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# Spin Coating of Low Carbon Steel by Polymer Matrix Composite

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## ABSTRACT

In this study the effect of spin coating for low carbon steel coated with 2% by weight of (Al, TiO2, and Zn) was result the corrosion rate of coated specimens with epoxy composites reinforcement (Al, $TiO_2$, Zn) are lower than the ones coated with epoxy by (55.32%, 83.56%, and 96.61%) respectively. The weight loss of erosion characteristics at90ºand 30$^0$of coated specimens with epoxy composites reinforcement (Al, $TiO_2$) lower than the ones coated with epoxy by (17.85%, 10.71%) and (30.43%, 4.3%) respectively. The weight loss of erosion characteristics at90º and 30$^0$ of coated samples with epoxy composites reinforced (Zn) are higher than coated samples with epoxy by (39.28%, 17.39%) respectively. The wet ability determined by measuring the contact angle that is smaller than 70º signifies hydrophilic surfaces have high surface energies and good wet ability. The adhesive strength of coated specimens with epoxy composite has lower adhesive strength than that of coated samples with epoxy. The atomic force microscopy used (AFM) to show surface morphology and roughness of coated surfaces with epoxy and epoxy composites. The Pore Size measurement of coated surfaces by scanning electronic microscopy (SEM), signifies that coated specimens with epoxy composites decreased than with epoxy.

**Key Words:** spin coating, epoxy, corrosion, erosion

**Source of Support:** None, **No Conflict of Interest:** Declared

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## INTRODUCTION

Carbon steel the most widely used engineering material, accounts for approximately 88%, of the annual steel production in world wide. Despite its relatively limited corrosion resistance, carbon steel is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, chemical processing, petroleum production and refining, pipelines, mining, construction, and metal-processing equipment. The cost of metallic corrosion to the total economy was measured in hundreds of millions of dollars per year. Because carbon steels represent the largest single class of alloys in use, both in terms of tonnage and total cost; it is easy to understand that the corrosion of carbon steels is a problem of enormous practical importance (Coburn, 1978). Five different main principles can be used to prevent corrosion: appropriate materials selection, change of Environment, Suitable design, application of coatings, Electrochemical i.e. Cathodic and anodic protection (Robert et al, 2002).

Figure1: Corrosion of steel bar (Verma, 2007).

The organic coatings have played the main role in corrosion protection of metals and have been used in a largely in many industries (Bierwagen, 1998).

**Couloumbi et al (1996)** used Steel specimens coated with particulate polymeric coatings composed of epoxy resin and iron powder by spin coating in quantity of iron particles that was varied (7.5, 15, 30)% wt. It was noted that these polymeric particulate composite coatings present a similar anticorrosive behavior to the surface of pure epoxy resin.

**Uddin et al (2004**) studied the curing behavior of the epoxy adhesive on a silicon substrate. The result showed that the curing reaction of the spin coated samples with epoxy adhesive is very slow compared to the ones without spin coating, because of the evaporation of relatively volatile species during the spinning.

## EXPERIMENTAL WORK

The substrate used for applying the protection coating by Spin Coating was (Low Carbon Steel 1022).The chemical composition of the substrate material is presented in table 1. Specimens with dimensions of approximately (10*10 * 2) mm for corrosion test according to ASTM G33 and (10 *30* 2) mm for erosion test according to ASTM G 76; they were cut from a plate to the required shape. The samples were prepared for coating process by grit blasting and cleaning before applying the coating material and measuring the roughness of the surface which gave the surface roughness of N9.

**Table 1:** Chemical Composition of Low carbon steel AISI 1022

| C% | Si% | Mn% | Cr % | Ni% | Cu% | Other |
|---|---|---|---|---|---|---|
| 0.22 | 0.24 | 0.41 | 0.06 | 0.05 | 0.05 | …… |

The coating materials used Epoxy resin matrix was (Quick mast 105) manufactured by Ayla Construction Chemicals under license from DCP-UK., which consists of components resin base and formulated amine hardener mixed at a ratio 3:1.Three types of reinforcement material powder were used by 2%weight of aluminum (Al) type (Himedia India), $TiO_2$(GCC England), and Zinc (BDH England), as reinforcement with epoxy for spin coatings. Each type of powder was ground and sieved to the average particles size of the powder of aluminum, Zinc, Titanium dioxide were (2.089, 1.139, 2.998) µm respectively.

**Spin Coating Technique**

During the course of this work, as spin coating device was manufactured to perform Spin coating of low carbon steel with different composite material. The spin coating apparatus is characterized by the following:

1. Speed revolution control ( 0 -20000 rpm).
2. Time Speed reader (1-60min).
3. Diameter of disk rotation (100mm).
4. The specimen is fixing by vacuum.
5. Plastic and glass cover for operation safety.
6. Motor Dc (220V, 2000 W).
7. Chamber of spin coating with dimension50×40×40 cm.

The spin coating formation of a thin, uniform layer of liquid on a flat rotating disk by centrifugal force is widely known as the spin-coating techniques how figure 1.

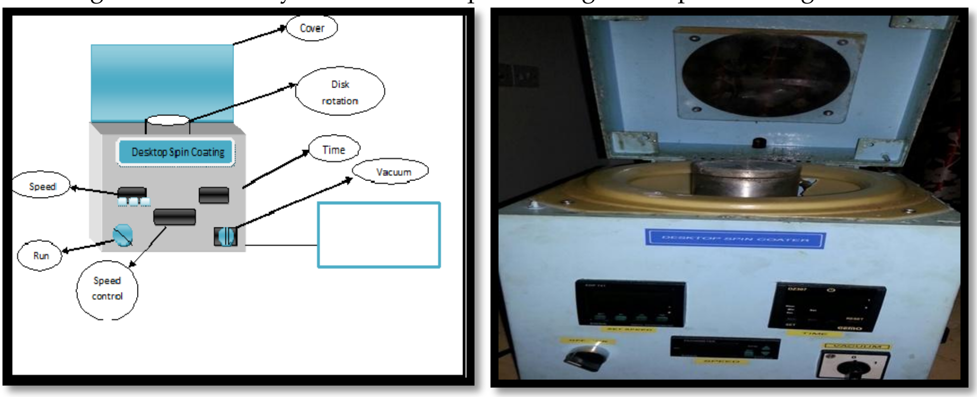


**Figure 1:** Schematic and actual Experimental Spin Coating device

The Specimen of spin coating was fixed on the base of the rotation disk by vacuum, Spin coating was achieved by pouring the composite on clean substrate to fully cover it, the parameter of process were, velocity of the spin 2000(rpm), duration 60(sec),air drying for one day, drying in oven at $50C^0$ 1 hr.

## RESULT AND DISCUSSION

**Corrosion Test**

The result indicate that coating low carbon steel with epoxy by spin coating reduced corrosion rate by (96%),while the reduction in case of coated low carbon steel with epoxy composite reinforcement at 2% weight of ($Al,TiO_2,Zn$) were (55.32%, 83.56%, 96.61%) respectively. General corrosion resistance was greater with the use of additives where corrosion protection is attributed to polymer coating (physical barrier). Also, the porosity was very effective on the corrosion rate as its increase the porosity would increase the corrosion rate (Leeds, 1969).

 

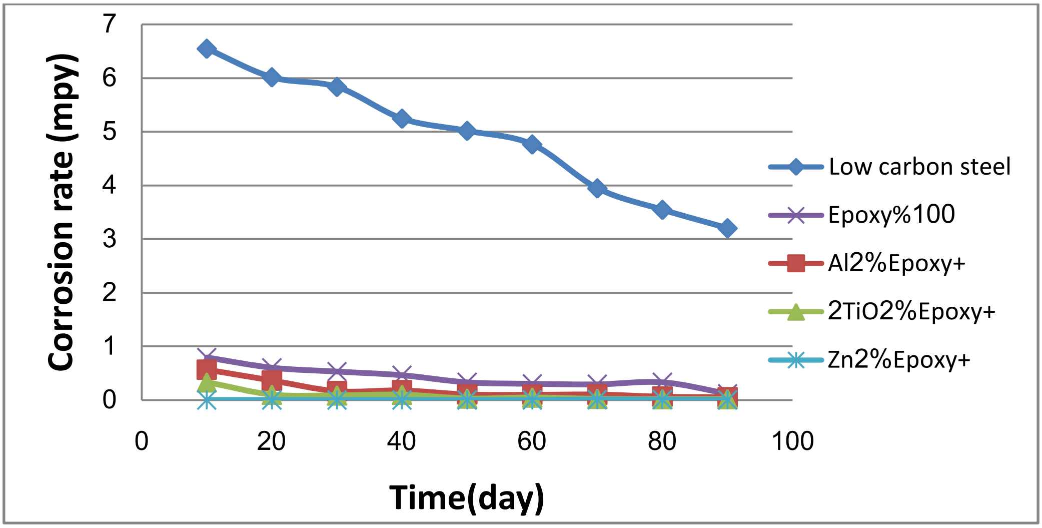


**Figure 2:** Corrosion Rate of Spin Coating

**Erosion Test**

The weight loss of low carbon steel coated with epoxy at90°and 30⁰ impingement angles are lower than that of uncoated specimens by (40.4%, 37.8%) respectively. The weight loss due to erosion of coated specimens with epoxy composites reinforcement (Al, $TiO_2$) at 90° and 30⁰ impingement angles was less than coated samples with epoxy by (17.85%,10.71) and (30.43%,4.3) respectively. The weight loss of coated specimens with epoxy composites reinforced with 2% (Zn) at90°,30⁰ impingement angles were higher than coated ones with epoxy by(39.28% , 17.39%) respectively. The results showed that coating composite of (Al) has less erosion wear than other types of coating, due to the shape of (Al) particles beings more regular than other. Show figures (3, 4).

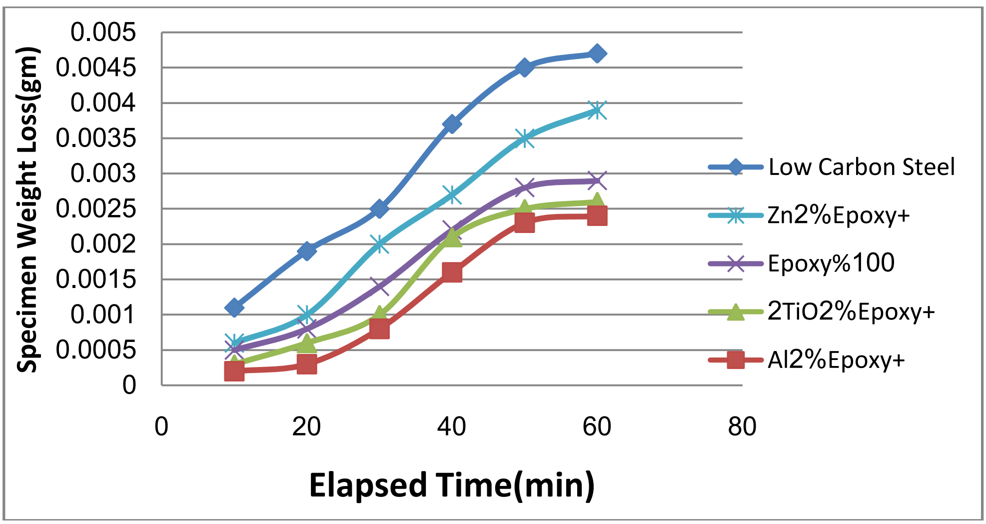


**Figure 3:** The weight loss with Elapsed time for low carbon steel and coated materials at 90°and impact velocity 30m/s by spin coating

 

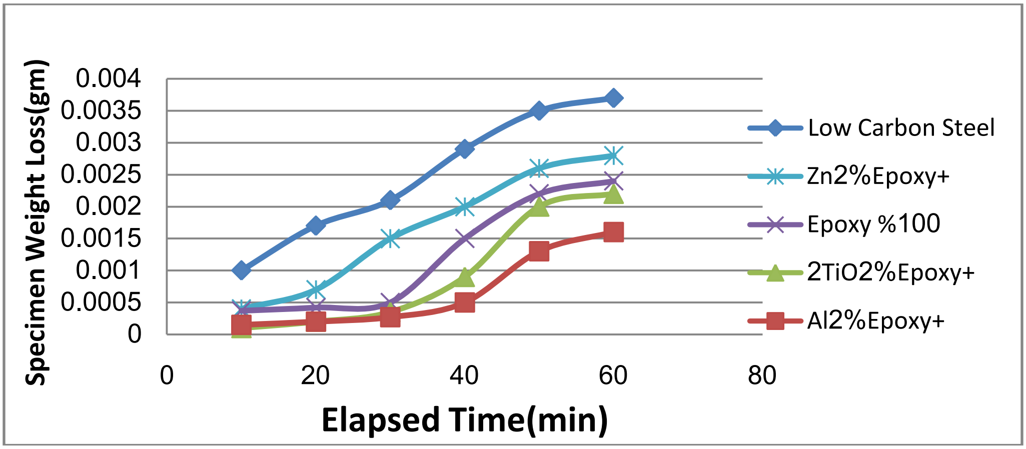


**Figure 4:** The weight loss with Elapsed time for low carbon steel and coated materials at 30°and impact velocity 30m/s by spin coat in

A statistical model for the prediction of the protective layer properties was concluded by regression function in SPSS software from the training data set.

$A_o = 5.37 * 10^{-5}X_1 + 1.11 * 10^{-6}X_2$……..(4-1)
$B_1 = 3.97 * 10^{-5}X_1 + 1.11 * 10^{-6}X_2$……....(4-2)
$B_2 = 2.57 * 10^{-5}X_1 + 2.72 * 10^{-6}X_2$……....(4-3)
$B_3 = 4.94 * 10^{-5}X_1 + 1.11 * 10^{-6}X_2$……….(4-4)
$B_4 = 4.34 * 10^{-5}X_1 - 1.7 * 10^{-6}X_2$………...(4-5)

**Table2:** Definition and values of independent variables used regression equation

| Designations of independent variable | Name of variable | Value |
|---|---|---|
| $X_1$ | Time (min) | 10-60, interval: 10 |
| $X_2$ | Angle | 30, 90 |

The values of the multiple correlation coefficients R, that tells how strongly the multiple independent variables are related to the dependent variable, were (0.984, 0.934, 0.909, 0.984, and 0.961). The figures (5, 6, 7, 8, and 9) show a comparison between the predicted and measured values.

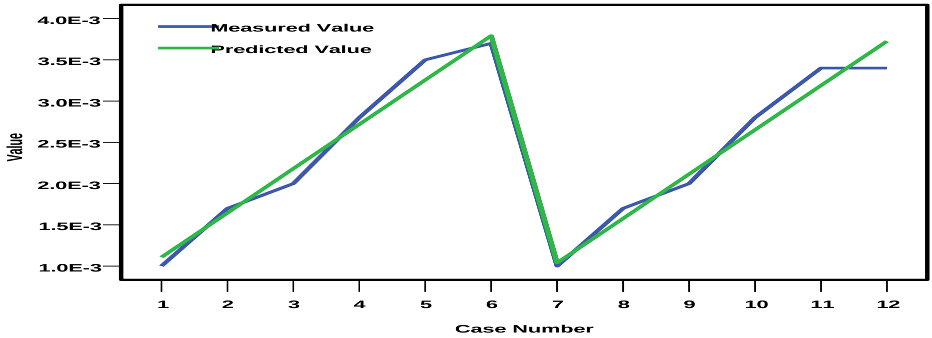


**Figure 5:** A comparison between measured and predicted values for the experimental data of erosion rate for Low carbon steel (case$A_o$)

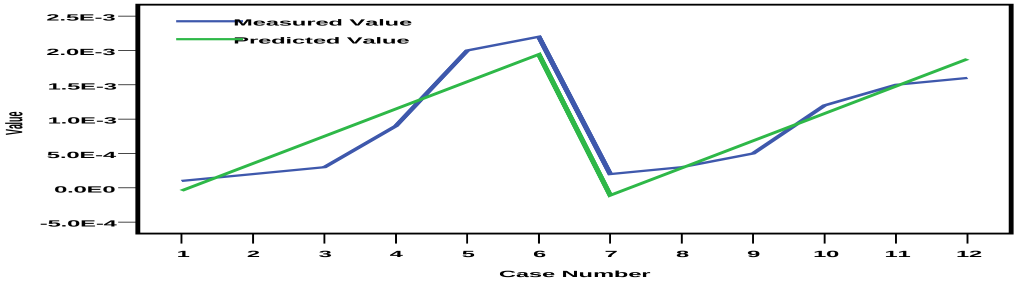


**Figure6**: A comparison between measured and predicted values for the experimental data of erosion rate for Epoxy+2%$TiO_2$ spin coating (case$B_1$)

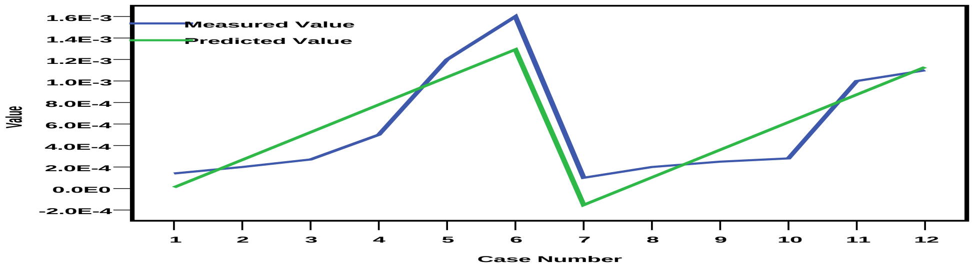


**Figure7:** A comparison between measured and predicted values for the experimental data of erosion rate for Epoxy+2%Al spin coating (case$B_2$)

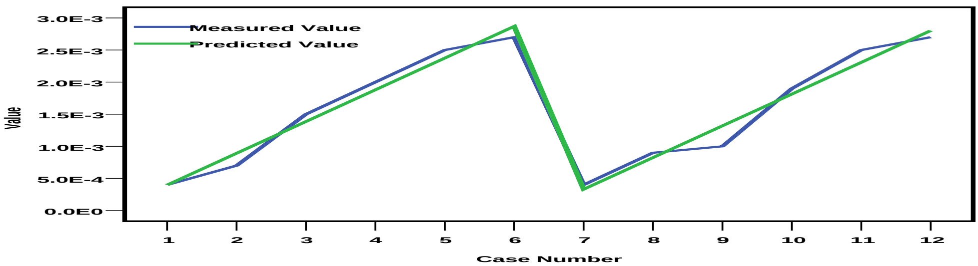


**Figure8:** A comparison between measured and predicted values for the experimental data of erosion rate for Epoxy+2%Zn spin coating (case$B_3$)

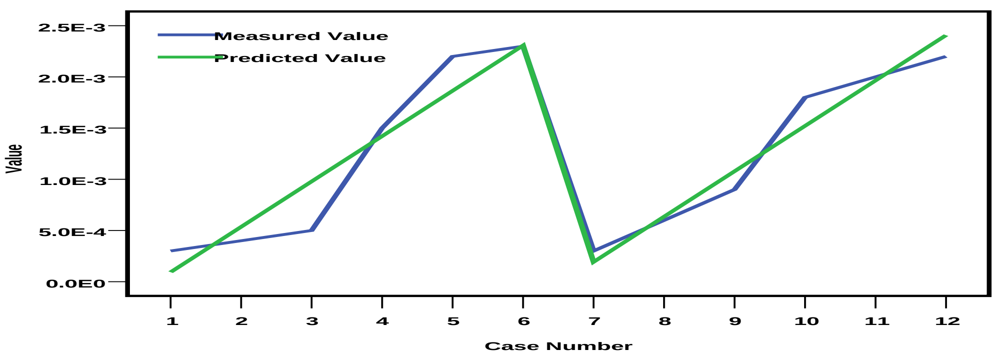


**Figure9:** A comparison between measured and predicted values for the experimental data of erosion rate for 100% Epoxy spin coating (case$B_4$)

**Shore D Hardness**

The specimens coated with epoxy composite reinforcement with 2%wt (Al, $TiO_2$) showed an increase in hardness by (13.25%, 10.84%) respectively as compared to low carbon steel coated with epoxy. While the coated specimens with epoxy reinforcement with 2%wt (Zn) had lower hardness than coated sample with epoxy (3.61%).The increasing of hardness was due to the presence of homogeneity in the form of particle shape which were more spherical and had stronger bonding with epoxy than other additions. The aggregation of particles led to the decrease of hardness. As shown figure (10) and table (3) below the hardness of shore D hardness values.

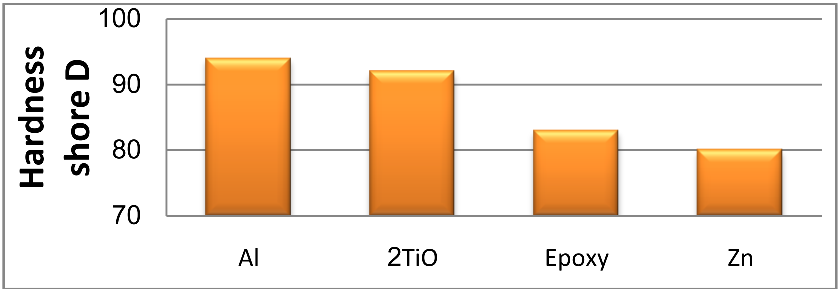


**Figure 10:** Hardens shore D

***Table3:*** *Shore D Hardness before and after erosion wear*

| *Materials* | *Shore D Hardness Spin Coating* | |
|---|---|---|
| | Before erosion wear | After erosion wear |
| **1-Epoxy+2%Al** | 94 | 97 |
| **2Epoxy+2%$TiO_2$** | 92 | 94 |
| **3- Epoxy+2%Zn** | 80 | 89 |
| **4- Epoxy100%** | 83 | 87 |

**Adhesive strength**

The adhesive strength of spin coating of coated specimens with reinforcements (Al, TiO2, Zn) was lower than the adhesive strength of coated ones with epoxy by (22.62%, 55.7%, 41.5%) respectively. The result of adhesive strength of the coated specimens with epoxy was lower further more than all samples, which was due to the presence of oxygen containing polar group (OH). As shown figure (11) below:

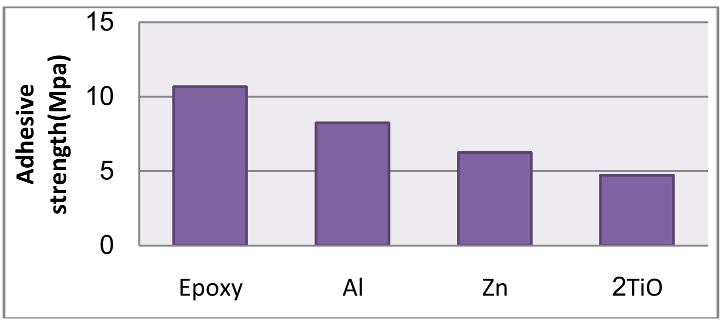


**Figure 11:** Adhesive strength (Mpa) of spin coating

**Atomic Force Microscopy**

The roughness average of coated specimen with epoxy composites reinforced with 2%wt (Al, $TiO_2$, Zn) were lower than the roughness average of the samples coated with epoxy by (85.4%, 95.21%, 90%) respectively. The surface roughness tests results are shown in table (4) and figure (12) which that indicate all coated specimens with composite material have significantly lower surface roughness than coated sample with epoxy. The adding particle filler which tends to occupy voids in thin film coating and serve as the bridges interconnected the matrix.

**Table 4**: Roughness average of spin coatings

| *Spin Coating* | |
|---|---|
| *Coating type* | **Roughness Average(nm)** |
| **1-Epoxy+2%Al** | 0.48 |
| **2-Epoxy+2%TiO2** | 0.158 |
| **3-Epoxy+2%Zn** | 0.33 |
| **4-Epoxy 100%** | 3.3 |

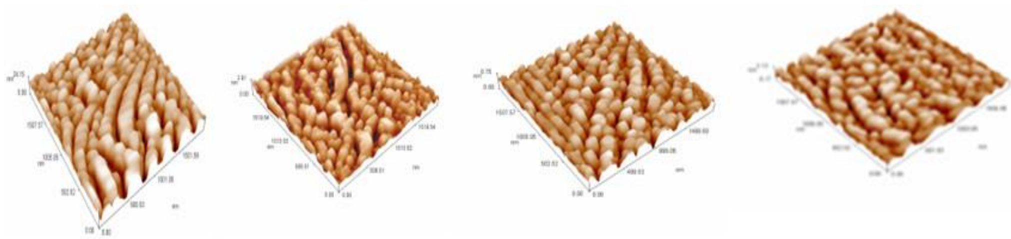

**Figure 12:** Atomic force microscopy of epoxy, aluminum, titanium dioxide and zinc respectively

**Contact Angle Measurement**

The contact angle of specimen coated with epoxy is (54°) while for samples coated with epoxy composites reinforcement (Al, TiO2, Zn) are (58°, 67°, 65°) respectively. The contact angle decreased due to the increasing of the roughness of coating materials on the substrate and the increasing of the adhesion strength as shown in figure13 and 14.

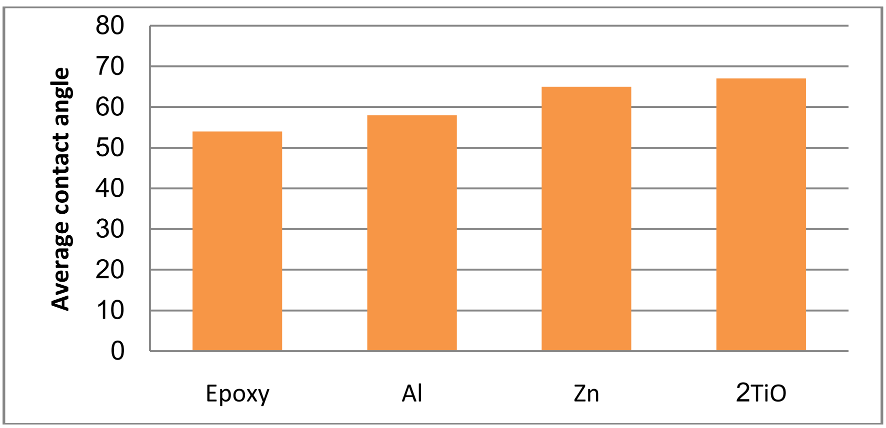


**Figure 13:** Average Contact Angle of spin coating

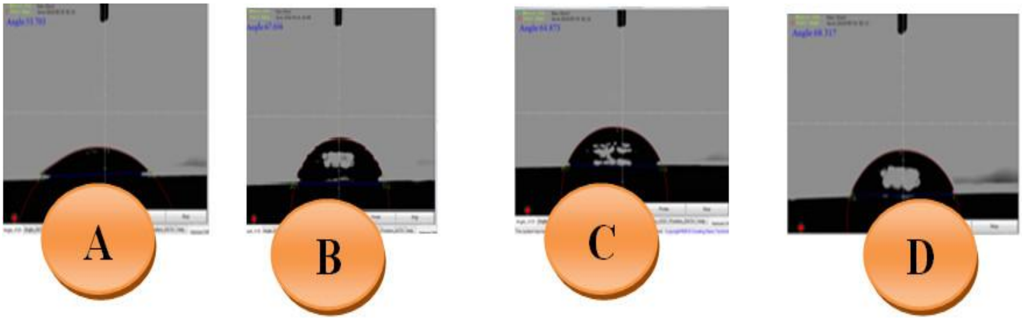


**Figure14:** photograph Average contact angle of spin coatingA: Epoxy**,** B:Al**,** C:Zn**,** D: $TiO_2$

**Porosity Measurement**

The results show that the pore size of coating specimens with epoxy composites reinforcements (Al, $TiO_2$, Zn)is lower than coated samples with epoxy by (58.80%, 78.53%, 90.57%) respectively. The decrease is due to the density of (Al, $TiO_2$, Zn) particles and (Zn, $TiO_2$) are heavier metal (transition metals).

**Table 5:** pore size of spin coating

| *Spin coating* | |
|---|---|
| ***Materials*** | ***Pore size*** |
| 1-Epoxy+2%Zn | 180.9 nm |
| 2-Epoxy+2%TiO2 | 412.2 nm |
| 3- Epoxy+2%Al | 790.9nm |
| 4-Epoxy 100% | 1920nm |

## CONCLUSIONS

1-The coated specimens with epoxy composites reinforcement (Al, $TiO_2$, Zn) by spin coating reduced Corrosion rate compared to coated samples with epoxy by (55.32%, 83.56%, 96.61%) respectively. While that coating low carbon steel with epoxy reduced corrosion rate by (96%) compared to uncoated sample.
2-The weight loss of erosion at $90^o$ and $30^0$ of coated low carbon steel with epoxy by (40.4%, 37.8%) respectively compared to low carbon steel, while the weight loss of erosion characteristics coated specimens with epoxy composites reinforcement (Al, $TiO_2$) lower than coated ones with epoxy by (17.85%, 10.71%) and (30.43%, 4.3%) respectively.
3-The weight loss of erosion characteristics at$90^o$, $30^o$of coated specimens with epoxy composites reinforced (Zn) was higher than coated samples with (39.28%, 17.39%) respectively.
4-The hardness of (shore D) of coated specimens with epoxy composites reinforcement (Al, $TiO_2$) was higher than coated specimen with epoxy by (13.25%, 10.84%) respectively, While the hardness of coated specimens with epoxy composites reinforcement (Zn) was lower than all samples.
5- The adhesive strength of coated samples with epoxy composites reinforcements (Al, $TiO_2$, Zn) was lower than that coated with epoxy by(22.62%, 55.7%, 41.5%) respectively.
6-The pore size of coated specimens with epoxy composites reinforcements (Al, $TiO_2$, Zn) was lower than that coated with epoxy by (58.80%, 78.53%, 90.57%) respectively.

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