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PREDICTION THE THICKNESS LAYER OF GALVANIZED IRAQI ELECTRICAL POLES USING MATHEMATICAL MODEL

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ABSTRACT: -Galvanized steel has a long history as an effective and economical material for manufacturing electrical poles**.** Galvanized steel consists of a thin coating of zinc fused to a steel substrate. This combination provides the pole high mechanical properties as the mechanical properties of steel enhanced with the corrosion resistance of zinc**.**
Corrosion rates have been calculated by Tafel extrapolation technique for different coating thicknesses (80, 90,100,110,120 and 130) µm**.** The soil resistivity is simulated by different concentrations (2, 2.5, 3, & 3.5) wt. % NaCl. Optical microscope examinations for their specimens were used successfully to evaluate corrosion rates for the galvanized steel poles**.**
Regression model has been used in this work to find the correlation between the corrosion parameters representing by thickness of galvanized layer of low carbon steel and resistivity of soil. Matlab (R 2013A) programme was used to get the unknown cofficients of the regression model . Theoretical mathematical equations were performed to predict the thickness layer of galvanized Iraqi electrical poles to get the best thickness of galvanized layer which has high corrosion resistance in different soil resistivity. This is considered the aim of this work**.** The results of the mathematical model show that the corrosion rate of galvanized steel decreases with the increase in coating thickness from 80 - 120 µm. The best corrosion resistance occurs at thickness 120 µm galvanized layer, while at 130 µm thickness micro cracks appear in the coating layer. The coating thickness has a direct influence on the performance or life of the electrical poles. As the thickness of galvanized layer increases, the life of protection increases until 120 µm.

Keywords Theoretical mathematical equations, Thickness of Galvanized layer, electrical pole, electrochemical behavior, corrosion rate.

INTRODUCTION

Electrical pole made of low carbon steel which suffers from extensive corrosion especially the lower part which immersed in the soil. The soil consider as corrosive environment .The corrosion in soil affected by several parameters such as moisture, the soil resistivity, salts, chemical reagents .etc. Melvin Romanoff and Irving Denison [1] showed that, the galvanized specimens were especially resistant to corrosion in alkaline soils that were highly corrosive to bare steel. In some soils and zinc coating after relatively short exposures was accompanied by marked corrosion of the steel. They also showed that weight of zinc coating required to protect steel from corrosion for a minimum of 10 yr. depends on the nature of the soil environment [2]. The protection obtained by zinc coating is due to barrier and galvanic double protective effect [1,2].

Hot dipping galvanized coatings are widely used in industry to protect the electrical pole against corrosion [3]. Galvanized steel first became an important material for pole manufacturers in the 1950's [4]. Zinc coating (Galvanization) protects steel substrate by two mechanisms [5], the first is barrier protection in which the galvanized layer isolates the substrate from the corrosive environment. The second mechanism is a sacrificial protection in which the active metal (Zinc) will be anode which is corroded and the steel substrate will be cathode Juraj G. etal [6] showed a significant improvement in corrosion properties of the coated steel material which can be achieved by adjusting the chemical composition of the zinc layer. The galvanized layer will be the anode .The substrate (steel) will be the cathode. Zamanzadeh M. [7] confirmed from field and laboratory work that galvanic action will protect the painted portion of a pole in moderately corrosive soil environments due to cathodic protection by zinc.

The aim of this work is to evaluate the corrosion rate of galvanized steel using as electrical pole depending on the thickness of the galvanized layer.

EXPERIMENTAL WORK

Low carbon steel type DIN St 52 provided by the AL- Sumod Company for Steel Industry was used in this work. Chemical composition analysis of this steel listed in Table 1. The galvanization process was done in AL- Sumod general Company-Iraq. The specimens were taken from production lines of galvanization factory. The galvanization took place by dry hot –dip process.

Galvanizing process consists of three basic steps: surface preparation, galvanizing, and inspection. The coating thickness in this work is varied from values of : 70, 80, 90, 100, 110, 120, and 130µm in order to made Mathematical Model to Predict the best Thickness Layer of Galvanized Iraqi Electrical Poles which has the high corrosion resistance**.**

Sodium chloride NaCl was used to equivalent the soil resistivity (as shown in Table 2.). The concentrations of NaCl were 2, 2.5, 3 and 3.5 wt. % ,which corresponded the values of Iraqi soil resistivity (Table 2). These values of NaCl solution were equivalent to 27, 24, 20 and 18 ohm.cm. All surfaces specimen were examined by using optical microscope (type.Nikon.120, Japan), equipped with digital camera and computer.

For corrosion tests , specimens were prepared with diminutions 1.5cm length 1.5cm width and 0.5 cm thicknesses. The reference electrode was an Ag/AgCl electrode .To construct the corrosion cell, three electrodes were place in an electrochemical cell with 1000 ml. Corrosion test was done by using a potentiostat type (PARSTAT 2273 mad by Advanced Electrochemical System, USA connected to computer and special software was used to calculate and measure the data**.**

Regression method is a statistical tool that allows to examine how multiple independent variables are related to dependent variable .It is usedfor predication by establishing a mathmatical relationship between a dependent variable and two or more independent variables. A multiple regression model has the following general form [8]:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \qquad \ldots\ldots\ldots (1)$$

Where:

β_0: The regression constant.

$\beta_1, \beta_2, \ldots, \beta_k$: The coefficients of regression model which represent the contribution of the independent variables.

$X_1, X_2, \ldots, X_k$: The independent variables.

Regression model has been used in this research to determine the correlation between independent variables representing by thickness and resistivity,and depented variable, corrosion rate. By using matlab R 2013 the unknown cofficients of the regression model can be estimated,and the equation is written in the following form.

$$F(X,Y) = \beta_0 + \beta_1 X + \beta_2 Y + \beta_3 X^2 + \beta_4 XY + \beta_5 Y^2 + \beta_6 X^3 + \beta_7 X^2 Y + \beta_8 XY^2 + \beta_9 Y^3$$

Where:

$F(X,Y)$: Corrosion rate

X: Resistivity
Y: Thickness
$\beta_0 = 7.745$
$\beta_1 = -1.455$
$\beta_2 = 0.1164$
$\beta_3 = 0.05714$
$\beta_4 = -0.001473$
$\beta_5 = 0.002474$
$\beta_5 = -0.001473$
$\beta_6 = -0.007716$
$\beta_7 = -2.883 \times 10^{-5}$
$\beta_8 = -6.029 \times 10^{-6}$
$\beta_9 = 5.403 \times 10^{-6}$

The coefficient of determinationR^2, which is widly used as ameasure of fit for regression model,has been determined. It ranges from 0to 1. The value of "0" indicates that there is no regression prediction whereas the value of "1" means perfect prediction. Most ofR^2 values are between the extremes [9].
The equations used for computing R^2 can be written as follows:

$$R^2 = 1 - \frac{SS_E}{SS_{yy}} \qquad \text{.................... (2)}$$

Where
SS_E: The sum of squares of error. It is calculated, in terms of notations used in this research, from the following equation.

$$SS_E = \sum\left(CR - \widetilde{CR}_{pred}\right)^2 \qquad \text{.......................(3)}$$

CR: The experimental values of corrosion rate.
$\widetilde{CR}_{pred}$: The predicted values of corrosion rate.

$$SS_{yy} = SS_{CR} = \sum CR^2 - \frac{(\sum CR)^2}{n} \qquad \text{.......................(4)}$$

After applying these equations, the coefficient R^2 was found to be 0.9, which means that is a very good prediction by using the regression model and there is a perfect correlation between the output and inputs.

Results and Discussion 3-

Table (3) shows the corrosion parameters of galvanized steel with the different thicknesses of galvanized (zinc) layer (80, 90,100,110,120 &130) µm in different values of soil resistivity which equivalent to concentrations of NaCl (2, 2.5, 3 & 3.5) wt. % respectively. The corrosion resistance of galvanized electrical pole with coating thickness of 120µm in different concentrations of NaCl 2, 2.5, 3 and 3.5 wt. % shows the best results. These results are getting by using Mathematical Model to Prediction the best Thickness Layer of Galvanized Iraqi Electrical Pole as shown in Fig(1).
These results confirm that as the coating thickness of galvanized layer increases the corrosion resistance improves until thickness layer value of 120 µm , then the corrosion resistance decreases at thickness layer of 130 µm value. Figure (2) illustrates the optical microscopic examination of surfaces of galvanized steel with 130 µm thickness layer in different concentrations of sodium chloride; it seems clearly that micro cracks and localized corrosion are visible in the surface. Corrosion of galvanized layer starts with the instantaneous formation of a film of zinc hydroxide, as shown in the following equation [10]:

$$2\,Zn + H_2O + \tfrac{1}{2}O_2 \rightarrow 2Zn\,(OH)_2 \qquad (5)$$

The corrosion process of zinc appears to proceed according to the following mechanism (8);

$Zn(OH)_2 + 0.5\ CO_2 + 2H^+ \rightarrow 2Zn\ OH\ (CO_3)_{0.5} + 1.5\ H_2O$ (6)

$Zn(OH)_2 + 0.25\ SO_2 + 0.125\ O_2 \rightarrow Zn\ (OH)1.5\ (SO4)_{0.25} + 0.5H_2O$ (7)

$Zn(OH)_2 + 0.6\ Cl^- + 0.6\ H^+ \rightarrow Zn\ (OH)_{1.4}Cl_{0.6} + 0.6H_2O$ (8)

These reactions began electrochemically, involved the anodic oxidation of zinc and the cathodic reduction of oxygen [8]. The corrosion rates of galvanized steel in NaCl solution were found to be under cathodic control (oxygen diffusion control). This was confirmed by the shape of the polarization curves (Fig.3). *i corr*, indicating that the layer could inhibit the corrosion of zinc coating to some extent.

The zinc carbonate particles form a layer of tightly adherent and relatively insoluble particles on the surface [9].As the thickness of galvanized layer increases, the zinc patina is increased to give the galvanized steel more corrosion resistance till 120 µm. During galvanizing, the molten zinc reacts with the iron in the steel to form a series of zinc-iron alloy layers. *Figure 4* is a photomicrograph of a typical galvanized coating microstructure consisting of three alloy layers and a layer of pure metallic zinc [10].

Fig.4 revealed the stages of alloying between steel sheet and molten Zinc coating to produce (Galvanized Steel). Variation in corrosion rate (mpy) of the galvanized steel with different coating thicknesses, depending on the different soil resistivity are as shown in table (2) as actual calculations and prediction by using mathematic model.

The correlation of corrosion rate and galvanized steel con obeys the following equations;

$Y_1=4\times10^{-8}x^5-2\times10^{-5}x^4+0.0036\times^3-0.3366\times^2+15.397\times-277.26$ (9)

$Y_2=8\times10^{-9}x^5-2\times10^{-6}x^4+0.0005\times^3-0.0312\times^2+0.7371\times+2.5$ (10)

$Y_3=6\times10^{-8}x^5-3\times10^{-5}x^4+0.0057\times^3-0.5572\times^2+27.065\times-520.54$ (11)

$Y_4=7\times10^{-8}x^5-3\times10^{-5}x^4+0.0067\times^3-0.669\times^2+33.057\times-647.26$ (12)

These equations give good indication to corrosion behavior of galvanized steel, depending on the coating thickness galvanized layer.

Conclusions 4-

From the results of the present work, the following conclusions are deduced:

1) When sodium chloride concentration increased from 2% to 3.5% the corrosion rates of steel and galvanized steel increase.
2) The thickness of a galvanize coating has a direct influence on the corrosion performance and life of the product, i.e., the thicker the coating, the longer its life. Galvanization process with different thickness layers of (80, 90,100,110,120 and 130) µm gives good corrosion protection for low carbon steel of electrical bar stand. As the galvanized layer thickness increases, the corrosion protection increases until 120 µm then the corrosion protection decreases.
3) When the coating thickness becomes 130µm micro-cracks appear in the galvanized coating layer. Some of them are vertical and the others are horizontal.
4) Mathematic equations are simulate the corrosion resistance of different galvanized layer thickness. These equations are represent the relationships of corrosion rates and thickness of galvanized layer in different concentrations (2, 2.5,3 &3.5) wt% NaCl.

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Table (1 A): The chemical composition of steel used in this work.

Comp. Wt %	C	Si	Mn	P	S	Cr	Mo	Cu	Ni	Fe
Measured	0.20	0.55	1.6	0.05	0.05	0.029	0.016	0.05	0.058	Balance
Standard	**0.22**	**0.55**	**1.6**	**0.035**	**0.035**	---	---	---	---	**Balance**

Table (1B); Chemical composition of the zinc coating

Element	C	Mn	P	S	Ti	Zn
Content (wt%)	≤ 0.04	≤ 0.02	≤ 0.02	≤ 0.008	≤ 0.03	Balance

Table(2): Equivalence of resistivity by NaCl concentration.

NaCl Content g/L	Concentration Wt. %	Resistivity Ω. Cm
20	2.0	27.5
25	2.5	24
30	3.0	20
35	3.5	18

Table(3); Shows the dependence of corrosion rate on the resistivity of soil and on the thickness of galvanized layer as corrosion rate calculations and predications.

No.	Resistivity of soil ohm.cm	Thickness (μm)	Corr. Rate (mpy) calculations	Corr. Rate (mpy) Predications
1	27	80	0.205	***0.1995***
2	27	90	0.205	***0.2129***
3	27	100	0.195	***0.1909***
4	27	110	0.205	0.166
5	27	120	0.109	0.1705
6	27	130	0.274	0.2368
7	24	80	0.216	0.2177
8	24	90	0.225	0.2318
9	24	100	0.225	0.2141
10	24	110	0.216	0.197
11	24	120	0.206	0.213
12	24	130	0.297	0.2945
13	20	80	0.236	0.2435
14	20	90	0.247	0.2503
15	20	100	0.244	0.2302
16	20	110	0.236	0.2156
17	20	120	0.235	0.2388
18	20	130	0.331	0.3323
19	18	80	0.37	0.3403
20	18	90	0.302	0.34
21	18	100	0.317	0.3153
22	18	110	0.316	0.2984
23	18	120	0.318	0.3218
24	18	130	0.43	0.4179

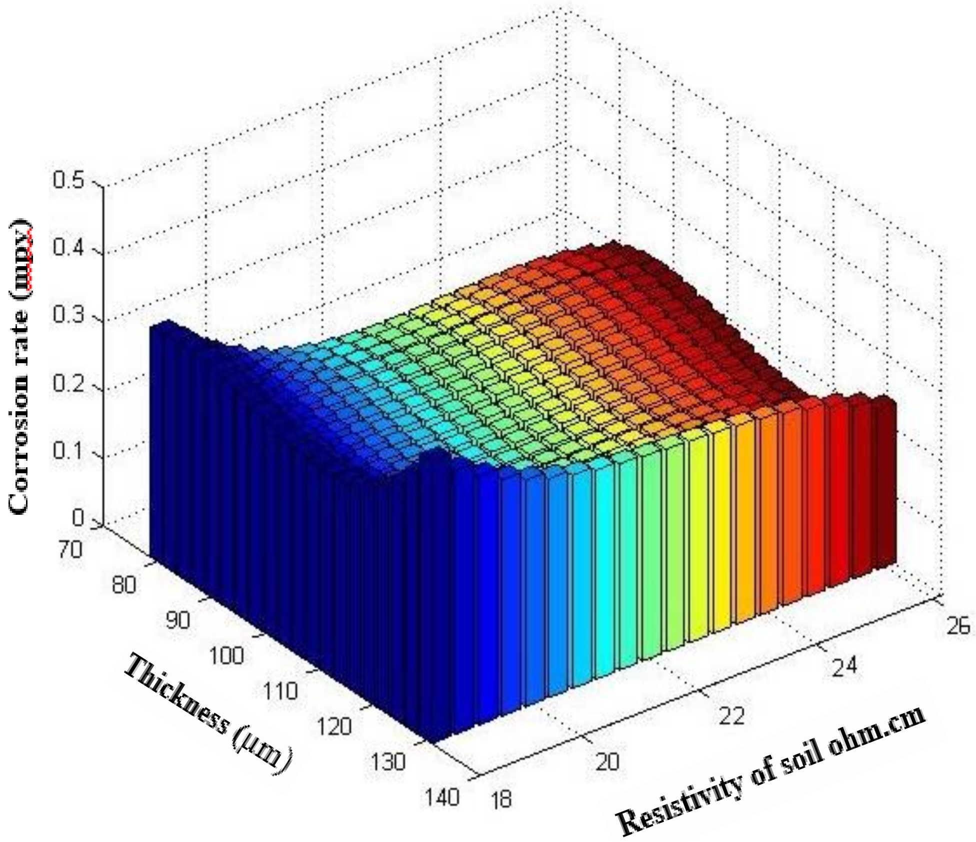

Fig. 1; Predications the corrosion rate, depending on the resistivity of soil and on the thickness of galvanized layer.

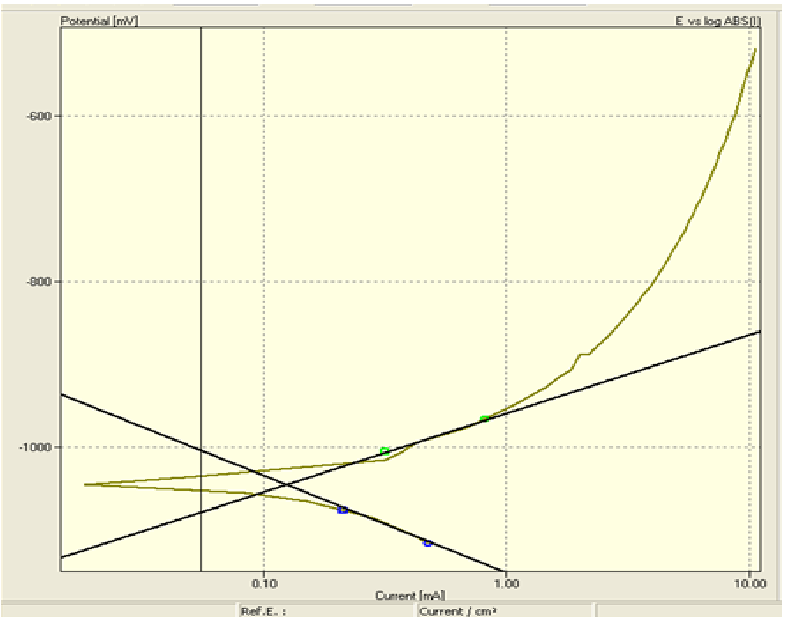

Fig. 2: Polarization curves of galvanized Electrical Bar Stands (thickness 120 μm) in 3.5% NaCl

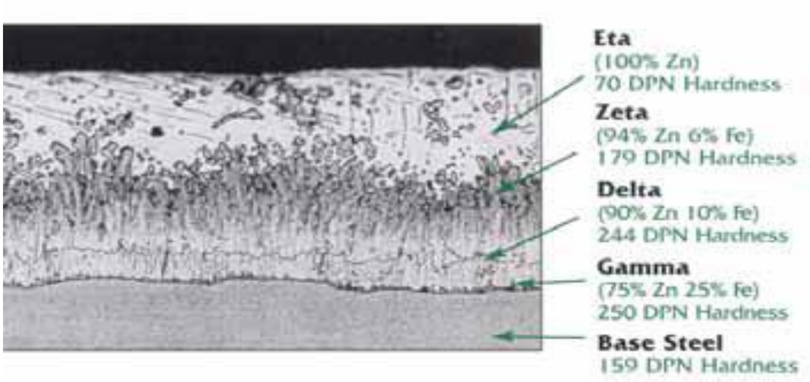

Fig.3: The stages of alloying between steel sheet and molten Zinc coating to produce (Galvanized Steel)[12].

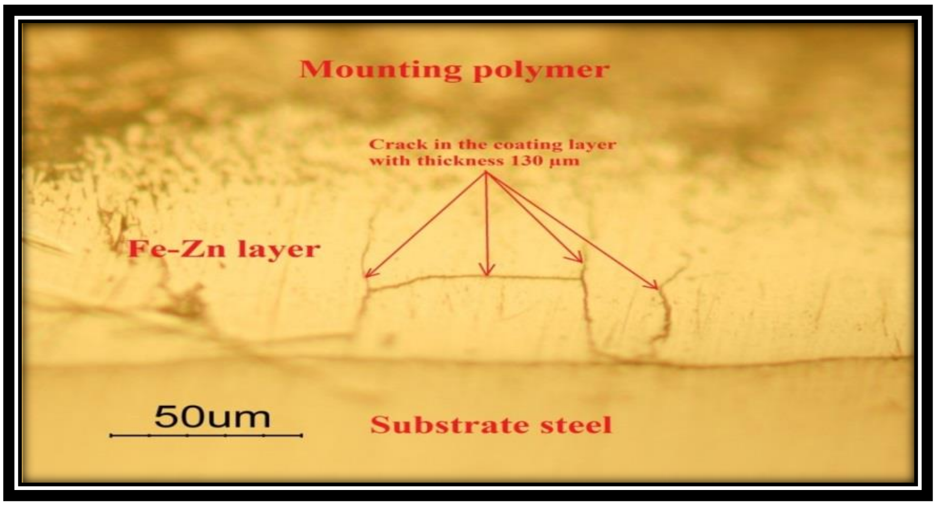

Fig.4: The micro-cracks in the galvanized layer which has 130µ m thickness.

تخمين سمك طبقة الغلونة للاعمدة الكهربائية العراقية باستخدام موديل رياضي

الخلاصة

يمتلك الفولاذ المغلون تاريخ طويل في استخدامه كمادة فعاله وا قتصادية في تصنيع الاعمدة الكهربائية. يتكون الفولاذ المغلون من طبقة خفيفة من الخارصين تغطي الفولاذ . لان هذا المزيج المعدني يعطي خواص ميكانيكية عالية يمتاز بها الفولاذ وخواص حماية من التأكل تعطيها طبقة الخارصين. تم حساب معدلات التاكل بطريقة استكمال منحني تافل ولسمك طبقة غلونة مختلف من 80 , 90 , 100, 110, 120 و 130 مايكرومتر . لقد تم تمثيل مقاومة التربة باستخدام تراكيز مختلفة من محلول كلوريد الصوديوم (2, 2,5 , 3 و 3,5) نسبة وزنية من كلوريد الصوديوم. تم الفحص بالمجهر الضوئي لسطوح العينات لغرض تقييم معدلات التاكل. لقد انجز موديل رياضي لتخمين سمك طبقة الغلونة لاعمدة كهربائية عراقية مغلونة لغرض الحصول على افضل سمك لطبقة الغلونة والتي تعطي افضل مقاومة تاكل في مختلف الاترب العراقية، وقد تم استخدام نموذج الانحدار في هذا العمل لإيجاد العلاقة بين معلمات التآكل المتمثله بسمك الطبقة المغلونه من الصلب منخفض الكربون و المقاومة النوعية للتربة. تم استخدام برنامج ماتلاب. للحصول على المعاملات من نموذج الانحدار. وأجريت المعادلات الرياضية النظرية على التنبؤ بسمك طبقة أعمدة الكهرباء العراقية المغلونه للحصول على أفضل سمك طبقة مغلون والتي لديها مقاومة للتآكل عالية في مقاومة التربة المختلفة والذي يمثل هدف البحث الحالي.

لقد بينت نتائج الموديل الرياضي ان معدل التاكل للفولاذ المغلون تنخفض مع زيادة سمك طبقة الغلونة من 80-120 مايكروميتر . ان افضل مقاومة تاكل حصل عليها كان عند سمك طبقة غلونة 120 مايكروميتر بينما لوحظ ظهور شقوق مجهرية عند سمك 130 مايكروميتر. يؤثر سمك طبقة الغلونة بشكل مباشر على اداء وعمر الاعمدة الكهربائية وبشكل عام كلما زاد سمك طبقة الغلونة يزداد عمر العمود الكهربائي ولغاية سمك 120 مايكروميتر.