Effect of TiO$_2$ Nanoparticles Addition on Contact Angle of Epoxy Resin

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Abstract. The contact angle is very important parameter in improving the self-cleaning property as well as increasing the wear resistance of engineering surfaces in addition to improving the thermal transfer properties of materials in general. In this study, titanium dioxide nanoparticles were added to the epoxy resin and sprayed on a substrate of the brass tube used in heat exchangers for the purpose of studying its effect on the angle of contact of the substrate where different proportions of the nanomaterial were added to the epoxy resin in (1%, 3%, 5%, and 7%)wt. The results showed that the contact angle increased with increasing the rate of titanium dioxide nanoparticles.

Keywords: contact angle, epoxy resin, Nano composite coating, TiO$_2$ Nanoparticles, self-cleaning.

1. Introduction

Epoxide is one of the highly corrosion resistance materials, and this feature can be improved with some other properties by adding nanomaterials to the epoxide when used as a coating to protect surfaces from corrosion(Chaudhari, Shaikh, & Pandey, 2013). Fouling and corrosion relates to the main problem with heat exchangers. Such a problem causes the heat exchanger to stop getting it out of work to disassemble it and clean it can be very expensive(Rathish, Dorothy, R M, Pandiarajan, & Rajendran, 2013). Fouling and corrosion in chemical factories and power plants, leading to the need to use large quantities of water for the purpose of improving the efficiency of the heat exchanger(Zhao, Liu, Wang, Wang, & Müller-Steinhagen, 2005). The phenomenon of fouling is the main problem that causes the efficiency of heat exchanger to decrease and is defined as the accumulation of unwanted materials on the inner or outer surface of the heat exchanger tube, such as scale, algae, suspended solids and insoluble salt(Al-Haj Ibrahim, 2012). Fouling and corrosion layer forms on the walls of tubes due to the low contact angle of the tube surface. It can lead to corroded of the tube metal, which increases Potential problems for conventional and nuclear power plants(Videla & Characklis, 1992). As this layer has a much lower thermal conductivity than the thermal conductivity of the tube metal and thus a deterioration in the heat transfer coefficient of the tube and the
heat exchanger in general, also high drop in pressure, this requires the use of pressure-lifting equipment (Karabelas, 2002). Due to the adhesion of the fouling layer on the surface of the pipes and the problems that lead to it in the cooling water systems and heat exchangers, it has taken a large portion of attention for the purpose of studying the means that limit or prevent this fouling and its growth (Hamza, Pham, Matsuura, & Santerre, 1997). The process of changing the surface characteristics is one of the most important methods by which the rate of fouling on the surface of tube of heat exchanger is reduced, it changes the nature of surface and make it less attractive to the fouling (Dexter, Sullivan, Williams, & Watson, 1975). Numerous attempts were made to increase the contact angle by coating, whether by metal or polymeric materials, for the purpose of reducing this problem. The results showed that the coating with nanomaterials increases the corrosion resistance and improves thermal transfer (Takata et al., 2005).

Sometimes composite coating consisting of polymeric material and nanomaterials are used for the purpose of improving surface properties and to take the advantage of the properties of both materials (Liu, Wang, Wang, & Müller-Steinhagen, 2005).

The aim of the work is enhancement of the contact angel of the brass tube surface grade (B-111) after coating by only epoxy and nanocomposite coating of epoxy with different weight ratio of TiO₂ nanoparticles.

2. Experimental work

2.1 Materials

Materials used in this experiment are epoxy resin type Quick mast 105 made in Focsroc Company in Jordan that is in liquid state where it was used as basic coating material in preparing the nanocomposite coating materials. The hardener is used to harden the epoxy and add a ratio 2:1 with continuous mixing. The TiO₂ nanoparticles (Eprui Nanoparticles & Microphares Co. Ltd) is used and add at four ratios (1%, 3%, 5% and 7%). wt

![Figure 1. properties of epoxy resin](image)

2.2 Coating Technique

Brass grade (B-111) samples with chemical composition shows in table No (1a) tested it by X-Ray Fluorescence and table (20 for ASTM stander it was taken from the same alloy of heat exchanger tube with dimensions 15×10 mm for purpose of its coating and then characterizing the coat and measuring the contact angle before and after the coating with the mentioned ratios. Before the coating process, firstly, in order to prepare the sample for etching, mechanical Polishing is used and then the sample is etching (Mixing 5 g
Ferric Chloride, and 10 ml Hydrochloric Acid with 100 ml water and the specimen is immersed), then the samples are washed and clean to remove impurities from the surface where they washed with distilled water and then dried.

Table 1: Chemical composition of brass tube

| Element | Cu   | Zn  | Pb  | P   | Sn  | Mn  | Ti  | Fe  |
|---------|------|-----|-----|-----|-----|-----|-----|-----|
| 73.32   | 25.08| 0.0084 | 0.0017 | 0.001 | 0.006 | 0.0042 | 0.09 |
| Sb      | 0.001 | 0.032 | 0.057 | 0.0026 | 0.003 | 0.0021 | 0.02 | 0.097 |
| Mg      | 0.0021 | 0.175 | 0.021 | 0.0579 | 0.045 | 0.0005 | 0.0011 | 0.002 |

Table 2. ASTM B111 Tube Chemical Composition

| Element | Ratio weight |
|---------|--------------|
| Cu      | 76.0-79.0    |
| Zn      | Reminder     |
| Al      | 1.8-2.5      |
| As      | 0.02-0.06    |
| Pb      | 0.07         |
| Fe      | 0.06 max     |

2.3 Coating Preparation

20 ml of epoxy mixed with 10 ml hardener, the weight of mixture 35 gm mixed by magnetic stirrer for 5 minutes and then using airbrush spray gun for coating the samples with epoxy alone. After that, the different proportions of titanium dioxide nanoparticles are added to the epoxy, where every time a percentage of the TiO₂ is added, it is mixed with the epoxy by using the magnetic stirrer for 1 hr and then placed in an ultrasonic homogenizer for five minutes, after which the hardener is added to the mixture and Place it on the magnetic stirrer for five minutes, after which it is sprayed on the samples for the purpose of coating them. At 5% and 7% wt of TiO₂ in epoxy resin a 3ml volatile diluent was used to dilute the coating and facilitate the spraying of samples.

3. Characterization

3.1 Atomic Force Microscopy

AFM was conducted for the purpose of characterizing the coating on the substrate of the disinfection. Microscopic examination of the AFM was carried out for the purpose of measuring surface roughness, as well as measuring the diameter of particles and surface morphology in addition to structures.

3.2 Scanning Electron Microscopy

A scanning electron microscopy SEM test was conducted for the purpose of characterizing surface topography after coating and knowledge of composition and information whereby the surface can be described as if it is woven, smooth or rough.

3.3 Measurement of Contact Angle

This test was conducted to knowledge the nature of surface whereas hydrophobic or hydrophilic and determined the affected of TiO₂ on the contact angle of epoxy resin. The test carried out by using the
instrument by put 3 droops on the surface of sample before and after coating from distilled water with $9\mu L$
volume at different positions on the surface of the samples, by using the needle in the position very near to
the surface of sample. The repeated tow times and the images in fig 3 shows the measurements of contact
angle for samples before and after coating.

4. Results and discussion

4.1 Atomic Force Microscopy (AFM)

Atomic Force Microscopy (AFM) is used to investigated the topography and roughness of the surface
of the coated samples respectively. Where the results of the examination showed a rate of superficial
roughness at a value 4.422, 7.912, 14.941 and 22.098 respectively for coated samples Epoxy with (1, 2, 3 and
7%) weight ratio of TiO$_2$ nanoparticles, as shown in the figure (1). Where we notice a decrease in the surface
roughness for the samples that were coated with reinforced epoxy by 1% and 3%. This indicates that the
titanium dioxide nanoparticles have a high dispersion within the epoxy resin and have a strong cross-linked.
While the high surface roughness in the samples coated with epoxy containing 5% and 7% weight ratio of
TiO$_2$ is due to the high ratio of TiO$_2$ nanoparticles to agglomerate, which leads to an increase in the tendency
of nanoparticles, thus the collective size of the particles will increase (Goyat, Rana, Halder, & Ghosh, 2018).

Figure (1-a): 2D and 3D AFM examination of sample No1 (epoxy with 1% TiO$_2$)

Figure (1-b): 2D and 3DAFM examination of samples No2 (epoxy with 2% TiO$_2$)
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Figure (1-c): 2D and 3DAFM examination of samples No2 (epoxy with 3%TiO₂)

Figure (1-d): 2D and 3D AFM examination of samples No2 (epoxy with 4%TiO₂)

4.2 Scan Electron Microscopy

SEM examination of all samples showed that the presence of individual titanium dioxide nanoparticles in the epoxy resin is possible but very limited within the coating. It is also noticed that there is an agglomeration state of the embedded particles in the epoxy, but in spite of this, there is a good dispersion condition of the nanoparticles of titanium dioxide as show in fig (2) a and b.

Figure 2a: SEM of 1% and 3% TiO₂ samples
4.3 Measurement of contact angle (CA)

A contact angle measurement test was performed in order to know the wettability of the surface to the samples before and after coating and to know the extent of the impact of the TiO$_2$ nanoparticle on that property by performing this examination as show in fig (5). The result showed that an increase in the ratio of TiO$_2$ nanoparticle on epoxy resin to some extent increases the contact angle as shown in the fig (4) the Max contact angle at 7%TiO$_2$ is 68.369°.
5. Conclusion
The addition of different ratios of TiO₂ nanoparticle to the epoxy resin increases the contact angle of the nanocomposite coating, which leads to a decrease in the build-up of fouling and improvement of the surface properties coated with the nanocomposite coating. The characterizations performed on the coating, AFM and SEM, showed a good cross-linking between nanoparticles and the epoxy.

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