The Use of Electrochemical Impedance Spectroscopy Method for Corrosion Resistance Evaluation of 2205 and 410s Stainless Steels in Aqueous Sodium Chloride Solution

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Abstract. Corrosion behaviour of SS 2205 and SS 410s were investigated in various concentrations of aqueous sodium chloride solutions. Experimental work was carried out by using electrochemical impedance spectroscopy method at room temperature to evaluate the impedance of the system. Sodium chloride solutions were prepared with various concentration i.e. 1, 2, 3.5, 4 and 5 w.t%. The testing results were represented by Nyquist plot for both alloys. It was observed that the lowest corrosion resistance of both alloys was at 3.5% w.t NaCl which was similar to typical seawater solution. It was also observed that SS 2205 had better corrosion resistance along with greater impedance than the SS 410s in every NaCl concentration.

Index Terms. SS 2205, SS 410s, Corrosion Behaviour, NaCl aqueous solution, Electrochemical Impedance Spectroscopy.

1. Introduction
Stainless steel is widely used in industry and utilization in various environment because its ability to resist material degradation caused by reactive environment. Stainless steel performs better, compared with another kind of steel in resisting material degradation. Stainless steel has four class of specification, such as: ferritic, martensitic, duplex, and austenitic.

Martensitic stainless steel is composed by higher carbon and lower chromium content, compared with another kind of stainless steel. Martensitic stainless steel is used as cutting tool in industry, because of its hardness. This characteristic develops since the steel is processed through quenching, which forms the martensite structure.

Duplex stainless steel is composed with higher chromium and low nickel content. This composition made duplex stainless steel has two phase, which are austenite and ferrite, therefore duplex inherits both characteristics of the phase. Duplex stainless steel is mainly applied as offshore oil and gas equipment, in chemistry industry and petrochemicals, and application in maritime sector of industry.

Pitting corrosion is the most common corrosion mechanism that attacks stainless steel, and also the most severe. The mechanism of this kind of corrosion is conducted by destroying passive layer of stainless steel, then penetrate under steel the surface and make a pit-like hole under its surface [1].

Stainless steel is a kind of alloy which forms passive layer, therefore it is susceptible to be attacked by pitting corrosion. Pitting corrosion could occur because of decayed passive layer as an outcome of reactive halide ion attack such as Cl-, Br-, or I , which commonly contained in seawater [2].

Aside from halide ion containing environment, another condition which could destroy stainless steel’s passive layer is oxygen content in the environment [3]. This occurs since oxygen is an electron receiver element of metals, which cause corrosion to occur [4].

Corrosion is a natural phenomenon, so it could not be stopped. However, corrosion phenomenon could be prevented by slowing the reaction rate of metals with the environment. Therefore, this research was aimed to observe corrosion behaviour of martensitic and duplex stainless steel in chloride ion with the variable of chloride concentration 1%, 2% 3.5%, 4% and 5% w/w of NaCl solution.
2. Details Experimental

2.1. Materials Specification

SS 2205 and SS 410s was used in this study. Both materials were machined and grinded well as preparation for EIS testing. Chemical compositions of both alloys shown in table I and table II and were tested using Optical Emission Spectrometer (OES).

| Chemical Composition (%) | C     | Si    | Mn    | P     | Chemical Composition (%) | C     | Si    | Mn    | P     |
|--------------------------|-------|-------|-------|-------|--------------------------|-------|-------|-------|-------|
| Ni                       | 0.028 | 0.483 | 1.41  | 0.038 | Ni                       | 0.015 | 0.740 | 0.504 | 0.017 |
| Mo                       | 5.32  | 2.81  | 0.005 | <0.004| Mo                       | 0.382 | 0.007 | 0.0116| <0.004|
| Ti                       |       |       |       |       | Ti                       |       |       |       |       |
| Nb                       |       |       |       |       | Nb                       |       |       |       |       |
| S                        |       |       |       | <0.0005| S                        |       |       |       |       |
| Cr                       |       |       |       |       | Cr                       |       |       |       |       |
| Cu                       |       |       |       |       | Cu                       |       |       |       |       |
| Fe                       |       |       |       |       | Fe                       |       |       |       |       |
| Bal.                     |       |       |       |       | Bal.                     |       |       |       |       |

2.2. NaCl Solutions

Sodium chloride solutions were prepared at several concentrations, which is 1%, 2%, 3.5%, 4%, and 5% w/w, by dissolving 10, 20, 35, 40, and 50 grams of sodium chloride powder in 1 litre of water respectively. The solution was stirred using magnetic stirrer at room temperature (27°C).

2.3. Samples Preparation

Both materials were cut into 5 pieces of 2cm x 2cm x 0.5cm plates from their original plates form. Samples then were grinded 60, 100, 180, 400, 500, 600, and 800 grades abrasive papers followed by polishing, cleaning and drying.

2.4. Polarization Cell

Electrochemical measurement by using EIS method was conducted in a cell chamber using carbon as counter electrode, stainless steel sample as working electrode and saturated Ag/AgCl electrode as reference electrode. Current range used was from 100 nA to 1A.

2.5. Electrochemical Impedance Spectroscopy Experiment

Electrochemical Impedance Spectroscopy experiment was carried out by Autolab potentiostat and NOVA 1.11 software.

3. Results and Discussion

3.1. Electrochemical Impedance Spectroscopy Testing

Electrochemical Impedance Spectroscopy methods was conducted to do qualitative comparison between impedances of SS 2205 and SS 410s. The result obtained from the methods were Nyquist plots of materials in different concentrations of chloride solution, which showed the impedance measured as comparison to observe corrosion resistance in different condition [5]. Nyquist plot was formed from the impedance of alternating current flowing back and forth on both samples surface.

Greater impedance correlates with less corrosion rate, as electron flow decreases with increasing resistance in the system. The data showed that straighter lines correlates with better corrosion resistance, as the lines have greater impedance [6].
Figure 1 and Figure 2 showed that the corrosion resistance of the alloys ranked from the highest resistance to the lowest resistance was 1%, 2%, 5%, 4% and 3.5% w/w sodium chloride concentration.

Figure 1. Electrochemical impedance spectroscopy curves of martensitic SS 410s in various sodium chloride concentration, zoomed (bottom), and original dimension (top).
3.2. Fit and Simulation

Besides the qualitative method conducted in this experiment, quantitative data was also provided by doing fit and simulation on provided nyquist graphs. Fit and simulation is a process that shows electrochemical equivalent circuit presenting the surface condition of the samples. Some of the elements that could be presented are the solution resistance (Rs), polarization resistance (Rp), double layer capacitance (CPE/Cdl), and constant phase element (Q). The difference between Rp and Rs is that the value of Rs is influenced by the condition of environment and material positioning, thus, the value of Rs does not represent the corrosion resistance of the sample. On the other hand, Rp is only influenced by the material itself. Thus, Rp should be considered as the corrosion resistance of the sample. The corrosion resistance of the sample has linear correlation with the value of Rp.

Table 3. Fit and simulation result of SS 410s

| NaCl Concentration (%w/w) | Rs (Ω) | Rp (Ω) | CPE (μF) | N   |
|---------------------------|--------|--------|----------|-----|
| 1                         | 56     | 448    | 29.7     | 0.968 |
| 2                         | 28.9   | 185    | 34.2     | 0.979 |
| 3,5                       | 10.2   | 19.9   | 69.1     | 0.876 |
| 4                         | 8.64   | 33.9   | 54.6     | 0.996 |
| 5                         | 13     | 51.6   | 17.7     | 1.05  |

Figure 2. Electrochemical impedance spectroscopy curves of SS 2205 in various sodium chloride concentration.
As shown in figure 3 and figure 4, according to conducted experiments both materials have less corrosion resistivity at 3.5% sodium chloride concentration. It is also shown that both materials at 1% and 2% sodium chloride concentration have higher resistance than at 4% and 5% sodium chloride concentration because the lack of sodium chloride as the electrolyte in the system. In addition, 4% and 5% sodium chloride concentration have better corrosion resistance than 3.5% concentration was occurred because of the lack of dissolved oxygen in the system [7].

3.3. Comparison of Nyquist Plots of SS 2205 and SS 410s

Figure 5. Nyquist plots of SS 2205 and SS 410s at 1% wt NaCl, original dimensions (Right) and zoomed (Left)
Figure 6. Nyquist plots of SS 2205 and SS 410s at 2% wt NaCl, original dimensions (Right) and zoomed (Left)

Figure 7. Nyquist plots of SS 2205 and SS 410s at 3.5% wt NaCl, original dimensions (Right) and zoomed (Left)
As shown in figure 5-9 above, the corrosion behaviour of both alloys could be considered by qualitatively comparing the graphics shown. As shown in figure 5-9 SS 2205 had far higher impedance value as well as better corrosion resistance compared to SS 410 at various sodium chloride concentration. The difference of the result and corrosion behaviour of the alloys was because the higher composition of chromium contained in the alloy of SS2205. This composition of chromium creates more passive layer to protect the alloy SS 2205. Thus, SS 2205 had better resistance than SS 410s.

4. Conclusions

Based on the experiment conducted in this study, we could make conclusion as follows using the Nyquist plot provided, we could conclude that the impedance and corrosion resistance for alloy SS 2205 and SS 410s at various chloride concentration from the highest to the lowest were 1%, 2%, 5%, 4%, 3.5% w.t NaCl consecutively. 3.5% sodium chloride concentration environment was the lowest corrosion resistance and impedance for both alloys, since the presence of maximum dissolved oxygen solubility and optimum electrolyte concentration occurred in the system. SS 2205 has higher corrosion resistance than SS 410s at any aqueous sodium chloride solution due to the effect of chromium addition which forms better passive layer in the alloy SS 2205.

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