Microstructural Corrosion Study of Thermo-Mechanical Treated Steel in Simulated Concrete Pore Solution in Presence of Chloride Ion

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ABSTRACT:
The effect of corrosion behaviour on the surface of TMT steel was investigated. The oxide layer was also explored and microstructure has significant effect on the corrosion resistance of TMT steel in simulated concrete pore solution and with 3.5% NaCl. TMT sample S is more adherent compare to second sample T as confirmed by conventional weight loss and electrochemical impedance spectroscopy studies. In chloride contaminated SCP solution more aggressive than SCP solution for both samples.

Key Words:-TMT, NaCl, Weight loss and EIS.

INTRODUCTION
Thermomechanically treated steel usually serves as construction materials exhibits a better combination of mechanical performance and bonding with concrete. However, considering the service condition of the concrete structure, it is necessary to elevate the corrosion resistance of TMT steel in simulated concrete pore solution and 3.5% NaCl with SCP solution. The penetrations of atmospheric CO₂ and chloride ions have been reported to cause pitting corrosion of TMT, which could lead to a significant decrease in service life of concrete structure. Carbonation of concrete takes place when the CO₂ from the atmosphere reacts with the components of concrete, resulting in the formation of CaCO₃. Chloride ions also penetrate through the corrosion product layer especially via defects and further reach the base metal surface. The presence of chloride ions frequently causes the passive film formed on the metal surface to be broken down. Continuous damage of the permanent corrosion product layer facilitates the active dissolution of the substrate metal. If the reaction reaches the steel reinforcement surface, its passive layer may disappear, exposing the steel surface to corrosion. Although numerous previous studies have been reported concerning the corrosion behavior of TMT steel, limited investigations are focused on the effect of microstructural corrosion behavior of TMT steel. The inhibitor efficiency and attributes of the corrosion layers are closely related to the microstructures of TMT steel. Furthermore, the corrosion behaviors of the TMT steel in simulated concrete pore solution and 3.5% NaCl with SCP solution were investigated [1-3].

2. EXPERIMENTAL
2.1. Materials
The chemical compositions of the used samples were measured by optical emission spectroscopy (OES) method and are shown in Table 1. The mechanical test results of the specimen shown in Table 2.
Experimental steel specimens were machined into cylinders of $\varphi$ 20mm × 10 mm, and the entire surface of the specimen was carefully ground to ensure the reproducibility.

2.2 Simulated concrete pore solution

The SCP solution prepared by 8.33g/l NaOH+2.0g/l CaO+3.36g/l KOH in distilled water. The solution was kept 24 hours under stirring then filtered on Watman paper of No.15 grade. The insoluble CaO was removed from solution [4, 5]. The working electrodes made of TMT steel were immersed in SCP solution and SCP with 3.5% NaCl (SCPN) for the corrosion test in both electrochemical impedance method and conventional weight loss method.

Table 1: Chemical composition of used specimen in weight %

<table>
<thead>
<tr>
<th>Sample</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Sn</th>
<th>As</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel 1</td>
<td>0.264</td>
<td>0.199</td>
<td>0.79</td>
<td>0.037</td>
<td>0.037</td>
<td>0.051</td>
<td>0.017</td>
<td>0.027</td>
<td>0.014</td>
<td>0.016</td>
<td>98.804</td>
</tr>
<tr>
<td>Steel 2</td>
<td>0.238</td>
<td>0.179</td>
<td>0.73</td>
<td>0.016</td>
<td>0.023</td>
<td>0.010</td>
<td>0.003</td>
<td>0.048</td>
<td>&lt;0.001</td>
<td>0.006</td>
<td>98.980</td>
</tr>
</tbody>
</table>

Table 2: Mechanical properties of used specimen

<table>
<thead>
<tr>
<th>Sample</th>
<th>Y.S. (Mpa)</th>
<th>U.T.S (Mpa)</th>
<th>% EI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel 1</td>
<td>571</td>
<td>692</td>
<td>21</td>
</tr>
<tr>
<td>Steel 2</td>
<td>572</td>
<td>686</td>
<td>21.3</td>
</tr>
</tbody>
</table>

2.3. Electrochemical impedance spectrometry measurement

The data was analyzed by using DC 105 and CMS 300 software of M/S Gamry instrument, the supplier of the potentiostat used in the present study. TMT steel specimen fitted in a corrosion cell with an exposed area of 1 cm² was used as the working electrode (WE). A saturated calomel electrode (SCE) and a graphite rod were used as the reference electrode (RE) and counter electrode (CE), respectively. Under each testing condition, at least three measurements were conducted on separate specimens to confirm the reliability of result. Before the electrochemical measurements, the working surfaces were wet grounded with SiC metallographic waterproof abrasive papers up to 1200 mesh; then, the samples were degreased with ethanol and dried. Electrochemical impedance (EIS) studies were performed by changing the frequency of 10 mV sinusoidal voltage from 0.001 Hz to 100 kHz. The data were collected by imposing the sinusoidal voltage at open circuit potential of the working electrode. EIS data were analyzed using constant phase element (CPE) model. All electrochemical experiments were performed at temperature of 25±1°C. The electrochemical impedance and open circuit potential measurements were made simultaneously for three samples and two data close to each other (± 2.5% variation) were averaged and produced in the paper [5-7].

Fig.1: Bode impedance-frequency of the TMT steels
2.4. Conventional weight loss method

For optical observation, the specimens were mechanically polished and then etched with Nital solution (2.0% HNO₃ +98% ethyl alcohol by volume). Weight loss tests were conducted to investigate the corrosion rates of steels. The test specimens were machined to a size of φ20mm × 10 mm. Tests were performed in a thermostatic water bath at room temperature of 28°C for 14 days. Three equivalent specimens were used for each test condition to ensure the reproducibility. Before the tests, all specimens were cleaned with distilled water and acetone, dried, and then weighed using a digital electronic balance with an accuracy of 0.0001 g before the weight loss test. After completing the tests, the corroded specimens were rinsed with distilled water. The corrosion products were removed according to ASTM standard, then rinsed, and dried again [3, 8]. The corresponding corrosion rates were calculated from the formula:

$$\text{mm/yr} = \frac{87.6 \times W}{D \times A \times T}$$

Where W is the weight-loss (mg), D is the density (g/cm²), A is the area (cm²) and T is the exposure time (hrs.).

### Table 3: Corrosion rate of the exposed TMT steel specimens at different pore solution

<table>
<thead>
<tr>
<th>Sample</th>
<th>SCP</th>
<th>SCPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel 1 [S]</td>
<td>0.0013051 mm/yr.</td>
<td>0.0117452 mm/yr.</td>
</tr>
<tr>
<td>Steel 2 [T]</td>
<td>0.0143580 mm/yr.</td>
<td>0.021602 mm/yr.</td>
</tr>
</tbody>
</table>

2.4. Results and Discussion

2.4.1 EIS plots

The curve shown in figure no.2 and 3 more corrosion in SCPN in comparison to SCP solution, due to the presence of aggressive ions in SCPN solution.

2.4.2 Surface morphology

The surface appearances of bare and exposed samples were observed by optical micrographs at different corrosive conditions which showed that at the bare conditions the steel has only ferritic-pearlitic microstructure (Fig.3. a and b) while after exposure the micrographs have shown oxide layers on the metal surface in the case of SCP solution (Fig.4. a and b). The formation of more oxide layers with more dimples have been found in SCPN solution (Fig.5. a and b).
3. CONCLUSIONS
The exposed samples micrographs of SCPN have aggressively attacked in the presence of chloride ions however the attack was comparatively less in the case of simulated solution. Thus the corrosion rate of SCPN exposed samples were found more in comparison to SCP solution.

REFERENCES


