Using Organic Coatings to Protect Mild Steel in a Viscose Industrial Atmosphere

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The viscose industrial environment contains sulfur dioxide (SO_2) fumes and water fog as the main pollutants. In this environment, steel structures and pipelines are easily corroded. In this study, the percentage of pollutants present in the atmosphere was identified and the corrosion rate of mild steel was determined. Four types of protective coating systems were evaluated after a 3-year exposure to a viscose industrial environment.

In general, acid fumes and high humidity affect viscose industrial atmospheres. Metal structures, concrete structures, and pipelines become highly corroded in this industry. Epoxy-polyamide coating systems have been found to perform well in this environment. Not all protective coatings will adequately protect these structures, however. There is a need, therefore, to study the condition of the structure and the pollutants present in the environment, and to develop a suitable protective coating scheme for the atmosphere. In our study, the corrosion rate of mild steel was determined and the pollutants present in the environment were identified. Four types of protective coating systems were applied on mild steel surfaces and their performance was evaluated using an impedance technique.

Experimental Procedures

CLIMATIC CONDITION OF THE INDUSTRY

The industrial site is ~40 km from Coimbatore, Tamil Nadu, India. In addition to this viscose industry, other chemical industries are also located in this area. Climatic conditions such as temperature and relative humidity (RH) were obtained from the meteorological station, and the pollutants such as sulfur dioxide (SO_2) and chloride were determined by using lead peroxide (PbO_2) and salinity candle methods, respectively (IS 5555-1970[1]).

DETERMINATION OF CORROSION RATE

Mild steel panels, 100 by 150 mm, were polished with a 120 emery wheel, degreased with trichloroethylene ($CHCl{:}CCl_2$), dried, and weighed, and then exposed on racks at 45 degrees from the horizontal for a period of 3, 6, 9, and 12 months. Visual inspections were made and photographs were taken. The corrosion rate of mild steel was calculated periodically from the value of the weight loss, determined as described elsewhere.[2]

PREPARATION OF COATED PANELS

The test panels were sand-blasted and coated with the following coating systems:

- System 1: aluminum spray coating
- System 2: epoxy powder coating
- System 3: zinc silicate primer + epoxy-polyamide high-build coating + polyurethane (PU) sealant coat

• System 4: zinc phosphate primer + epoxy-polyamide high-build coating + chlorinated rubber finish coat

The coated panels were allowed to cure for 15 days and were then subjected to atmospheric exposure and electrochemical measurements.

ATMOSPHERIC EXPOSURE

Sets of painted panels were exposed in the viscose industrial environment for a period of 3 years. These exposed panels were periodically observed for failure analysis once every 3 months.

ELECTROCHEMICAL IMPEDANCE MEASUREMENTS

Impedance spectroscopy is a tool to assess the degradation of a coating system quantitatively in a duration shorter than in an accelerated test. In this study, this method was used to predict the protective life of a coating system. A set of unexposed panels and 3-year exposed panels were subjected to an alternating current (AC) impedance test as follows:

Impedance measurements were carried out at open-circuit potential using the PAR Model 5208[†], two-phase, log-in-analyzer with IBM[†] computer and PAR Model 273[†]. The impedance measurements in all the panels were carried out over a frequency range of 10 kHz to 100 mHz using 10 mV peak to peak sinusoidal voltage. A computerized Bode plot was used to analyze the experimental data. The test was carried out in an aerated 0.5 M sodium chloride (NaCl) solution. A three-electrode configuration was formed by fixing a glass tube on the surface of the coated panel (working electrode) and filling it with the NaCl solution. A platinum mesh and a saturated calomel electrode were used as the counter and reference electrodes, respectively.

Results and Discussion

CLIMATIC CONDITIONS

Table 1 gives the climatic parameters at the viscose industrial site. SO_2 is the main pollutant in this area and there are

[†]Trade name.

TABLE 1

CLIMATIC PARAMETERS AT THE VISCOSE INDUSTRIAL SITE

	Temperature (°C)				
Month	Minimum	Maximum	RH (%)	SO_2 mdd	Cl^- mdd
February	19.0	37	95	5.5	Traces
March	19.0	37	95	5.4	" "
April	23.0	40	95	6.0	" "
May	22.0	40	91	4.5	" "
June	22.0	38	91	5.2	" "
July	22.0	36	90	6.3	" "
August	22.5	36	95	4.5	" "
September	22.0	37	95	5.2	" "
October	21.5	36	95	6.2	" "
November	19.0	32	95	4.8	" "
December	15.5	30	95	4.6	" "
January	15.2	33	95	5.3	" "

FIGURE 1


(a)


(b)

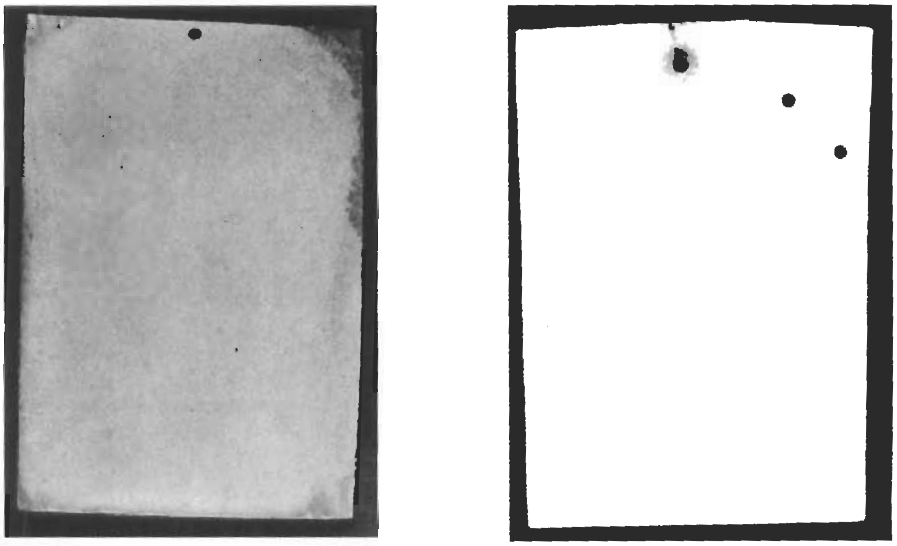
Appearance of uncoated mild steel panels after (a) 3 and (b) 12 months of exposure at the viscose industrial area.

TABLE 2

ATMOSPHERIC CORROSION RATE OF MILD STEEL IN THE VISCOSE INDUSTRIAL ENVIRONMENT FOR DIFFERENT EXPOSURE PERIODS

Sl. No.	Month	Mass Loss (g/m^2)	Corrosion Rate (mm/y)	Remarks
1	1	22.23	0.332	Uniform corrosion with yellowish brown rust is formed
2	3	73.00	0.364	Brownish rust powder is formed
3	6	142.08	0.354	Brownish flakes are formed
4	9	209.02	0.347	Brownish flakes are formed
5	12	241.63	0.300	Rust flakes are formed

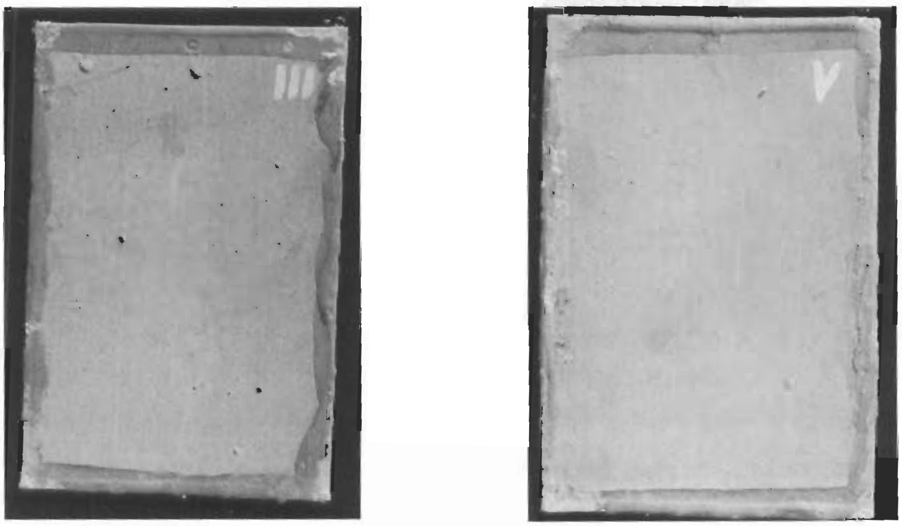
FIGURE 2



(a) (b)

Appearance of coated mild steel panels after 3 years of exposure at the viscose industrial area. (a) Aluminum spray and (b) epoxy powder.

FIGURE 3



(a) (b)

Appearance of coated zinc silicate primer plus two coats of epoxy, plus one coat of PU sealer on mild steel panels after 3 years of exposure at the viscose industrial area. (a) Zinc silicate primer plus two coats of epoxy, plus one coat of PU sealer. (b) Zinc phosphate primer plus one coat of epoxy, plus one coat of chlorinated rubber finish.

traces of chloride ions. The RH is always higher than 90% throughout the year. In addition, the temperature variation is 15 to 37°C. This factor also induces the corrosion of steel structures because of condensation. The SO_2 content is in the range of 4.5 to 6.3 mdd. Thus, the SO_2 in combination with high RH and temperature variation has contributed significantly to the corrosion of metals in this industry.

PERFORMANCE OF UNCOATED PANELS

Figure 1 shows the corrosion of mild steel panels after an exposure of 3 and 12 months. Figure 1(a) shows that surface after 3 months of exposure. The condition of the panels after 6 and 9 months of exposure indicates that the rust is further grown and formed as flakes. At the end of the 12-month period (Figure 1[b]), both sides of the panel had large detached flakes of rust. After a complete removal of the rust from the surface, the thickness of the panel was very thin. This clearly indicates that the atmosphere is highly corrosive because of the corrosive gases and humid environment.

The corrosion rate was calculated and the results are reported in Table 2. The mass loss was found to be very high in this atmosphere. As the exposure period was increased, the mass loss also correspondingly increased, and finally total destruction of the panel was observed. The very high corrosion rate is also caused by SO_2 and water fog. SO_2 dissolved in the water fog forms sulfuric acid (H_2SO_4). This acid layer further accelerated corrosion with the evolution of hydrogen. In the presence of SO_2, the corrosion film formed is nonprotective, and the rusted steel absorbs SO_2 from the atmosphere.[3-4] Moist air accelerates the absorption of SO_2 and thereby accelerates the rust as follows:

$$Fe + SO_2 + O_2 \rightarrow FeSO_4 \quad (1)$$

Ferrous sulfate ($FeSO_4$) acts further in the presence of moisture and oxygen:

$$4FeSO_4 + O_2 + 6H_2O \rightarrow 4\,FeOOH + 4\,H_2SO_4 \quad (2)$$

PERFORMANCE OF COATED PANELS

Periodic examination of the coated panels indicated that there were no corrosion spots or blisters on the surface after 2 years of exposure. Figure 2(a) indicates that rust spots developed along the edges of the aluminum-spray-coated system after 36 months. This failure may be attributed to the attack of acid deposit on the surface. Acid reacts with aluminum to produce aluminum sulfate [$Al_2(SO_4)_3$]. Once this salt is formed on the surface, it will give way to the penetration of acid into the substrate and rust will be formed along the edges of the panel. It will further

TABLE 3

RESISTANCE OF THE VARIOUS COATING SYSTEMS ON MILD STEEL SURFACE BEFORE AND AFTER EXPOSURE TO THE VISCOSE INDUSTRIAL ENVIRONMENT FOR 3 YEARS

Sl. No.	Coating System	Resistance (Ω·cm²) Before Exposure	After 3 Years Exposure
1	Aluminum spray coating	2.0×10^3	3.5×10^5
2	Epoxy powder coating	9.2×10^8	8.6×10^6
3	Zinc silicate primer + two coats of epoxy + one coat of PU sealer coating	8.6×10^9	6.1×10^7
4	Zinc phosphate primer + one coat of epoxy + one coat of chlorinated rubber-finish coat	2.1×10^9	5.7×10^7

penetrate to the surface of the panel in due course.

Figure 2(b) indicates the behavior of epoxy powder-coated panels after 3 years of exposure. The coating is intact on the surface but the glossy appearance of the coating has disappeared, followed by the formation of chalk throughout the surface. This result indicates that the epoxy coating is protecting the steel from the viscose industrial environment, but started to disintegrate because of the poor ultraviolet radiation stability.[5] The other two high-build coating systems performed well. Figures 3(a) and (b) indicate that the gloss and color of the zinc silicate primer (two coats of epoxy plus one coat of PU sealer) and the zinc phosphate primer (one coat of epoxy plus one coat of chlorinated rubber finish systems) have faded from environmental effects. The adhesion is intact mainly because of protection from the top coat.[6-7]

IMPEDANCE MEASUREMENTS

Impedance measurements were made on the coating systems before and after exposure in a 0.5 M NaCl solution. Table 3 gives the results. Generally, the Bode plots exhibited the various stages of degradation of the coatings on the steel panels. The organic coating systems acted as a pure dielectric, separating the steel substrate from the aggressive NaCl electrolyte. This character of the coatings resulted in purely capacitive behavior.[8]

Table 3 shows that the charge transfer resistance values produced by the epoxy powder-coated system, zinc silicate with epoxy PU system, and the zinc phosphate, epoxy, and chlorinated rubber system before exposure in the viscose environment were 9.2×10^9 Ω·cm², 8.6×10^9 Ω·cm², and 2.1×10^9 Ω·cm², respectively. These resistance values were in a highly protective region of an intact film on the steel surface.[9] The resistance of the aluminum spray coatings before exposure in the atmosphere was 2.0×10^3 Ω·cm². This low resistance value is equal to the resistance produced by aluminum metals in 0.5 M NaCl solution (1.8×10^3 Ω·cm²). This result clearly indicates that the spray coating protects the surface for quite a long period as long as the contacts between aluminum particles are intact. The aluminum spray coating protects the surface through galvanic action.[10] Further, the aluminum readily reacts with the viscose environment and forms $Al_2(SO_4)_3$ followed by the oxide of aluminum on the surface.[11] This corrosion product plugs the pores formed on the surface, thus protecting the steel surface for quite a longer duration. This explains why the charge transfer resistance produced by the spray-coated system after exposure (3.5×10^5 Ω·cm²) is higher than the resistance exerted on it before exposure. Before exposure, the conductivity of the aluminum coating is high because of particle-to-particle contact, so the resistance is very low. After exposure, however, the corrosion products block the particle-to-particle contact, so the conductivity decreases and the resistance is higher than that of the original aluminum spray coating.

Table 3 also shows that the charge transfer resistance values produced by these coating systems are in the range above 10^8 Ω·cm². The values show that the coatings are highly protective. No corrosion spots or dissolution were observed on the surfaces. Further, the PU sealant coating systems perform better than the chlorinated rubber-finish coated system. Our previous study of coating systems in marine atmospheres also revealed that the PU top-coated system perform better than the other systems.[12]

Conclusions

This study revealed that the viscose industry is severely affected by SO_2 and a high-humidity environment. The humidity is always in the range of 95% and the corrosion rate of mild steel is found to be 0.35 mm/y. The impedance measurement indicates that the two organic coating systems performed well in this acidic environment and exerted the high resistance value of 10^7 Ω·cm² even after an exposure of 3 years in this atmosphere. Further, the PU sealant coated system performed better than the chlorinated rubber-based finish-coated system. Finally, the study suggests that for the protection of mild steel structures from the viscose industrial environment, the coating system with zinc silicate primer followed by two coats of epoxy high-build coating and a PU sealant coat performed well longer than the other coating systems.

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