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Corrosion and Wear Properties of Nanoclay- Polyester Nanocomposite Coatings Fabricated by Electrostatic Method

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Abstract

In this paper, polyester coating as the matrix was combined with 5wt% of clay nanoparticle and nanocomposites coating was applied on the surface of plain carbon steel components by electrostatic device. Coating structure and morphology of nanoparticles were investigated by SEM and TEM. The effect of adding nanoparticles and curing type on the corrosion resistance properties of coatings were investigated by Tafel test. The results of Tafel test shows that coating corrosion resistance is increased highly by adding nanoclay. Furthermore coatings cured in oven show higher corrosion resistance than coatings cured in microwave. The results of wear test show that adding nanoparticles markedly increases wear resistance of nanocomposite coating also, the type of curing affects on this properties.

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Keywords: Electrostatic; Nanocomposite coating; Corrosion tests; Wear test.

1. Introduction

Polyester coatings is one of the organic coatings, that are most widely used to protect steel against corrosion, Mafi et al. (2008). However, due to weak resistance of polymer coating against penetration of electrolyte and thus penetration of corrosive solution to the metal/coating interface, coating resistance exposed to corrosive environments is reduced gradually. Voids and defects in the coating are caused more penetration of corrosive agent so blistering can occur and corrosion resistance of the coating is reduced. Research has shown that adding nanoparticles to a polymer

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coating has a great effect on the behavior of the coating and improving the mechanical, chemical and optical properties, Shi et al. (2009). Higher corrosion resistance of nanocomposite coatings can be attributed to the barrier properties of nanoparticles, Ramezanzadeh and Attar (2011). These particles by reducing voids in coating and increasing penetration route for corrosive solution creates a better barrier properties in polymer coatings, Rostami et al. (2014). Bagherzadeh et al. (2007) showed in their study that water absorption in pure epoxy coating was three times more than nanocomposite coatings contain 1wt% nanoclay, so penetration of corrosive solution in nanocomposite coating is lower and corrosion resistance is higher. Hedayati et al. (2012) found in their research that addition of SiO_2 nanoparticles increases wear resistance of the PEEK polymer coating and thus wear rates are reduced.

Incorporation of clay nanoparticles in the polymer matrix, markedly improves mechanical properties, abrasion resistance, thermal stability and barrier properties of this coatings, Piazza et al. (2012). In this paper, polyester coating as the matrix was combined with 5wt% of clay nanoparticle and polymer based nanocomposites was formed. The objective of this research is to improve the wear and corrosion resistance properties. Clay nanoparticles were dispersed into polyester powder using different methods of dispersing. After applying nanocomposite powder on the steel surface by electrostatic method and curing in both oven and microwave, corrosion properties of coating were assessed using tafel test. Wear properties of nanocomposite coatings were evaluated by abrasion test. The results show that adding nanoparticles markedly increases corrosion and wear resistance of pure polyester samples. The type of curing also affects on these properties. Corrosion and wear properties of samples cured in the oven is better than other samples.

2. Materials and Methods

2.1. Preparing the substrate and nanocomposite powder

Carbon steel plates in 5×6×0.5 cm^3 sizes were prepared as a substrate. Preparation operations is included: sanding (800, 1200), degreasing, washing and drying. Polyester powder was purchased from Nikfam Gostar Company. Also MMT, Cloisite 30B commercially nanoparticles, were purchased from Rockwood America. The shape and structure of the clay particles were investigated by transmission electron microscope (TEM) Zeiss (model EMIOC Germany). Filament voltage was set at 80kv. Structure of polyester powder, surface structure and the cross section of the films were studied by scanning electron microscope (SEM) Philips-XL30 model. SEM micrograph of pure polyester powder as well as SEM and TEM images of clay nanoparticles is shown in Fig. 1. As shown in this figure, polyester particles are typically range between 10-60 μm. TEM images of nano clay indicate that the size of particles is 5-10 nm.

For the production of nanocomposites, first the clay nanoparticles in distilled water through ultrasonic homogenizer machine (Topsonics Iranian model), under the power of 200 W, frequency 20 kHz, were dispersed for 2 hours. This was done to open lamination sheets of clay nanoparticles. Then slowly, polyester powder was added to the solution and dispersion operation was performed for 2 hours with the previous conditions with ultrasonic. Then dispersion operations was performed with using a mechanical mixer (speed 2000 rpm) at room temperature for 12 hours. To obtain a more complete and better dispersion of nanoparticles in the matrix of polymer, after drying the mixture obtained in the previous step, fabricated powder was mixed with the satellite mill with ball to powder ratio of 190-90 for 12 hours and nanocomposite powder was prepared for apply on the surface of metal.

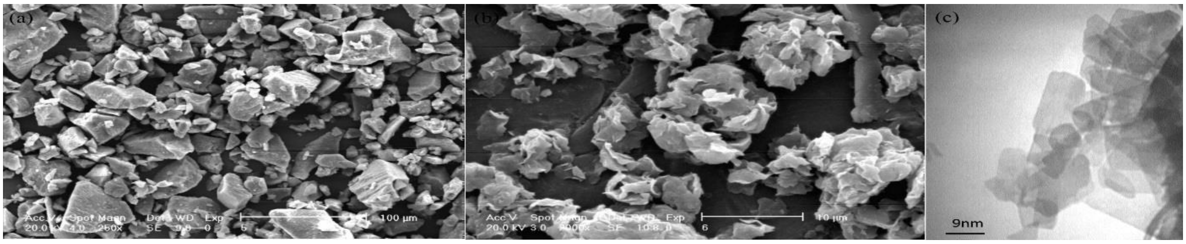

Fig. 1. (a) SEM image of pure polyester powder; (b) SEM images of clay nanoparticles; (c) TEM image of nanoclay.

2.2. Coating method

To apply powder coating, electrostatic device (IRIS models) with corona gun by 100 kV DC voltage source was used. Coating operation by electrostatic gun at a distance of 10 cm from the piece was applied on both sides of the surface. Plates were cured two types. In the first case, coated plates were cured in a conventional oven for 12 minutes at a temperature of about 200 °C. In the second case, plates were cured in the microwave with a power of 900 W for 12 minutes. Table 1 Shows condition of the coated samples with abbreviated names of them.

Table 1. Characteristics of coated samples with their abbreviated name.

Sample	Nanoparticle(%Wt)	Curing method
PM	---	Microwave
PC	---	Oven
PM-5	5%nanoclay	Microwave
PC5	5%nanoclay	Oven

2.3. Corrosion and wear properties of the coating

Corrosion protection properties for coated samples were investigated by Tafel test in order to evaluate the effect of clay nanoparticles on corrosion resistance. Tafel test was performed by EG&G Potentiostat-Galvanostat (model 273A). All tests have been carried out in open circuit potential (OCP) under atmospheric conditions at a temperature of 25°C using three-electrode systems includes a calomel reference electrode, a platinum plate as the auxiliary electrode and coated samples as working electrode that immersed in 3.5% NaCl solution. In Tafel test, after a delay of about 15 minutes, the potential was increased with 1 mV/s scanning rate. The required data were obtained using Powersuite software. Wear test was performed using pin on disc test at room temperature and 35% humidity. Diameter of test samples was 2.3 cm and thickness was 0.5 cm. Steel pin 52100 with 64 HRC hardness was considered as parts in contact with the coated disks. For each coated sample, wear test was performed by the load of 10 N and 0.05 m/s linear sliding speed in a circular path with a radius of 0.5 cm at different cycles depending on the wear resistance of the samples. Wear rate is calculated using the equation (1). In this equation, m is the total weight loss of material (gr), S is slip distance in meters and F is the load (N), Hedayati et al. (2012).

$$W = \frac{m}{S.F} \tag{1}$$

3. Result and discussion

3.1. Coating microstructure

Figure 2 shows SEM micrograph of cross section and top surfaces related to polyester coatings and nanocomposite coatings on the metal substrate. As shown in Fig. 2a, PC sample shows poor adhesion to substrates, but fabricated coating have a good density and also, crack is not observed. It is known that PM coating has non-uniform thickness and also has a relatively large voids and other defects that will cause better penetration of corrosive agents into the substrate. Another point is that the adhesion of this coating to the substrate compared with PC coating was proper. SEM images from cross section of nanocomposite coating containing 5% nanoclay represents a homogeneous structure, no cracks, good adhesion to the substrate and almost compact for PC-5 coating. As is clear, nanocomposite coatings cured with a microwave, do not have the quality and uniformity of PC-5 sample and there is some cracks and pores in its structure. Also, fabricated coatings were studied in terms of homogeneity and surface morphology (see Fig. 2). As is clear, pure polyester surface is uneven and of course, the amount of cavities and other defects in the surface of the PM sample is more than PC sample. Samples containing nanoclay have a higher level of quality compared to pure polyester samples and the cavity and surface defects are less than pure polyester coating.

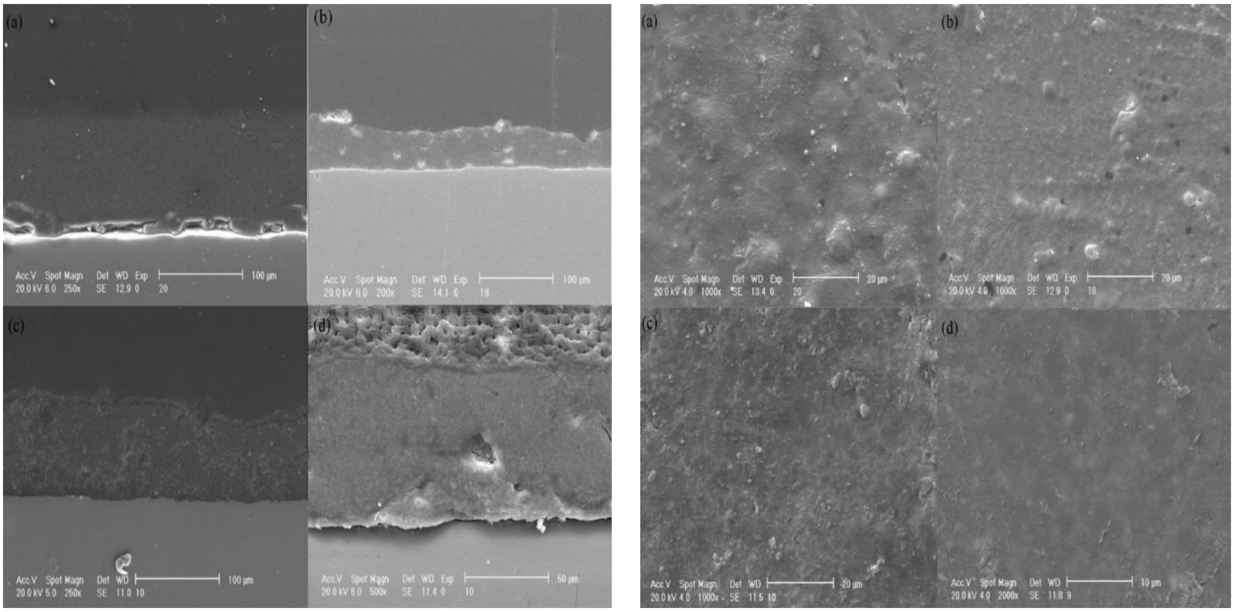

Fig. 2. SEM images from cross-section and top surfaces of the coated samples: (a) PC; (b) PM; (c) PC-4; (d) PM-4.

3.2. Tafel test

In order to evaluate anti corrosion properties of nanocomposite coatings, the corrosion behavior of coatings in 3.5% NaCl solution were studied. Fig. 3 shows the polarization curves for pure polyester coating and nanocomposite coating in the potential range of -250 mV to + 250 mV than OCP. Table 2 shows the values of corrosion potential (E_{corr}), corrosion current density (i_{corr}) that derived from extrapolation of Tafel plots. Lower corrosion rates and lower corrosion current density indicates less inclined to corrosion in terms of kinetic and more noble corrosion potential represents less inclined to corrosion in terms of thermodynamically, Liu et al. (2015), Yang et al. (2010). As polarization test results indicate, the presence of nanoparticles in polyester reduces the corrosion current density. The results show that corrosion behavior of nanocomposite coating compared to pure polyester coatings for both curing regime (microwave and oven) is better. A comparison of results show that in general, corrosion resistance of coatings cured in the oven are better than coating cured in microwave. It seems that the higher corrosion resistance of coating cured in the oven given that other factors are constant, only is concerned on the type of curing.

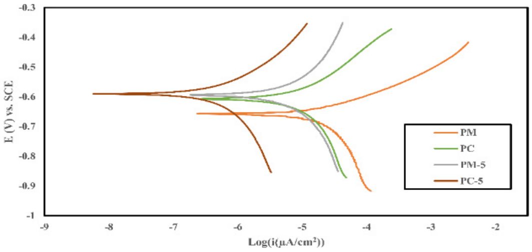

Fig. 3. Tafel polarization curves for coated samples.

It is estimated that full curing condition for powder coating in a microwave was not available and the cross linking was not enough for the powder, Liu et al. (2015). Therefore, the density of this coating is less than the coating cured in the oven, as a result the corrosion resistance is less than the coating cured in the oven. The lowest corrosion current density is 0.78 µA/cm^2, which is related to the PC-5 sample. Corrosion current density of this coating is about 15 times than pure coating in the same curing conditions. The results are in good agreement with SEM micrograph. In general, corrosion current density of nanocomposite coatings is less, so exhibits better corrosion resistance than pure polyester coatings.As shown in Fig. 2, samples containing nanoparticles are without cracks. Due to the absence of cracks and defects such as cavities, access of corrosive electrolyte to the substrate surface is difficult, therefore the corrosion resistance is improved. Another issue is nanoparticles dispersed in the polymer matrix. Dispersed nanoparticles acts as a barrier against leakage and penetration of electrolyte to the metal substrate, and thus both corrosion and barrier properties of coating are improved, Hosseini et al. (2009). Therefore it can be concluded that embedded nanoclay in the polyester matrix improves the corrosion behavior by filling surface defects such as micro and nano scale cavities, holes and cracks, and acts as a barrier against penetration of corrosive ions on the electrode surface.

Table 2. Parameters of polarization curves for cured samples obtained by Powersuite software.

Sample	E_{corr}(mV vs. SCE)	i_{corr}(µA/cm^2)	β_C(mV/decade)	β_a(mV/decade)	Corrosion rate (mpy)
PM	-657.2	39.03	487.9	106.4	17.77
PC	-576.5	12.07	381.1	167.3	5.53
PM-5	-686.2	12.10	319.1	89.8	4.35
PC-5	-578.3	0.78	435.1	178.5	0.36
BARE	-634.5	26.22	596.8	66.1	12.01

3.3. Tribological behavior

Wear properties of nanocomposite coatings and pure polyester coatings were evaluated. Wear rate of coated samples were calculated with a total amount of weight loss during wear test in terms of grams (Fig. 4). As is clear, incorporation of nanoparticles in polyester matrix can greatly reduce the wear rate. This means that the addition of nanoparticles was highly effective to improve tribological properties and performance of polyester coating. These effects can be attributed to improving the stiffness of coating surface and thus increase the wear resistance through the addition of nanoparticles, Zhang et al. (2005).

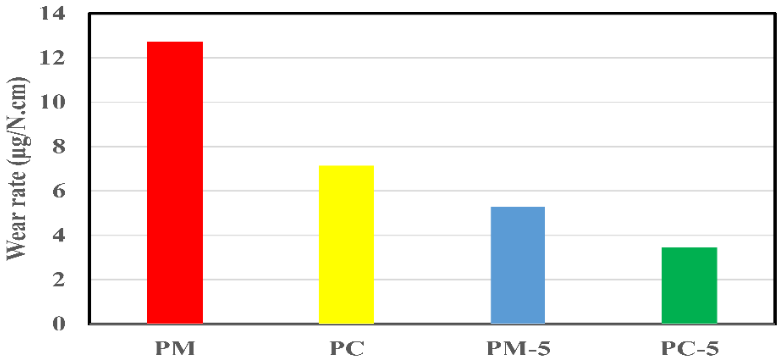

Fig. 4. The calculated wear rate values for coated sample.

The looser internal structure of pure polymer coating will cause easier wear for them than the relatively dense structure of nanocomposite coating. In addition, because of micro cavities on the surface of pure polyester coatings, wear debris is embedded in them and thus create a higher wear rate, Luo et al. (2005). The results show that PC-5 coating has the lowest wear rate. As is known, the amount of wear rate for samples cured in oven are less than samples cured in the microwave. Therefore, the arguments mentioned in the previous sections, can be confirmed here, means more favorable curing in oven than the microwave and creates structure with better crosslinking.

4. Conclusion

Embedding Nanoparticles in polyester coatings creates a denser coating, more uniform and less pores in comparison with the pure polyester coating. The absence of pores and flaw in coating, as well as creating a barrier against corrosive electrolytes penetration leads that corrosion resistance properties of nanocomposite coatings will be higher than the pure coatings. Corrosion test results show that coating cured in the oven in both cases (nanocomposite coatings and pure), have better corrosion resistance. We can conclude that curing conditions in oven were much better than curing in the microwave and the crosslinking for coatings cured in the oven was further than coatings cured in the microwave.

Wear rate of nanocomposite samples were much lower than pure samples because of relatively denser structure in the presence of nanoparticles. Also the amount of wear rate for samples cured in oven is less than samples cured in the microwave that is in agreement with corrosion test results. In general, it can be concluded that the presence of nanoparticles will be effective greatly to increase the corrosion resistance and wear resistance of polyester coating. However the curing type of coated samples will be involved in this issue. Microwave condition in this study was not appropriate enough for curing samples. As a result, it can be concluded that for a more complete curing in the microwave, higher power or more time are needed.

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