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Corrosion protection of mild steel using electroplating by chrome coating

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حماية الفولاذ الطري من التآكل باستخدام الطلاء الكهربائي بالكروم

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Abstract:
This study aims to investigate the protection of mild steel from corrosion in a seawater environment using electroplating. Mild steel samples measuring 1 × 4 × 0.1 cm were prepared, cleaned, and primed before the plating process. 0.2 M potassium dichromate ($K_2Cr_2O_7$) solution was used as the electrolyte for the electroplating process. The steel samples served as the cathode, and platinum electrodes as the anode, under a voltage of 7 V and a current of 1 A for 4 hours. Corrosion resistance was evaluated by measuring the weight loss of uncoated and coated steel samples after immersion in seawater for 24, 48, and 72 hours. The results showed that the uncoated steel samples experienced significant weight loss due to corrosion, with the rate of loss increasing with increasing exposure time. In contrast, the chrome-plated samples showed a significant reduction in corrosion, with plating loss after 24, 48, and 72 hours being approximately 0.0006, 0.0017, and 0.0020 grams, respectively. This demonstrates the effectiveness of the chrome coating in mitigating the impact of the marine environment on the steel. These results indicate that chrome electroplating is an effective method for enhancing the corrosion resistance of low-carbon steel in marine environments. It provides a protective layer that reduces metal loss and extends service life. The study also underscores the importance of controlling the electroplating conditions to achieve homogeneous coatings with high corrosion protection.

Keywords: Mild steel, corrosion, electroplating, potassium dichromate.

الملخص:
تهدف هذه الورقة إلى دراسة حماية الفولاذ منخفض الكربون (Mild Steel) من التآكل في بيئة مياه البحر باستخدام طلاء الكروم بطريقة الطلاء الكهربائي (Electroplating). تم تحضير عينات من الفولاذ منخفض الكربون بأبعاد (1 × 4 × 0.1 سم)، ثم تنظيفها وتجهيزها قبل عملية الطلاء. استُخدم محلول ثنائي كرومات البوتاسيوم ($K_2Cr_2O_7$) بتركيز 0.2 مولاري كإلكتروليت لعملية الترسيب الكهربائي، حيث استُخدمت عينات الفولاذ ككاثود وأقطاب البلاتين كأنود تحت جهد 7 فولت وتيار 1 أمبير لمدة 4 ساعات. تم تقييم مقاومة التآكل من خلال قياس الفقد في الوزن لعينات الفولاذ غير المطلية والمطلية بعد غمرها في مياه البحر لفترات مختلفة بلغت 24 و48 و72 ساعة. أظهرت النتائج أن عينات الفولاذ غير المطلية تعرضت لفقدان ملحوظ في الوزن نتيجة التآكل، حيث ازداد معدل الفقد بزيادة زمن التعرض. في المقابل، أظهرت العينات المطلية بالكروم انخفاضًا كبيرًا في معدل التآكل، إذ بلغ الفقد في طبقة الطلاء بعد 24 و48 و72 ساعة حوالي

0.0006 و0.0017 و0.0020 غرام على التوالي، مما يدل على فعالية طبقة الكروم في تقليل تأثير البيئة البحرية على الفولاذ. تشير النتائج إلى أن الطلاء الكهربائي بالكروم يُعد وسيلة فعالة لتحسين مقاومة التآكل للفولاذ منخفض الكربون في البيئات البحرية، حيث يوفر طبقة واقية تقلل من فقدان المعدن وتزيد من عمره التشغيلي. كما تؤكد الدراسة أهمية التحكم في ظروف الطلاء الكهربائي للحصول على طبقات متجانسة ذات قدرة عالية على الحماية من التآكل.
الكلمات المفتاحية: الفولاذ الطري، التآكل، الطلاء الكهربائي، ثنائي كرومات البوتاسيوم.

Introduction:

Low carbon steel, which is the most cost-effective type of steel, is commonly used in construction because it is easy to obtain, affordable, and has good mechanical qualities. However, it is very susceptible to corrosion, especially when it comes into contact with atmospheric oxygen in damp conditions. Mild steel, a common type of low carbon steel, remains one of the key materials used across many industries [1].

A typical way to address this problem is by modifying the surface with a thin protective metallic electroplating coating. There are several types of metallic electroplating coatings, such as chrome, which provide corrosion protection by applying a thin layer of metal with a more negative electrode potential than the base metal. These coatings are more resistant to corrosion than the underlying metal substrate [2,3].

One of the main industrial uses of chromium is electroplating, where metal surfaces are coated with a thin layer of chromium either for decorative purposes or to create a corrosion-resistant barrier. This application accounts for about 20% of the total chromium used by chemical industries [4].

Chrome (chromium) offers excellent corrosion resistance, especially when used in plating or as an alloying element, by forming a passive oxide layer that shields the underlying metal. It is highly resistant to atmospheric corrosion, moisture, and various acids such as citric and nitric [5].

The electrochemical processes involved in chromium corrosion in acidic conditions begin with activation corrosion, where chromium metal is oxidized to Cr^{2+} at low potentials (near the corrosion potential) before the surface potential is high enough for passive film formation. As the potential of the metal increases in the more noble direction, an active/passive transition typically occurs, leading to a reduction in the corrosion rate, followed by a passive region. At high potentials, trans passive dissolution occurs through the formation of Cr (VI) ions [6].

Faraday's law and its related equation govern the electroplating process. According to Faraday's law, the amount of electricity is directly proportional to the chemical activity or decomposition power. Electrochemical equivalents are the same as chemical equivalents. Moreover, several physical and metallurgical factors influence the rate of corrosion in metals [7]. The thickness of the coating is one of the physical factors affecting corrosion, and electrolyte conductance is strongly related to coating thickness. The quantity and speed of ions in electrolyte solutions are determined by electrolyte conductance; a higher resistance results in lower conductance [8].

Electroplating is one of the essential processes in the metal industry. The original purpose of electroplating was to enhance the mechanical and physical properties of base metals to increase their value.[9] The electroplating parameters must be carefully controlled during electrodeposition, as they significantly affect coating properties, deposition efficiency, and hydrogen evolution. In addition to current density, the pH of the bath and bath temperature are among the main electroplating parameters.[10]

Material and methods:

In this study, several mild steel samples were prepared. The samples were similar in certain properties, such as weight, size, and shape. More than one sample was prepared, and the readings were averaged. The samples were then cut into similar shapes with dimensions of 1 cm × 4 cm × 1 mm (with a surface area of 4 cm^2 per face), as shown in Figure 1.

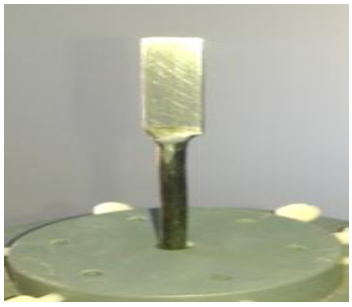

Figure. (1): Similar sizes of mild steel were placed in the middle of a food container and left for a limited period of one to two days, with and without paint.

Sample Preparation:

Manual cleaning was performed to remove dirt and surface impurities using black carbon sandpaper (P100 and P400, Figures 2 and 3).

The sample surfaces were also cleaned with distilled water to remove any remaining impurities.

1. Drying the sample by dryer and wait until it is cool.
2. Weight the sample of mild steel in a sensitive balance, and recording the first weight W_1(g).

The samples were cleaned by rubbing with carbon black sandpaper. and surface was cleaned with distilled water then sample was dried and allowed to cool, the sensitive balance was used to weigh a sample of mild steel, and the initial weight reading was recorded as W1 (g).

Figure (2)

Figure (3)

Potassium dichromate solution preparation:

Solution of $K_2Cr_2O_7$ was prepared following these steps:

The beaker was cleaned, washed, and dried, then placed on a magnetic stirrer. The beaker (1000 mL capacity) was filled with distilled water. The required amount of nickel chloride for the experiment was then calculated and weighed using a sensitive balance. The concentration was calculated **using the following relationship:**

- Molar Concentration = Number of Moles / Volume of Solution.
- The basis for this study was a solution volume of 1000 mL and a molar concentration of 0.2 mol/L.

From this, we can deduce that the number of moles of solvent is 0.2 mol. From the relationship between concentration and volume of solution, the mass of the sample can be calculated by multiplying the number of moles by the molecular weight of potassium dichromate (294.18 g/g mol). This gives the required amount of solvent, which is 58.836 g.

The material was then weighed until the beaker was full, resulting in the required concentration of the solution (0.2 mol/L).

Potassium dichromate $K_2Cr_2O_7$ dissolves in water to form a bright orange, homogeneous solution, dissociating into potassium (K^+) and dichromate ($Cr_2O_7^{2-}$)ions**.**

Figure (4): $K_2Cr_2O_7$ solution

At the cathode, chrome ions gain electrons and are reduced to form chrome metal atoms:

$$Cr^{+2} + 2e^- \longrightarrow Cr \qquad \text{Eq.1}$$

At the anode, chrome metal atoms lose electrons and are oxidized to form chrome ions:

$$Cr \longrightarrow Cr^{+2} + 2e^- \qquad \text{Eq.2}$$

These reactions occur simultaneously, with chrome ions being continuously supplied to the solution by the anode and deposited onto the cathode. The plating process can be controlled by adjusting factors such as the current density, temperature, and pH of the electrolytic solution.

Preparation of Electroplate Coating:

After preparing the samples and platinum, the mild steel and platinum are immersed in a beaker with 1000 ml of potassium dichromate solution, and then connected to a DC power source with the mild steel as the cathode (-) and the platinum as the anode (+) and as shown in figure (5). The current and time are recorded. After 4 hours, the immersed sample is removed from the beaker, and the mild steel sample is weighed with a sensitive balance. The second weight, W2 (g), is recorded. The weight of the plating is the difference between W2 and W1[10] **.**

The weight of coating film Δw (g) = $W_2 – W_1$

Figure (5): Criteria electroplate coating

Measurement of Weight Loss:

The coated samples are immersed in a 200 ml beaker of seawater, and the time of immersion is recorded, After specific time (1 and 2 days). Remove the immersed samples from the beaker. Weight the sample by a sensitive balance, and record the third weight W3. the loss in weight is difference between W2 and W3.

The weight loss ΔW (g) = $W_2 - W_3$

Results and Discussion:

Mild steel Corrosion testing before coating in a seawater environment:

When placed mild steel in the sea water, figure (6). It is directly in the ionization to give the iron ions dissolved in the solution (oxidation process), consumed by the hydroxide group formed by dissolved oxygen in the water to give a fragile layer of iron hydroxide on the surface of this layer is weak and easy to detach on iron, this process continues as long as iron ions are still produced.

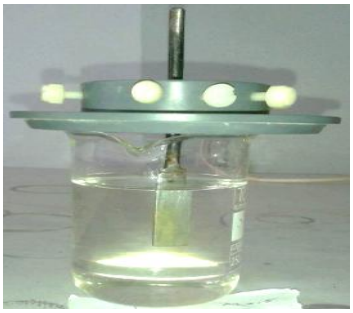

Figure (6): Mild Steel Specimen Immersed in Seawater during Corrosion Experiment

Mild steel samples were tested in seawater for a period of time of (24 hours) and (48 hours) to study weight loss and then compared with chrome-coated samples to determine the effect of the coating on the resistance of mild steel to corrosion. The following results were obtained in Table 1.

Table (1): Mild steel without protection in sea water environment

Specimen	Time exposure (hr)	W1(gr)	W2(gr)	Δw (gr)
1	24	26.7371	26.7253	0.0118
2	48	27.2460	27.1127	0.1333
3	72	26.8808	26.7285	0.1523
4	96	27.0003	26.8365	0.1638

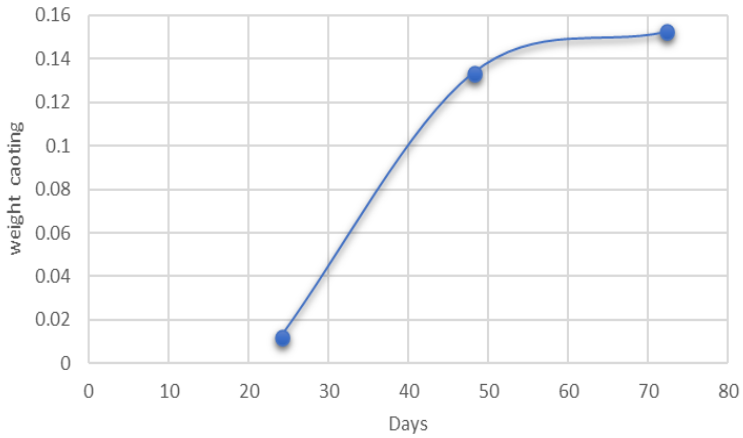

Figure (7): Mild steel without protection in sea water environment

Electroplate Coating of mild steel by chrome:
The chrome coating values are illustrated in table 2.

Table (2): Electroplate Coating of mild steel by chrome

Specimen	T (hr)	I(A)	V(v)	w1(g)	w2(g)	coating Δw (g)
1	4	1	7	24.8435	24.8485	0.0050
2	4	1	7	17.3238	17.329	0.0052
3	4	1	7	23.9016	23.9071	0.0055

Mild steel corrosion test in a seawater environment following coating:

Three samples of mild steel were tested in sea water for one, two and three days. It was found that the first sample decreased the weight of coating 0.0006 g, while the other sample decreased the weight of coating, 0.0017 and 0.0020 g.

The coating values are illustrated in table 3, so the protective layer was 0.0038, 0.0049 and 0.0035 that meaning in a corrosive seawater environment, the coating layer effectively prevented mild steel from corroding. Then the Protective layer of coating suitable for more exposure time of mild steel.

Table (3): Protection of mild steel in seawater after potassium chromate

Weight of Specimen (gr)	weight of the coating layer Δw (gr)	Time exposure (hr)	weight loss of coating(gr)	Protective layer (gr)
23.9016	0.0055	24 48 72	0.0006 0.0017 0.0020	+0.0049 +0.0038 +0.0035

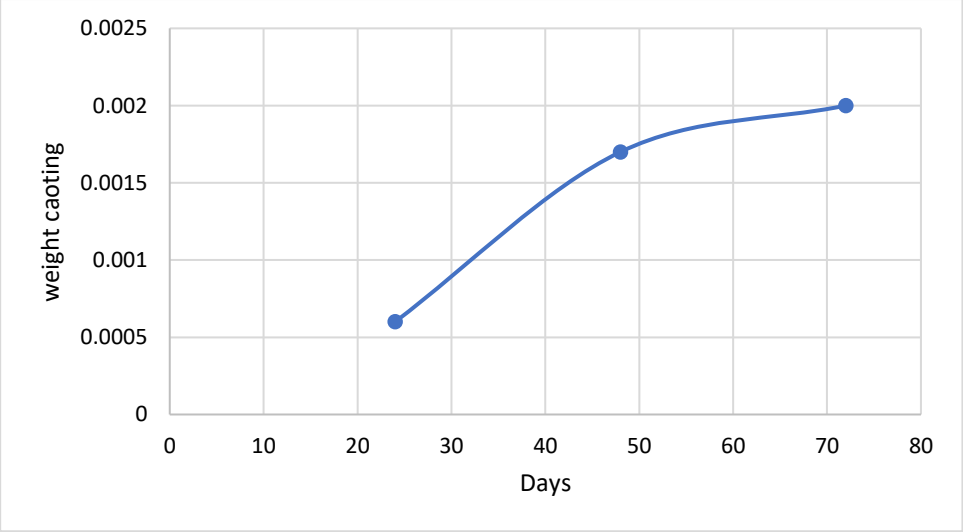

Figure (8): relationship between the number of days and the weight coating

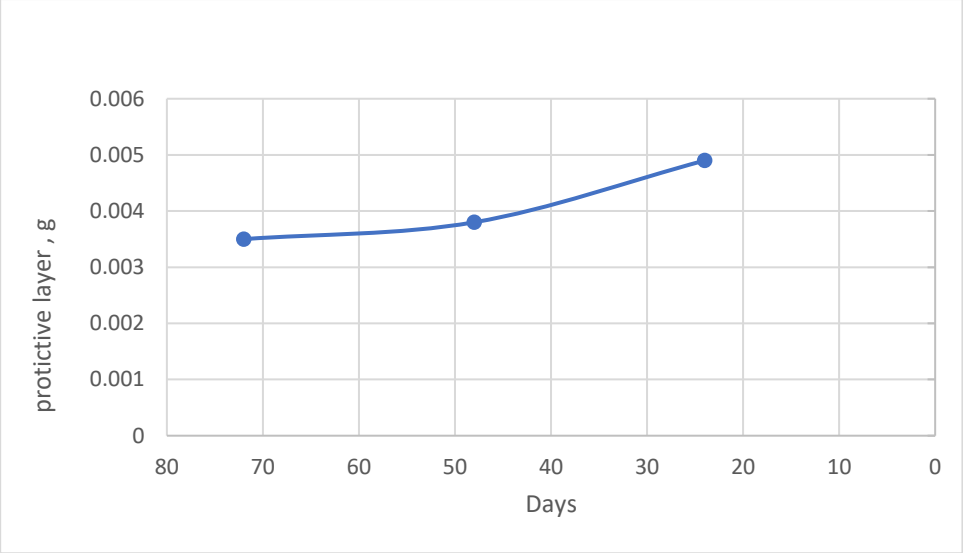

Figure (9): Protection of mild steel

Conclusion:

The following conclusions were reached during the course of the experimental investigation into the corrosion behavior of mild steel in a seawater environment:

1. The corrosion results of mild steel revealed that the weight loss obtained over time is sensitive to the seawater environment.
2. When exposed to seawater, Cr coatings exhibit exceptional corrosion resistance.
3. In a corrosive seawater environment, mild steel corrosion can be controlled by applying a chrome electroplating coating.

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