Enhancement of Corrosion Resistance in Steam Turbines Blades Using Nanoparticles Coatings

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Abstract

Corrosion in turbine blades may be considered the most crucial problems in power plants. Corrosion may lead to unbalance masses in turbine blades and therefor serious vibration problems. In this study coating nanomaterials namely Al_2O_3 and TiO_2 are used to resist the corrosion. Coatings consist of Al_2O_3 with 13 wt% TiO_2 are generally used to improve the corrosion, erosion and wear resistance. Tests specimens were taken from the portion of turbine blades in Al-Doura station which located in the south of Baghdad. The specimens are divided into two groups, the first group without coating and the second group with nanoparticale coating including alumina (Al_2O_3) and (Al_2O_3-13 % wt TiO_2), the coating applying by airbrush device using atomization technique with the aid of nitrogen 2 bar pressure . The properties of coated specimens have been investigated by SEM. The SEM showed that the deposition of nanoparticles on the surface of the samples was uniform and homogeneous. The thickness of coated layers was obtained using gravimetric method. Nano alumina with 13% wt of Titanum oxide coating gave the highest thickness 7.1 µm because of agglomeration of these particles comparing with other particales. Electrochemical properties was achieved by corrosion test at 90 ° for 20 min, the properties indicated that the corrosion resistance increased for coated specimens and these properties showed that the nano alumina with 13% wt of nano Titanium oxide was better than other coating and get a protection efficiency equal to 85.56%.

Keywords: *Corrosion; Nanoparticles coating; Atomization; Electrochemical properties.*

1. Introduction

Steam turbine is the most efficient and simplest device which converts thermal energy into mechanical work. With the expanding of steam, it gains increase in the velocity and makes high forces on the turbine blades [1]. The turbine blades are used to convert the linear motion of the entering steam with high pressure and temperature to rotating the turbine shaft. The statistics show that the blades of low pressure turbine are more capable to failure than those of the blades of high pressure and intermediate pressure turbine. In the low-pressure stage the problem becomes much more difficult because of that the particles of water suspended in the wet steam and that leads to erosion, which may be assisted by corrosion when the material is susceptible to it. Besides, about 50% of the failures due to pitting [2]. A. Turnbull and S. Zhou [3] carried out a comparative estimation for the resistance of stress corrosion cracking in the turbine blade steel (PH13-8) and the (FV3566) which considered an effective turbine blades, During a test in a temperature of 90 °C at a normal water chemistry conditions typically 300 ppb Cl^- and 300 ppb $SO^{2-}{}_4$ and with aerated solution, K_{ISCC}. The results indicate that the rate of crack growth for the higher strength (PH13-8) steel was about an order of magnitude greater than that for the FV566 steel. Vikas Chawlaa et.al [4] discussed the erosion and hot corrosion problems in coal based power plants in India and its suggestion solutions. The development of modern coal fired power generation systems with high thermal efficiency needs to use of construction materials of high strength and with increased resistance to the aggressive service atmospheres. These things can be fulfilled by applying effective coatings. Abdul jabbar Saad Jomah [5] used thick Al_2O_3 coatings deposited by EPD to increase the corrosion resistance of aluminum substrates. The corrosion resistance of the coatings has been obtained by using electrochemical methods as a function of different parameters such as: the thickness of coating, applied voltage and time of deposition. Alumina coatings showed an significant resistance in sea water. AFM inspections indicate that the coatings applied by EPD are uniform and free from defects.

Mohammed Hussein J. Al –Atia [6] used the potentiostate for obtaining the polarization curve in 3.5% NaCl solution at 250 °C for a single alumina layer deposited on stainless steel samples by using a dipping technique for four solutions containing different alumina concentration 0.25, 0.26, 0.61 and 0.93 mole/ liter gat by dissolving aluminum is opropoxide in water, the coated specimens then heat treated to 6000 °C. The results show that the possibility of evaluating good protective properties that easily the comparison between the different kinds of thin coatings deposited on the surfaces of the stainless steel by sol gel way. Mohammed Saieed Waheed and Niveen J. Abdalkadir [7] presented the static electrochemical corrosion behavior of nano (Al_2O_3) and nano (SiC) according to aluminum in Fao water was compared. The nanocomposites were preparing by used liquid metallurgy technique. The behavior of nanoparticulates weight percentage 5%, 15% and 25% on the corrosion was obtained. The results indicated that the Al reinforced with nano (Al_2O_3) composites behaved lower corrosion rates comparing with the Al reinforced with nano (SiC) composites.

The aim of present work is to increase the corrosion resistance of steam turbine blades by apply nano particle coatings of alumina and alumina with 13% wt of nano Titanium oxide on the specimens taken from a portion of steam turbine blades in Al-Doura station by cold spaying using airbrush device and test the corrosion in 300 ppb Cl^{-} and 300 ppb SO_4^{-2} solution for 20 min at 90 °C in addition to inspection the coated surfaces by SEM.

2. Experimental work

2.1. Material Selection

A portion of the failed steam turbine blades shown in Figure 1 were taken from Al-Doura thermal power plant was used in this work. The chemical composition of the blade is shown in Table 1 obtained by AMETEK; SPECTRO MAX in the Ministry of industry and minerals, state company for inspection and engineering rehabilitation.

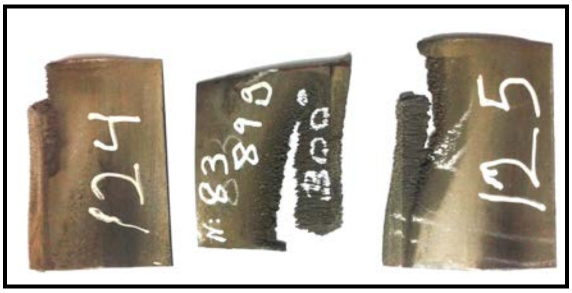

Figure 1: Corroded steam turbine blades

Table 1: Chemical composition of steam turbine blade

Alloy	C	Si	Mn	S	P	Ni	Cr	Cu	Mo	V	Co	Fe
Wt%	0.168	0.228	0.504	0.011	0.013	0.351	12.49	0.042	0.490	0.022	0.010	Bala.

2.2. Specimen Preparation

To perform the electrochemical test, the portion of steam turbine blade was cutting and prepared according to the ASTM G4 and used as specimens as shown in Figure 2.

After cutting, the specimens were ground with abrasive papers in sequence of 300, 400, 600, 800, 1200 and 2000 grit to get flat and free from scratches surface by Grinder and Polisher MoPao 160E shown in Figure3.

Figure 2: Cutting specimens

In order to relief the stress the specimens were annealed by heating in the Muffle Furnace shown in Figure 4 from room temperature to 600 °C in one hour, then the specimens were keeping for one hour, cooling from 600 °C to 400 °C during two hours and to room temperature in approximately 12 hours.

2.3. Suspension preparation

The coating solutions were prepared by adding 20 ml ethanol liquid to (3 gram) weight of nanoparticle powders of pure (Al_2O_3) with particle size 20-30 nm and (Al_2O_3-13%wt TiO_2) with particle size10-30 nm. All powders were weighted by using a sensitive balance device shown in Figure 5.

Figure 3: Grinder and Polisher

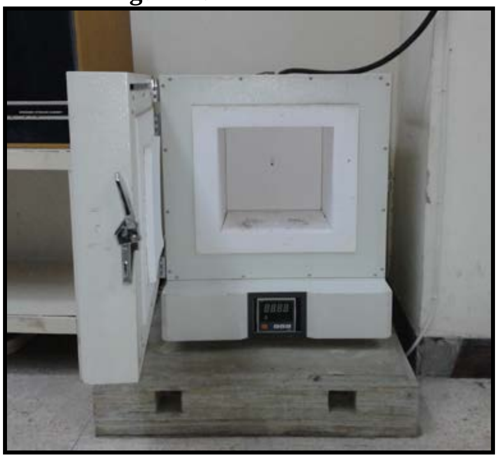

Figure 4: Muffle Furnace

Figure 5: Sensitive balance device

Suspension was prepared by using Ultrasonic stirrer device (Ultrasonic cleaner, model: KQ 3200 E, Origin: China) for 30 min. and then magnetic mixing device (Brand Name: chtech, Model Number: MS200, Origin:China) for 45min. as shown in Figure 6. Homogenize solutions were obtained.

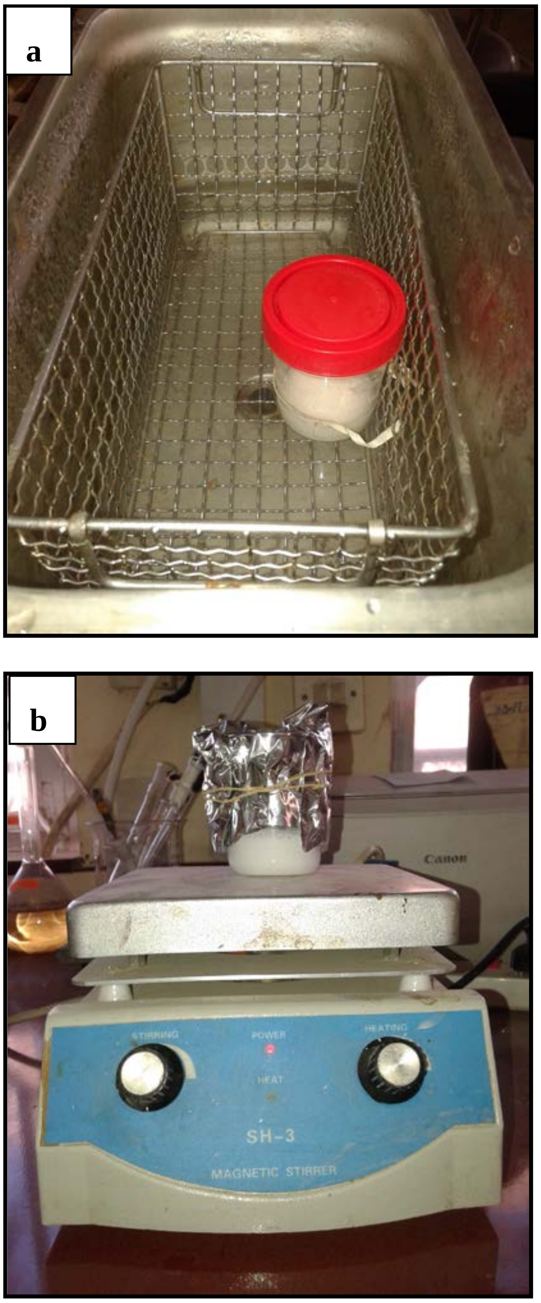

Figure 6: Coating solutions mixing by: (a) Ultrasonic device. (b) Magnetic mixing device

2.4. Coating Process

Uniform coating was achieved by atomization technique using the set up system which consist of:

- Electrical heater: used to heat the specimens to about 150±5 ^{o}C which measured by using Thermocouple.
- Nitrogen gas at purity 99.999%: used for spraying solution into the atomizer at flow rate equal to 2 bars.

- Atomizer: contains container for mixing solution and nozzle for spraying the solution which is directed forward the specimen surface at about (5 cm) above specimens as shown in Figure 7. After spraying solution on the specimens, the coated specimen was heated to increase the adhesion between the metal and coating layer. The spraying of suspension performed by airbrush device which shown in Figure 8, while Figure 9 shows the specimens after coating.

2.5. Corrosion Test

Corrosion measurements for uncoated and coated specimens were performed in 300 ppb Cl^{-} and 300 ppb SO_4^{-2} solution for 20 min at 90 °C (that solution was simulated of steam environment in last stage of steam turbine blades at constant conditions and can gives accurate measurements of the corrosion potential.

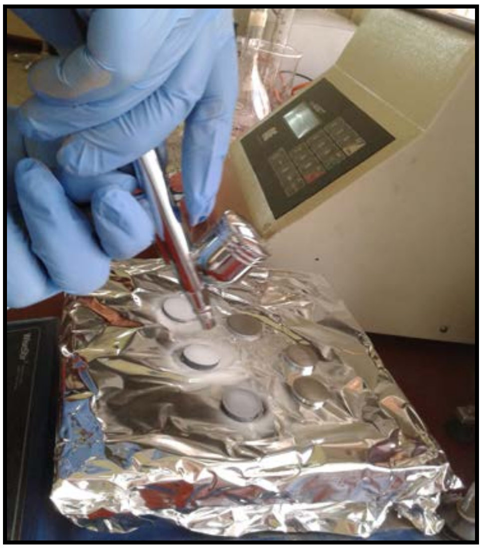

Figure 7: spraying technique

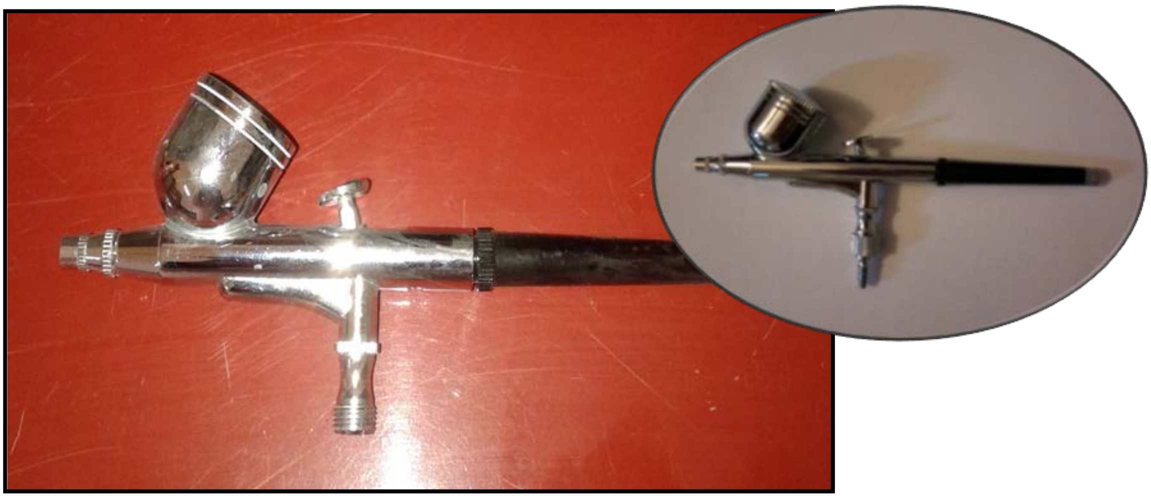

Figure 8: Airbrush device

Figure 9: Coated specimens.

A general condensate environment on the steam turbine would consist of a few hundred parts per billion of Cl and SO_4 at normal operated conditions) using potentiostatic. In this work the electrochemical cell was used as present in Figure 10; using the working electrode holder to fix the uncoated and coated specimens, while reference and counter electrodes were Pt and Saturated Calomel Electrode (SCE), respectively. In order to get 90 °C, the corrosion cell was placed in a water path. The first step in this measurement is open circuit potential, and the polarization curve will start at open circuit potential over a potential range about ±200 mV from the open circuit. Corrosion current density (i_{corr}) and corrosion potential (E_{corr}) values were obtained from the polarization curve by Tafel extrapolation method. The corrosion test set up is illustrated in Figure 11.

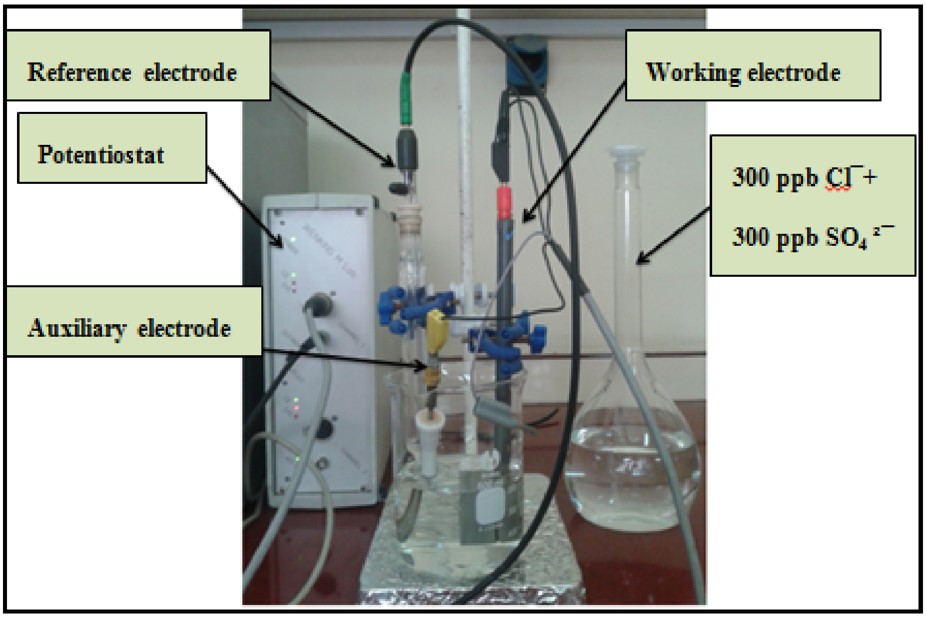

Figure 10: Corrosion cell

Figure 11: Set up of corrosion test

3. Results and Discussion

3.4. Electrochemical Behavior

Figure 12 illustrates the polarization curve of uncoated specimen in 300ppb Cl^- and 300ppbSO_4^{-2} solution for 20 min at 90 °C. Corrosion parameters were obtained by Tafel extrapolation method. These parameters included corrosion current density (i_{corr}), corrosion potential (E_{corr}) and Tafel slopes (b_a and b_c). The corrosion currant density is 306.88 $\mu A.cm^{-2}$ and the corrosion potential of uncoated specimen is -582.9 mV.

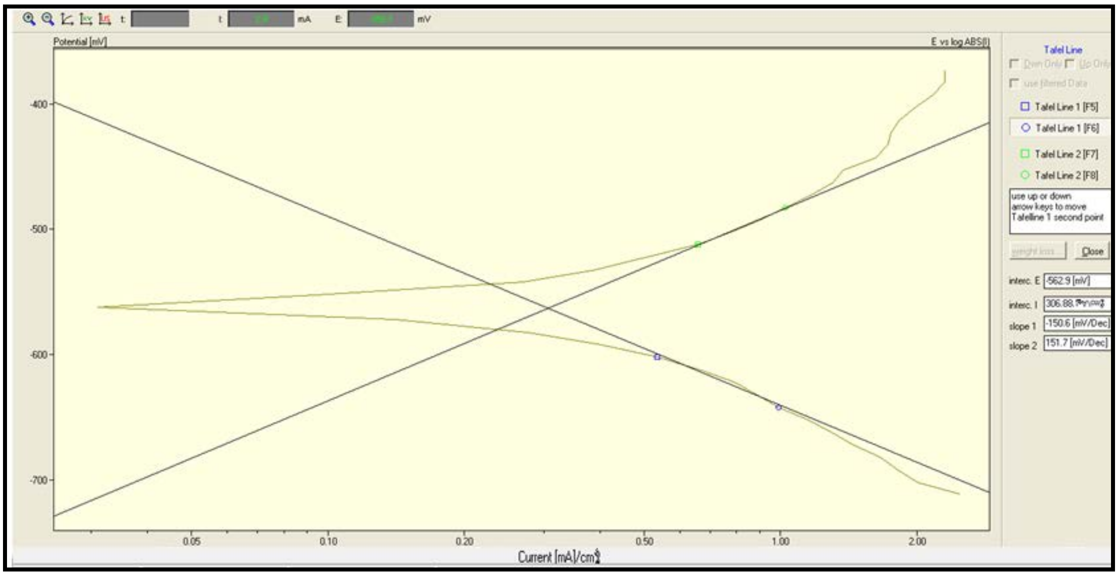

Figure 12: Tafel plot of uncoated specimen in 300 parts per billion Cl^- and 300 parts per billion SO_4^{-2} solution at 90 °C.

While, Figures 13 and 14 presents the polarization curves for coated specimens by nano particle coatings, including Alumina and Alumina with 13% wt of nano Titanium oxide. From this figures, it can be seen that the curve of coated specimen with nanoparticles Al_2O_3 gave lower effect than other coating. Besides, the curve of the current density for coated surfaces with Alumina+13% wt of nano Titanium oxide was lowered and more positive values of corrosion potential. The measured corrosion data from these curves are listed in Table2, these parameters indicate that the corrosion current densities were decreased and the corrosion potentials became more positive values. Also the cathodic Tafel slope was decreased; its means that the polarization decreased after coating applying and the rate determining step controlled by concentration polarization due to nanoparticle coatings which reduce the dissolution of metals and then reducing the electrons production which are need to reduction reaction at cathode.

The thickness of coated layer was 6.42 μm for Al_2O_3 coating, while it was 7.1 μm for (Al_2O_3-13 % wt TiO_2) coating, calculated from the following equations [8]:

$$T = \frac{w}{A \times \rho} \quad \text{…..……….. (1)}$$

Where:
T: The thickness.
w: The weight of coating.
A: The surface area.
ρ: The density.

For the same method of spraying, the nano alumina with 13% wt of nano Titanium oxide coating had the highest thickness; this is because conglomerate particles faster than others.
The rate of corrosion (C_R) in a given conditions is directly proportional to its corrosion current density (i_{corr}) according to the following relation[9]:

$$C_R = 0.13 \times i_{corr} \times \left(\frac{e}{\rho}\right) \quad \text{………... (2)}$$

The above equation is used to evaluate C_R in mil per year (mpy).
Where:
e: equivalent weight
ρ: density of specimens.
It can be found from the data of corrosion rate that the nanoparticle coatings lead to decrease corrosion rate of specimens. The protection efficiencies (PE) of applied coatings can be calculated from the corrosion current densities for uncoated and coated specimens as follows [8]:

$$PE\% = \left[1 - \frac{i_{corr\ coated\ specimen}}{i_{corr\ uncoated\ specimen}}\right] \times 100 \quad \text{…….. (3)}$$

From the Stern – Geary equation [10] it can be founded polarization resistance (R_p) as follows:

$$R_p = \frac{b_a b_c}{2.303(b_a + b_c) i_{corr}} \quad \text{……… (4)}$$

From the data of PE%, the nano Alumina with 13% wt of nano Titanium oxide coating has the highest efficiency followed by pure nano Alumina coating. While the data of polarization resistance of coated surfaces compared with uncoated specimen indicates that the coated specimens have resistance more than uncoated specimens and when it compared among coated specimens, it can be seen that the nanoparticle of (Al_2O_3-13 %wt TiO_2) has the highest polarization resistance as illustrate in Table3

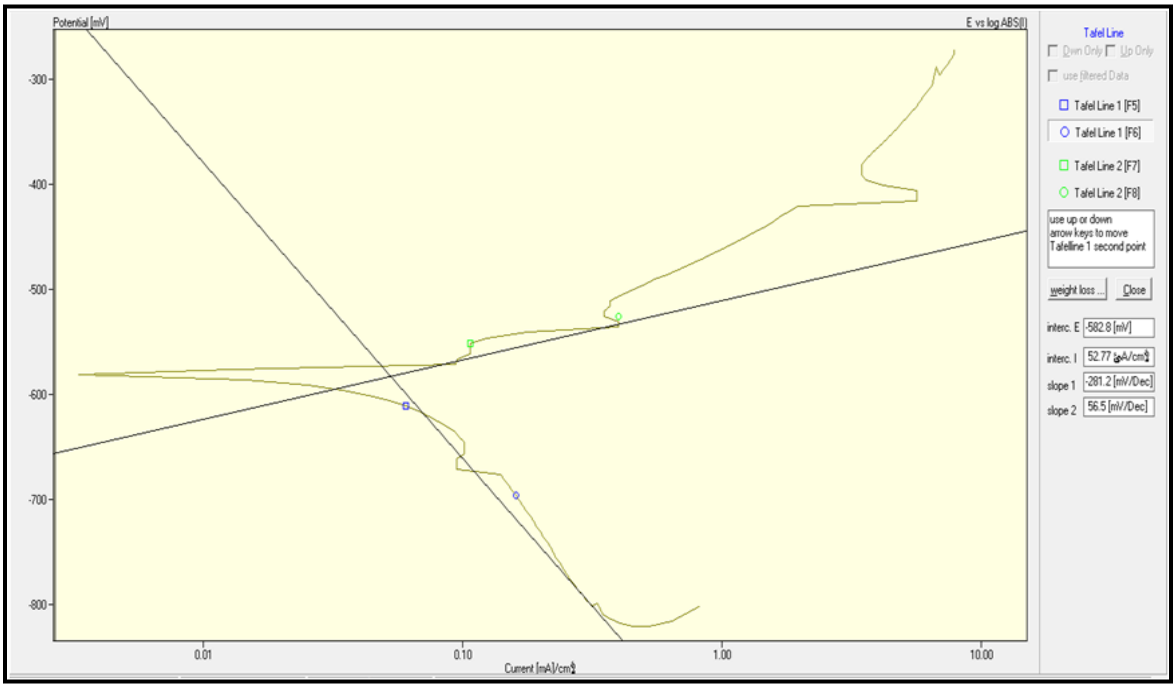

Figure 13: Tafel plot for specimen coated with (Al_2O_3).

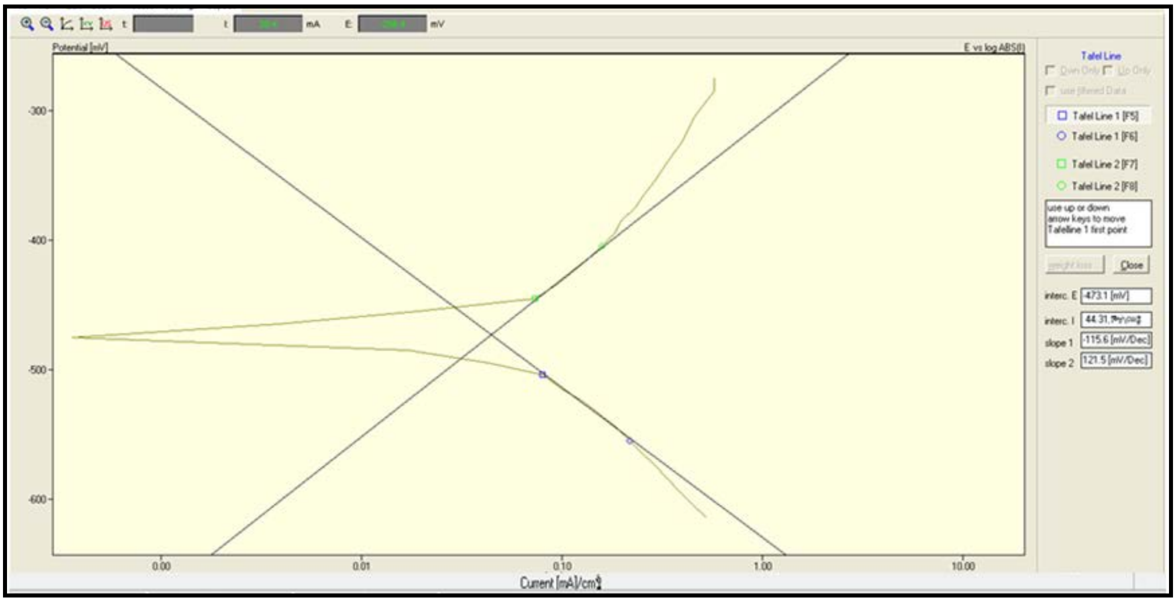

Figure 14: Tafel plot for specimen coated with (Al_2O_3-13 % wt TiO_2).

Table 2: Electrochemical properties of uncoated and coated specimens measured in 300 parts per billion Cl^- and 300 parts per billion SO_4^{-2} solution at 90 °C.

Specimens	***E_{corr} mV***	***i_{corr} $\mu A.cm^{-2}$***	***$-b_c$ $mV.dec^{-1}$***	***$+b_a$ $mV.dec^{-1}$***
Uncoated	-582.9	306.88	150.6	151.7
Coated with 100% Al_2O_3	-562.8	52.77	281.2	56.5
Coated with (Al_2O_3-13 % wt TiO_2)	-473.1	44.31	115.6	121.5

Table 3: Corrosion calculations for uncoated and coated specimens.

Specimens	C_R/mpy	PE%	$R_p x10^3/\Omega.cm^2$
Uncoated	12.5	------	0.10693
Coated with 100% Al_2O_3	2.16	82.8	0.3854
Coated with (Al_2O_3-13 % wt TiO_2)	1.82	85.56	0.5805

3.5. SEM inspection

The surface topography and particle distribution of the sprayed coatings were inspection by using (VEGA 3 TESSCAN) Scanning Electron Microscope (SEM). Figures 15 to 17 show the SEM after corrosion in 300 parts per billion Cl^{-} and 300 parts per billion SO_4^{-2} solution at 90 °C. Figure 15 shows the specimen surface without coating by any nano particles which shows some scratches due to grinding and polishing in addition to non-uniform corrosion and pitting corrosion, while other figures illustrate the distribution of deposited particles on the specimens, it can be observed more pits in corroded specimens coated by pure nano Alumina than corroded specimen coated by nano Alumina with13% wt of nano Titanum oxide.

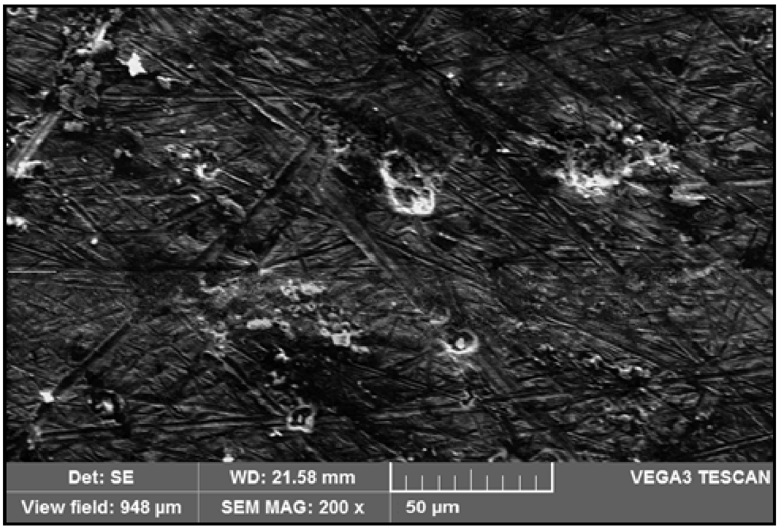

Figure 15: Scanning Electron Microscope image of uncoated specimen after corrosion.

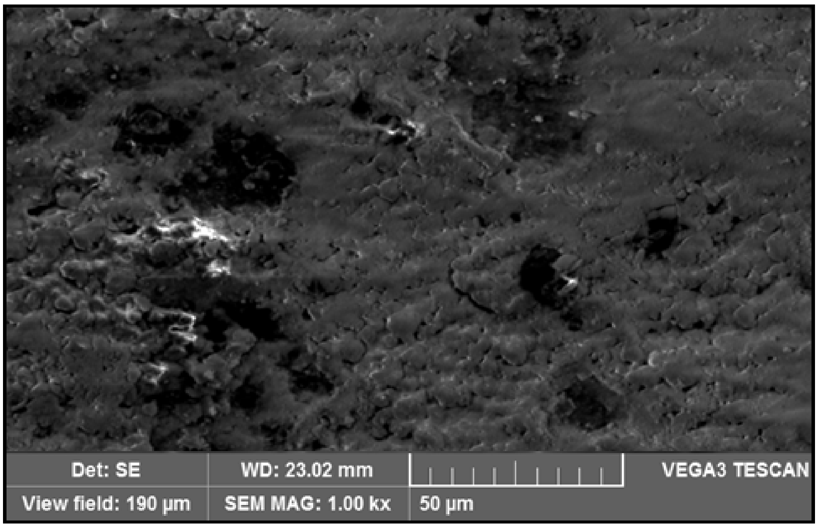

Figure 16: Scanning Electron Microscope image of specimen coated with (100% Al_2O_3) after corrosion.

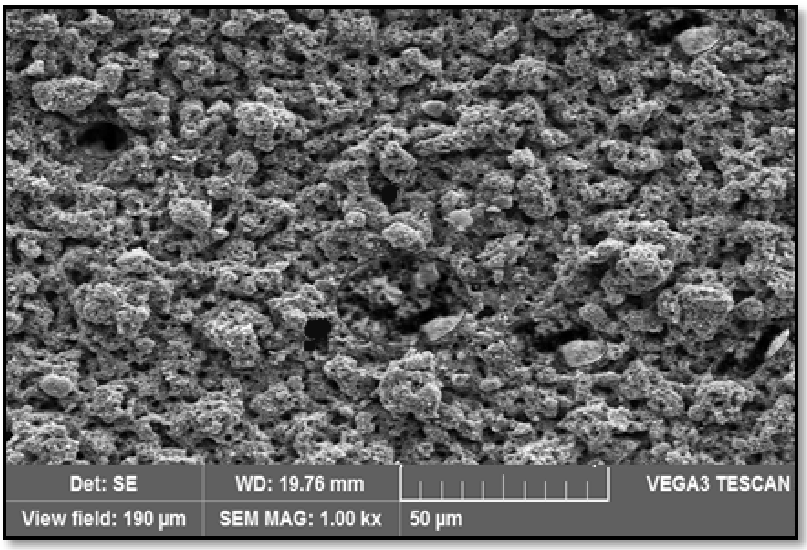

Figure 17: Scanning Electron Microscope image of specimen coated with (Al_2O_3-13 % wt TiO_2) after corrosion.

4. Conclusion

Coating nanomaterials namely Al_2O_3 and TiO_2 were used to resist the corrosion in power plants, especially in the turbine blades. General observations are:

1- It is clear that all coatings applied have enhanced corrosion protection; the layers deposited by airbrush spray method gave excellent protection.
2- The nano alumina with 13% wt of nano Titanium oxide coating had the highest thickness due to agglomeration of particles faster than others.
3- The curve of the current density for coated surfaces with Alumina+13% wt of nano Titanium oxide was the most lowered than the surfaces coated with pure Alumina.
4- The current density for uncoated surfaces has the higher value which recorded 306.88 $\mu A.cm^{-2}$ comparing with the current density for coated surfaces by Alumina+13% wt of nano Titanium oxide and pure Alumina which recorded 44.31 $\mu A.cm^{-2}$ and 52.77 $\mu A.cm^{-2}$ respectively.
5- The corrosion potential for the specimens coated with Alumina+13% wt of nano Titanium oxide have more positive values equal to -473.1 mV comparing with uncoated specimens and specimens coated with pure Alumina which recorded -582.9 mV and -562.8 mV respectively.
6- The nanoparticle coatings lead to decrease corrosion rate of specimens.
7- The specimen coated with (Al_2O_3-13 % wt TiO_2) has higher corrosion protection than coating nano particle of pure (Al_2O_3).
8- The Tafel polarization curve indicates that the nano Alumina with 13% wt of nano Titanum oxide coating has the higher pitting resistance than other coating compared with Tafel polarization of uncoated specimen.
9- Depending on the results that have been obtained from the SEM inspection, there are more pits in corroded specimens coated by pure nano Alumina than corroded specimen coated by nano Alumina with13% wt of nano Titanum oxide.

5. References

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زيادة مقاومة التآكل في ريش التوربينات البخارية باستخدام الطلاءات النانوية

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الخلاصة:

يعتبر التاكل في ريش التوربينات من اهم المشاكل في محطات توليد الطاقة الكهربائية, قد يؤدي التاكل الى عدم الاتزان في توزيع الكتل في ريش التوربينات وبالتالي مشاكل اهتزاز خطيرة. في هذه الدراسة تم استخدام طلاءات نانوية من اوكسيد الالمنيوم (Al_2O_3) و اوكسيد التيتانيوم (TiO_2) لمقاومة التاكل في ريش التوربينات. بصورة عامة تستخدم الطلاءات النانوية المكونة من اوكسيد الالمنيوم النانوي مع نسبة 13% من اوكسيد التيتانيوم النانوي لتحسين مقاومة البلى, التاكل و التعرية. تم اخذ عينات الاختبار من اجزاء من ريش التوربينات الموجودة في محطة كهرباء الدورة الحرارية والتي تقع جنوب بغداد. تم تقسيم العينات الى مجموعتين: المجموعة الاولى عينات بدون طلاء والمجموعة الثانية تحتوي عينات تم طلائها بنوعين من المواد النانوية, النوع الاول من اوكسيد الالمنيوم النانوي (Al_2O_3) والنوع الثاني هو اوكسيد الالمنيوم النانوي مع اضافة نسبة 13% من اوكسيد التيتانيوم النانوي (Al_2O_3-13 % wt TiO_2). تم الطلاء باستخدام جهاز الرش بتقنية التذرية بواسطة غاز النيتروجين وبضغط (2 بار). تم التحقق من خصائص السطوح المطلية باستخدام المجهر الالكتروني الماسح, حيث بينت الفحوصات بواسطة المجهر ان جميع الطلاءات تم ترسيبها بصورة موحدة ومتجانسة على اسطح العينات. تم حساب سمك طبقة الطلاء باستخدام الطريقة الوزنية. الطلاء من نوع اوكسيد الالمنيوم النانوي مع نسبة 13% من اوكسيد التيتانيوم النانوي اعطى اعلى سمك (7.1 مايكرومتر) بسبب تجمع هذه الجزيئات النانوية مقارنة بجزيئات اوكسيد الالمنيوم النانوي. تم الحصول على الخصائص الكهروكيميائية بواسطة اختبار التاكل بدرجة حرارة 90 درجة سيليزية ولمدة 20 دقيقة, بينت هذه الخصائص زيادة في مقاومة التاكل للعينات المطلية اضافة الى ان تلك الخصائص اوضحت ان الطلاء النانوي من نوع اوكسيد الالمنيوم مع 13% من اوكسيد التيتانيوم هو افضل من الطلاء النانوي باستخدام اوكسيد الالمنيوم وحده, حيث اعطى الطلاء النانوي من نوع اوكسيد الالمنيوم مع 13% من اوكسيد التيتانيوم اعلى كفاءة حماية تساوي 85.56 %.