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UV Performances and Corrosion Behavior of Nanocoating on Carbon Steel

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ABSTRACT. Corrosion is gradual degradation process of metal through chemical reaction. Mostly happen by electrochemical and reaction with the surrounding environment. It affects material properties. Coating industry continuously working on the growing demand on modern coating and strives to improve their products especially to meet requirement in petrochemical industries. This paper reviews $ZnO-SiO_2$ as formulation as the agent for new and improved corrosion and UV resistant coating industry.

Keywords: Nanocoating, $ZnO-SiO_2$, UV, Epoxy, Corrosion, Carbon steel;

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1. INTRODUCTION

Corrosion is always the major reason of energy and material loss. It was reported that 1/5 of energy globally and average 4.2% of gross national product (GNP) is lost every year due to corrosion behavior and the economic impact of corrosion is estimated to be greater than $1billion/year in the United States alone [1-6]. According to Cabrera-Sierra et al. [2] plants have suffered from continuous economic loss and human casualties because of metallic materials corrosion. Over the past years nanotechnology has become more and more important in the development of coatings. Nanocoatings offer great potential for various applications due to their superior characteristics that are not typically found in conventional coatings. Applying coating nanomaterial on the steel surfaces can prevent corrosion. According to the research study by Thomas [1], the nanocoatings market is envisaged to grow over the next 5 to 10 years across all market segments. This is attributed to growing need for better facilities and advances in nanocoating technology. This industry is segmented by type of future markets that includes anti-bacterial, anti-fouling, anti-fingerprint, easy to maintain and self-cleaning nano-coatings. In addition, the anti-corrosive nanocoatings market is expected to grow on the strength of demand from oil and gas industries for protection of pipeline surfaces [10-12]. Behavior of the coating was studied by exposing the coated test panels to UV Test according to ASTM D 4587.The purpose of testing was to observe how a material would react to long-term sunlight exposure. Salt spray test based on ASTM B117 was used to evaluate the performance of the nanocoating samples.

2. MATERIALS AND METHODS

In UV testing, the apparatus located in an area maintained between18-27°C. The ambient temperature was measured at a maximum distance of 150 mm from the plane door of the apparatus. The apparatus was 300 mm from walls or other apparatus. The purpose of testing was to observe how a material would react to long-term sunlight exposure. At the every 24 hours exposure the samples was observed. The salt spray test was an accelerated corrosion test by samples exposed to salt condition. The salt solution employed was prepared with NaCl analytical grade reagent and distilled water. All the samples were placed in the salt spray chamber for 24 hours until 2000 hours. Then all the samples were cleaned in running water not warmer than 38°C to remove salt deposits from the surface and then immediately dried with compressed air at 60°C. Photographs were taken before and subsequent to exposure to document the surface conditions.

The samples were exposed to a salt fog generated from a 3.5% sodium chloride solution with a pH between 6.5 and 7.2 in salt spray testing. The test condition as showed in Table 1. Table 2 shows MSDS of UV epoxy resin.

Table 1 Test Condition of UV Test

Lamp type	Xenon Arc
Temperature	65±3°C
Relative humidity	50±5% RH
Irradiation wavelength	368nm
Radiation condition	Continuous radiation
Time exposure	2000 hours

Table 2 MSDS of UV epoxy resin

Test	Value
Durometer Hardness 2hr@60°C	82±3
Tensile Strength, psi	7700
Flexural Strength, psi	12200
Flexural Modulus	400848

3. RESULTS AND DISCUSSION

Fig. 1 shows the surface micrographs of UV exposed samples after 24 hours, where the source of irradiation used was UV lamp that emits wavelength of 368 nm as stated in Table 1. At the very early stage of exposure (24-1560 hours), the neat sample and in corporation nanoparticles into coating was good. Instead no appearance of surface defects was observed. After 2000 hours of exposure, all samples still in good condition since no any pinholes were observed on sample. Table 2 showed MSDS of UV epoxy resin used. Table 3 showed that, the thickness before and after exposure to UV was not fully changed especially for $3ZnO+2SiO_2$of hybrid sample. The reason because, the type of epoxy resin used was purposely for preventing UV exposure. The type of epoxy resin used was epoxy UV clear coat. It has been formulated to improve UV resistance in order to reduce yellowing and surface degradation from UV exposure. The degradation of coating due to photochemical interaction was preventing. There was also no presence of surface heterogeneity seen clearly indicates that the degradation of coating due to long term exposure to UV radiation was prevent (Fig. 2a-i).

The improvement of UV resistance of the modified coating can be attributed to the fact that, nano-ZnO has a wide band gap (3.37 eV) and large excitation binding energy of 60 meV, therefore it can absorb light that matches or exceeds their band gap energy and which lies in the UV range of the solar spectrum [1-2]. Thus, a well-dispersed nano-ZnO particle attenuates UV radiations and protects the polymer matrix from degradation. It appears that the addition of the nanoparticles lowers the degradation rate of the coating. The degradation time of neat resin and coating with the addition of nanoparticles remains unaffected until 2000 hours. This may be attributed to the fact that, at nanoscale the particles themselves effectively absorb rather than scatter the UV radiation providing UV protection to the polymer [3-4]. It also proved that small surface area per unit mass and a volume of nanoparticles increases the effectiveness of blocking UV radiation and prevents photo degradation of polymer matrix. Good UV blocking property to the coating system achieved since photochemical activity was low. Thus, prevent interacting with UV radiation as shown in Fig. 2

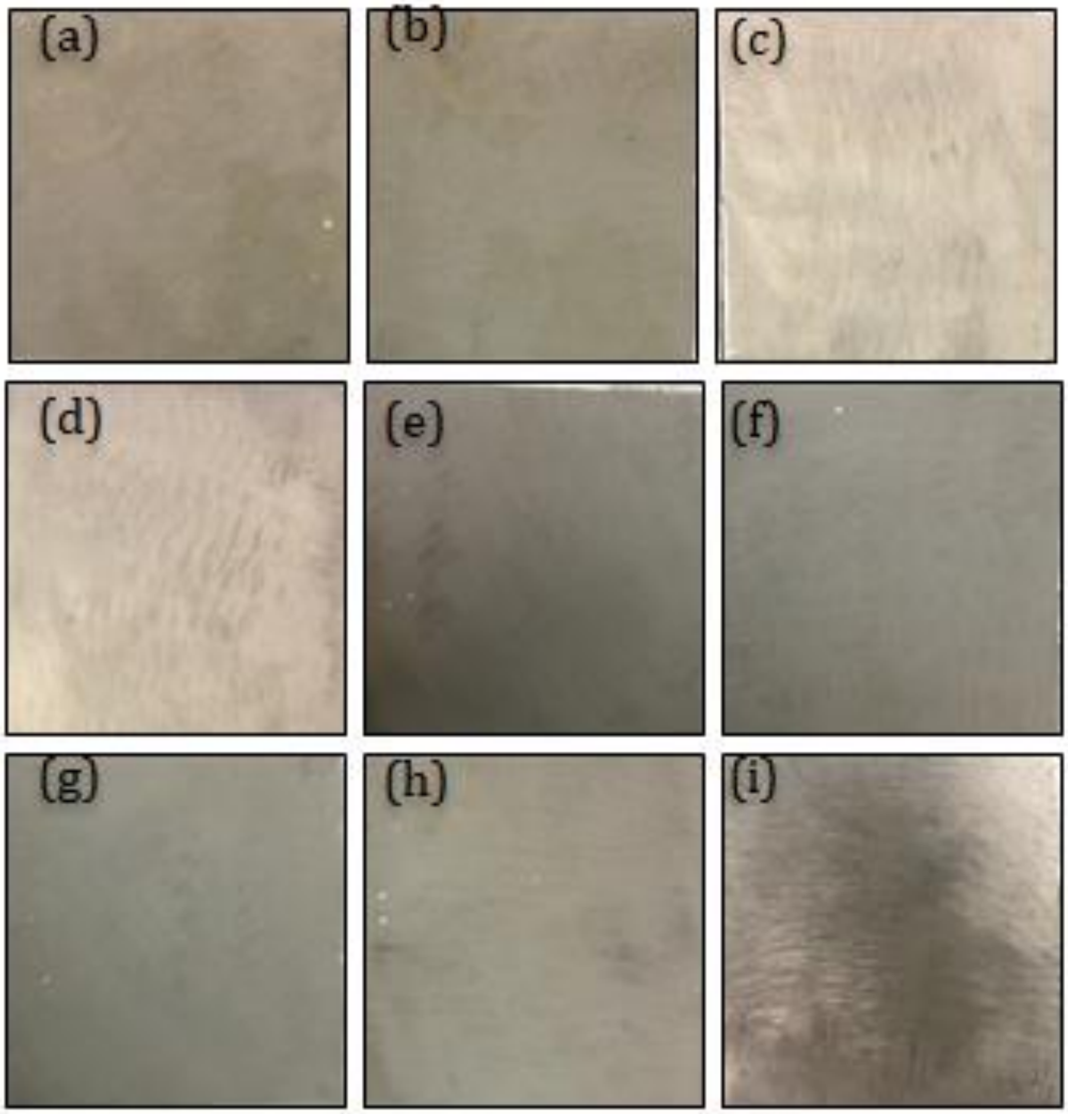

Fig. 1 UV images of nanocoatings in 24 hours. (a) 2wt.% ZnO coating,(b) 3wt.% ZnO coating, (c) 2wt.% SiO_2 coating, (d) 3wt.% SiO_2 coating, (e) 1wt.% ZnO+4wt.% SiO_2, (f) 2wt.% ZnO+3wt.% SiO_2, (g) 3wt.% ZnO+2wt.% SiO_2, (h) 4wt.% ZnO+1wt.% SiO_2, and (i) Plain epoxy

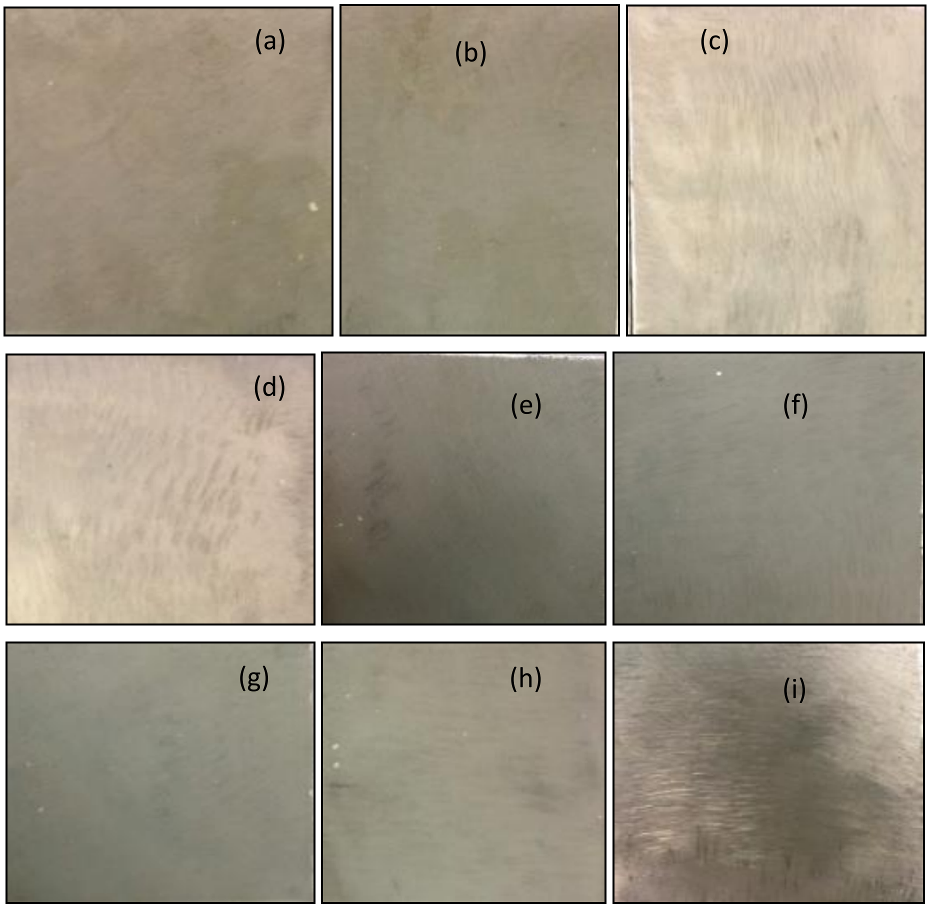

Fig.2 UV images of nanocoatings in 2000 hours. (a) 2wt.% ZnO coating,(b) 3wt.% ZnO coating, (c) 2wt.% SiO_2 coating, (d) 3wt.% SiO_2 coating, (e) 1wt.% ZnO+4wt.% SiO_2, (f) 2wt.% ZnO+3wt.% SiO_2, (g) 3wt.% ZnO+2wt.% SiO_2, (h) 4wt.% ZnO+1wt.% SiO_2, and (i) Plain epoxy.

To improve the corrosion performance of the coating, nanoparticles were added to the epoxy. Nanoparticles having ability to penetrate and adhere in coating on the metal surface and work under the gaps and micro cavities providing a molecular layer of corrosion protection. Based on Fig.5, sample containing nanoparticles was greatly improved the properties of metal. The effectiveness of nanoparticles in preventing corrosion was clearly demonstrates. The amount of addition nanoparticles in epoxy coating was important. It was approved that the thickness of nanocoating samples still remains almost same for all samples as shown in Fig.4.

The addition of nanoparticles increased the corrosion resistance of the coating. The level of corrosion area was reduced when compared with samples without any nanoparticles. It was because by the ability of nanoparticles to migrate underneath the micro gaps and voids that exist between the nanoparticles and metal substrate as explained in proposed mechanism before. Nanoparticles works as protective network layer in epoxy coating as clearly shown in Fig. 5. Fig. 6 shows XRD of nanocoating.

Table 3 Thickness of nanocoating on mild steel with different wt.%

Different loading (wt.%)	Thickness (milimeter)					
	0 hour	1560 hours	1680 hours	1848 hours	2000 hours	Differences
Epoxy	5.01	5.00	5.00	5.00	5.00	0.01
2ZnO(single)	5.02	5.02	5.02	5.01	5.01	0.01
3ZnO(single)	5.03	5.03	5.03	5.02	5.01	0.02
2SiO_2(single)	5.03	5.03	5.03	5.02	5.01	0.02
3SiO_2(single)	5.03	5.03	5.02	5.01	5.01	0.02
1ZnO+4SiO_2(hybrid)	5.02	5.02	5.02	5.01	5.01	0.01
2ZnO+3SiO_2(hybrid)	5.02	5.02	5.02	5.01	5.01	0.01
3ZnO+2SiO_2(hybrid)	5.02	5.02	5.02	5.02	5.02	0.00
4ZnO+1SiO_2(hybrid)	5.02	5.02	5.02	5.01	5.01	0.01

Additionally, when sample failed to overcome UV radiation, it is because crosslinking and simultaneous chain reduction caused embrittlement and a weakening of internal resistance. Degradation of ether groups in epoxy resins takes place via the intermediate stage of peroxides, which then suffer cleavage in the molecular chains on account of ultraviolet light. Consequently, by increasing temperature it is possible to detect not only the expected accelerations of esterification and oxidation reactions but also direct cleavage due to depolymerization and statistically distributed opening of the base chain. Side chains are cleaved homolytically by the ultraviolet light of the sun. Various radicals occur on account of the opening of C-C and C-O bonds, which stabilize owing to hydrogen abstraction or combination with other radicals. The connecting of new bonds involves crosslinking. As a result, embrittlement of the coating happened as showed in Fig. 3 below.

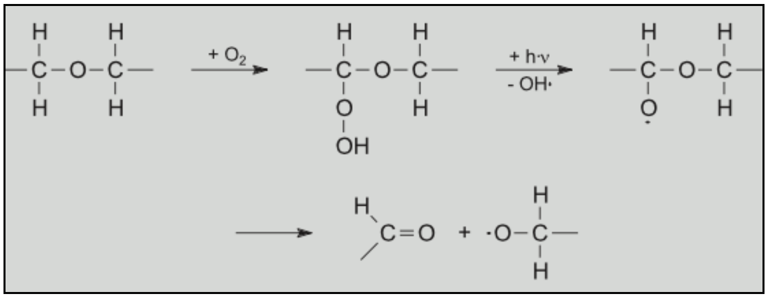

Fig.3 Crosslinking of epoxy resin in UV radiation

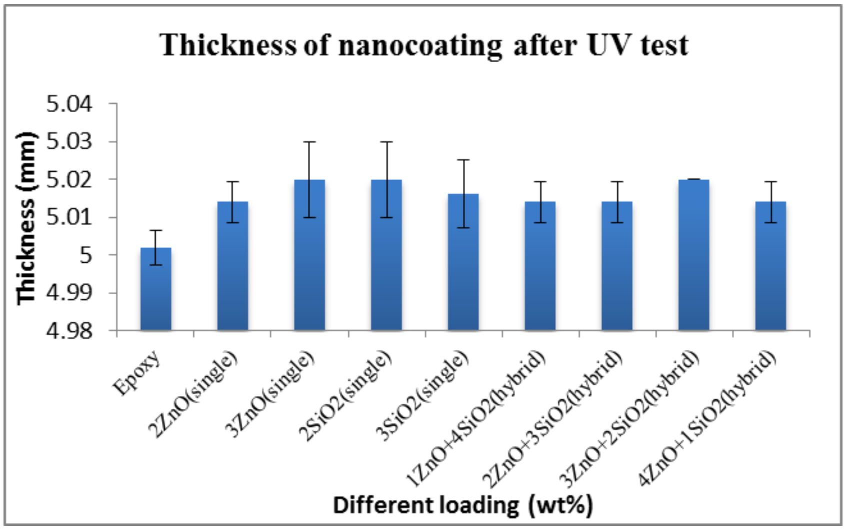

Fig. 4 Thickness of nanocoating after UV test

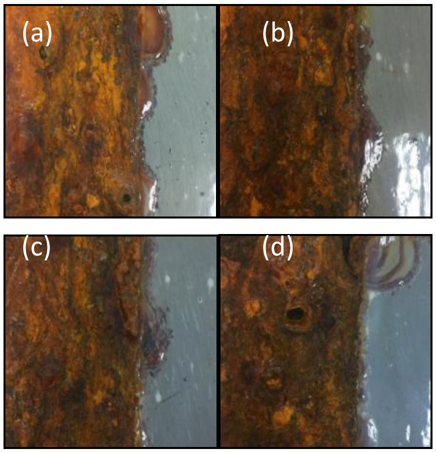

Fig. 5 Images of nanocoatings in salt spray after 1080 hours exposure,(a) 1wt.% ZnO+4wt.% SiO_2, (f) 2wt.% ZnO+3wt.% SiO_2, (g) 3wt.% ZnO+2wt.% SiO_2, (h) 4wt.% ZnO+1wt.% SiO_2

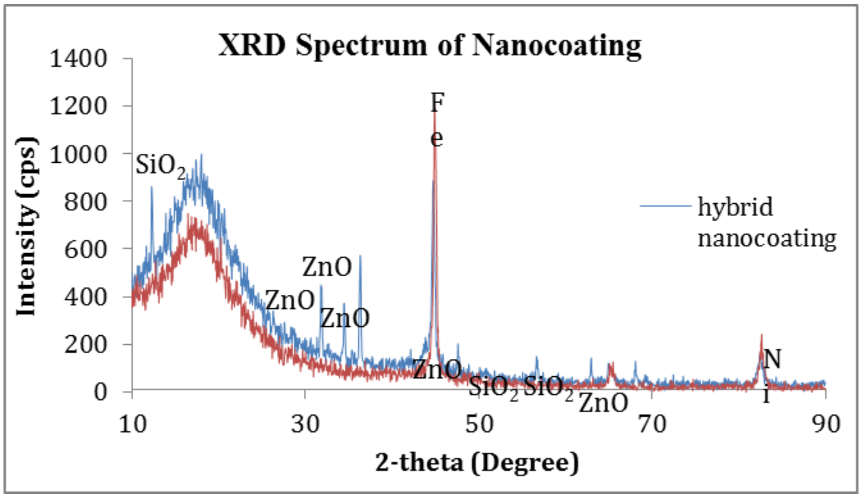

Fig. 6 XRD of Nanocoating

4. SUMMARY

As conclusion, nanoparticles significantly improve the long- term corrosion protection of epoxy coating that was applied directly to the metal. The additional network layer of nanoparticles provides multi-layer defense of corrosion resistance. Salt spray test revealed that nanoparticles giving higher level of service life of metal coating

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