Potential anti-corrosion additives derived from waste plastic sachets

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Abstract. Corrosion is a perennial problem that has a significant burden on the economy and environment. Recent studies have suggested that organic fillers can serve as corrosion inhibitors. In this work, the use of comminuted waste plastic sachets (WPS) as an anti-corrosion additive to commercial coating was explored. The effect of WPS lamination and loading on the viscosity, film thickness, and corrosion behavior of a red oxide primer paint was investigated. Results show that the viscosity and film thickness of the coating were only affected by the addition of WPS at high loading. At low loading, comminuted WPS reduced the corrosion rate of the coating by 99%. The presence of metal lamination in WPS contributes to the corrosion resistance of the coating. In conclusion, comminuted WPS demonstrates its potential in enhancing the anti-corrosion properties of coatings.

1. Introduction

Metal corrosion is a serious problem that has grave economic and environmental consequences. Corrosion weakens or destroys metal to the point that in the long run its economic value is rendered useless [1]. Corrosion is caused by an electrochemical reaction between the metal and an electrolyte, or by the oxidation of the metal atoms. While corrosion may be inevitable, many processes have been devised to slow down corrosion. Coatings are one of the generally-accepted methods of providing corrosion resistance to metals as they provide a barrier between the metal and the environment, preventing electrochemical reactions that cause corrosion from occurring. Many coatings also include anti-corrosion additives usually made of inorganic metal compounds (e.g. lead oxide). However, in recent years, the use of these compounds has been discouraged as studies have shown that the use of such metals has detrimental health effects not only to humans but to the environment [2,3].

Recent studies show that another method of supplying corrosion resistance to coatings involves the use of organic fillers and composites, usually alone or combined with other organic polymers such as epoxy, acrylic and polyurethane [4,5]. These anti-corrosion additives can also act as pigments [6]. As mechanisms and applications of such anti-corrosion additives are varied, various research involving effective anti-corrosion additives continue [7]. Waste plastic sachets (WPS) is primarily composed of polymers, and as an additive may impart sufficient barrier properties to increase the corrosion resistance of coatings. The use of such materials is primarily motivated by the fact that the use of synthetic polymers, in general, is hounded by recycling issues and that developing countries usually rely on sachet-packaged products to fill their basic needs [8,9].
To confirm this assumption, this work studied the effects of adding comminuted WPS on the viscosity and corrosion resistance of commercially available primer coating.

2. Experimental

2.1. Materials
WPS was acquired from the industrial rejects of a manufacturing company (Doxo Ingredients Inc., Philippines). Grinding wheel (Qingdao Sisa Abrasives Co., Ltd, China) with a grit number of 100 was used for comminution. High purity ethanol (99.5 wt%, Scharlab S.L., Spain) was used for optical microscopy. Silicon carbide sandpaper with 220 and 600 grit numbers, and acetone (99.5 wt%, RTC Laboratory Services & Supply House, Philippines) were used for the preparation of metal substrates before coating. Red oxide primer paint (Pacific Paint (Boysen) Philippines, Inc.) was purchased from a local hardware store. A 5.7 cm platinum counter electrode (ALS Co., Ltd, Japan) was used along with a 6 mm Ag/AgCl reference electrode (ALS Co., Ltd, Japan) containing 3M NaCl solution (potential \( E^\circ = 0.209 \) V vs normal hydrogen electrode/NHE at 25°C).

2.2. Preparation and characterization of waste plastic sachets
WPS were segregated according to presence of metal lamination before washing to remove trace amounts of dirt, grease, and residues. Comminution was done using a 4460 rpm bench grinder (John Benzen Power Tools, Philippines). These were collected and subsequently sieved (US Standard Sieve Mesh 325, particle size <45 µm) yielding the additive.

The additives were subjected to optical microscopy (Novex B-Range Optical Microscope, Euromex Microscopes, Netherlands) in order to observe the size, shape, and features of comminute WPS. Samples were diluted with ethanol prior to application via drop casting on pre-cleaned glass slides. This was done at the 200× magnification.

2.3. Viscosity measurement
Viscosity was measured using a model PDVdi-120 falling needle viscometer (Stony Brook Scientific, Ltd., USA). Methodology used is similar to ASTM D5478. A 25 ml-sample was prepared for each coating and was placed at the provided syringe. The density of the sample \( \rho_f \) was measured. The needle density \( \rho_s \) was calculated using equation (1). In the aforementioned equation, \( m_{\text{needle}} \) refers to the needle mass.

\[
\rho_s = \frac{28.9673 + m_{\text{needle}}}{9.8988}
\]  

A stainless steel extension bar having etched markings was attached to a needle, gently placed on the exposed layer of the fluid and allowed to fall vertically. A stopwatch was used to measure the time \( t \) required by the second needle mark to be fully submerged in the solution. Fluid viscosity \( \mu \) was calculated using equation (2) for fluids having a density not equal to 1 g cm\(^{-3}\):

\[
\mu = 9.1463 \left( \rho_s - \rho_f \right)
\]

2.4. Preparation of coated substrates
Carbon steel A36 coupons having a dimension of 1 × 3 cm were prepared by polishing with sandpaper, and degreasing via sonication in acetone for 15 min using an ultrasonic water bath (WUC-D03H, DAIHAN Scientific, South Korea). Prior to use, metal coupons were dried and kept in vacuum using a vacuum oven (LVO-2030, LabTech Instruments, Inc., USA). Coupon thickness was measured using a digital micrometer (MDC-1 SX, Mitutoyo Corp., Japan). WPS was added to the commercial red oxide primer paint at the following loadings: 0, 1, 2, 4, and 10 wt%. The blended coatings were applied onto
the metal coupon substrates via spin coating (SCK-200 P, INTRAS Scientific, USA) at 1200 rpm for 10 s. The coated metal samples were air dried at least 24 h prior to testing.

2.5. Potentiodynamic polarization tests
Potentiodynamic polarization scan was performed following ASTM G102 with the coated metal coupons acting as the working electrode. A plate material evaluating cell (ALS Co., Ltd, Japan) made of Teflon was used. The platinum counter electrode and reference electrode were prepared and attached to the evaluating cell as shown in figure 1.

To simulate the corrosive environment, approximately 1 ml of 5 wt% NaCl solution was dropped in the 7.8-mm diameter hole of the evaluating cell. All electrodes were connected to a potentiostat (CS315, Wuhan Corrtest Instruments Corp. Ltd., China) which scanned the coupon from -0.5 to +0.5 V with scan rate 1 mV s\(^{-1}\) and frequency of 1 Hz. Corrosion potential \(E_{corr}\) and corrosion current density \(i_{corr}\) were determined from Tafel extrapolation plots [10]. This was done in triplicate, with results being averaged prior to treatment.

![Figure 1](image1.png)

**Figure 1.** The potentiodynamic polarization scan set-up showing the plate material evaluating cell along with the attached counter electrode (CE), reference electrode (RE), and working electrode (WE).

3. Results

3.1. Morphology
Figure 2 shows the results of optical microscopy. It can be seen from the images that the comminuted WPS exhibits an irregular shape due to the abrasive nature of the grinding process. The contrasting focus within a particle in the images also show that the surface of each particle exhibits some irregular lumping. This is also an expected result of the abrasive grinding process. Based on the images, there are no apparent differences between the morphologies of laminated and non-laminated WPS.
Figure 2. Morphology of (a) laminated WPS (b) non-laminated WPS.

3.2. Effect of additive on viscosity

Viscosity was measured primarily to investigate the ease of application of the coating mixture onto the metal substrate. Figure 3 shows the viscosities of coating mixtures having different loadings of WPS measured at 27 ± 1°C.

![Viscosity Graph](image)

Figure 3. Viscosities of WPS-infused coating mixtures.

The data show that a higher WPS loading resulted in a higher dynamic viscosity. As solid particles, comminuted WPS contributes to the thickening and flow resistance of the coating. At 10 wt%, laminated WPS imparted a higher viscosity to the coating than non-laminated WPS. The metal film present in the laminated WPS offers more resistance to the flow of the coating. Viscosities of commonly available paints may vary depending on type, application, and preparation, as many paints are non-Newtonian fluids. For primer coatings, viscosities of commercially available primer paints are varied, many of them having viscosities ranging from 500 to 2000 cP [11]. The viscosity of paints, however, can be lowered by adding an appropriate solvent such as paint thinner.
3.3. Effect of additive on corrosion resistance

Figure 4 shows the representative Tafel plots of primer coatings blended with laminated and non-laminated WPS.

![Figure 4](image)

**Figure 4.** Representative Tafel plots of coatings infused with (a) laminated WPS and (b) non-laminated WPS at 0 (Control), 1 (I), 2 (II), 4 (III), and 10 wt% (IV).

Table 1 lists the properties of the WPS-infused coated substrates along with their respective coating thickness, $E_{\text{corr}}$, and $i_{\text{corr}}$ values. Coating thickness was only affected by the addition of WPS at high loading. WPS shifted the $E_{\text{corr}}$ of coatings to the positive (nobler) direction. Non-laminated WPS resulted in greater shifts in $E_{\text{corr}}$ compared to laminated WPS. This denotes that the metal in the laminated WPS increases the overall tendency of the coating to lose electrons during exposure to corrosive medium, resulting to lower $E_{\text{corr}}$ shift than non-laminated WPS. WPS lowered the $i_{\text{corr}}$ of coatings by as much as 99%. As polymeric films, WPS improves the barrier properties of the coating by hindering the bulk diffusion of the corrosive medium into the coating [12,13]. The $i_{\text{corr}}$ of coatings filled with laminated WPS are lower than with non-laminated WPS. The metal layer in the laminated WPS contributes better barrier properties to the coating. The same metal layer could also get passivated during exposure to corrosive medium which further enhances its contribution to the barrier characteristics of the coating. It is also possible that the metal layer lost electrons during corrosion and reacted with the dissolved oxygen to form a passivating oxide layer having stronger barrier properties [14,15]. On the other hand, higher loadings result in a lower drop of $i_{\text{corr}}$ values as the dispersion of the filler interferes with the wet adhesion of the coating on the substrate [16].

**Table 1.** Properties of WPS-infused coatings.

| Additive          | Loading (wt%) | Coating thickness (mm) | $E_{\text{corr}}$ (V) | $i_{\text{corr}} \times 10^7$ (A cm$^{-2}$) | Change of $i_{\text{corr}}$ relative to control (%) |
|-------------------|---------------|------------------------|------------------------|---------------------------------------------|--------------------------------------------------|
| None (control)    | 0             | 0.104                  | -0.7247                | 103.5                                       | 0.0                                              |
| Laminated         | 1             | 0.100                  | -0.7232                | 0.610                                       | 99.4                                            |
| Laminated         | 2             | 0.107                  | -0.5851                | 0.589                                       | 99.4                                            |
| Laminated         | 4             | 0.123                  | -0.4457                | 0.223                                       | 99.7                                            |
| Laminated         | 10            | 0.128                  | -0.6330                | 1.400                                       | 98.6                                            |
| Non-Laminated     | 1             | 0.097                  | -0.5841                | 1.006                                       | 99.0                                            |
| Non-Laminated     | 2             | 0.099                  | -0.3505                | 3.640                                       | 96.4                                            |
| Non-Laminated     | 4             | 0.097                  | -0.5757                | 2.267                                       | 97.8                                            |
| Non-Laminated     | 10            | 0.116                  | -0.3546                | 2.924                                       | 97.1                                            |
4. Conclusion
The addition of comminuted WPS to a red oxide primer paint improves the corrosion resistance of the coating. At low loading of laminated WPS, e.g. 1 and 2 wt%, the corrosion rate lowered by 99% with negligible change in coating thickness and viscosity. This work demonstrates for the first time the application of WPS in improving the anti-corrosion properties of coatings.

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