

Behavior of Galvanized Steel in Tropical Marine Environments

The Patina Project

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Most galvanized structures exposed to marine environments worldwide show evident signs of deterioration, particularly in tropical climates. This happens shortly after erection, especially with those exposed to erosive environments because of the high wind speeds in those areas. This article discusses results that were obtained from the Iberoamerican network PATINA (Anticorrosive Protection for Materials Exposed to the Atmosphere) after 42 months' exposure, and from a new station set up at the Lake Maracaibo crossing after 36 months' exposure. These results showed that bare galvanized steel should not be used in these atmospheres, but should be coated with high-performance systems.

A global investigation project was initiated to study the performance of galvanized structures in tropical marine environments. This article describes the results of the study and makes recommendations on more effective corrosion protection for those atmospheres. The study included two evaluation phases for metallic and nonmetallic coating systems.

La Voz station was selected for the Patina Project¹ (Anticorrosive Protection for Materials Exposed to the Atmosphere). The station is located in the State of Falcón, Venezuela, and is classified as special because of its high aggressiveness (Table 1) and strong wind incidence (speeds of up to 7 m/s with gusts to 9 m/s). Corrosion rates reach 921.70 $\mu\text{m}/\text{y}$ (36.29 mpy) for steel, 8.88 $\mu\text{m}/\text{y}$ (0.35 mpy) for copper, and 26.53 $\mu\text{m}/\text{y}$ (1.05 mpy) for zinc (these corrosion rates go well beyond the range established for a marine atmosphere).¹⁻³ The atmosphere has a very high chloride content (374.76 $\text{mg}/\text{m}^2\cdot\text{d}$). The test probes were placed directly facing the sea and they are flat and rectangular, with dimensions of 100 by 150 mm. The test banks were set up for evaluating the coating systems, all according to ISO 2810.⁴

The coating systems evaluated in this project were divided into six groups—metallic and nonmetallic—one of them being galvanizing. Metereochemical agents (ISO/DP 9225⁵) on the coatings were monitored during the exposure time. The metallic coatings were evaluated by monitoring during visual inspection to see whether or not there were corrosion products on the coating and substrate, peeling of the coating, or corrosion at the edges.

The Cruce del Lago Project

During the second phase of the Cruce del Lago project,⁶ a more specific evaluation of the galvanized steel was carried out, including the results of some galvanized towers located in this area.

The test banks were located perpendicular to the direction of the prevailing winds. The stations were placed at two different heights: 44 m and 117 m above the Lake Maracaibo level. There were two types of galvanized test probes: structural pieces from the towers, ~1-m long by 50-mm wide, placed for 36 months' exposure and 150- by 100- by 3-mm galvanized steel sheets, placed for 22 months' exposure to this aggressive environment. Visual evaluation was done in the same

TABLE 1

ANNUAL AVERAGE OF METEROCHEMICAL AGENTS AT LA VOZ STATION (ISO/DP 9225)

Station	T (°C)	RH (%)	fTOW ^(A) (%)	Rain mm/y	SO ₂ mg/m ² ·d	Cl ⁻ mg/m ² ·d	Wind Velocity (m/s)
La Voz	32	92	68	398	29.85	374.76	7.20

^(A)Time of wetness fraction.

way as for the PATINA project. To determine the corrosion rate on galvanized steel, metallography was used to measure thicknesses.

Results and Discussion

THE PATINA PROJECT: LA VOZ STATION

The results of the visual inspection on galvanized test probes with 42 months' exposure are analyzed in general in this article. Morcillo, et al.,¹ gave details about this research project.

The galvanized probes had a 60- μ m thickness. After just 24 months' exposure, the formation of white corrosion products on the coating in the form of scales on 100% of the surface and on 7% of the base steel was observed. In addition, severe corrosion was found on the borders (Lmax = 12.5 mm/0.49 in.) because of the strong winds, which have an erosive effect on the corrosion products formed on the galvanized steel. Although the coating provided galvanic protection to the substrate in the incision area after 42 months' exposure, the base steel began to corrode at a rate of 100% at this location. Figure 1 shows the effects on two different sheets, with and without incision.

MARACAIBO LAKE CROSSING PROJECT

Visual Inspection of the Towers After 36 Months' Exposure

Figure 2 shows one of the towers where some of the stations are located. Visual inspection of the towers revealed severe corrosion in the area exposed to the prevailing winds, where there is no longer any zinc because of the erosive action of the winds on the corrosion products. Erosion varies with the height, being more severe at higher levels. This erosion effect was not observed on the leeward (downwind) side (Figure 3), as there was corrosion on 100% of the surface, with the characteristic white products on galvanized steel exposed to marine environ-

FIGURE 1



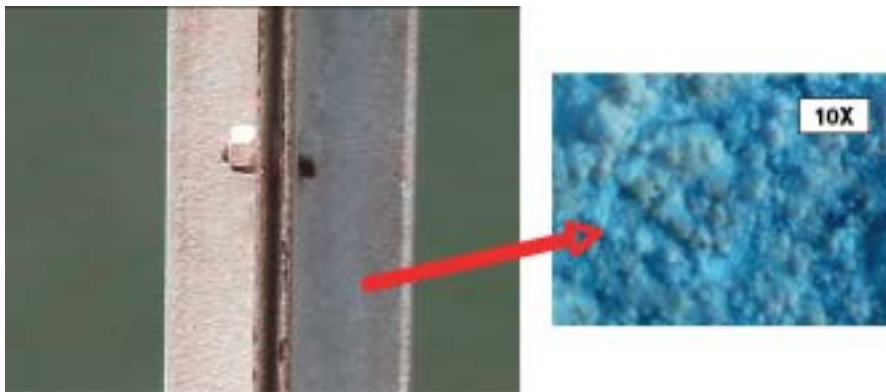
Galvanized steel: a) without incision, and b) with incision, after 42 months' exposure at La Voz Station.

FIGURE 2



Towers (Cruce del Lago de Maracaibo project).

FIGURE 3



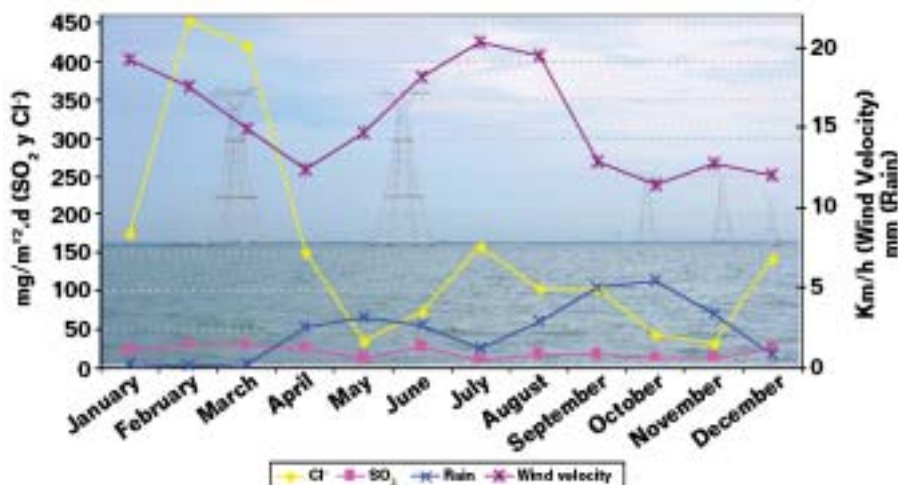
White products on galvanized steel exposed to marine environments.

FIGURE 4



Initial phase of the exfoliation process.

FIGURE 5



Meteorological agents at El Cruce del Lago de Maracaibo.

ments. In each of the corroded profiles (Figure 4), there were small fissures, which constitute the initial phase of the exfoliation process. This is because of severe erosion in the border zones, caused by wind incidence on such a small area. High relative humidity (RH) and chloride concentrations, which diffuse toward the interface between the corrosion products, accelerated the process, originating voluminous products that cause exfoliation of the coating.

Probes Exposed in the Stations for 22 Months

In these plates, there is evidence of the same behavior as that on the structural elements of the towers. The corrosion rate for galvanized steel, using the plates exposed at the Lake Maracaibo crossing, is $52.92 \mu\text{m}/\text{y}$ in the area facing the prevailing winds; this rate coincides with the deterioration found at the towers ($\sim 80 \mu\text{m}$ galvanized coating, completely gone after a two-year exposure) and $35 \mu\text{m}/\text{y}$ in the leeward area. These corrosion rates are high for galvanized steel, since ISO 9223⁷ considers values of $8.4 \mu\text{m}/\text{y}$ for the category of greatest corrosiveness (C5). These results indicate that this coating is not the best for climates with a high presence of chlorides, high RH, and especially high wind speeds.

The maximum corrosion rate for steel, estimated by gravimetric techniques, was $233 \mu\text{m}/\text{y}$. This also indicates how highly aggressive the medium is ($>C5$ according to ISO 9223); considerably lower values were obtained in other stations previously studied at ground level in areas surrounding the region under study.⁸ The aggressiveness of the study area is higher than the one found in the Iberoamerican project (MICAT), where the highest corrosion rate found for zinc was $4.5 \mu\text{m}/\text{y}$, compared with $52.92 \mu\text{m}/\text{y}$ in the parts of the towers facing the prevailing winds. Wind action, which was not a factor in the stations used in the MICAT project, accounts for the high corrosion rate of zinc at the Lake Maracaibo crossing. Figure 5 shows the chloride ion and sulfur dioxide (SO_2) concentrations in the atmosphere surrounding the test station throughout one year. Notice the high concentration during

the dry season and the low concentration in the rainy season. This figure also shows the high wind velocity in the area from January to April (dry season). The high wind (trade wind) brings the chloride ions from the sea, because the towers are near the Gulf of Venezuela, which is located to the north of the towers.

Conclusion

These tests indicate that bare galvanizing is not the most adequate coating for a high-chloride-content environment and high RH, especially with high wind speeds that slowly erode the galvanized steel. It is suggested that galvanized steel has to be protected by a high-performance coating system, which must resist erosion, high-temperature gradients, and high ultraviolet exposure.

Acknowledgment

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