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The Effect of NanoParticle Coating on Anticorrosion Performance of Centrifugal Pump Blades

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Abstract

A common problem in the production of a centrifugal pump is the corrosion caused by fluid communication. The use of nano-coatings is one of the most effective methods for preventing and postponing corrosion. Nano-coatings have a higher thermal expansion coefficient, higher hardness and toughness, and more resistance to corrosion, abrasion and erosion. The purpose of this study was to investigate the effect of TiO2nano-particle coating on the construction of corrosion resistant blades of centrifugal pumps. Thin layers of titanium dioxidenano-particles were created in two separate steps on GG25 gray cast iron samples with specific dimensions and characteristics using the sol-gel process and immersion method. After each step, heat treatment was performed to stabilize the nano-coating. The thickness of applied coatings was measured by scanning electron microscopy (SEM). In order to measure the corrosion rate, the samples were exposed to petrochemical wastewater. The corrosion rate was measured by atomic absorption spectrometry method. The experiments were carried out in a factorial arrangement in a completely randomized design with three temperature levels of 40, 50 and 60 ºC and four thicknesses. The results showed that coating of titanium dioxide nano-particles increased the corrosion resistance of GG25 gray cast iron. With an increase in temperature from 40 to 60 ºC, the corrosion rate of all samples increased by 46.6%. Coated samples with thicknesses of 440-550, 840-970, and 1030-1330nm reduced corrosion rates by 39.1%, 67.8% and 73.6%, respectively.

Keywords: *Corrosion; Centrifugal pump; Nano-particle coating; Titanium dioxide.*

1. Introduction

Corrosion causes the destruction of materials through a chemical reaction with the environment. The corrosion phenomenon occurs in all major categories of materials, including metals, ceramics, polymers and composites, but its occurrence in metals is much higher [1-2]. One of the most important issues facing the industry, especially the oil industry and its related industries, is the presence of corrosion problems [3]. Centrifugal pumps are widely used in various industries, including petrochemicals, refineries, military, power plants, and agricultural industries[4]. The most important performance problem of these types of pumps is the appearance of corrosion and abrasion. The major effects of corrosion in the blades and shells of the centrifugal pumps appear in the forms of performance drop, noise, and unwanted vibrations, resulting in a great deal of damage [5].

Studies have shown that corrosion costs and damages are estimated to be about 2-4% of gross national product, of which 21 to 51% is reduced by appropriate methods [6-8]. Nowadays, new technologies with the application of various materials, including metals and alloys, plastics, tires, ceramics, corrosion protection coatings, and so forth are trying to reduce the corrosion damage. Among the methods of preventing and postponing corrosion, the use of coatings is considered as an effective method [1].

Studies on nano-coatings show that the properties of nano-coated materials are significantly improved in comparison with the conventional coatings [9]. Better appearance, higher chemical resistance, less permeability to corrosive environments, easy surface cleaning, good adhesion of coating, and scratch resistance are among the prominent features of nano-coatings [10]. Among these types of coatings, the use of ceramic nano-structured coatings such as titanium dioxide (TiO_2) has attracted the attention of researchers because of their electrical and thermal properties, oxidation and corrosion and abrasion resistance. Shanghi et al. [11] investigated the corrosion properties of TiO_2nano-particles applied on the simple carbon steel using a sol-gel process by immersion method. They stated that the quality of the applied coating depends on the speed of the immersion process, the drying time, the heat treatment, and the number of applied layers. In another study, Curkovic et al. [12] examined the corrosion behavior of a thin layer of titanium dioxide nano-particles on steel AISI 304. In order to examine the effect of the

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number of layers on the degree of corrosion, coating was carried out in one and three layers on the surface of the samples. The corrosion properties of the applied coatings were investigated in sodium chloride solution 3% by electrochemical method. Based on the results, with increasing the number of layers of titanium dioxide nano-particles, the amount of cracks and roughness of the surface decreased and caused the potential defects in the surface to be discarded. According to the results of this study, after corrosion tests, it was found that by increasing the number of layers, the corrosion of coating of titanium dioxide nano-particles applied on the surface of AISI 304 steel was reduced. Baghal Nezhad et al. [13] investigated the effect of titanium dioxide nano-particles on the corrosion behavior of nano-composite coatings of chromium, titanium dioxide and pure chromium by potentiodynamic polarization and electrochemical impedance spectroscopy. The results showed that the titanium dioxide nano-particles deposited in the coating increased in corrosion resistance and reduced the corrosion rate of chromium coatings in salt and alkaline solutions. Khaledinia et al. [14] investigated the application of nano-particle coatings in the production of corrosion-resistant machinery components against agricultural pesticides. The results showed that the coating of titanium dioxide on high-carbon steel surface significantly contributes to its corrosion resistance against agricultural pesticides.

The current study aimed at providing anticorrosion blades for centrifugal pumps. Hence, the performance of GG25 gray cast iron coated by TiO_2nano-particles was investigated using immersion and electron microscopy methods.

2. Materials and Methods

2.1. Samples preparation

In this study, 36 GG25 gray cast iron samples with the dimensions of 30 x 15 x 4mm were used to apply the coating of titanium dioxide nano-particles on. Table 1 shows the weight percent of GG25 gray cast iron components.

Table 1: Specification of gray cast iron GG25

Element	Fe	Cr	S	P	Mn	Si	C
Weight percent	93.63	0.04	0.11	0.12	0.5	2.2	3.4

In order to apply the coating of titanium dioxidenano-particles, the operation of working on metal coupons was done in several steps. First, the coupons were polished with Silicium Carbide and washed with distilled water. Then, they were polished with Aluminum Oxide and washed with distilled water. The coupons were washed by Acetone for 10 minutes before exposure to ultrasonic in degreasing process. Finally, the samples surface was activated by soaking them in Hydrochloric acid for 3 minutes.

2.2. Preparation of titanium dioxide solution

The steps for preparing the titanium dioxide solution are shown in Fig. 1.After preparing the titanium solution and preparing the samples, immersion method was used to apply nano-particle coating on steel surfaces. Three samples were deposited randomly in each step. The difference in thermal expansion coefficient in metal samples and nano-coatings cause cracks and defects in the surface of the samples[11]. To solve this problem, the coating operation was carried out in two separate steps (i.e. primary and secondary steps). Performing the initial coating minimizes the thermal expansion coefficient variation and increases the final quality and properties of metal samples [12]. After the initial coating, the samples were subjected to heat treatment as in Fig. 2.

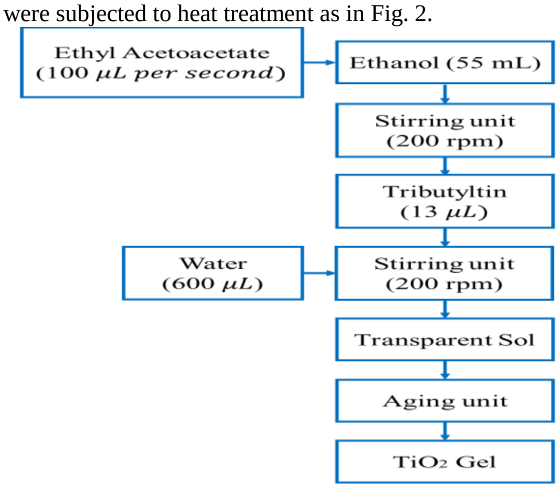

Figure 1: Steps for preparing a titanium dioxide solution**.**

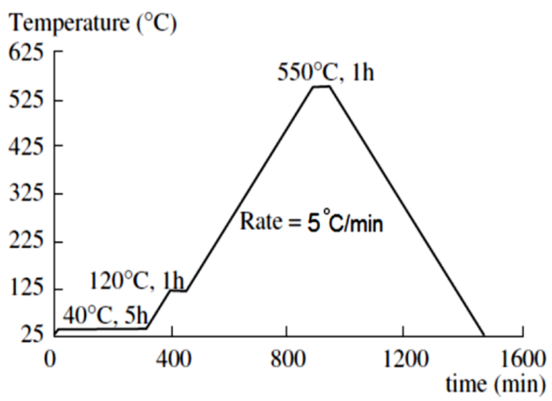

Figure 2: Applied Heat Treatment Cycle

After initial deposition of the thin layer, the samples were washed in distilled water, acetone and ethanol in ultrasonic apparatus and prepared for final coating. To create the final coatings at different thicknesses, the samples were coated in three groups with speeds of 30, 60, 120 mm / min. In each group, the samples were carefully immersed in the solution and after 5 minutes, they were removed at the same initial rate. The coated samples were again subjected to the mentioned heat treatment. The thickness of the coatings was measured using a scanning electron microscope (Fig. 3). The thickness of the coated samples at three speeds of 30, 60 and 120 mm / min was in the range of 440-550, 870-970, and 1350-1030 nm, respectively.

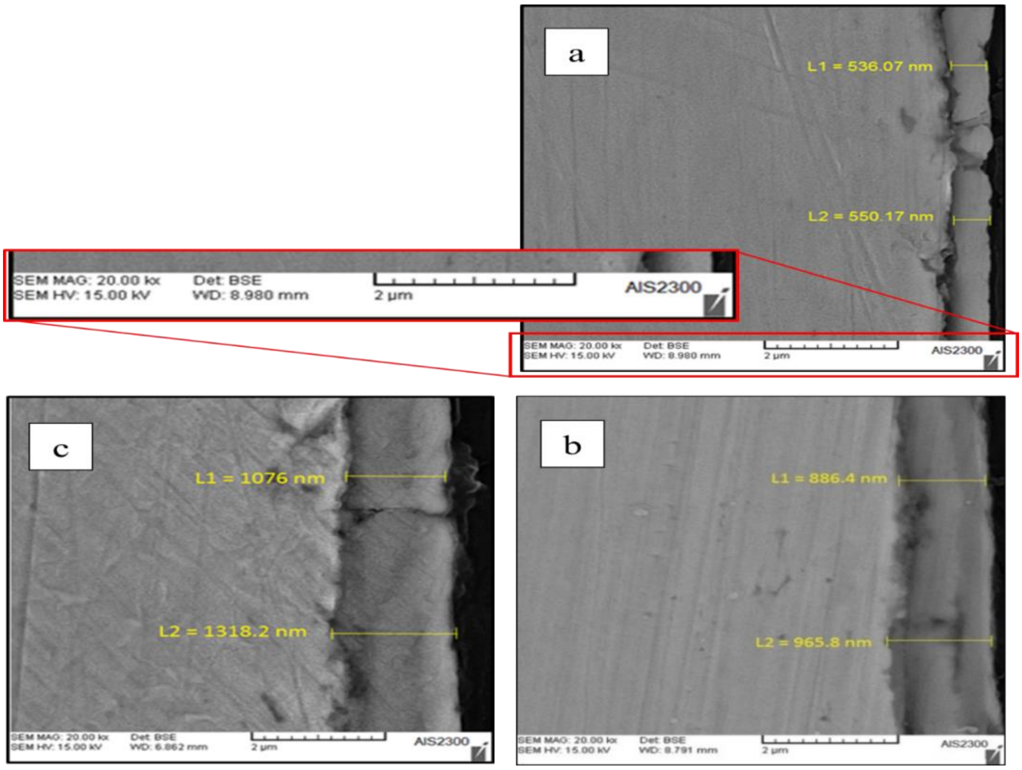

Figure: The thickness of the coatings a) coating at 30 mm / min; (b) coating at 60 mm / min; (c) coating at 120 mm / min.

2.3. Providing Petrochemical Wastewater

Petrochemical wastewater was used to evaluate the corrosion rate of cast iron samples. The wastewater was produced from Ilam Petrochemical Complex. Wastewater characteristics are given in Table 2.

Table 2. The properties of the wastewater.

Parameter	Unit	Value
Conductivity	µS/Cm	1412
Turbidity	NTU	3
P−Alkality	ppm	NIL
M-Alkalinity, AS CaCO3	ppm	44
Ca-H, AS CaCO3	ppm	100
Total Phosphate	ppm	8
O- Phosphate	ppm	5
Organic Phosphate	ppm	3
Zinc	ppm	1.8
Total Hardness	ppm	<1200
Chloride (cl^-)	ppm	...
T.SS	ppm	...
Free chlorine	ppm	0.2-0.5
Totalchlorine	ppm	0.7-1
pH	ppm	7

2.4. Testing corrosion rate

The corrosion rate of samples was measured by atomic absorption spectrometry (AAS).AAS is the measurement of absorption of radiation by free atoms. The total amount of absorption depends on the number of free atoms present and the degree to which the free atoms absorb the radiation. At the high temperature of the atomic absorption flame, the sample is broken down into atoms and it is the concentration of these atoms that is measured. To measure the corrosion rate of samples, a factorial test was used in a completely randomized design. Variables in these experiments were the thickness of the nano-coating (D) at four levels (i.e. d_0=0, d_1= 440-550, d_2= 840-970, d_3= 1050-1330) and corrosive fluid temperature (T) at three levels (i.e. t_1=40, t_2= 50, t_3= 60).

2.5. Corrosion tests

In order to conduct a corrosion test, three WISD Heater stirrer devices, a closed Erlenmeyer flask and a magnet---for generating flow in a flame---were used. The heater stirrer device was adjustable (up to 550 ºTemperatures), rotary speed (up to 1500 rpm) and time. The GG25 gray cast iron samples were tested in the wastewater by adjusting the device at a specified temperature, rotational speed and time. A specific volume (200 ml for all samples) of petrochemical wastewater was poured inside a closed Erlenmeyer flask and then the cast iron samples were immersed in a solution at a certain height (i.e. 15 mm for all samples). A magnet was used to create fluid flow in the Erlenmeyer. In this way, the magnet rotation inside the fluid caused fluid circulation and rotational movement of the cast iron sample. The rotational speed at all stages was the same and about 1000 rpm. For all thicknesses, each sample was exposed to fluids for 72 hours.

After the prescribed time, the sample was removed from the fluid and the solution was examined by an automated compact spectrometer (novAA 400P, Analytik Jena AG, Germany) to determine the corrosion rate. The results were used to report corrosion rate in ppm scale. The results present the amount of corrosion in ppm. According to this method, the samples should be soluble. The petrochemical wastewater that was in contact with the cast iron samples was evaluated to determine the absorbed amount of the metal. To obtain the concentration of the examined sample in the spectroscopy, the relationship between the amount of absorbed light by the sample and the concentration of the sample was used. The electrons of the atoms with certain wavelength absorption energy can go to higher levels of energy and come to the excited state for a short time. This amount of energy is different for each atom in comparison with other atoms. When the excited atom returns to the base state, it emits a certain wavelength. By measuring the absorbance of the sample and drawing the calibration curve, the unknown value was determined in the sample. Each test was repeated three times to minimize the test errors. As a whole, 36 tests were performed, and the data were then analyzed.

3. Results and discussion

3.1. Effect of temperature and coating thickness on corrosion rate

The results of ANOVA test for the effect of temperature and thickness of nano coating are given in Table 3. As it can be seen, the effect of temperature, nano coating thickness and interaction of these factors on corrosion rate were significant with a probability of 99%. Significance at a 99% probability level indicates a significant difference in the levels of the factors. Considering the significance of the interaction between temperature and coating thickness, it can be concluded that these two factors have not worked independently on their own levels.

3.2. Effect of temperature on corrosion

The Duncan multidimensional test was used to examine and compare the mean of the temperature effect on the corrosion rate (Table 4).According to Table 4, there was a significant difference between corrosion rates of different temperatures. The maximum and minimum corrosion rateswere at 60 and 40 ºC, respectively. With an increase in temperature from 40 to 60 ºC, the mean corrosion rate increased from 1.64 to 3.7 ppm. As the temperature rises, the speed of reactions and interactions increases, which increases the level of corrosion at the surface of the GG25 gray cast iron samples.

Table 4: Duncan test results of comparing the mean of the temperature effect on the corrosion rate

Temperature (˚C)	corrosion rate (ppm)
40	1.64^{c}
50	2.43^{b}
60	3.07^{a}

With increasing temperature from 40 to 60 ºC, the corrosion rate increased in all uncoated (d_0) and coated samples with different thickness of d_1, d_2 and d_3 (Fig. 4).

Table 3: Analysis of variance of the effect of temperature and thickness of the nano coating on the corrosion rate (ppm)

Source of variance	Degree of freedom	Sum of squares	Mean squares	F
Temperature	2	12.37	6.18	248.96**
Thickness	3	55.52	18.50	745.00**
Temperature×Thickness	6	0.97	0.16	6.15**
Error Total	24	0.59	0.02	-
Corrected Total	35	69.46	-	-

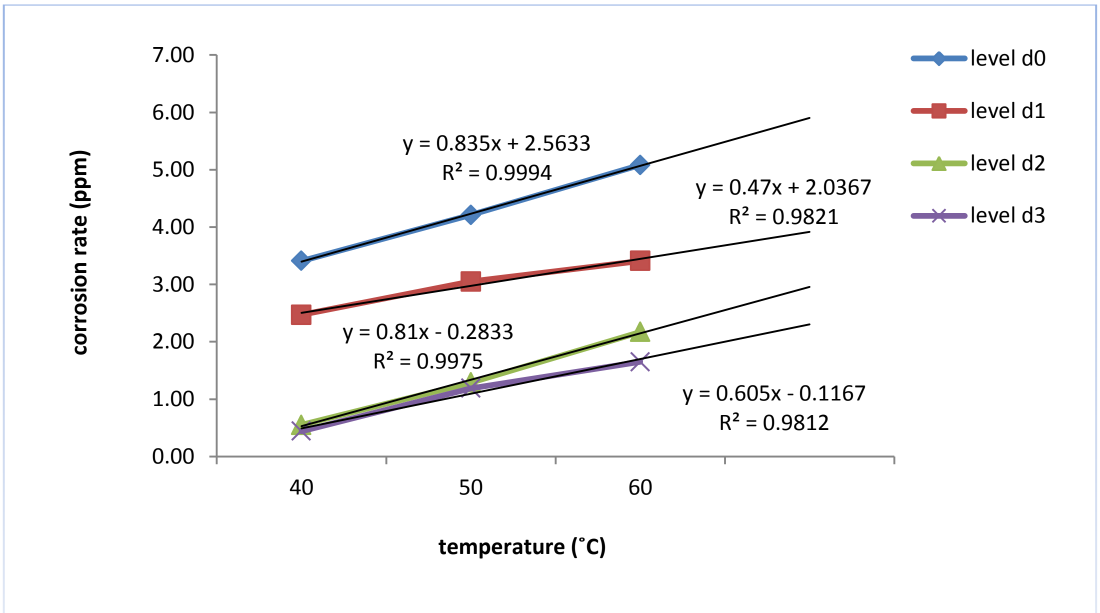

Figure 4: Changes of corrosion rate with different coating thicknesses.

It is noted that the correlation between the corrosion rate and the temperature was linear, so the corrosion could be predicted at an acceptable accuracy at any point outside the measured range. Also, line slope in the graph of the corrosion rate for uncoated samples was greater than the coated ones. This means that the effect of increased temperature on the corrosion rate of the uncoated samples (d0) was greater than that of the coated ones with d1, d2 and d3 thicknesses and uncoated samples tended to be more sensitive to temperature rise. The gentler slope in the coated samples than the uncoated ones indicated that the coating prevented rapid corrosion changes when the temperature rose. Therefore, the corrosion rate in coated samples was more consistent than that in the uncoated ones.

To reduce corrosion in the petrochemical industry and other industries using centrifugal pumps, it is possible to reduce the temperature of the fluid. To compare the thickness effect of TiO_2nano-particle coating on the corrosion rate, Duncan test was used and the results were shown in Table 5.

According to the results of Duncan's classification test (Table 5), there was a significant difference between the corrosion values of four different coating thicknesses. The results showed that the corrosion rate in all samples was significantly different from each other. The results also showed that the corrosion resistance of samples coated with nano-particles of titanium dioxide was higher than that of uncoated samples against reacting with petrochemical wastewater. According to Table 5, the corrosion rate was decreasing with increasing coating thickness from 550-440 to 1350- 1050 nm. Corrosion rate in the thickness of $d_3$was3.8, 2.72, and 1.22 times less than that for d_0, d_1, and d_2, respectively.

Table 5. The results of the Duncan's test to compare the mean effect of coating thickness on corrosion rate (ppm)

coating thickness(nm)	corrosion rate (ppm)
d_o	4.13^a
d_1	2.97^b
d_2	1.33^c
d_3	1.9^d

The variation in the corrosion rate in proportion to the thickness of nano-coating at various temperatures was shown in Figures5 and 6. According to Fig. 5, the corrosion rate of the uncoated samples (d_0) was higher than other thicknesses. By applying coatings of titanium dioxidenano-particles in different thicknesses, the corrosion rate was strongly reduced at all temperatures as well as with increasing in thickness of coating, the corrosion rate in all samples decreased.

At first, the slope of the line at different temperatures is very high which then decreases (Fig. 5). This shows that the coating of titanium dioxide nano-particles acts as a barrier to develop corrosion at the surface of the samples, and causes a lower corrosion rate[16]. The coating of TiO_2 nano-particles applied by the sol-gel method had a good adhesion, and by reducing the surface defects of the field on a molecular scale by creating a smooth (e.g. low roughness on a nanometer scale), non-cracking, water-resistant and abrasion-resistant surface increased the resistance to corrosion.Other researchers reported the same results for using Titanium Dioxide nano-coatings [11,12, 14-17]. By increasing the thickness of thenano-particle coating to a range of 1050-1330 nm, the corrosion rate significantly decreased. The coatings produced in two immersion stages with a 120 mm / min deposition rate had the highest corrosion resistance and the best performance. This was observed byShanaghi et al. [18] in usingTiO_2 nanostructure coatings on mild steel.

By increasing the coating thickness from 550-440 to 1350-1030 nm, the corrosion rate reduced at different temperatures (Fig. 6). Corrosion rate also increased with increasing degree in the wastewater temperature. In general, the corrosion rate was significantly reduced by increasing the thickness of the coating and reducing the temperature of the wastewater.

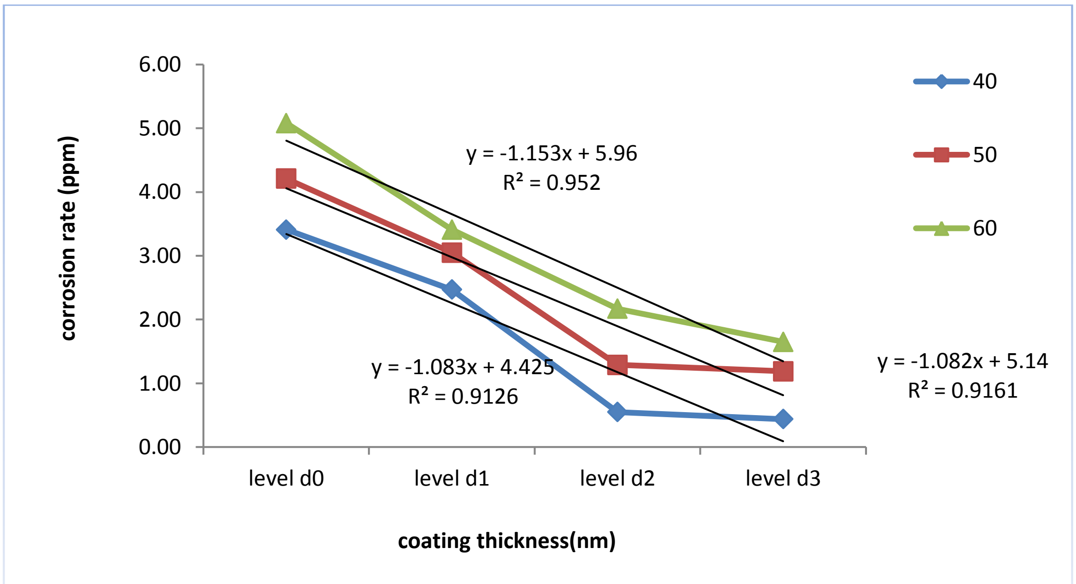

Figure 5: The chart of corrosion rate with coating thickness at different temperatures

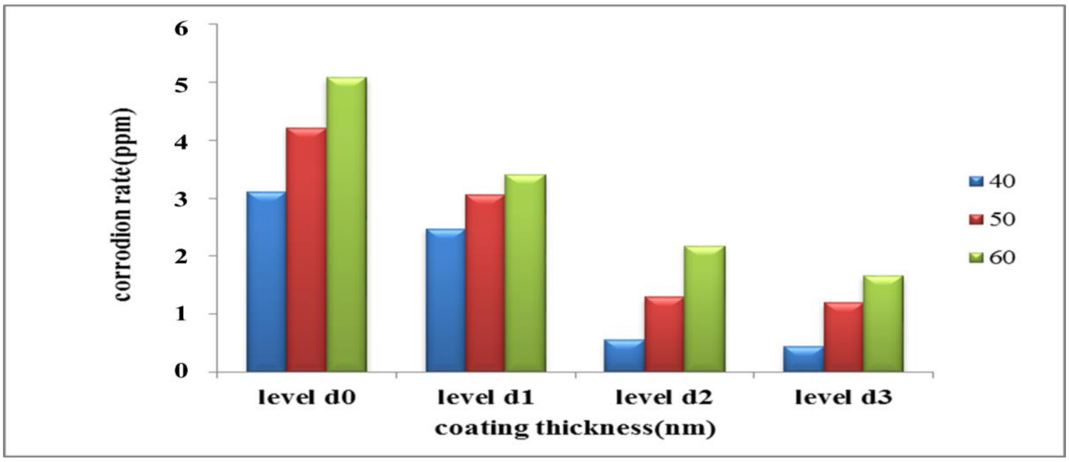

Figure 6: The effect of coating thickness at different temperatures on corrosion

4. Conclusion

In this study, coating of titanium dioxide nano-particles was applied on GG25 gray cast iron using the sol-gel method and in three different thicknesses. The corrosion rate of the coated samples was compared with the uncoated ones at three different temperatures.

By analyzing and investigating the data obtained by atomic absorption spectroscopy and measuring the corrosion rate of all samples, the results are reported as follows:

1. The coating of titanium dioxide nano-particles improved the corrosion resistance of GG25 gray cast iron against reacting with petrochemical wastewater.
2. With an increase in the temperature of the petrochemical wastewater from 40 to 60 ºC, the corrosion rate of all samples increased by 46.6%.
3. The samples coated with titanium dioxide nano-particles with thicknesses of 440-550, 840-970, and 1050-1330 nm reduced the corrosion rate by 39.1%, 67.8% and 73.6%, respectively.
4. By increasing the coating thickness, the corrosion rate of all samples decreased. The best performance among the samples in terms of corrosion resistance is from a sample with a thickness of 1050- 1330 nm.

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