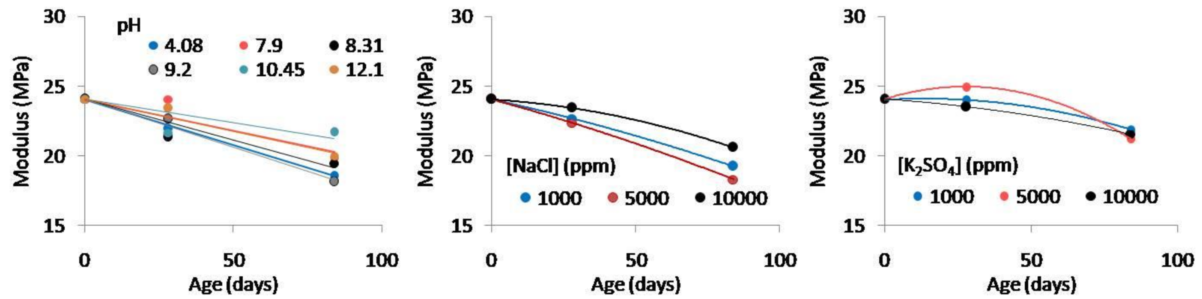

Figure 7: Effect of pH and salt on mortar prepared from fine and coarse sand and pretreated contaminated water with various ages.

Based on the study, the overall outcome can be summarized as follows:

1) A lower pH of the curing water will lower the strength.
2) If the surrounding groundwater contains lower pH, diffusion protection is mandatory

3) A lower concentration of NaCl in curing water slightly decreases the strength whereas higher NaCl strengthens the system. The NaCl in surrounding groundwater in the coastal belt region will diffuse into the building over time and make a moderately concentrated deposition of Na^+ and Cl^- ions. Na^+ ions will replace the Ca^{2+} ions from C−S−H bonds and Cl^- will form Ca−Cl clusters causing structural damage. Coarse sand is more resistant to ion attack than fine sand.
4) The kinetics of the ion attack and hence the mortar deterioration is mainly diffusion controlled.
5) Ions in the surrounding groundwater will take time to affect the structure.
6) Ions placed inside the mortar don’t need diffusion time and attack very quickly.

4. CONCLUSIONS

The study revealed that the pH of the water used during preparation and curing should be between 7 to 10. Any lower pH accelerates the deterioration. For the water pH higher than 10 is reached in sodium and chloride ions, which has a major effect on the structural damage. The appearance of NaCl salt at around 1000ppm initially strengthens the structure but in the long run, it also degrades the C−S−H bonds. Using coarse sand rather than fine sand is more effective in avoiding ion attack. The ions in the surrounding groundwater will take time to affect the structure. Even if ions appear in the groundwater, quick removal of salinity through external measures can save and delay the ageing of the building. The water for curing the mortar needs to be purely ion-free. This is the major criterion for preparing building materials. If possible, the building materials need to be washed with ion-free water before use. The cases where removal of ions from the surrounding ground or rainwater is difficult, a protective layer impermeable to the ions needs to be applied.

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