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INFLUENCE OF SEAWATER ON REINFORCED MORTARS WITH VARYING FLY ASH REPLACEMENT RATIO

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ABSTRACT

By 2025, more than 3 billion people could be living in water-stressed areas and fresh water scarcity will soon become a major problem. The construction industry uses approximately 1 trillion liters of fresh water a year for mixing water alone. That is enough to provide almost 137 million people with fresh water per year. This study reports the results of using seawater as a substitute for mixing water on the properties of reinforced mortars in terms of compressive strength, corrosion rate and chloride content. In addition, partial substitute of type F fly ash, varying from 0% to 50% at 10% intervals, was used to determine its effects on seawater mixed mortars. Destructive testing was used to determine the compressive strength while half-cell potential and polarization resistance were utilized in determining the corrosion rate of the embedded steel bars.

After 18 weeks of testing, results show that by adding fly ash as cement substitute, early compressive strength is retarded. However, on the 28th day, 20% to 30% fly ash replacement was able to provide a higher compressive strength than the others. The results also show that seawater mixed mortars produced a higher compressive strength than its fresh water mixed counterpart regardless of the amount of fly ash substitute. In terms of the corrosion susceptibility of the embedded steel bars, the higher the fly ash replacement, the more vulnerable the steel bars are for corrosion. Half-cell potential, polarization resistance and chloride content readings favored a higher corrosion rate when type F fly ash was substituted to ordinary Portland cement, probably due to the fly ash's low CaO content. Despite this, there has been no significant difference between using seawater or fresh water as mixing water on the steel bar's corrosion susceptibility for the entire duration of the study.

Key Words: Seawater; Fly ash; Chloride-induced corrosion; Half-Cell Potential; Polarization Resistance

1. INTRODUCTION

The construction industry uses approximately 1 trillion liters of water each year for mixing water alone.[1] The use of seawater in its raw state could not only save construction cost but also contribute to the community into conserving fresh water. Therefore, its possibilities should be investigated seriously.

Generally, it is said that seawater-mixed concrete should be avoided particularly in reinforced concrete structures. In fact, NSCP provisions limit the amount of chlorides that should be present in mixing water. It is common belief amongst engineers that seawater is not suitable for use in making concrete. This is because studies say that seawater changes the behaviour of concrete and is also believed that the chloride content of seawater would cause corrosion to the steel reinforcements.[2] However, some studies state that presently, there are some areas where seawater or brine water are being used as mixing water with or without intension.[3] In addition, the need to use seawater for construction can arise in situations where no other source of water is available and where transport of fresh water is too costly, such as construction sites along the sea coast.[2] Therefore, it is important to define and establish its consequences thoroughly for safe and optimal use.

Coal combustion wastes (CCW) are a collective term referring to the residues formed during the combustion of pulverized coal and these wastes are produced most commonly by coal-fired power plants. Coal-fired power plants are given special attention by the public concerning the safe handling and disposal of CCW due to their hazardous impact to the environment. One of these wastes is fly ash and it comprises nearly 60% of all the CCW. Studies have found that fly ash possesses a pozzolanic property and its use as a high-performance substitute for ordinary Portland cement (OPC) offers as an attractive alternative for disposal.[4] Aside from the benefit of proper disposal, it is also believed that fly ash may help assist in the problem of chloride penetration on concrete therefore minimizing the risk of chloride induced corrosion. This is because fly ash is a finer material than Portland cement and could be compacted within the pores of the concrete matrix. By filling in those pores, the concrete would then have a lower permeability making it difficult for chloride ions to penetrate the concrete cover.[5]

Minerals or substances within the mixing water can affect the concrete or its reinforcements depending on the type of substance and its concentration amount. Chloride ion is one of the most common of these deleterious substances since they can be present from improperly washed aggregates, when exposed to seawater and when salt is used for de-icing. Many studies have determined the effect of different chloride concentrations on mixing water in concrete. And their results show that water-soluble chlorides on concrete are greatly dependent on the mixing water's chloride concentration.[6,7]

The main objective of this research is to determine the influence of using seawater as mixing water on the behaviour of mortars and embedded steel bars while determining the effects of using fly ash as partial cement substitute.

2. METHODOLOGY

2.1 Preparation and Materials

The experimental method was used as the research method in this study. The experiments were done under a controlled condition with varying parameters. All parameters were mixed with seawater and fresh water, the latter being the control parameter. The seawater used had a salinity of 17,937 ppm (1.79% Cl), while the fresh water had a salinity of

16.67 ppm (0.00167% Cl). ASTM Type 1 ordinary Portland cement and ASTM Class F fly ash were used for the study.

With a mortar mix design of 0.45:1:2 (water:binder:sand), the fly ash replacement ratio was varied from 0% to 50% at 10% intervals having a constant water to binder ratio of 0.45. They were cured through fresh water immersion and will be tested for its compressive strength, corrosion activity and chloride content. The compressive strengths were determined using 101.6 mm (4 inches) by 203.2 mm (8 inches) mortar cylinders. While, rectangular mortar prisms having a dimension of 40 mm by 40 mm by 160 mm with embedded steel reinforcements of 10 mm diameter and 100 mm length were used for the determination of the corrosion activity and chloride content.

2.2 Testing

The compressive strength of the mortar was determined using ASTM C39 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens). ASTM C876-91 (Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete) and ASTM G59-91 (Practice for Conducting Potentiodynamic Polarization Resistance Measurements) were used as the basis for determining the corrosion potential and polarization resistance, respectivelty. Data were gathered from a testing age of 7, 14, 21, 28, 84, 140 days for the compressive strength; weekly until the 18th week for the corrosion activity; and on the 18th week for the chloride content.

The Corrosion Monitor CT-7 made by Japan RIKEN electronic Co. Ltd. and Ag/AgCl reference electrodes were used to determine the corrosion potential and polarization resistance. [8,9] Equation 1 was used for determining the microcell current density, then using Equation 2, the corrosion rate was determined.

$$\boldsymbol{I_{corr} = \frac{K}{R_p S}} \qquad \textbf{(Eq. 1)}$$

$$\begin{aligned} where,\ K &= 0.0209 \\ R_p &= polarization/solution\ resistance \\ &= R_t - R_c \\ S &= surface\ area\ (cm^2) \end{aligned}$$

$$\boldsymbol{CR = 3.27x10^{-3}\frac{i_{corr}EW}{\rho}} \qquad \textbf{(Eq. 2)}$$

$$\begin{aligned} where,\ i_{corr} &= corrosion\ current\ density \\ EW &= equivalent\ weight\ of\ steel \\ \rho &= density\ of\ steel \\ &= 7.86\, g/cm^3\ \ (as\ per\ ASTM\ G1\ for\ carbon\ steel) \end{aligned}$$

The Salmate chloride ion machine was the device used to determine the chloride content surrounding the steel bars. The machine uses electrolysis to determine the Chloride ion desnity. [10] The rectangular mortar prisms was split to collect the embedded steel bars, then thoroughly washed with water using an ultrasonic cleaner to extract the chloride ions surrounding the steel bar. The resulting solution was then placed into the chloride ion machine to determine its chloride content. [6]

3. RESULTS AND DISCUSSION

The figures below show the results of the compressive strength, corrosion potential and current density, respectively. The results indicate the behavior of each parameters in terms of the early or late compressive strength of the mortars and the corrosion risk of the embedded steel bars. Specimens were labeled as “RF” for fresh water mix and “RS” for seawater mix. The number within the parenthesis indicates the amount of fly ash replacement in percentage (%).

3.1 Compressive Strength

By comparing seawater and fresh water mix, it can be seen that seawater mixing was able to produce averagely 10% higher compressive strength. Seawater mixing yielded a higher compressive strength on its early age even until the 28th day. This may be due to the chlorides which accelerate cement hydration and reduces setting time. This may also be the reason why the behaviour of the pure OPC (0% fly ash replacement) parameter showed the largest increase in compressive strength when mixed with seawater throughout the entire testing days. More cement availability could have boosted the reaction of the chlorides in increasing the compressive strength of the mortar. Despite varying the fly ash replacement ratios, the use of seawater as mixing water was more or less the same as when fresh water was used.

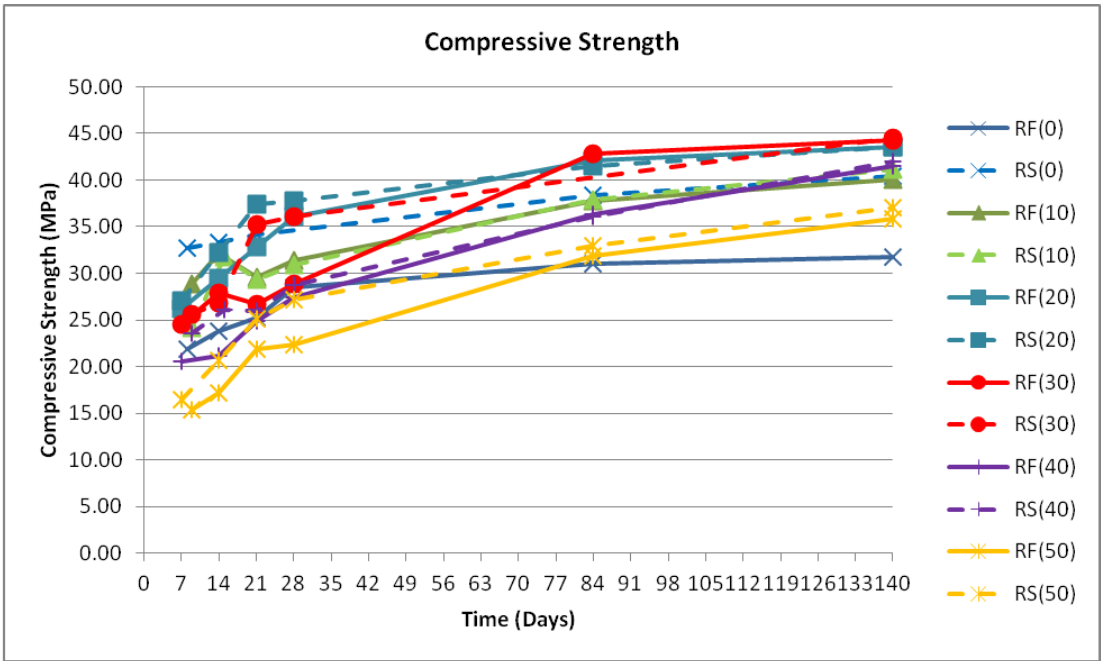

Figure 1 Compressive Strength

3.2 Corrosion Activity

The corrosion behaviour of seawater mix with varying fly ash replacements are analyzed based on using the corrosion potential and current density. It can be seen that with increasing fly ash replacement, there is a decrease in corrosion potential and an increase in current density. Both signify that higher fly ash replacement provides higher corrosion risk. In some researches, it states fly ash should improve the chloride binding capacity of the mortar due to its high amount of alumina. However, they also state that since fly ash consumes cement hydrate, or $Ca(OH)_2$, for its pozzolanic reaction, it decreases the pH value of the mortar inhibiting the formation of the passive film. In addition, fly ash Class F has a low amount of CaO (lime), which is the main ingredient in forming calcium silicate hydrates (C-S-H). The use of other fly ash type, such as Class C, may produce a better result for chemically binding chlorides since it has a higher amount of CaO. Ultimately, the optimum fly ash replacement value against corrosion was found to be 0%, and this was both supported by the results of the corrosion potential and the current density.

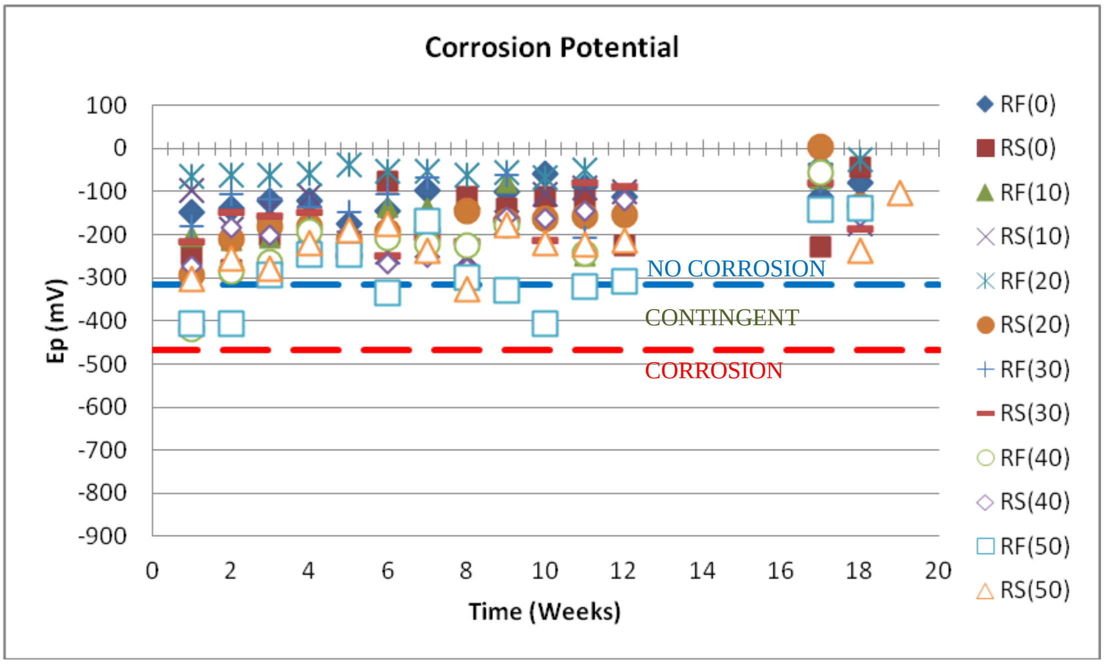

Figure 2 Corrosion Potential

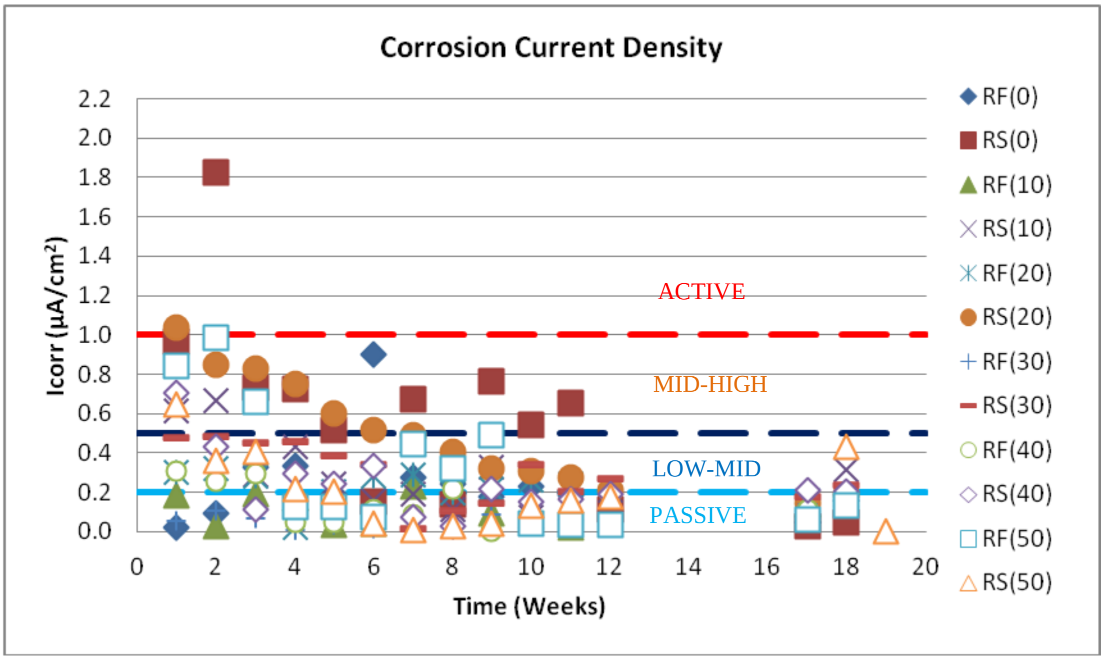

Figure 3 Corrosion Current Density

4. CONCLUSIONS

The study presents the use of seawater as mixing water to be viable given certain restrictions in different parameters. The difference between seawater and fresh water mix on the compressive strength was very minimal and at times seawater mix can even produce higher values at a longer curing time. On both seawater and fresh water mix, the use of fly ash as a partial cement substitute produces a lower early strength compared to pure cement but eventually surpasses it after the 28th day. Between 20% to 30% replacement ratio may be recommended to attain the highest compressive strength for a 28th day design target. Regardless of the fly ash replacement ratio, the use of seawater as mixing water did not pose any significant effect, in terms of corrosion problem, as compared to fresh water mixed mortars even after 18 weeks. However, results show that higher flyash replacement ratios gives a higher corrosion rate as compared to using pure ordinary Portland cement. Future researches should consider longer exposure/testing time in order for the corrosion activity to be more apparent.

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