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The effect of adding Silicon Carbide microparticles to the optimum chromium plating on improving the corrosion resistance of carbon steel in concentrated sulfuric acid medium (98%)

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Abstract: In order to increase the working life of the carbon steel conveying concentrated sulfuric acid from the acid production stage to the storage tanks, the steel was coated with a composite coating of microparticles (SiC) embedded in chromium metal. The concentrations of silicon carbide relative to the volume of chromium solution were (10, 20, 30). Three tests were conducted to show the corrosion resistance in acid for five samples (Carbon steel(substrate),Cr-coating,Cr-10g/l SiC, Cr-20g/l SiC and Cr-30g/l SiC), simple immersion test, acid flow exposure test and electrochemical test (polarization test). The results of the corrosion tests confirmed the success of the coating process for carbon steel with composite coatings, especially when the amount of silicon carbide added was equivalent to (20) grams per liter of chromium solution.

Keywords: H_2SO_4 (98%), Chromium plating, Cr-Sic Composite coating, Erosion-corrosion effect, the optimum Chromium plating

1. Introduction

Corrosion is damage that affects the metal as a result of exposure to corrosive media so that the metal returns to its initial form before the extraction process in the form of ores so that it is at the lowest level of energy levels and then the amount of change in free energy is a value with a negative sign, evidence of the occurrence of the corrosion process spontaneously [1]. Corrosion may be the result of a chemical or electrochemical reaction due to the contact of the metal or alloy with a corrosive medium. It may happen in some engineering applications that the chemical effect of the corrosive medium coincides with the effect of changing the physical state of the medium so that the medium is in a state of continuous movement and at a fairly high speed, which causes collapse and erosion of the metal surface layers because this combined effect is greater than the case in which the sum of both effects Chemical and physical alone, where this effect is known as (synergistic effects).This failure occurs in pipes carrying petroleum products and chemicals[2]. In the concentrated sulfuric acid plant (98%), carbon steel is subjected to corrosion due to the nature of this acid as a corrosive medium, but the nature and severity of the corrosion vary depending on the physical state of the acid. In which the acid state is stagnant, as in the storage tanks of the final product, and the reason for this is due to the formation of a layer of ferrous sulfate as a result of the reaction of acid with steel, where this layer is insulating the metal from acid and reduces the rate of corrosion of steel, but the problem appears and the corrosion becomes severe in the case in which it is The acid is mobile and at a high speed, as in the tubes that transport the acid, where the current sweeping the moving mass of acid at a high speed breaks and breaks the ferrous sulfate layer and does not allow it to take enough time to form and from it the action of the acid is strong and fast in removing the layers of steel, which caused the surface to erode and thus collapse The occurrence of cracks, collapse and failure of pipes[3,4]. In order to reduce corrosion damage due to exposure of the metal surface to currents of the corrosive medium, surface modification technology was used so that this modification creates new properties for the surface or increases the values of the original properties of the surface to be of high resistance to corrosion by isolating the metal from the corrosive surroundings and increasing the surface hardness and raising the resistance to erosion and this is obtained from the use of deposition of composite coatings of inert ceramic particles fused with metals on the surface of the base metal (substrate)[5].

The aim of this research is to show the extent of improvement that occurs to carbon steel in a medium of concentrated sulfuric acid when it is coated with composite coatings of chromium and silicon carbide microparticles.

2. Experimental work

The chemical formula in Table (1) was used as a substrate for the purpose of plating chromium on it. The surface of the steel was prepared by smoothing with sandpaper of a degree (400,600,800,100,1200,1500,2000 and 2500), then polishing with diamond paste, then immersion in acetone, followed by immersion in hydrochloric acid at a concentration (10%) for a period of (15) seconds. Chromium plating solution consists of chromium III with concentrated sulfuric acid (98%) with a ratio of (1:100), respectively. The chrome electroplating process was carried out according to the conditions shown in the table (2).

Table (1): Chemical composition of carbon steel (substrate)

C %	Si %	Mn %	P %	S %	Cr %	Mo %	Ni %	Cu %	Fe %
0.4	0.3	0.82	0.01	0.01	0.08	0.02	0.13	0.19	Rest

Table (2): Process conditions of Chromium electroplating

Process conditions	
PH	2
Deposition temperature(°C)	(40,50,60)
Deposition time (hours)	(1,1.5,2)
Distance between electrodes (cm)	5
Voltage (volts)	4.5
Magnetic stirring(rpm)(S.V.)	300
Current density (Am/dm^2)	20

In general, electrodeposition entails the dissolution of a metal to the positive electrode in an electrolytic solution containing ions of the same dissolved metal, where a constant electric current passes from the positive electrode to the electrolyte solution, where the electric charge is discharged at the electrode of the other metal, which is the cathode. The operating current is generated by applying an external voltage differential between the two electrodes, with the anode electrode having a positive charge and the cathode electrode having a negative charge. Positive metal ions in the solution tend toward the negative electrode (the cathode), whereas negative metal ions gravitate toward the positive electrode (the anode), resulting in an electric current [6]. (9) Experiments were carried out based on Takeuchi's design (the gray method) according to two variables of the chrome plating process, which are the temperature of the plating solution and the plating time, and with three levels of temperature and time as shown in the table (3).

Table (3): Influential variables and their levels

Parameters	**levels**		
Temperature (°C)	40	50	60
Time (hour)	1	1.5	2

3. Grey relational analysis (GRA)(statistical analysis method)

Grey Relational Analysis is a popular technique for monitoring relationships between different data sets. It is also utilized to make selections in multi-attribute situations. The key advantages of Grey Relational Analysis are that it is based on original data, that it is straightforward to calculate, and that it is one of the greatest tools for making business decisions. Grey Relational Analysis compares variables quantitatively in a complicated fashion using information from the Grey System. This strategy develops links between variables based on their similarity and variability [7]. The GRA technique consists of converting the output of all choices into a sequence of comparability, which is known as grey relational generating. Based on these sequences, a reference sequence (ideal target sequence) is defined. The grey relational coefficient is then computed for all comparability sequences and the reference sequence. Lastly, using these grey relational coefficients, the grey relational grade between the reference sequence and each comparability sequence is calculated. A comparability sequence translated from an alternative with the highest grey relational grade between the reference sequence and itself is the best option. Figure (1) depicts the techniques for grey relational analysis [8].

The stages in Grey Relation Analysis are as follows: [8]

- It is necessary to specify quality characteristics, often known as issues and response variables.
- The procedure for gathering data.
- Data should be standardized in such a way that the lower the number, the better the quality attributes, and the larger the number, the worse the quality qualities.
- Calculate the grey connection coefficient using normalized data.
- Determine the grade of a grey reference.
- Choose the surest bet according on the grade value.

The adjusted value (Xi* (k)) for a higher, greater feature is given by equation (1).

$$Xi^*(k) = \frac{Xi(k) - \min Xi\ (k)}{\max Xi(k) - \min Xi\ (k)} \qquad (1)$$

The adjusted value (Xi*(k)) is provided by equation for the lower the better quality characteristic (2).

$$Xi^*(k) = \frac{\max Xi\ (k) - Xi(k)}{\max Xi\ (k) - \min Xi\ (k)} \qquad (2)$$

Where xi (k) is the originating sequence, $Xi^*(k)$ is the adjusted value of xi(k), min xi (k) is the lowest number of xi (k) for the k^{th} response, and max Xi(k) is the highest amount of xi(k) for the k^{th} responding; k=1, 2,..., n.

When processing data, it is critical to establish a link between ideal and real normalized experimental values. It is accomplished by calculating the grey relational coefficient, which may be calculated using the formula below: [7]

$$\S i\ (k) = \frac{\Delta \min + \beta\, \Delta \max}{\Delta 0i(k) + \beta\, \Delta \max} \qquad (3)$$

$$\Delta 0i\ (k) = |\ X0^*(k) - Xi^*(k)\ | \qquad (4)$$

Where $\Delta 0i(k)$ is the deviation sequence of the reference sequence $X0^*(k)$ and the comparability sequence $Xi^*(k)$.

Δ min is the smallest divergence; Δ max is the highest standard deviation. β is the coefficient of differentiation or identification. If all of the parameters are prioritized equally, it is taken as (0.5).

The grey relational grade is determined by plugging each outcome characteristic's grey relational coefficients into the formula below [8].

$$\delta i = \frac{1}{n} \sum_{k}^{n} \S i(k) \qquad (5)$$

Where i = 1, 2, 3,... 9 (the L_9 orthogonal array is chosen), **§**i (k) is the Grey relational coefficient of (k^{th}) response in the i^{th} experiment, and(n) is the number of responses, and(δi) the grey relational grade for the(i^{th}) trial, and (n) is the quantity of execution attributes.

Analysis of variance (ANOVA)

The analysis of variance (ANOVA) is used to discover which process parameters have a significant impact on quality. Using the Grey relational grade value, ANOVA is recommended for identifying significant components. Along with the degree of freedom (DF), the mean of squares (MS), the sum of squares (SS), the F-ratio, the p-value, and the contribution (C) were displayed. The bigger the percentage contribution, the greater the influence on output qualities [7] .

4. Mechanical tests

The mechanical tests for metallic chrome plating included three tests for each sample of plating for nine experiments according to the changing plating conditions (temperature of the plating solution and the time of plating), considering the results of the tests represent the outputs of the plating process, which are used in the statistical analysis of the outputs and the impact of factors on the properties of chrome plating, on the basis of which the obtaining the optimum coating conditions and then using the optimum conditions to generate a composite coating of chromium with silicon carbide particles of different concentrations(10,20,30)g/l.

4.1 Hardness test

This check was doing in the lab of the mechanical features estimating. There were three readings for each test sample and the average was taken for the readings. The load used in the micro-hardness test is equal to (25g) for 30 seconds as a load applying period.

4.2 Coating thickness test

The investigation was carried out in the lab of the Department of Polymer Engineering and Petrochemical Industries utilizing (Digital Coating Thickness Gavage (TT260)), where the average thickness was extracted for six values of the surface for each model.

4.3 Coating roughness test

The rough outer layer of the coating layer was measured in the (Lab of Metallurgical Engineering Department) using a harshness tester type (HSR210). A harsh check of six readings was performed, and the rate for these readings was recorded. This technique was used to measure the tribological properties of carbon steel (substrate) and the rough of metallic coatings composed of Chromium metal for nine coating samples, which represent experiments in which optimal coating conditions were established using statistical analysis.

5. Structure checks of the coating layer

5.1 Energy-dispersive, X-ray, spectroscopy, (EDS,) test

This technique is used to obtain the elements of, samples in order to determine the characteristics and behavior of the samples based on the type and amount of elements present in the samples. The components of the chemical composition of the substrate (carbon steel), metallic chromium plating (Cr-plating) and chromium composite coatings with different concentrations of silicon carbide (Cr-SiC) were examined to show the chemical composition of the components of the coating layers and their effect on the extent of corrosion resistance.

5.2 Scanning Electron Microscope (SEM)

This examination is characterized by greater accuracy than examination with a scanning electron microscope, as it uses electrons instead of light. Through this examination, the layers of coating that were deposited on the surface of the substrate are studied and the effect of the difference in the concentration of ceramic particles on the shape and appearance of the surface is analyzed.

6. Corrosion tests

6.1 Simple immersion weight loss test

This test includes immersion of samples (carbon steel as a base metal, chromium-coated carbon steel and chromium-coated carbon steel with different concentrations of silicon carbide (Cr-(10, 20, 30) g/l SiC) in concentrated sulfuric acid (98%).

The corrosion rate is calculated by the weight loss method according to the equation (6) below: [9].

$$\text{Corrosion rate} = \frac{\Delta W}{t.A} \qquad (6)$$

ΔW: It represents the difference in weight between the starting weight (W0) and the weight after immersion (W1), which is equal to (W0-W1).A: Acid-exposed surface area (cm^2).

t: Acid exposure time (day).

6.2 Erosion-corrosion test in concentrated Sulfuric acid

This test was carried out at the factory site where the corrosion problem is required to be treated. This test involves exposing the samples to the effect of (Erosion-Corrosion) on the surface of the metal as a result of the movement of the concentrated acid (that is, this test is the opposite case to the immersion test), which results in the study of the behavior of the metal due to the impact of the acid mass on the surface as a physical action of movement with the chemical effect of the acid as a corrosive medium. The testing mechanism depends on the presence of a tube to transfer the concentrated acid from the factory to a tank, where it is used to check the extent of (Erosion-Corrosion) resistance of the samples.

The acid transport tube has a diameter of (25) mm and a flow rate of (100) m^3/hr, a temperature of (65°C). The density of acid is (1.84) kg/m^3. In order to fix the samples in the acid collection tank, stripes of Teflon resistant to concentrated sulfuric acid were used by cutting two symmetrical strips. Making holes in the Teflon strips with a diameter less than the diameter of the test samples and then fixing each stripe on a carbon steel plate with bolts and nuts as shown in figure(1).

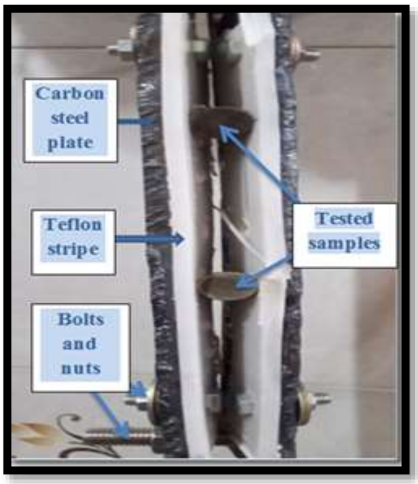


Fig (1): The mechanism of fixing samples for (Erosion-Corrosion) test in concentrated sulfuric acid

Samples, Teflon strips and carbon steel plates are all one piece. The test system is suspended under a hollow cylinder located on a vertical line with the tube from which the concentrated acid comes out to be poured into the tank, and thus the acid will pass through the test samples and cause (Erosion-Corrosion) on the surface of the test samples as shown in fig(2) .

With this test mechanism, we have established similar conditions to what the acid transport tubes are exposed to in the test samples. The acid passes over the test samples under operating conditions similar to the acid flow in pipes in that it is a corrosive medium at a specific speed and temperature. To estimate the corrosion rate in this test, we use the equation (6) and apply the same steps as in calculating the corrosion rate in the immersion test.

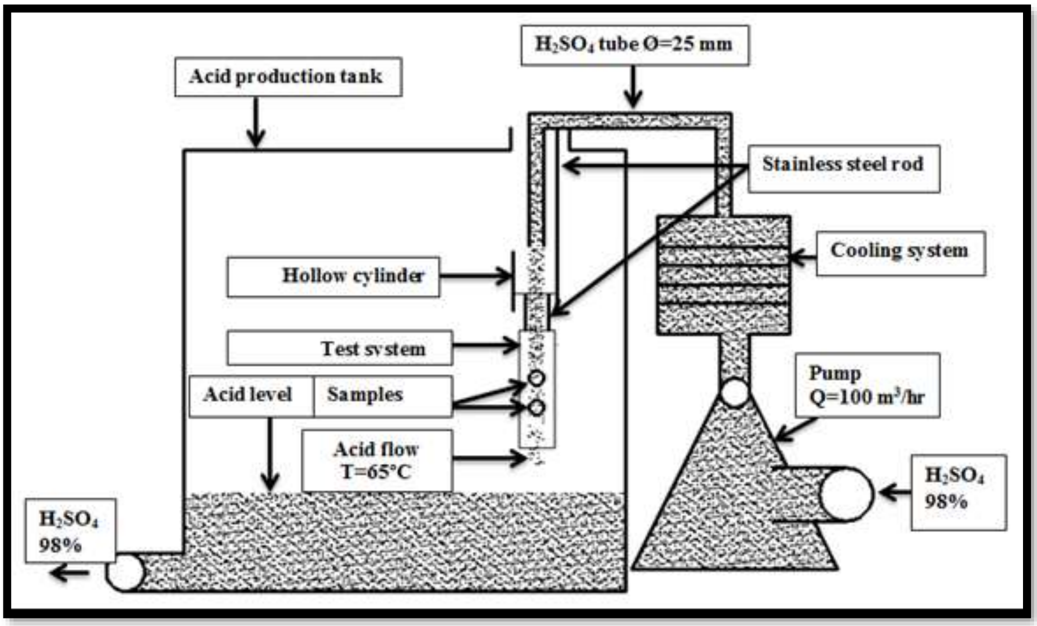


Fig (2): Diagram showing the mechanism of the (Erosion -corrosion) examination

6.3 Electrochemical test (polarization test)

This type of examination includes the electrochemical test of the corrosion rate based on the extraction of the value of the corrosion current and the corrosion potential difference for the samples under examination based on Tafel extrapolation as shown in Fig(3) where the test container contains (500 ml) of concentrated sulfuric acid as a solution in which the test was carried out and the first three electrodes It includes carbon steel (the base metal without a protective layer), carbon steel coated with chromium metal plating and the base metal coated with chromium composite coatings with different concentrations of silicon carbide particles where this electrode represents the working electrode and the second platinum electrode as a counter electrode and the third electrode as a reference electrode from (Ag/AgCl). The linear potential sweep was done at a (-0.250 to +0.250) V potential range around the observed OCP, from the cathodic to the anodic side, at scan rates of (1) mV/s, to acquire polarization curves potentiodinamically. After immersion, the open circuit potential (OCP) was recorded, and polarization measurements were taken once the OCP had stabilized.

Fig (3): Polarization test in concentrated Sulfuric acid

Corrosion current values can be calculated using electrochemical cells and polarization measures, such as Tafel extrapolations or polarization testing. We can calculate the corrosion rate of the samples, according to ASTM G102-89 [10]. This equation can be written as follows:

$$\textbf{Corrosion Rate (mpy)} = \frac{0.1288 \times I_{cor.} \times (EW)}{A \times \rho} \qquad (7)$$

0.1288: conversion factor for metric and time ((mpy g)/ (µA cm))

Icor. : Corrosion current (µA)

A: acid exposed area in (cm^2), which be equal for all samples (1.13) cm^2

ρ: Sample density (g/cm^3) for carbon steel (7.87 g/cm^3),for Chromium coating (7.19g/cm^3), Cr-10g/l SiC (6.47g/cm^3), Cr-20g/l SiC (6.59g/cm^3), Cr-30g/l SiC (5.36g/cm^3). The densities of Chromium coating and composite coating were estimated according ASTM G102 [10], depending on (EDS) Analysis for samples.

EW: equivalent weight, these values can be calculated according to ASTM G102-89 as the formula below: [10]

$$EW = \frac{1}{\sum \frac{nifi}{wi}} \qquad (8)$$

fi: the element's mass fraction in carbon steel and electroplating samples.

wi: the element's atomic weight in carbon steel and electroplating samples.

ni : the element's valence in carbon steel and electroplating samples.

For carbon steel EW=19.4, for Cr-coating EW=26.7, for Cr-10g/l SiC (EW=19.9), for Cr-20g/l SiC (EW=13.3).for Cr-30g/l SiC (EW=6).

7. Result and discussion

7.1 Chromium coating properties

In the table (4) that shows the results of the tests for the chrome plating layer on carbon steel (coating hardness, coating thickness and coating surface roughness) and for nine experiments and according to the gray method for Taguchi design, as well as the table (5) which shows the analysis of variance (ANOVA) for the effect of temperature and coating time on the coating process experiments.

Table (4): Electroplating experiments and coating properties

Exp.No.	**Temp(°C)**	**Time(hr.)**	**Hardness (Vickers) HV (Kg/mm^2)**	**Thickness(µm)**	**Roughness(µm)**
1	40	1	432	11.66	0.043
2	40	1.5	521	13.08	0.052
3	40	2	602	16.98	0.060
4	50	1	512	13.85	0.073
5	50	1.5	707	16.76	0.090
6	50	2	740	20.91	0.098
7	60	1	464	11.83	0.065
8	60	1.5	536	15.56	0.081
9	60	2	644	18.65	0.101
Carbon steel(substrate)			209		0.0112

Table (5): ANOVA Table for coating (hardness, thickness, roughness)

Output	Head	DF	SS	MS	MS	F	P	Contribution%
Hardness	Temp	2	30040	30040	15020	13.16	0.017	33
	Time	2	56678	56678	28339	24.83	0.006	62.1
	Residual Error	4	4564	4564	1141			4.9
	Total	8	91283					100
	R-Sq.= 95%							
	Temp	2	16.081	16.081	8.0407	18.79	0.009	20.2
	Time	2	61.967	61.967	30.9835	72.40	0.001	77.7

Thickness	Residual Error	4	1.712	1.712	0.4279			2.1
	Total	8	79.76					100
	R-Sq.= 97.85%							
Roughness	Temp	2	0.002211	0.001105	0.002211	41.97	0.002	66.3
	Time	2	0.001016	0.000508	0.001016	19.29	0.009	30.5
	Residual Error	4	0.000105	0.000026	0.000105			3.2
	Total	8	0.003332					100
	R-Sq.= 96.84%							

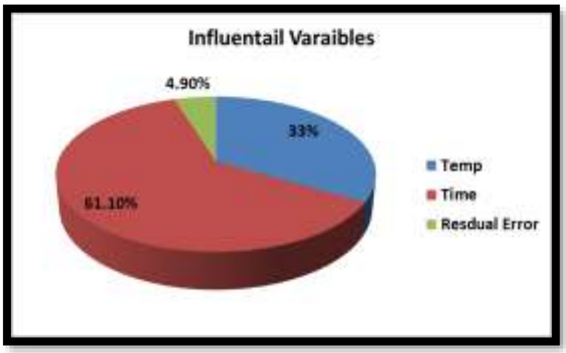


Fig (4): Percentage contribution for hardness

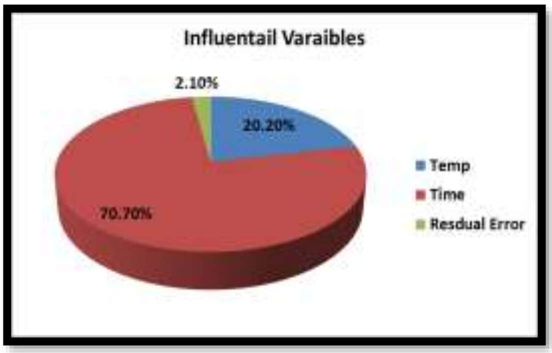


Fig (5): Percentage contribution for thickness

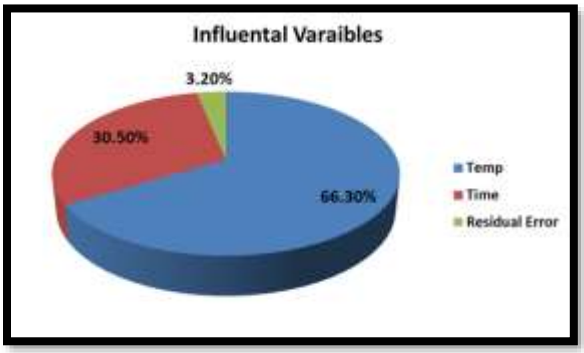


Fig (6): Percentage contribution for hardness

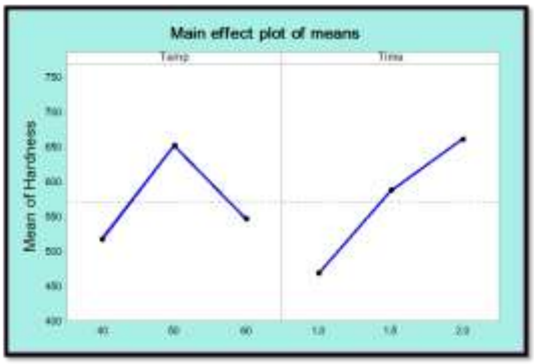


Fig (7): Effect of factors on coating Hardness

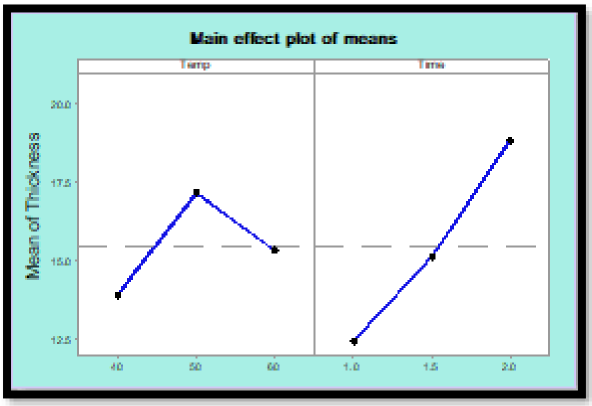


Fig (8): Effect of factors on coating Thickness

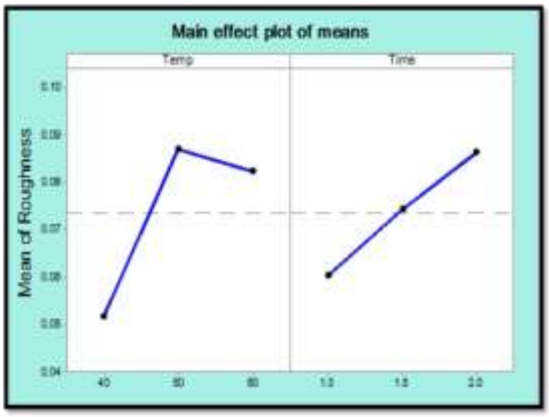


Fig (9): Effect of factors on coating Roughness

(P value) probability value for temperature (0.017) and time (0.006) that is smaller than (0.05) ($p< 0.05$) for both plating process variables (temperature, time), implying that (temperature, time) have a substantial effect on coating layer hardness. Time (24.83), temperature (13.16) (F-ratio).The values indicate the degree of the variance in the influence of the coating process parameters, as we find that the time of the electroplating process has a bigger influence on the hardness of the chrome plating than the coating temperature. The probability value for both plating process factors (temperature, time) is ($p< 0.05$), indicating that (temperature ($p=0.009$) and time ($p=0.001$) have a significant impact on the thickness of the coating layer as shown in fig (4) . 'The (F-ratio) This number represents the amount of variation in the influence of coating process parameters on the thickness of the chrome coating layer, as shown by the fact that the electroplating process time (F-ratio=72.4) has a greater influence on the chrome coating layer thickness than the coating temperature (F-ratio=18.79) as shown in fig (5). (P value) probability value is ($p < 0.05$) for both variables of the plating process (temperature ($p=0.005$), time ($p=0.018$)), which gives us the conclusion that (temperature, time) the harshness of the covering layer is strongly influenced. (Proportion of fisher) . This value gives an indication of the extent of the variation in the influence of the parameters of the coating process as we found that the temperature (F-ratio=41.97) of the electroplating process has a greater effect than the time (F-ratio=19.29) of the coating on the roughness of the chrome coating layer as shown in fig (6).

In figure (7), the hardness values of the chrome plating layer rise with the temperature up to the temperature (50°C) and then begin to decrease between (50-60) ºC. With increasing temperature, the hardness of the chromium deposited increases while the particle size of the chromium deposited decreases. The results showed scarcely detectable variations between 50°C and 60°C. This observation leads us to believe that this electrochemical process might be carried out at 50°C without causing significant changes in the end product, so decreasing the generation of acid mist, which is common at higher temperatures, and thereby benefiting the environment [11]. As for the time factor, we notice that the hardness of chromium increases with the increase in the depositing time, as the time will be sufficient to precipitate the largest amount of chromium ions on the surface of the piece to be coated. By extending the deposition time, the hard chromium layer becomes more coherent and thicker [12]. As shown in figure (8), the thickness of the chromium coating layer increases with increasing temperature up to 50°C, then the thickness decreases with increasing temperature to 60°C. The drop in cathodic film thickness as temperature rises is owing to a decrease in the viscosity of the cathodic film, which promotes a more uniform distribution and a faster rate of dissolution [11]. The thickness of the coatings grows as the coating duration increases. According to Faraday's law, as the amount of coating time rises, the thickness of the coated metal increases [12]. As shown in figure(9) the surface roughness increase with increasing temperature (40-50)ºC ,then be decrease at (60) ºC . As the temperature of the chromium plating solution increases, the surface roughness values of the plating layer rise as a result of the process of depositing chromium ions on the surface of the cathode (the work piece), but a decrease in the amount of surface roughness occurs when the temperature rises above (50) ºC . When electroplating hard chrome, the temperature should be higher than 50°C. These high temperatures are essential to avoid the formation of abrasive deposits at elevated sedimentation rates [13]. The relationship of the surface roughness of chrome plating is directly proportional, as the surface roughness increases with the growth of chromium granules with an increase in the time of deposit of chromium granules on the surface of the plating sample [14].

According to equations (1) and (2) the output values of the chromium plating process have been modified in order to unify all the output values for each experiment between (zero to one) where the equation (1) is used for the values of hardness and thickness of the coatings, considering that the preferred values for these larger outputs are the best, and the equation (2) is used for the surface roughness values for coatings on the basis that the least is the best according the results of schedule (6).

Table (6): Adjusted magnitudes of the outputs of the chromium plating process

Exp. No.	Hardness	Thickness	Roughness
1	0	0	1
2	0.288961	0.153514	0.844828
3	0.551948	0.575135	0.706897
4	0.25974	0.236757	0.482759
5	0.892857	0.551351	0.189655
6	1	1	0.051724
7	0.103896	0.018378	0.62069
8	0.337662	0.421622	0.344828
9	0.688312	0.755676	0

The deviation sequence was calculated using equation (4), and the findings are illustrated in Schedule (7).

Table (7): The deviation sequence calculation

Exp. No.	**∆0i (Hardness)**	**∆0i(Thickness)**	**∆0i(Roughness)**
1	1	1	0
2	0.711039	0.846486	0.155172
3	0.448052	0.424865	0.293103
4	0.74026	0.763243	0.517241
5	0.107143	0.448649	0.810345
6	0	0	0.948276
7	0.896104	0.981622	0.37931
8	0.662338	0.578378	0.655172
9	0.311688	0.244324	1

GRC (Grey Relational Coefficient §i (k)) is computed from the normalized data after data pre-processing to build a relationship between the preferred and real data. Where using the eq.(3) to find a value for the output values Grey Relational Coefficient as listed in the table (8)

Table (8): Grey relational coefficient values

Exp. No.	**Grey Relational Coefficient (GRC)(§i(k))**		
	(§i(1))Hardness	**(§i(2))Thickness**	**(§i(3)Roughness**
1	0.333333	0.333333	1
2	0.412869	0.371337	0.763158
3	0.527397	0.54062	0.630435
4	0.403141	0.395807	0.491525
5	0.823529	0.527066	0.381579
6	1	1	0.345238
7	0.35814	0.337468	0.568627
8	0.430168	0.463659	0.432836
9	0.616	0.67175	0.333333

According to equation (5), table (8) contains the values of the Grey Relational Coefficient. We'll calculate the Grey Relational Grade for each experiment (GRG).Experiment number six has the greatest GRG, indicating that it is the most successful.

Table (9): Shows the results

Experiments	**GRG (δi)**	**Run**
1	.555556	4
2	.515788	6
3	.566151	3
4	.430158	8
5	.577391	2
6	**.781746**	**1**
7	.421412	9
8	.442221	7
9	.540361	5

The ideal process parameters are at the level with the highest GRG, as shown in table (10).

Table (10): Table of responses for the grey relationship grade

parameters	**GRG**			**Principal influence**	**Run**
	level 1	**level 2**	**level 3**		
Time	.4827	.5313	**.6448***	.1621	1
Temp	.5611	**.6075***	.4903	.1172	2
The grey relational grade's total mean value β_m= 0.552866					
(*)optimal GRG levels					

At optimal factors (Temperature (50°C), Time (2 hr.), table (11) It shows the estimated values of the properties of the coating layer by taking advantage of the equations (1),(2) and (3) compared to the practically calculated values. As well as the predicted error which obtain from the equation (9).

$$\text{Predicted error \%} = \frac{\text{Estimated value} - \text{Predicted value}}{\text{Estimated value}} \qquad (9)$$

Table (11): Estimated versus prediction values of Chromium coating

Cr-coating property	**Estimated value**	**Predicted value**	**Predicted error %**
Vickers hardness	740	741.889	0.255
Thickness	20.91	20.5444	1.748
Roughness	0.098	0.0996667	1.02
GRG	0.781746	0.759227	2.2519

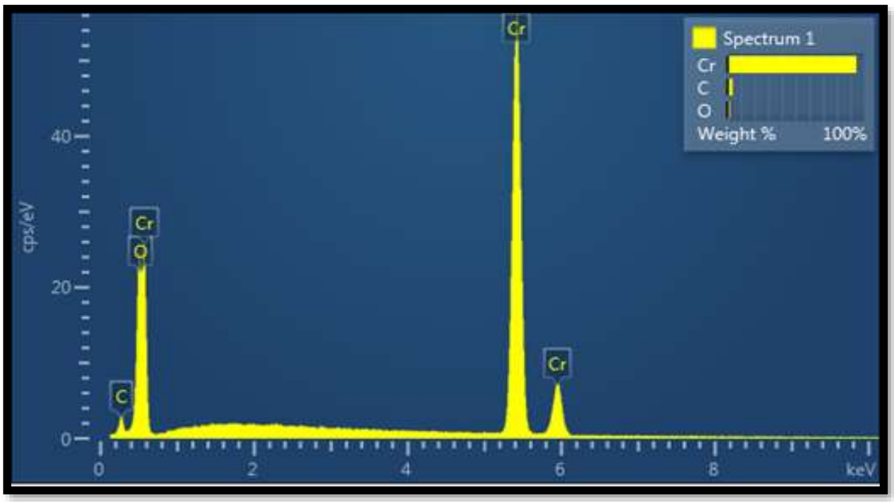


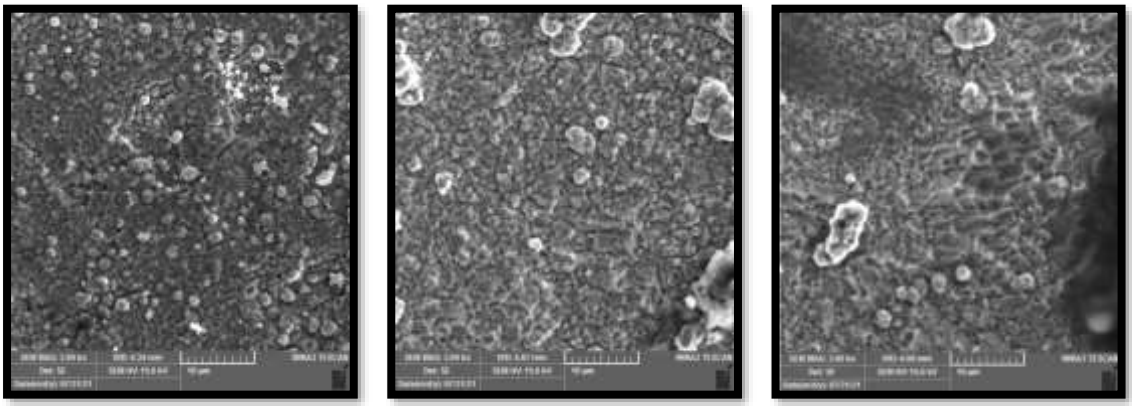
Fig (10): EDS analysis of optimal Chromium coating

For the purpose of obtaining composite coatings, chromium plating was carried out with silicon carbide particles based on the optimum factors for chromium coatings (temperature and time of the plating process), which were extracted by using the gray method for statistical analysis, where the deposited temperature was (50°C) with deposited time (2 hours). With a change in the proportions of silicon carbide (SiC) added. The values of the tests for the layer of composite coatings (Cr-Sic) are shown in table (12).

Table (12): (Cr-SiC) composite coating properties

Cr-Sic (g/l)	Vickers Hardness H.V. (Kg/mm^2)	Roughness(µm)	Thickness(µm)
10	766	0.087	10.67
20	902	0.421	17.74
30	665	0.158	12.9

From the table (12) we notice that the properties of the composite coating layer of silicon carbide particles integrated within the chromium metal has decreased when the concentration of silicon carbide became equivalent to 30 grams per liter of chromium plating solution. The ability of the solution's driving velocity to raise these particles for the purpose of achieving their amalgamation with chromium ions and their adhesion with the required efficiency on the surface of the sample to be coated (the cathode electrode) compared to the lower concentrations of the same substance and solution, which generated a poorly formed coating layer, as shown in fig(11) (the scanning electron microscope images of the surface of the composite coatings.



Cr-10 g/l SiC Cr-20 g/l SiC Cr-30 g/l SiC

Fig (11): Scanning electron microscope images of the surface of the composite coatings

7.2 Results of Erosion- Corrosion test

In the table (13) the values of corrosion rates in the (Erosion-Corrosion) test in the center of concentrated sulfuric acid under flow conditions and a temperature of (65)°C to show the extent of the effect of the samples under examination on the effect of acid flow depending on the amount of weight loss during the area exposed to the acid in a time of (30) days of each model and extracting the erosion rate of the models during one day with drawing a relationship between the amount of corrosion rate over time as shown in the figure (12).

Table (13): The improvement of corrosion rate for (Erosion-Corrosion) test

Samples	Corrosion Rate(g/cm^2.day)	IP%
Carbon steel	152×10^{-5}	–
Chromium coating	114.7×10^{-5}	24.53
Chromium coating- 10 g/l SiC	41.7×10^{-5}	72.56
Chromium coating- 20 g/l SiC	30×10^{-5}	80.26
Chromium coating- 30 g/l SiC	61×10^{-5}	59.86

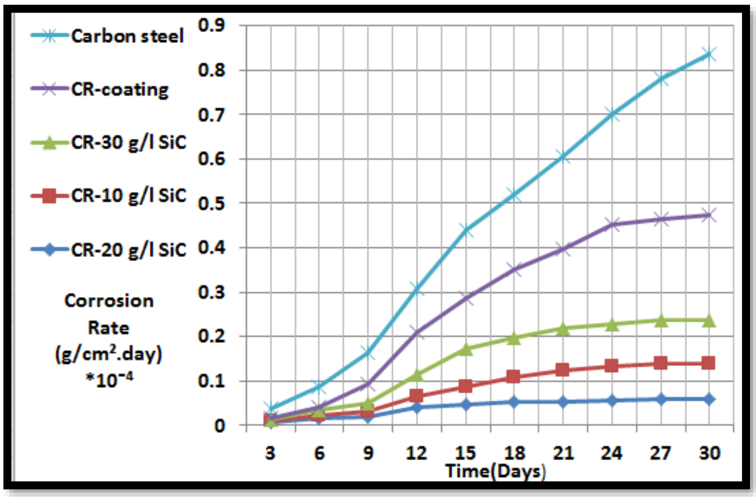


Figure (12): The relationship between corrosion rates for samples with time in (Erosion-Corrosion) test

7.3 Immersion corrosion result

In the table (14), which includes the results of the corrosion rates of samples in the immersion test in concentrated sulfuric acid (98%), where the results depend on the amount of weight loss of the area exposed to the acid during a time of (30) days of each sample. Also, a relationship was drawn between the corrosion rates of the samples over time, as shown in the figure (13).

Table (14): The improvement of corrosion rate (Immersion test)

Samples	Corrosion Rate(g/cm^2.day)	IP%
Carbon steel	31.2×10^{-5}	–
Chromium coating	13.5×10^{-5}	56.73
Chromium coating- 10 g/l SiC	10.2×10^{-5}	67.3
Chromium coating- 20 g/l SiC	7.19×10^{-5}	76.95
Chromium coating- 30 g/l SiC	14.6×10^{-5}	53.2

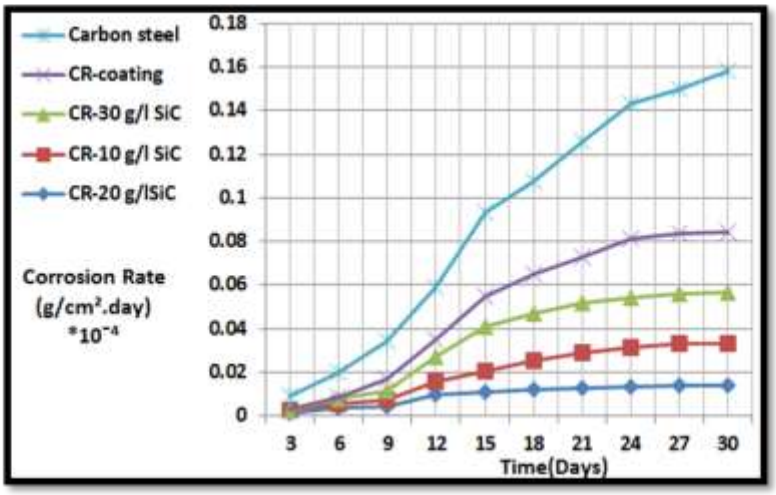


Figure (13): The relationship between corrosion rates for samples with time in (Immersion Corrosion) test

Figure (14): Comparison of test samples (Erosion-corrosion) in concentrated sulfuric acid (A: (Cr-20 g/l SiC) coating, B: (Cr coating), C: Carbon steel (substrate))

7.3 Polarization test results

The polarization test for samples in concentrated sulfuric acid (98%) includes obtaining voltage readings (V) and current (A) where the relationship between the voltage and the logarithm of the current is drawn, and then a Tafel extrapolation is made on the resulting curve by the intersection of the contact lines for both the cathode and anode curves, where the coordinates of the intersection point represent the corrosion voltage and the corrosion current by dropping the point on the axis of voltage and axis of current, respectively As shown in the figure below.

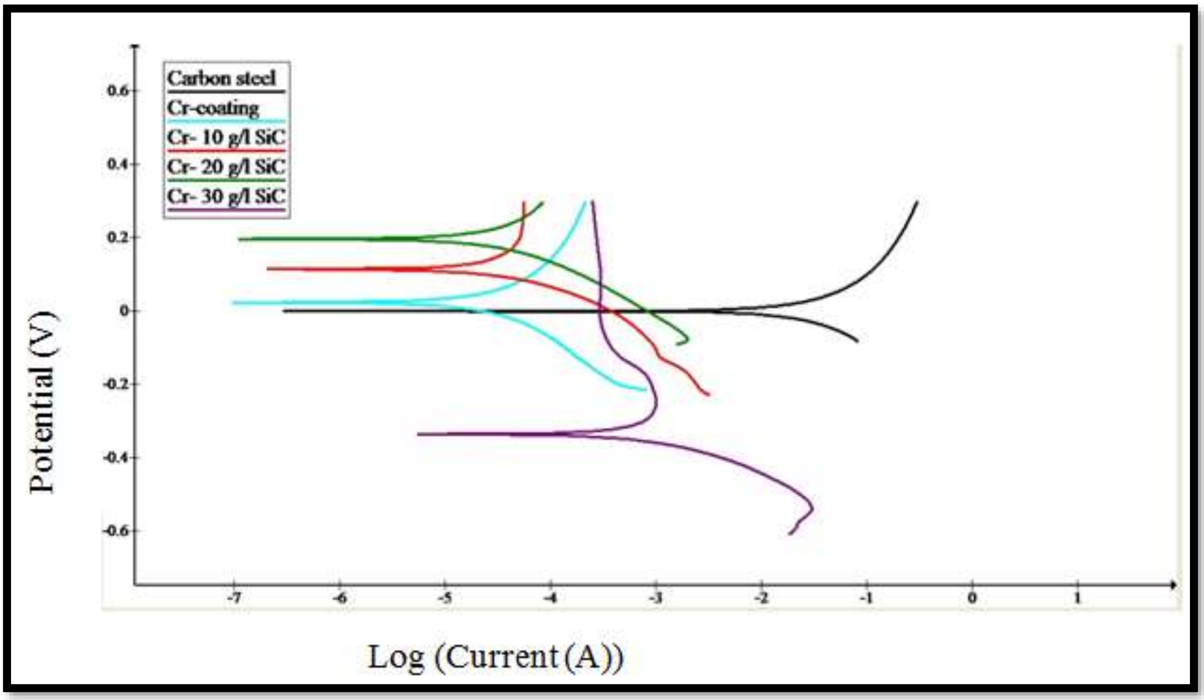


Fig (15): Polarization curves for tested samples

In table (15), in compared to carbon steel that is not protected from corrosion in concentrated sulfuric acid, the values of corrosion current, current density, and corrosion rates, as well as the percentage of improvement that occurred owing to the employment of metallic and composite coatings (98%).

Table (15): Polarization test factors and Corrosion rates for the models

Samples	Corrosion Current (μA)	Current density(μA/cm^2)	Corrosion rate(mpy)	Improving%
Carbon steel	1412	1249	396.55	-
Cr-coating	19.95	17.65	8.44	97.8
Cr-10 g/l SiC	17.78	15.73	6.23	98.4
Cr-20 g/l SiC	7.94	7	1.82	99.5
Cr-30 g/l SiC	398	352.2	45.36	88.5

We observe a significant reduction in corrosion rate as a result of the use of chromium metal coatings and composite coatings of micro-particles of silicon carbide embedded in chromium in comparison to the corrosion rate of the base metal (carbon steel without coating), where the micro-particles of silicon carbide play an important role in enhancing corrosion resistance in concentrated sulfuric acid because it forms a protective layer on the surface. Furthermore, these particles alter the microstructure of the metallic chrome plating, resulting in an enhancement in the composite coating's corrosion resistance. Many corrosion micro-cells developed as a result of reinforcement distribution particles in the chromium coating, with SiC particles functioning as cathodes and chromium acting as anodes (SiC has a stricter degree power as Cr metal). These corrosion metal electrodes enhance anodic polarization. As a result, when silicon carbide is present, regional corrosion is inhibited, and homogeneous corrosion takes over. [15]

In the figures below, images of the scanning electron microscope show the difference in surface for carbon steel, metallic chromium plating, chromium and SiC micro particles composite coatings, before and after the polarization test in concentrated sulfuric acid.

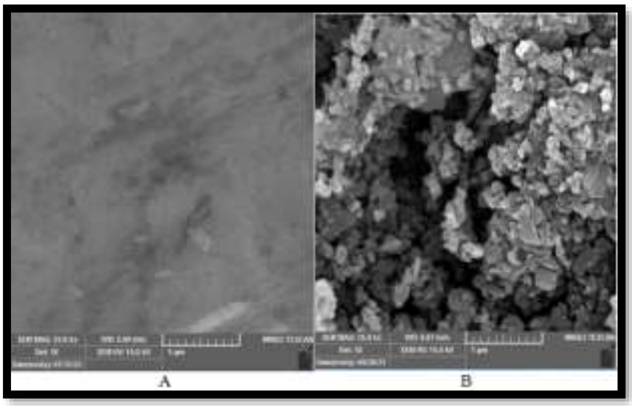


Figure (16): SEM images for carbon steel (A is for since the polarized testing, while B is until after the polarizing examination.)

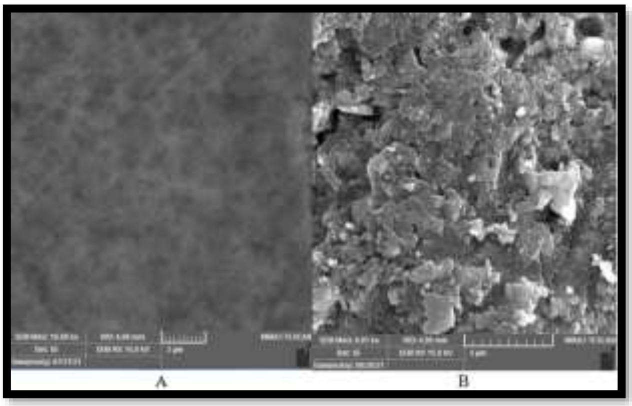


Figure (17): SEM images for Cr-coating (A is for since the polarized testing, while B is until after the polarizing examination.)

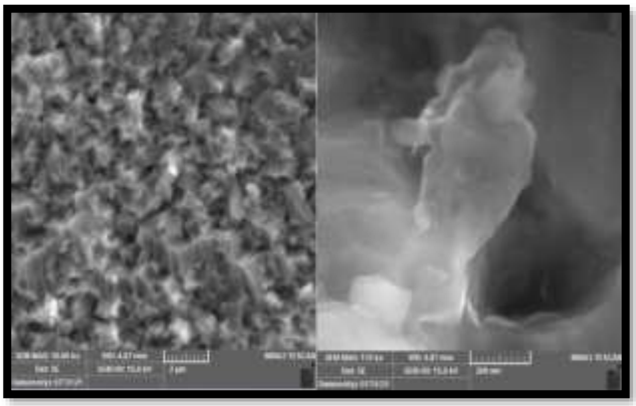


Figure (18): SEM images for (Cr-20g/l SiC) composite coating before polarization test

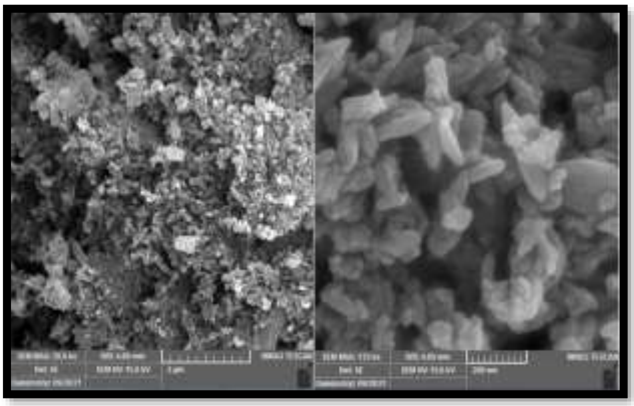


Figure (19): SEM images for (Cr-20g/l SiC) composite coating after polarization test

8. Conclusion

1. The optimum conditions for chrome plating on carbon steel were (50) degrees Celsius for the chrome plating solution and a time of (2) hour.
2. The effect of plating time was the most influential on the hardness and thickness of the chrome plating layer, while the temperature had the most effect on the surface roughness of chrome plating.
3. Increasing the concentration of silicon carbide microparticles higher than (20) grams per liter of the chromium plating solution led to the failure to obtain the efficiency of a homogeneous composite coating layer on the steel surface, which caused poor properties of the layer and negatively affected the corrosion resistance under conditions of concentrated sulfuric acid and the dielectric efficiency of the composite layer of steel against concentrated acid.
4. The corrosion rate of carbon steel in the (corrosion - stripping) test exceeds the corrosion rate in the simple immersion test several times, and the reason for this is due to the lack of ferrous sulfate layer on the carbon steel.
5. The use of metallic chromium coatings and chromium-composite coatings with silicon carbide particles has had an effective role in reducing the corrosion rate compared to unprotected carbon steel. The acid in addition to the fact that these particles constitute a kind of hardening of the surface and work to impede the movement of dislocations and thus resist the forces of erosion resulting from the flow of the acid mass on the surface.
6. In the electrochemical test by polarization, the amount of improvement in corrosion resistance was very high for composite and metal coatings relative to unprotected carbon steel, especially when the concentration of silicon carbide was (20) grams per liter of chromium plating solution.

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