Different Setup of Capacitive Coupling Protection System on Mild Steel

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Abstract. A Capacitive Coupling Corrosion Protection (CCCP) technology based on coupler pads was investigated. The layout of the coupler pads on the mild steel surface was studied to get the best outdoor corrosion protection. A square wave of current/voltage is supplied to the steel surface for 72 hours via a copper coupler pad in three arrangements, i.e., single, double-sided, and opposite configurations. The efficiency of the CCCP configuration was assessed by measuring electrical current consumption, weight loss, and post-experimental surface morphology observations. It is found that the current consumption of 600 µA/cm² in the double-sided configuration is practically stable. The lowest weight loss and clean surface morphology also prove that the double-sided configuration can improve the corrosion protection of mild steel. It was discovered that by employing more coupling pads on both sides of the metal sheet, the excessive positive charge capable of producing oxidation of mild steel could be easily discharged.

1 Introduction

Corrosion issues have recently become a severe problem of industries, resulting in a plant shutdown and a significant loss. An electrochemical reaction occurs when water, oxygen, and ions (Cl⁻ and F⁻ ions) come into contact with metal [1-2]. As a result, some corrosion protection techniques have been developed, such as cathodic, sacrificial, corrosion inhibitors, and passive barrier protection; however, most of these techniques have limitations in conducting non-electrolyte corrosive conditions, especially in outdoor environments [3]. Cathodic protection (CP) is a corrosion-prevention technique that has been widely used to protect metals from corrosion. The main principle of this technique is applied impressed current, which induces negative steel polarization [4].

CP technique required a more electronegative external power supply or galvanized metal immersed in electrolytes. Unfortunately, CP does not work on metal exposed to the outdoor, as this creates an inductive environment that prevents electrical current from flowing from the anode to the cathode [5]. As a result, a new technique known as capacitive coupling corrosion potential (CCCP) has been developed as a suitable alternative for cathodic protection.

This method employs the exact capacitor concept, with a substantial amount of current supplied to the sample via an external power supply. To provide protection, CCCP does not rely on electrolytes. Instead, an electric current is impressed on the surface of a metal sample to protect it from oxidation as the surface charge increases. This experiment employs a squarewave input of electric current/voltage on mild steel via a coupler pad. Corrosion protection employs a concept capacitor. The squarewave current/voltage signal acts like an alternating current applied to the steel via a coupler pad, which serves as a capacitor plate, while the paint coating serves as a dielectric material. The purpose of this study is to determine the optimal setup configuration that will protect metal surfaces from outdoors corrosion.

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2 Methodology

Mild steel is the metal sample that needs to be protected from corrosion. The chemical composition of mild steel was investigated using optical emission spectroscopy, OES (Q8 Magellan, Bruker). Firstly, mild steel sheets are cut into pieces that measure 1.7 x 20 x 0.3 cm. After that, the mild steel sample was ground by SiC paper up to a grit of 600. In this experiment, the samples were sprayed with polymer-based paint, applied to the entire surface, with an exposed area measuring 2.0 cm x 1.5 cm.

The CCCP technique was conducted with different setup configurations during the experiment, i.e., single, double-sided and opposite arrangement. It is shown by the red circle that represents the coupler pad arrangements, as depicted in Fig. 1. The squarewave current/voltage signal was applied using a function generator (DG1022, Rigol). The coupler is made of copper sheets that have been trimmed to 1 X 2 cm and then connected by the copper wire. The sample's weight was assessed before and after the experiment to ascertain the amount of weight loss. After the CCCP experiment, the surface morphology was visually evaluated using a stereomicroscope.

3 Results & Discussion

3.1 Chemical composition

The chemical composition of the steel samples used in this study is shown in Table 1. Analysis of the chemical composition using an OES compared with the American Iron and Steel Institute (AISI). The results of the analysis found that the steel samples used can be classified as AISI 1016. In practice, when carbon steel contains a chemical composition of silicon of 0.10 wt. %, the steel is classified as killed carbon steel (or killed carbon steel). However, with a carbon content ranging from 0.12 to 0.18 %, the steel employed in this study falls under the category of semi-killed carbon steel. In general, steel belonging to the AISI 1016 classification is susceptible to chloride pitting and ion stress corrosion.
Table 1. The chemical composition of Mild steel (%).

| Element | Sample (%) | AISI 1016 |
|---------|------------|-----------|
| C       | 0.164      | 0.12 - 0.18 |
| Si      | 0.167      |            |
| Mn      | 0.679      | 0.60 - 0.90 |
| P       | 0.012      | ≤ 0.040    |
| S       | 0.011      | ≤ 0.050    |
| Cr      | 0.029      |            |
| Mo      | 0.0070     |            |
| Ni      | 0.036      |            |
| Cu      | 0.127      |            |
| Al      | 0.0067     |            |
| Co      | 0.013      |            |
| Fe      | 98.70      | 98.13 - 99.58 |

3.2 Current consumption

Generally, the electric current consumed by these three types of setup configurations is significantly different, as illustrated in Fig. 2. The opposite coupler pad arrangement consumes the most electrical current to feed the mild steel samples in the CCCP system. It records current densities ranging between 620 to 660 µA/cm². It is noted that the tendency of the electrical current curve on the opposite coupler pad arrangement increases over time, and it is not impossible for it to exceed 700 µA/cm² or higher after 72 hours of operation. In the meantime, the current consumption for a double-sided arrangement was kept stable between 580 and 605 µA/cm². From the first to the third day of the experiment, the current consumption stayed constant. Such findings show that double-sided coupler pads practically consume a stable electrical current. When viewed from the charging angle, such an arrangement successfully delivers a symmetrical capacitive charge on both sides of the capacitor plate, which is indeed the nature of a capacitor.

On the other hand, the electrical current consumption measured by the single-sided setup was the lowest throughout the experiment, ranging between 450 to 480 µA/cm². The use of a single coupler pad, which consumes only a tiny amount of current in activating the capacitive effect on the mild steel sample surface, is thought to be the reason for the lowest electric current consumption.

3.3 Weight loss

The weight of the mild steel sample was measured both before and after the experiment. The weight loss of mild steel for all three types of CCCP configuration setups is shown in Fig. 3. The fact that the sample with less weight loss than expected shows that it has outstanding corrosion resistance. The most negligible weight loss was found to occur in the double-sided arrangement, at just 5.4mg. Meanwhile, the weight loss reported in the single and opposite coupler pad setups is relatively significant, with 28.9mg and 14.3 mg, respectively. The results showed
that the double coupler pads arrangement might provide excellent corrosion protection for mild steel exposed. It allowed the charge to be dispersed uniformly across the mild steel surface, making this achievable. As a result, double-sided setups are the optimal configuration for the CCCP approach.

![Graph showing weight loss of mild steel sample for three types of configuration setups of CCCP.](image)

**Fig. 3.** The weight loss of mild steel sample for three types of configuration setups of CCCP.

### 3.4 Visual inspection

The effectiveness of the CCCP technique in confirming the presence of corrosion reactions against mild steel was evaluated through macroscopic inspection of the exposed area. Fig. 4 shows the image of mild steel sample (a) before and (b-d) after carrying out the CCCP experiment. It is seen in Fig. 4 (a) that a mild steel sample before the experiment is clean with no oxidation marks nor contaminant traced on the surface. In Fig. 4 (b) and Fig. 4(d), which are from single and opposite coupler pad arrangement setups, the brownish rust dominates on both surfaces. This brownish rust is an iron oxide deposit that formed uniformly due to the oxidation reaction of the mild steel atom on the surface. The uniform corrosion is getting severe as the sample is exposed to the moisture environment longer. However, in Figure 4 (c), the preparation of a double-sided coupler pad arrangement produces less rust on the sample surface. It can be said that by applying the double-sided setup, the oxidation rate is slower compared to others. Therefore, the double-sided setup provides better corrosion protection for the mild steel sample. Even though both double-sided and opposite coupler arrangement setups use two units of pads, the corrosion formed on the opposite configuration setup is more severe. When applying an opposite pad arrangement setup, the charge is distributed in the opposite direction, which subsequently disturbs the electron flow and creates non-uniform charge distributions on the sample surface. This certainly leads to a lower surface charge density and consequently hinders the corrosion protection to the surface.
4 Conclusion

The CCP system employs three configurations: single-sided, double-sided, and opposite-sided. The most efficient setup for the CCP technique is the double-sided setup. This setup provides a more stable current supply on mild steel samples with the lowest weight loss readings. Additionally, the both-sided setup shows the most negligible corrosion effects on the mild steel surface compared to other setups. This setup will be applied for the further experimental of CCP.

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