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EFFECTS OF FLY ASH AND SEAWATER ON CORROSION BEHAVIOR OF STEEL-REINFORCED MORTAR

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Abstract: In construction, large amounts of water are being used especially for the mixing and curing of concrete. Ordinary mortar mix requires clean freshwater, a resource which is expected to vastly deplete as a result of global water scarcity. Therefore, the need for an abundant alternative source is necessary – seawater. With this method, not only the environmental issues are lessened, but also the economical aspect of construction projects. To help reduce the problems on water scarcity, the use of seawater instead of fresh water is being proposed in some construction processes. But the high chloride content of seawater may cause corrosion to reinforced concrete structures. Adding reactive inorganic materials like fly ash improves the resistance against chloride penetration. However, the influence of various fly ash replacement ratios on reinforced mortar mixed with seawater needs further studies to determine applicability in the construction industry. This paper focuses on the effects of fly ash and seawater to the corrosion of the reinforcing steel bars in mortar specimens. Mortar specimens with 0%, 10%, 30%, 40%, and 50% fly ash replacement ratios and ordinary Portland cement mixed with seawater and fresh water were prepared. Rectangular prism specimens of size 4 cm x 4 cm x 16 cm were used. Ten millimeter in diameter round steel bars were suspended in the specimens with constant cover of 5 mm in order to accelerate the corrosion process. All specimens were cured in fresh water. The corrosion behavior was assessed by corrosion current densities, corrosion potential, and polarization resistance measured every week for a period of 18 weeks. Comparing the freshwater to the seawater specimens, it was observed that the use of seawater as mixing water produced a more erratic corrosion current density. Meanwhile, low replacement ratios of 10% and 30% exhibit good corrosion resistance.

Key Words: fly ash; mortar; seawater; corrosion

1. INTRODUCTION

Concrete structures such as bridges, buildings, sanitary and water facilities might suffer severe damages due to corrosion of the reinforcing steel. These damages are caused by the consequent cracking and spalling of the concrete which are very costly to repair. Thus, concrete must provide both physical and chemical protection from atmospheric attacks.

A key solution to this problem is one that would address environmental, economic, and practicality issues. The solution lies with using materials abundant in the Philippines and maximizing their use. Both of which are seawater and fly ash. But the use of seawater is not a common practice in concrete construction due to its high amounts of chloride. However, the addition of fly ash will mitigate the harmful effects of chloride with its chemical properties. Fly ash and cement have similar chemical compositions. Fly ash is abundant in aluminum trioxide and silicon dioxide which react to the high calcium oxide (lime) content in cement to form calcium silicate hydrate (CSH), resulting with concrete that is stronger and less permeable.

The introduction of fly ash as a cement replacement will lower concrete cost while reducing carbon dioxide emission from the production of cement (Odchimar and Otsuki, 2011). The introduction of fly ash in concrete indicates that the protection against corrosion begins and ends in the mixing process. The need for corrosion prevention techniques will no longer be necessary in the near future of the structure's life span.

2. METHODOLOGY

This research is an experimental type of research. Comparative analysis was made between mortar mixtures with fly ash mixed with seawater and mixtures using only ordinary Portland cement and fresh water. The experiment was divided into two phases: first, investigation of the effects of various fly ash replacement ratios to the compressive strength of the mortar specimens mixed with seawater and; second, determination of the effects of various fly ash replacement ratios mixed with seawater to the corrosion of the reinforcing steel bars.

Figure 2.1 is an illustration of the research methodology.

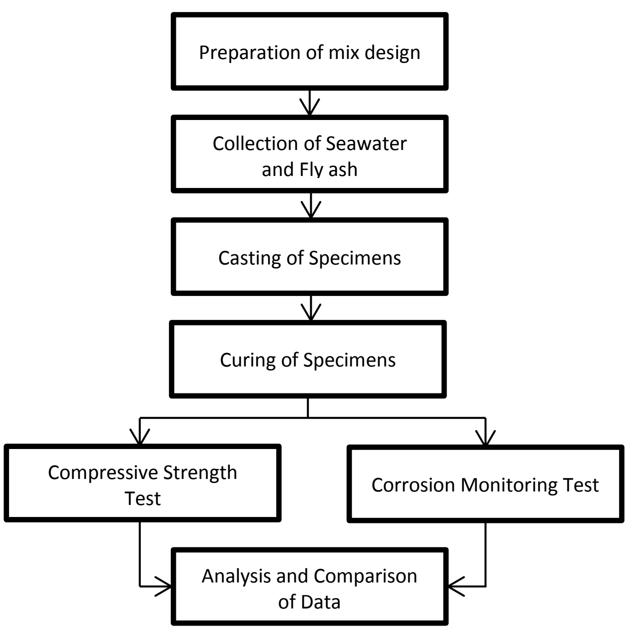

Fig. 2.1: Research Methodology

The researchers tested the compressive strength and corrosion resistance of the mortar specimens. In testing the compressive strength of the mortar specimens, the researchers followed the ASTM C39 (Standard Test Method of Cylindrical Concrete Specimens). ASTM C305 (Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency) was followed for the preparation of the mortar mixture. Measuring the corrosion potential of the rectangular prisms was based on 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).

3. RESULTS AND DISCUSSION

Compressive strengths of the test specimens up to the 84th day were recorded and plotted, as seen in Figure 3.1. Examining this plot, the presence of seawater in the mortar mixture significantly increases its early day compressive strength compared to a similar mix with freshwater exhibited in all the samples except specimens with 10% replacement ratio. Similar observations were made by Wegian (2010) in early stages of the mortar specimens. The anomalous data might have been due to an inconsistency in the amount of water in the mix as moisture contents were not tested for all fine aggregate batches. The presence of fly ash from ratios 10% to 40% with the exception of CF(40) yields compressive strengths greater than that of OPC specimen on the 28th day. The highest recorded 28th day strength was that of CS(30) with a value of 36.037 MPa. The increase in strength is lower in high replacement ratios of 40-50% similar to the findings of de Gutierrez, et.al. (2000) attributed to excessive bleeding, segregation, and decrease in viscosity which caused early failure on the upper portion of the cylindrical specimen. The specimens exhibited a diagonal pattern due to shear failure. This mode of failure governed due to the weak aggregate interlock of the fine aggregates present in mortar as opposed to concrete with stronger aggregate interlock from the coarse aggregates. Despite this, strengths equal or surpassing that of concrete is achieved due to the increase in binder requirement (cement and fly ash) resulting to stronger cement matrix binding the fine aggregates.

However, all specimens surpass the compressive strength of OPC on the 84th day with the highest value of 42.86 MPa obtained from CF(30), 38% greater than that of OPC. It was observed that an increase of at least 16% is exhibited in specimens with 10-40% replacement ratios on the 84th day. This increase in strength can be attributed to the abundance of silicon dioxide and aluminium oxide in fly ash which reacts with lime during the hydration process occurring in the OPC, forming compounds of calcium-silica-hydrate, essential for the hardening and strength development of cement. A decrease in compressive strength was not observed in this study, as it was in the study of Wegian (2010), considering decrease in strengths was observed on the 90th day. The shorter curing period may have not been prolonged to solidify the formation of salt crystalline structures that may cause sulphate attacks in the mortar matrix.

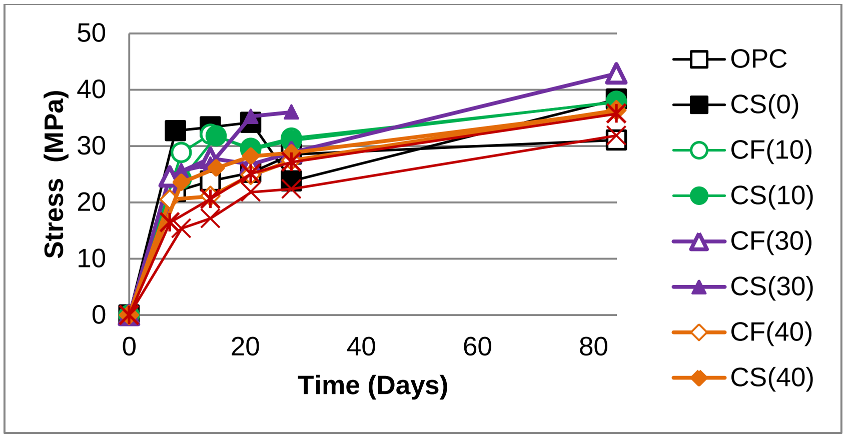

Fig. 3.1: Compressive Strength

To obtain the relationship between the various replacement ratios of fly ash with respect to its corresponding compressive strength, regression analysis was performed for freshwater and seawater specimens recorded on the 7th, 28th, and 84th day to establish a relation for the early strength to the late strength of the specimens. The acceptance of the trend was based on the obtained correlation coefficient, R, summarized in Table 3.1.

Table 3.1 Regression Analysis Result Summary

Freshwater				
Day	Equation	R^2	R	Optimum FA %
7	$y = -0.0126x^2 + 0.4566x + 23.214$	0.9046	0.951	18.12
28	$y = -0.0078x^2 + 0.2611x + 28.864$	0.9632	0.981	16.74
84	$y = -0.0173x^2 + 0.8678x + 31.066$	0.942	0.971	25.08
Seawater				
Day	Equation	R^2	R	Optimum FA %
7	$y = -0.2378x + 30.67$	0.7236	0.851	0.851
28	$y = -0.0152x^2 + 0.7946x + 24.172$	0.845	0.919	26.14
84	$y = -0.053x + 38.348$	0.9958	0.998	-0.053

Comparing the freshwater to the seawater specimens, as seen in Figure 3.2, it was observed that the use of seawater as mixing water produced a more erratic corrosion current density. From the given data, a replacement ratio as low as 10% greatly reduced corrosion rates as none of the specimens with fly ash reached an active corrosion rate. Good corrosion resistance was achieved with replacement ratios greater than 30% as the specimens generally remain in the state of passivity.

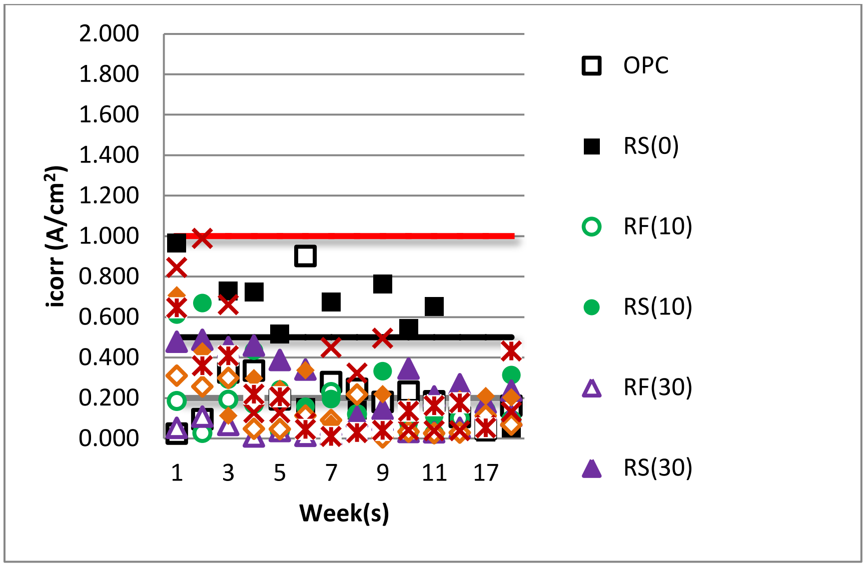

Fig. 3.2: Corrosion Current Density

Figure 3.3 shows the plotted average corrosion potential measured throughout 18 weeks and using the corrosion criteria computed. Similar to the corrosion current density graph, the corrosion potential shows little or no signs of corrosion in the reinforcing steel; a probable cause of which is the short duration of the testing period.

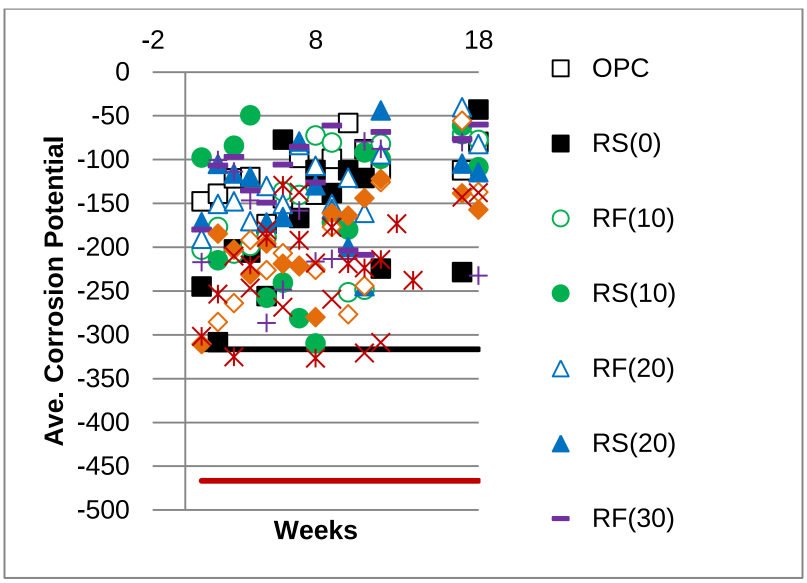

Fig. 3.3: Average Corrosion Potential

4. CONCLUSION

The optimum design mix was obtained based on the compressive strength, corrosion current density, and chloride content results of the experiment. For the compressive strength: (a) Seawater increased the early strength of mortars. (b) The use of seawater is suitable as mixing water for periods of up to 84 days. (c) Compressive strengths higher than OPC were obtained for fly ash replacement ratios up to 50% on the 84th day. (d) Forty percent (40%) and fifty percent (50%) replacement ratios have lower compressive strengths due to excessive bleeding, segregation, and decrease in viscosity. (e) The highest compressive strength recorded was on the 84th day with a value of 42.86 MPa and was obtained from the specimen mixed with freshwater with a replacement ratio of 30%. For the corrosion evaluation: (a) Ten (10%) and thirty (30%) replacement ratios exhibit good corrosion resistance due to the reaction of fly ash with calcium oxide in OPC. (b) Replacement ratios of 40% and 50% show higher corrosion rates. (c) The corrosion potential shows that all specimens are not more than 10% corroded.

From the experimental data, a mortar specimen mixed with seawater with a replacement ratio of 30% will provided the highest compressive strength on the 28th day. Also, a 30% replacement ratio mixed with fresh water produced high compressive strengths for periods up to 84 days. On the other hand, the optimum replacement percentages for a period of 28 days were obtained to be 16.74% and 26.14% for mortar specimens mixed with freshwater and seawater, respectively.

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