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Effect of carbon nano-tubes on the corrosion resistance of alkyd coating immersed in sodium chloride solution

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ABSTRACT

Effect of carbon nano-tubes (CNTs) on corrosion protection of carbon steel coated by alkyd resin and tested after immersion in 3.5% NaCl solution for different periods was evaluated by electrochemical impedance spectroscopy (EIS) measurements and scanning electron microscopy (SEM) investigations. Changes in the impedance characteristics of the systems were found to be greatly affected by the percentage of CNTs. Degradation of alkyd resin film without CNTs was observed after 72 h. On other hand no blisters, pin-holes and delamination were observed for alkyd resin containing 0.5% CNTs. It was found that CNTs improved the corrosion resistance and the adhesion strength of alkyd resin.

1. Introduction

The corrosion of metals is an enormous economic problem. Thus, efforts to develop more efficient and environmentally compliant methods to prevent corrosion have been ongoing throughout this century [1–5]. Often, the best strategy to control corrosion of an active metal is to apply a protective surface coating. Coatings are effectively used for the protection of metals due to their capacity to act as a physical barrier between the metal surface and the corrosive environment in which they perform their function [6,7].

Nevertheless, all resin coatings are permeable to corrosive species such as oxygen, water and ions [8,9]. Water molecules localized at the metal/film interface may induce a decrease in the coating adhesion, thus favoring the electrochemical corrosion of the metal under the film. The permeability characteristics of a coating are determined by diverse coating properties such as the nature and polymeric structure of the resin, the existence of pores, the distribution of pigments and additives, etc. [10].

The protectiveness of organic coatings against corrosion can be enhanced by introducing inorganic pigments and anticorrosive additives in the coating matrix. However, commercially available inorganic pigments are associated with number of drawbacks, such as poor adhesion, coating flexibility reduction and loss of impact resistance.

Addition of nano-materials into the conventional coatings has found to improve their properties and had produced new multi-functional coatings [11–13].

CNTs show characteristics of unique size distributions, novel hollow-tube structures, high specific surface areas as well as properties such as electrical semi-conductivity and conductivity. These characteristics allow CNTs to be used in a broad range of applications [14–16]. The addition of CNTs to a polymer (like resin) remarkably improves thermal conductivity of materials, electrical conductivity, proton conductivity, and strengthening of adhesion and cohesion properties of films [17–19]. The incorporation of CNTs enhances the mechanical properties of the coatings due to the presence of strong interfacial interaction between the polymer (alkyd resin) and the nanotubes in polymer composites [20–22].

With the quest for new developed coating systems with better performance, use of CNTs in coating is a recent practice. Hence, in this paper, we report the results of an electrochemical impedance spectroscopy (EIS) and adhesion strength studies on the effectiveness of alkyd resin containing different concentration of CNTs in enhancing the corrosion resistance of carbon steel specimens in 3.5% NaCl solution at different exposure times. The morphology structures of the coated carbon steel surface of some samples were characterized by SEM.

2. Experimental

2.1. Materials

To characterize the anti-corrosion capability of resin, carbon steel sheet with dimension 50 mm × 40 mm × 1 mm was used as

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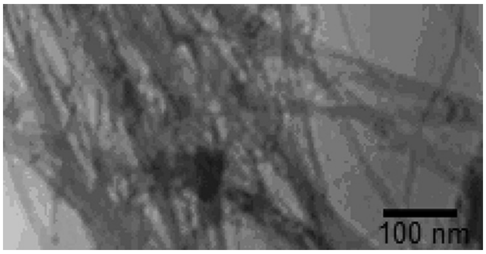

Fig. 1. TEM photograph of CNTs with average particle size = 10–15 nm.

working electrode. Its composition in percentage weight was C = 0.24, Mn = 0.48, Si = 0.30, P = 0.04, S = 0.03 and Fe to 100. Metallic surfaces were abraded with 800 emery paper, then degreased with xylene and ethanol, washed with distilled water, drip-dried, and then painted with the coating. The nano-particle based coatings were applied on the surface by dip-coating on pretreated carbon steel sheets. The sheets, after coating were cured in oven at 130 °C for 30 min and were cooled to room temperature. The coating thickness measured was 30–40 μm (measured by using a hand held micrometer (B.C. Ames Co.).

2.2. Preparation of corrosive medium and CNTs coating

The corrosive medium (3.5% NaCl, pH 6.5) was prepared from distilled water by adding NaCl (reagent grade).

Long oil alkyd resin (soyabean oil based alkyd resin) with trade name SOAL 660 (purchased from Knightsbridge Chemicals FZE Co.) with isophorone diamine as cross-linker in the mixing ratio of 70:30 was developed and was used as a base matrix for preparation of CNTs coating.

CNTs that were prepared by Egyptian Petroleum Research Institute (diameter: 20–30 nm, length: 1–10 μm, layers: 5–20) were used for preparation of CNTs coating. The transmission electron microscopy (TEM) microstructure of CNTs was shown in Fig. 1 [23]. Different concentrations (0.2, 0.3, 0.4 and 0.5% by weight) of CNTs powder were mixed with 5% of chloroform and then they added to base matrix. The particles were dispersed by using a high speed mechanical stirrer.

The quality of the CNTs dispersion in base matrix was investigated by optical microscopy (ISSCO co., model ML5000 series). When agglomerates of CNTs particles are observed, the dispersion was qualified as insufficient and not further used.

2.3. Electrochemical impedance measurements

For the classical EIS measurements, a three-electrode cell was used with a platinum auxiliary electrode, a saturated calomel reference electrode (SCE) and carbon steel electrode as reference electrode counter electrode, and working electrodes, respectively. EIS measurement was performed by using Potentio-Galvanostat EG&G model 273 with electrochemical impedance M 398 software. The impedance measurements were carried out over a frequency range of 30 kHz to 10 mHz with seven points per decade using 10 mV and 30 mV peak-to-peak sinusoidal voltage at open circuit potential.

Each electrochemical measurement has been repeated three times under the same conditions; meanwhile the mean values and standard deviations of electrochemical parameters are reported.

2.4. Morphology analysis

The morphology structures of the coated carbon steel surface of some samples were determined by employing scanning electron microscopy SEM with a JEOL/Quantek detector.

2.5. Adhesion tests

Pull-off adhesion tests were performed to measure the adhesion strength of the alkyd resin with varying CNTs content, according to the ASTM D 4541 standard method.

Pull-off adhesion tests were performed using pull-off adhesion testers (PAT model GM01/6.3 kN).

For each test, three samples were tested and the average values and standard deviations of the result have been reported as adhesion strength.

3. Results and discussion

3.1. Electrochemical impedance measurements

Typical plots of the impedance spectra obtained at different exposure times at 298 K during the immersion 3.5% NaCl solution

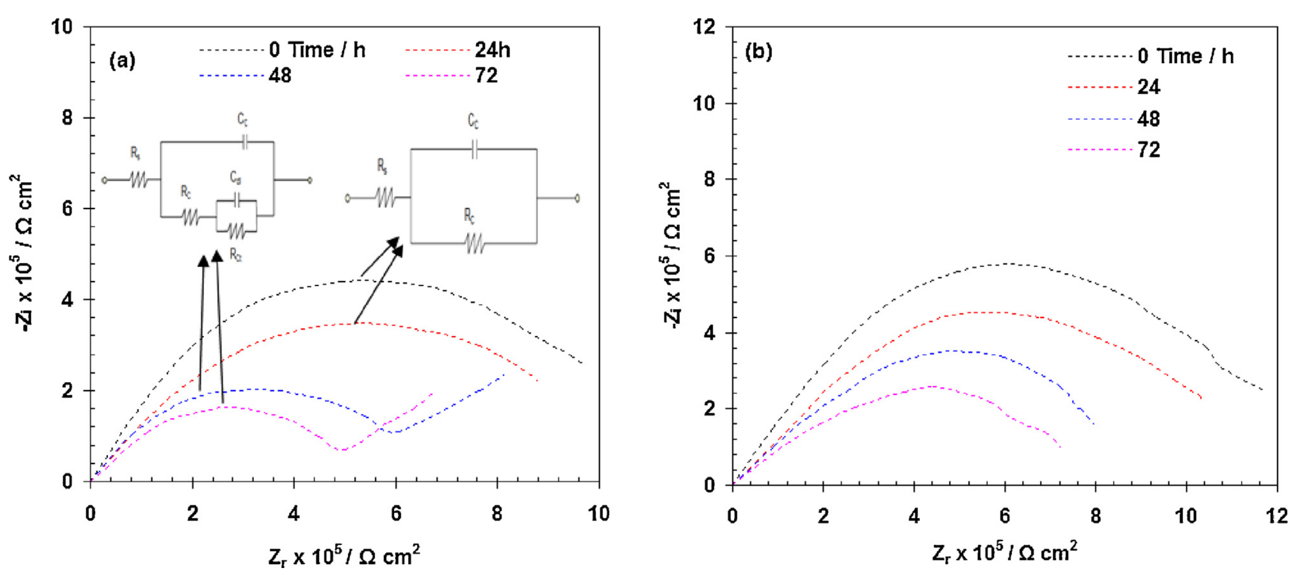

Fig. 2. Nyquist plots for carbon steel coated by (a) alkyd resin, together with the equivalent circuits used to simulate the impedance data, (b) alkyd resin containing 0.2% of CNTs, in 3.5% NaCl solution at different exposure times at 298 K.