CORROSION ASSESSMENT OF EMBEDDED REINFORCEMENT IN NANO-MODIFIED SEAWATER-MIXED CONCRETE

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Abstract

Concrete is the second-most consumed material after water on Earth, and the production of concrete consumes 18% of the total industrial demand for freshwater annually. Water-stressed nations need replacing freshwater in concrete production and have attempted seawater-mixed concrete in the last decade. The inclusion of supplementary cementitious materials (SCMs), nanoparticles, and corrosion inhibitors can increase the feasibility of producing concrete by seawater mixing. The current study focuses on investigating the time for corrosion initiation in seawater-mixed concretes produced with fresh and seawater. 9 concretes were designed for the study with slag and metakaolin as SCMs, nanosilica, and corrosion inhibitors. The compressive strength and surface resistivity values of the concretes were measured at 28 days in concretes made with similar binder content and water-to-binder ratio. The inclusion of SCMs and nanoparticles could enhance the resistivity of concretes against the ingress of aggressive ions. Specimens produced in accordance with ASTM G109 were exposed to a 3.5% NaCl solution, and macrocell current from the top rebar with respect to the bottom rebar was measured to understand the corrosion initiation.

Keywords: Seawater-mixed concrete, supplementary cementitious materials, corrosion inhibitors, surface resistivity, and ASTM G109

1. INTRODUCTION

Seawater-mixed concrete (SWC) is being extensively investigated in the current decade in countries expected to have extremely severe water-stress by 2040 [1]. Limitations on the upper threshold of chloride and sulphate contents in mixing water for reinforced concrete were proposed by several international standards and codes of practice to mitigate localised corrosion in embedded steel reinforcement [2]. Nevertheless, the arrival of alternative reinforcements such as fibre-reinforced polymer, stainless steel, and galvanised rebars facilitated the possibility of using seawater with a higher chloride content as a mixing water for reinforced concrete [3]. Researchers demonstrated the feasibility of using these alternative reinforcements in concrete produced with seawater, sea sand, and coral aggregates [4]. However, more research is required on improving the chloride binding ability of the cementitious matrix with the addition of supplementary cementitious materials (SCMs) [5]. This work presents the corrosion performance of embedded reinforcement in ternary blended SWC made with SCMs such as ground granulated blast furnace slag (slag), metakaolin, nanosilica (nS), and corrosion inhibitor.

2. MATERIALS AND METHODOLOGY

CEM I 42.5 R, conforming to EN 197-1, was used as the primary binder throughout the study. A ternary blended cementitious combination with slag (30 wt%) and metakaolin (15 wt%) was produced by replacing the CEM I content by 45%. Furthermore, nanosilica (nS) and corrosion inhibitor (Sika Ferrogard) were used additives to enhance the early hydration of the cementitious matrix and the corrosion resistance of the embedded steel in concrete. River sand aggregates with a maximum particle size of 4.75 mm conforming to the EN standards were utilized for producing concrete mixes. Also, the maximum size of coarse aggregates (rounded) was limited to 8 mm for preparing the specimens for ASTM G109 samples. Tap water/Freshwater (FW) and artificial seawater (SW) prepared according to ASTM D1141 were used to prepare concrete. Quenched and self-tempered steel rebars of 16 mm diameter were used for assessing the corrosion performance of FW and SW-mixed concretes. The total binder content and water-to-binder ratio of the concrete mixes were kept constant at 360 kg/m^3 and 0.45, respectively. In addition, reference specimens with the same mix proportion were prepared for continuous monitoring of the compressive strength and surface resistivity values of the concrete combinations considered in this study. Table 1 summarizes the concrete mix details used in this study.

Concrete cubes of size 100 mm were prepared and exposed to under-water curing for 28 days to evaluate the strength of concrete made with fresh- and seawater. Compressive strength was evaluated by applying a uniaxial load using a hydraulic press with a maximum capacity of 5000 kN. The load rate applied for the compressive strength evaluation was selected in accordance with EN 12390 Part 3. Concrete cylinders with a diameter of 100 mm and a height of 200 mm were used to determine the surface resistivity using the Wenner 4-probe resistivity method. The electrical resistivity measurements were taken from the specimens immersed in water for 28 days. The Wenner 4-probe method works on the principle that voltage is applied to the concrete using two probes, and the other two probes measure the current passing through the porous network of concrete. The measurement of surface resistivity was carried out according to EN 12390 – Part 19.

Table 1: Mix proportion details.

<table>
<tr><th rowspan="2">Mix ID</th><th rowspan="2">Description</th><th colspan="4">Concrete proportions (kg/m^3)</th></tr>
<tr><th>Total binder</th><th>Water</th><th>Fine aggregate</th><th>Coarse aggregate</th></tr>
<tr><td>1</td><td>CC-FW</td><td rowspan="9">360</td><td rowspan="9">164</td><td rowspan="3">732</td><td rowspan="3">1172</td></tr>
<tr><td>2</td><td>CC-SW</td></tr>
<tr><td>3</td><td>CC-I-SW</td></tr>
<tr><td>4</td><td>CS30M15-FW</td><td rowspan="3">723</td><td rowspan="3">1160</td></tr>
<tr><td>5</td><td>CS30M15-SW</td></tr>
<tr><td>6</td><td>CS30M15-I-SW</td></tr>
<tr><td>7</td><td>CS30M153nS-FW</td><td rowspan="3">721</td><td rowspan="3">1156</td></tr>
<tr><td>8</td><td>CS30M153nS-SW</td></tr>
<tr><td>9</td><td>CS30M153nS-I-SW</td></tr>
</table>

Note: CC- CEM I, CS30M15 – CEM I + 30% Slag + 15% Metakaolin; 3nS – 3% nano Silica; I – Inhibitor; FW- Freshwater; SW – Seawater.

ASTM G109 specimens were prepared to study the macrocell corrosion mechanisms in FW-mixed and SW-mixed specimens with and without inhibitors. A top rebar and two bottom rebars were used as anodes and cathodes, respectively. A 3.5% NaCl solution was filled in the tank above the samples to ensure one-directional transport of chlorides to the top rebar (anode). The voltage drop was measured across a 100-ohm resistor periodically, and the cumulative macrocell current (CMC) is calculated to check the time taken for the specimens to reach a threshold CMC value of 150 coulombs.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the measured values of compressive strength and surface resistivity values of the 9 concrete mixes evaluated in this study. Ternary blended concretes with slag and metakaolin (CS30M15) show higher strength and surface resistivity values at 28 days compared to the CEM I concretes (CC) produced. Also, the addition of inhibitor at a recommended dosage did not alter the evolution of strength and microstructure of the concretes. The concrete mixes with nanosilica (CS30M15-nS) showed a significant increase in the surface resistivity at 28 days compared to the CS30M15 concrete. The ASTM G109 specimens are kept in the continuous exposure under 3.5% NaCl exposure for monitoring the corrosion behaviour of embedded steel. The comparison between the time taken for corrosion initiation will be determined for all 9 concretes and the results will be presented. Also, the level of chlorides at the level of steel will be determined to understand the amount of free and bound chlorides in the concretes made with slag, metakaolin, and nanosilica.

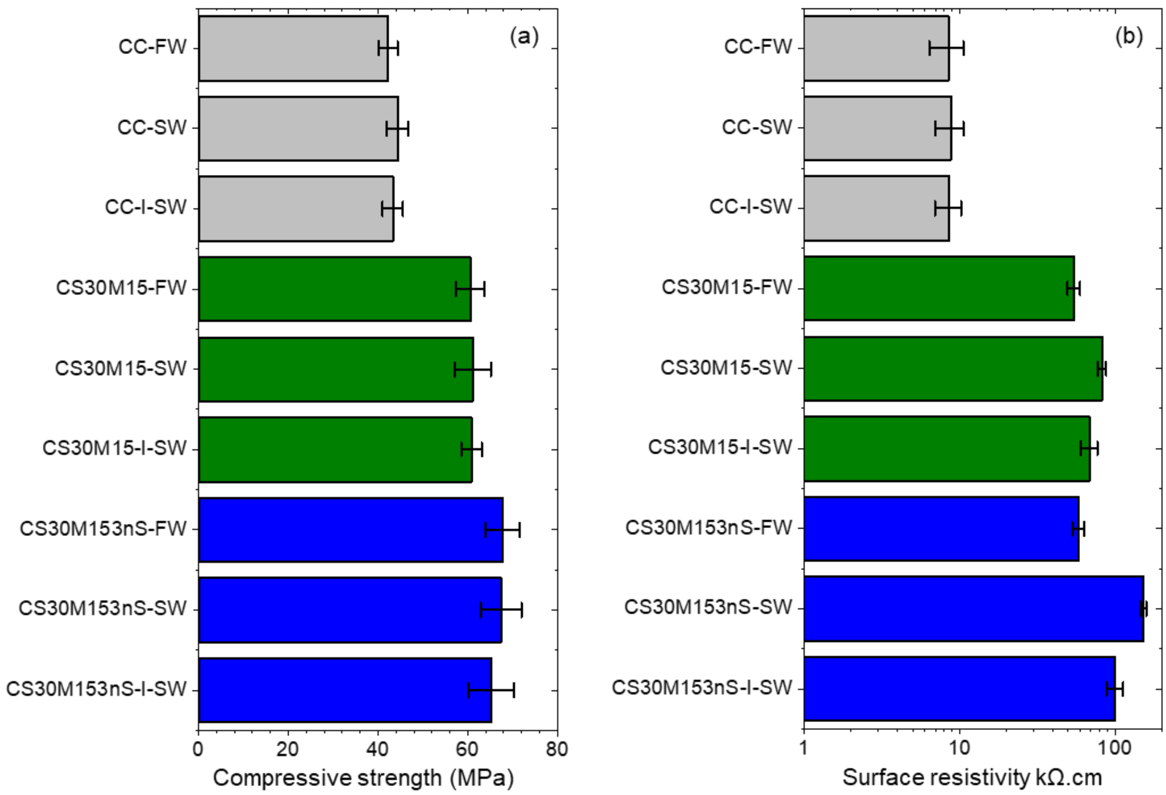

Figure 1: Compressive strength (a) and Surface resistivity values at 28 days

4. CONCLUSIONS

- The concrete mixes were in the moderate strength category and the surface resistivity values of nanosilica added concrete with seawater achieved a negligible level of permeability at 28 days.
- Continuous monitoring of steel-embedded specimens with and without corrosion inhibitors are ongoing and the comparison between the time for corrosion initiation on the specimens prepared by using seawater for mixing.

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