Effect of zero charge corrosion protection (ZCCP) on the carbon steel surface in 3.5% NaCl solution

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Abstract. The application of the zero charges concept is the latest and promising corrosion protection technique as compared to the cathodic protection (CP) technique. The study was conducted using carbon steel as metal to be protected. The effectiveness study was carried out on carbon steel in 3.5% NaCl solution with and without corrosion protection system. The results showed that carbon steel surface under zero charge corrosion protection (ZCCP) had no corrosion effect and consumed a very low electrical current. The protection effectiveness of ZCCP technique is found to be comparable to impressed current corrosion protection (ICCP), while unprotected carbon steel in the same corrosive solution undergoes severe corrosion attacks.

1 Introduction

The losses caused by corrosion are about 3.4% of the country's GDP excluded an indirect cost that finally will affect the quality of life [1]. Existing corrosion protection techniques are coating technology, corrosion inhibitor, and cathode protection (CP). All of these techniques are complementing each other, and of course, have their own weaknesses. The basic principle of CP just manipulation of polarization of the two-electrode system that requires a large electrical current and high voltage to overcome the electrolyte resistance in order to provide ionic flow paths. In some places and circumstances, CP may not be used for a number of specific reasons as discussed at the actual stage of implementation [2].

The zero charge corrosion protection (ZCCP) is a new and promising technology to control metal structures damage caused by oxidation reaction due to climate changes, environmental factors, and operational harsh conditions. Potential of zero charge (E_{pzc}) is a characteristic value of the electrode potential for any metal at which a clean surface of the metal will not acquire any electrical charge when it comes into contact with an electrolyte [3]. At E_{pzc}, a metal surface is not in contact with an aqueous solution due to the absence of electrical charge and no electrostatic attraction [4].

The effectiveness of ZCCP is studied by current/voltage pulses on the exposed carbon steel in the corrosive environment. The power supply is customized to eliminate the excessive charges on the metal surface to be zero and prevent metal-solution corrosion reaction [5].
The objective of this study is to prove that ZCCP technique can act as corrosion protection of carbon steel in the corrosive electrolyte of 3.5% sodium chloride (NaCl) solution.

2 Methodology

The AISI 1016 grade carbon steel plate was ground and polished to remove the oxide layers, rust and corrosion deposits to get a smooth and shiny surface. The steel samples were then painted by leaving 1 to 2 cm² exposed area on the surface. The test to determine the effectiveness of ZCCP was performed by comparing it with the steel sample that soaked in 3.5% NaCl consisting of the test system; (i) without corrosion protection (Cond-A), (ii) impressed current cathodic protection, ICCP, (Cond-B) and, (iii) zero charge corrosion protection, ZCCP, (Cond-C). Cond-A and Cond-B tests were conducted for 3 and 5 days respectively, whereby Cond-C was carried out for 7 and 14 days. In Cond-B, ICCP was performed by applying an electric current to the exposed area of steel sample. The protected potential (On and Off potential) was controlled at −780 to -1030 mV vs SCE. In Cond-C, ZCCP was applied by using a customized power supply that capable of supplying current/voltage pulses to steel samples. The ammeter with USB connection was connected in series in the circuit to measure electrical current consumption for both techniques at 1 reading/hour interval.

All corrosion protection tests were performed at room temperature with 1-atmosphere pressure. After immersion testing, the sample was rinsed with distilled water while the paint was removed from the steel surface. The surface condition was visually inspected and documented by digital DSLR camera (D3100, Nikon) to record the original condition. The topography of the steel sample surface was cleaned by stain remover solution and analysed by stereomicroscope (SZX16, Olympus).

3 Results and discussion

A visual examination of the surface conditions of steel samples that immersed in 3.5% NaCl solution with and without corrosion protection are shown in Fig. 1. Fig. 1(a) shows a fresh steel sample. It looks smooth and shiny after being ground and polished. The immersed steel sample without corrosion protection for 3-days (Cond-A) is covered by a non-homogeneous stain or deposits of reddish-brown on its surface (Fig. 1b). This rust layer is quite thick. The white residue on the green paint-coated steel surface shows the deposition of NaCl salts from the solution. At Cond-B, ICCP-prevented sample is observed to have no corrosion effect (Fig.1c). Corrosion protection through ICCP technique is quite perfect with the experimental setup condition (Fig. 1c). On the other hand, the surface condition of the steel sample immersed under ZCCP (Cond-C), shows that it is protected from the corrosion process (Fig. 1d). However, upon closer inspection, the surface of the ZCCP protected steel is somewhat faded due to a slight oxidation reaction at the early stages of immersion at which, it was the time when the steel potential has not yet reached the $E_{pzc}$. This observation is initially acknowledged to be a bit disappointing as its protective effects are less clear effective. Further observations are therefore made more closely using stereomicroscopes.

The topographical of steel surface as the immersion and corrosion protection effect are shown by the stereomicroscope images in Fig. 2. To demonstrate the effectiveness of corrosion protection through ZCCP, the stereomicroscope images focused on the boundary of the removed paint-coated and the exposed areas of steel (marked as red X). From the above point of view, it is noted that the steel soaked in 3.5% NaCl solution for 3-days without corrosion protection showed rough and irregular surfaces with the residual stubborn oxide deposits left on the steel surface (Fig. 2a). The steel sample in this Cond-A experimental
setup suffered from severe corrosion. As for steel immersed under the ICCP and ZCCP, there was no significant effect of corrosion reaction (Figure 2b, c, d).

Fig. 1. Camera photographs of (a) fresh, and immersed samples; (b ) without & with (c) ICCP and (d) ZCCP corrosion protection.

Fig. 2. Stereomicroscope images of immersed samples (a) without, and with (b) ICCP, and (c) 7 days ZCCP) and 14 days ZCCP corrosion protection.

The ICCP technique has proven to protect against corrosion, nevertheless, ZCCP is also comparable to the established ICCP. The efficacy of the ICCP technique can be seen in the
topography of ZCCP samples immersed at 7 and 14 days that appear almost identical. Fig. 2 (c-d), is the answer where the surface of the steel is faded and somewhat disturbed. At the initial stage of immersion, it takes about 12 to 48 hours before the ZCCP goes into effect. At this period, there is a spontaneous reaction between the metal and the solution by which the charge transfer process takes place in the electrode-electrolyte interface. Once the steel potential reaches at $E_{pzc}$, the corrosion process is continuous to be prevented from invading the surface and penetrating the next steel atoms.

ZCCP is different from a conventional cathodic protection method. This protection technique applies an alternating current (ac) mode as compared to ICCP which applies a direct current system. Referring to Table 1, the ICCP records a current consumption of 90 $\mu$A/cm$^2$. It is a high reading compared to 20 to 30 mA/cm$^2$ in stagnant seawater as stated by Baboian & Treseder [6]. This current reading is acceptable without doubted because the current consumption at the initial stage of ICCP is known to be very high. Oppositely, ZCCP was found to record significantly lower current consumption readings. The decreases of current consumption as protection extend from 7 to 14 days reflected the significant economic savings by the ZCCP.

| Corrosion Protection | Average Current Density ($\mu$A/cm$^2$) |
|----------------------|----------------------------------------|
| ICCP                 | 90                                     |
| ZCCP (7 days)        | 0 (2-6)                                |
| ZCCP (14 days)       | 0 (0-2)                                |

* ( ) AC current mode

### 4 Conclusion

Zero charge corrosion protection (ZCCP) is proven can hinder corrosion processes on carbon steel in the corrosive electrolytes such as 3.5% NaCl solution. It consumed a multiple smaller amount of electric current than impresses current cathode protection (ICCP) techniques.

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