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Research Article

Six-Year Evaluation of Thermal-Sprayed Coating of Zn/Al in Tropical Marine Environments

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The main objective of this research was to evaluate the performance of thermal-sprayed coating of Zn/Al (double layer) after six years of exposure, with and without the use of sealant (wash primer) in tropical marine environments of very high aggressiveness: La Voz Station (located at the Peninsula de Paraguaná/Falcón State) and Lake Maracaibo Crossing Station (located at Zulia State), in Venezuela. To that effect, carbon steel coupons ($100\,mm \times 150\,mm \times 2\,mm$) were sprayed by flame process. The coupons were characterized by means of initial weight, thickness, metallographic, adherence, and roughness, being evaluated monthly by visual inspection during six years. After removal, the coupons were evaluated by microscopic analysis to determine the morphology of attack, microstructure, penetration of contaminants, composition, and morphology of corrosion products. The results showed that after six years, the double-layer system represents an excellent choice for corrosion protection of steel by combining the galvanic protection of zinc with the erosion resistance of aluminum. However, due to the erosion-corrosion effect, a sealant such as wash primer can be used in order to extend its service life.

1. Introduction

Worldwide, many organizations have made numerous efforts in terms of studies and research looking for new coating systems to improve the durability of structures exposed to marine and coastal marine environments, providing protection to the steel during its service life and producing a minimal impact on the environment. In marine and coastal marine environments, where a number of factors are present such as high-chloride concentrations, strong winds, changing conditions of relative humidity and temperature (especially in tropical climates like Venezuela), organic coatings do not perform properly. In this regard, thermal-sprayed coatings appear as an alternative to protect steel structures in those environments. In the United States, Europe, and Japan [1, 2], these coatings are gaining importance for their promising low environmental impact, corrosion resistance, cost benefits, durability, and other advantages over other conventional paint systems.

In 1974, the American Welding Society [3] performed a study that was considered a pioneer in thermal sprayed coating where it reported that these coatings with Zn and Al, with and without sealer, exposed in marine and industrial environments, provided protection against corrosion for 19 years. Moreover, in 1987, the Laque Center for Corrosion Technology, INC. [4] reported that the degree of protection of the coatings, after 34 years of continuous exposure in a moderately aggressive marine atmosphere, varies considerably with alloy content, type of material applied, and method of application. They also highlighted that the best thermal sprayed system is given by the coating of Zn/Al, double layer, and Zn/Al alloy (with a higher content of aluminum).

In tropical marine environments, for example, Venezuela, little is known about the application and performance of this coating technology. Venezuela's environment is completely different from the above-mentioned places given the high incidence of winds, high temperatures, and relative humidity during all the year. Only the PATINA Network [5] is known to have studied the effect of these environments on coating systems. In it, the behavior under corrosion of a wide variety of conventional and new generation coatings in the atmospheres of the Ibero-American region

Table 1: Characterization of coating system [10].

Coating	Thickness (μm)	Adhesion (MPa)	Porosity (%)		Anchor profile (μm)
Zn/Al by flame process	215.9–469.9	2.90	23 (Zn)	8 (Al)	37.85 ± 4.01

was evaluated. The performance of metal-based sacrificial coatings (aluminum, zinc and their alloys, among them thermal sprayed aluminum and Zn/15Al with vinyl sealer and wash primer) was also evaluated. The Zn/15Al with sealer gave the best performance in the atmosphere at La Voz. Recent research [6–13] in Venezuela (at Centro de Estudios de Corrosión, Faculty of Engineering, Universidad del Zulia) on thermal sprayed coatings with different materials (Zn, Al, Zn/85Al, and Zn/Al Double Layer) applied by two processes (flame and electric arc) with and without the use of different sealants (wash primer 1, wash primer 2, phenolic, and polyurethane), indicates that thermal sprayed coatings applied with only zinc or aluminum do not provide adequate protection in the exposure environments evaluated. However, the Zn/Al double-layer system has performed excellently in comparison with other thermal-sprayed systems. This coating system represents one of the best options for countering these aggressive environments. This paper presents the results after six years of evaluation.

2. Experimental Procedure

2.1. Preparing the Coupons [6–10]

2.1.1. Preparing the Surface. The company applying the thermal spray coating (flame) used its own steel coupons (100 mm × 150 mm × 2 mm) and its own criteria for preparing the surface; it did not supply the latter information. Because of this, indirect measurements of the anchor profile left on the substrate were made by using optical microscopy at 200x magnification, in transversal sections in some of the coupons, sweeping and measuring the distance between the peaks and valleys left on the substrate, with an average value of the measurements being reported.

2.1.2. Coatings and Application Methods. Two systems were evaluated: (1) a dual system (Zn/Al) formed by a first coat of thermal sprayed Zn as a primer and a second coat of thermal sprayed aluminum as a top coat, applied by the flame process without sealer; (2) the same coating but with the application of two additional layers of wash primer sealer.

In each of the test stations, 5 coupons per coating were installed. Each year, one coupon per coating was removed for evaluation in the laboratory to complete the total exposure period of six years, presented in this paper.

2.2. Characterization of Coatings [6–10]. Before being set up in the test stations, the coupons were swabbed with acetone to remove any oil and grease, then, cleaned with distilled water and dried immediately with an air pistol. After cleaning, they were characterized with respect to thickness, microscopic analysis, porosity, and adhesion.

2.2.1. Thickness. This measurement was carried out in accordance with Standard ASTM D 1186 [14], using a nondestructive instrument ("constant pressure probe DFT", "gauge (type II)") that measures the dry-film thickness of nonmagnetic coatings on ferrous metallic substrates. Due to the variability of thicknesses (nonuniform thicknesses) in this type of coating even on the same coupon, it was decided to use a template with the same dimensions (100 mm × 150 mm) with ten evenly distributed orifices and located at 2 cm away from the edges so that the measurements would be always taken on the same spot.

2.2.2. Metallographic Analysis and Porosity. An optical microscope with magnifications of 200x and 400x was used to analyze microstructure and porosity as well as to verify the thickness of these coatings. Samples were prepared by means of 2.5 cm × 2.5 cm cuts and then encapsulated in Bakelite with a cupping machine. It was then surfaced with emery paper and burnished with alumina to a specular aluminum finish. Specifically, Standard ASTM E 2109-01 [15] was used to determine the percentage of porosity in the thermal sprayed coatings with an image analysis program.

2.2.3. Adhesion. Adhesion tests were run by the "Pulloff test" method of tensile strength according to ISO Standard 4624 [16]/ASTM4541 [17], using an adhesion tester.

2.2.4. Incisions. In order to evaluate the galvanic effect of the coatings, a horizontal incision of approximately 6 cm was made into each coupon to reach the metal base in the lower part; a 2 cm space was left between the incision and the lateral and lower borders for observation.

Table 1 shows a summary of the initial characterization of the coupons.

2.3. Evaluating the Coatings [6–10]

2.3.1. Visual Inspection. The coating systems were examined and photographed monthly, collecting data on registration forms. The presence or absence of corrosion products detected during these inspections indicated whether they were coating corrosion products or substrate corrosion products, both on the general surface of the coupon as well as on the edges and incisions.

2.3.2. Analysis under the Scanning Electron Microscope. After the coupons were taken out from the test stations, cuts were made in the places of interest, using a diamond-point cutter, for subsequent encapsulation in conducting Bakelite to enable the execution of the elementary chemical analyses. The chemical analyses and the morphology of the transversal area of the coatings were carried out using the Energy Dispersion Spectroscopy (EDS) technique on a PHILLIPS Model XL 30 Scanning Electron Microscope.

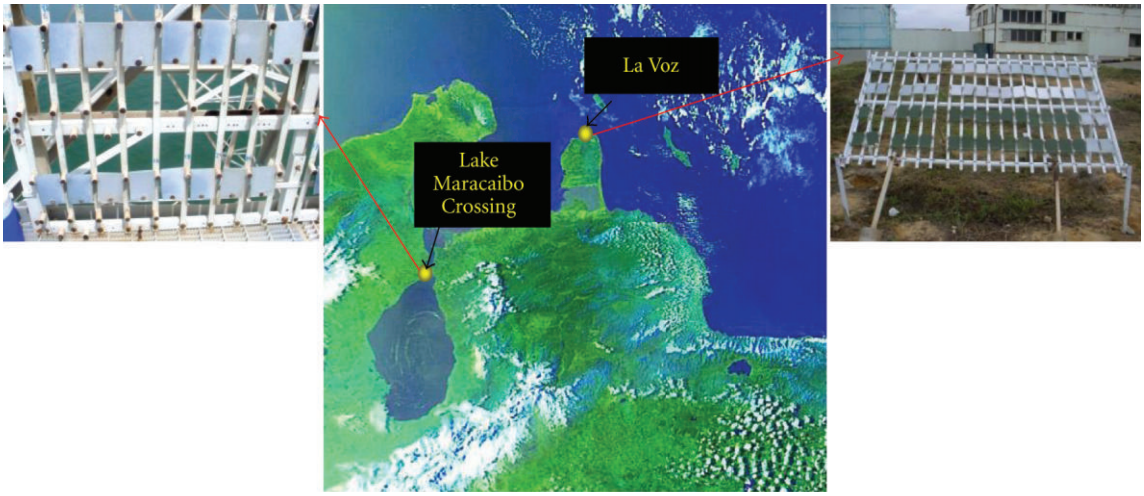


Figure 1: Geographic location of the Lake Maracaibo Crossing Station and La Voz Station.

2.3.3. Analysis by X-Ray Diffraction (XRD). This analysis was carried out to identify compounds and oxides formed after exposure, using a BRUKER AXS equipment of eight radiation sources of copper. Each sputtering lasted 45 minutes.

2.4. Test Stations. Two very aggressive tropical marine environments with high wind impingement were selected.

2.4.1. Lake Maracaibo Crossing Station (LMC). This station is located at the crossing with Lake Maracaibo, Venezuela, at 117 m above lake level (Figure 1). Besides being a marine atmosphere, it is characterized by strong winds, as well as changing conditions of high humidity and high temperatures. The station is also surrounded by two industrial complexes, both of which release sulfur dioxide into the atmosphere from fossil combustion processes.

2.4.2. La Voz Station. It is Located on the Peninsula of Paraguaná, Falcón State (Figure 1), in the direction of the prevailing winds, 21 nautical km away from the refinery at Aruba, and 300 m from the Caribbean. This atmosphere is classified as a special atmosphere in accordance with the MICAT Project (Latin American Map of Atmospheric Corrosion), because of its high aggressivity and strong prevailing winds, reaching corrosion rates of 921 μm/year for steel and 27 μm/year for zinc [18].

2.4.3. Chemical Pollutant Levels and Meteorological Variables. Chemical pollutant levels were measured according to ISO 9225 [19]. For the measurement of meteorological variables (relative humidity, temperature, time of wetness, wind speed, and rainfall), the data belonging to the station nearby was used [10]. Corrosivity of atmospheres was determined using ISO 9223 [20].

2.4.4. Location of Coupons on the Test Bank. The test bank at La Voz Station is placed at an angle of 45° to avoid the accumulation of water on the coupons and they are located facing the prevailing winds. At the Lake Maracaibo Crossing Station, the test bank is fastened to the railing of a tower at a height of 117 m above sea level, with the coupons in vertical position and facing east. The incidence of the prevailing winds at this station is particularly on the right edge of the test coupons.

3. Results and Discussion

3.1. Characterization of Environments. The results of the characterization of the environments under study are shown in Tables 2 and 3; notice their high aggressiveness (high–very high) where it is evident a more corrosive environment in La Voz Station (C_5/C_4) in relation to the Lake Maracaibo Crossing Station (C_4).

3.2. Behavior of the Thermal-Sprayed Systems in La Voz Station

3.2.1. Double-Layer System without Sealer. During the first twelve months of evaluation, the double-layer system Zn/Al without sealing (Figure 2(a)) had an excellent performance, presenting corrosion only at the coating in the bottom border. It must be pointed out that the area of the coupons hit by the prevailing winds, where the erosive effect is manifested, is different for each station. In the case of LMC station, winds impinge on the right edge whereas impingement is frontal in La Voz station.

However, for the second period of evaluation (24 months) [8], it was reported that these are susceptible to present border flaws, as after 14 months of evaluation, one of the valued samples evidenced detachment of the coating in the lower-left corner (Figure 3). This type of flaw in the border of the probe was possibly caused by an inadequate application of the coating due to the geometry of the probe (90° degrees angle/Figure 3(c1)), as being a critical and difficult area to cover; however, this can be corrected by guaranteeing a good thickness in that area or diminishing the angle of the

TABLE 2: Meteorological data during four and six years of exposure in La Voz Station and Lake Maracaibo Crossing Station (LMC), respectively.

Station	Time (years)	Temperature (°C)	Relative humidity (%)	Precipitation (mm)	Wind speed (m/s)
La Voz	1	28.3	82.4	834.6	5.6
	2	28.6	80.4	758.4	6.0
	3	28.7	82.5	538.4	7.3
	4	28.4	82.4	482.6	7.0
LMC	1	28.1	81.2	794.6	6.4
	2	27.8	83.4	1036.3	6.6
	3	28.0	80.3	544.3	6.5
	4	27.0	83.6	656.3	6.6
	5	26.7	80.4	698.4	6.6
	6	26.7	82.6	197.6	6.4

Source: For the LMC Station, the first 3 years correspond to meteorological data supplied by the "Air Base Rafael Urdaneta" (BARU), Zulia State, located at 30 km from the station. The rest of data for that station for the following three years was provided by a pilot station installed in situ at 110 m of height in the tower of the mentioned station.

TABLE 3: Average levels of air chemical agents during four and six years of exposure in La Voz Station and LMC Stations, respectively.

Station	Time (years)	Sulphur compounds mg/($m^2 \cdot d$)	Chloride mg/($m^2 \cdot d$)	Time of Wetness fraction	Corrosion category according to ISO 9223
La Voz	1	27.2	284.23	0.79	P_1S_2 T_5/C_5
	2	16.3	178.13	0.70	P_1S_2 T_5/C_5
	3	9.0	320.76	0.58	P_0S_3 T_5/C_5
	4	12.2	178.63	0.59	P_1S_2 T_5/C_5
LMC	1	16.4	125.3	0.48	P_1S_2 T_4/C_4
	2	17.8	89.49	0.46	P_1S_2 T_4/C_4
	3	13.1	100.44	0.52	P_1S_2 T_4/C_4
	4	45.0	80.72	0.71	P_2S_2 T_5/C_5
	5	—	—	0.62	—
	6	—	—	0.63	—

edge to reduce the drag coefficient, as the ones applied for the process of electric arch (Figure 3(c2)).

After 36 months of an excellent performance, the system started to diminish its protection capacity as it was affected by the erosive effect (Figures 2(c) and 2(d)), specially the border effect (lower-left corner); a worn area was noticed as well as some coating oxidation products; there were also deposits of salts and dust and even some substrate corrosion spots. In relation to the incision, an excellent galvanic protection was observed covered by the corrosion products from the coating, mixed with dust.

3.2.2. Double Layer System Sealed with Wash Primer. After 4 years of exposure, this system (Figure 4), contrary to the one without sealer, presented an excellent appearance, with some corrosion spots of the aluminum spread over the exposed surface and dust deposits in the low border. At the incision, the coating provided an excellent galvanic protection. It was totally covered by the corrosion products of the coating and dust, without signs of damages to the steel base.

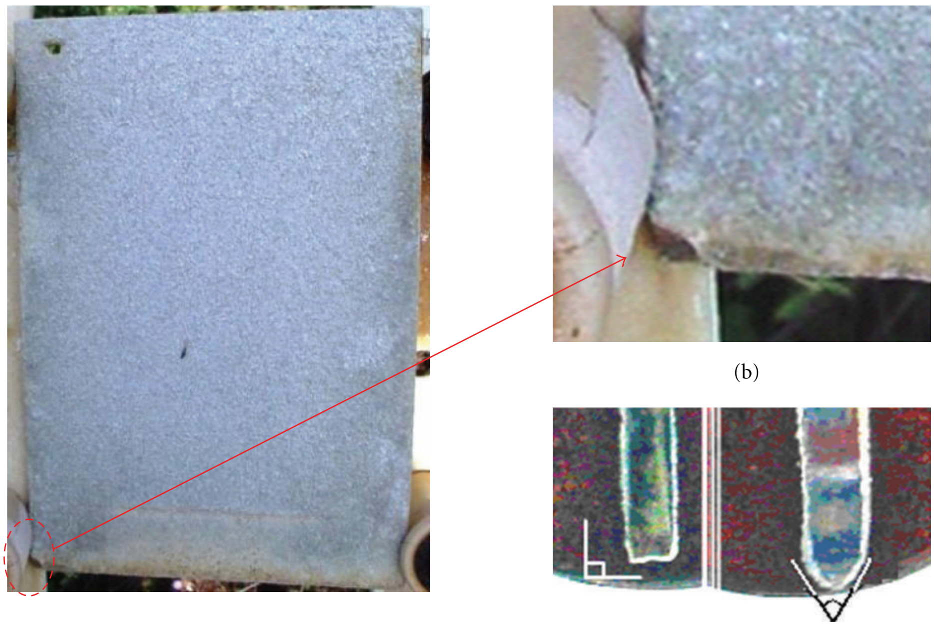
According to the observations done, it can be said that the use of the sealer wash primer improves significantly the performance of this system (aluminum as finishing), as it offers an additional barrier to the erosive effect of the environment as well as it enhances its esthetic appearance. The reason for this improvement is the chemical composition of the sealant. This chemical analysis was carried out in another research [9] at the Centro de Estudios de Corrosión, Faculty of Engineering, Universidad del Zulia, on samples of thermal sprayed aluminum sealed with the same wash primer (wash primer 1) used in this evaluation and other sealer (wash primer 2), of another manufacturer, obtaining different performances.

Table 4 shows the chemical analysis for EDS that was made on the surface of a thermal sprayed sample with aluminum, sealed with wash primer 1 and its comparison with wash primer 2, on which some localized corrosion in the pores of the coatings was observed.

It was determined [9] that the improvement of this system is due to the chemical composition of this sealer (wash primer 1) as it presents, titanium (4,84%), a high chromium percentage (11,54%) and aluminum phosphates that are formed on the surface which increase the resistance of the passive aluminum film to the erosive effect. It should be noted that the performance of this system was better than each of the separate coatings (Al and Zn) [6–11].

(a) (b) (c) (d)

Figure 2: Thermal-sprayed coating of Zn/Al by the flame process (470 μm). (a) 12 months of exposure. (b) 24 months of exposure. (c) 36 months of exposure. (d) 48 months of exposure.



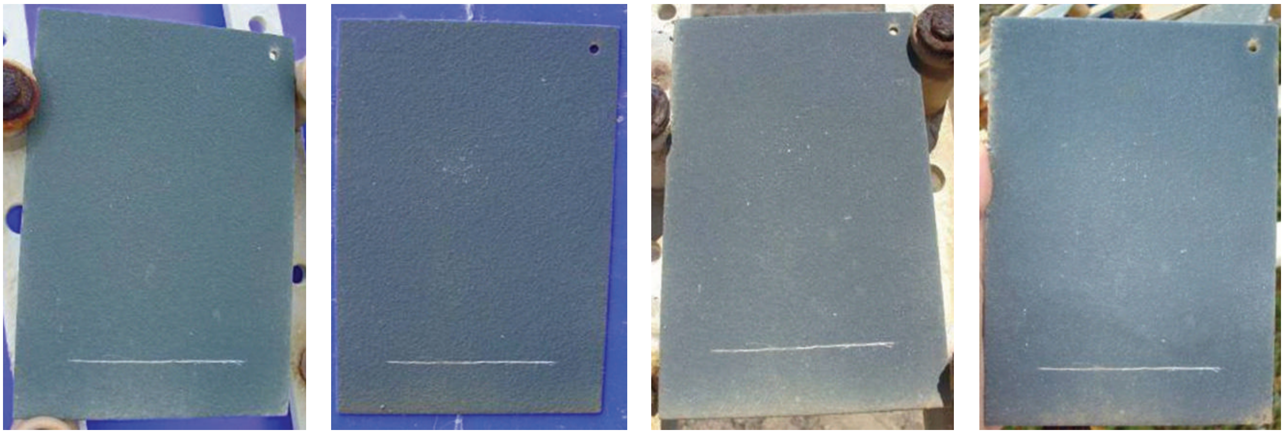
(a) (b) (c1) (c2)

Figure 3: (a) Thermal-sprayed coating of Zn/Al, Thickness = 445 μm. (b) Details of the edge flaw in the lower border. (c) Transversal cutting: details of the edge of the sample applied by the flame process (90° angle (c1) and acute (c2)), sample applied by electrical arch.

3.3. Behavior of the Thermal-Sprayed Systems in the Lake Maracaibo Crossing Station

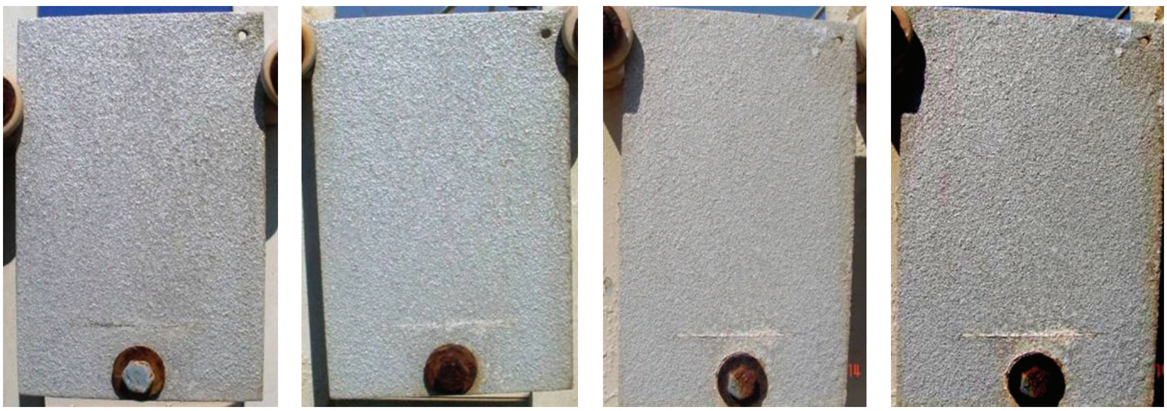
3.3.1. Double-Layer System without Sealing. The environment in LMC Station is less aggressive (C_4) than in La Voz Station (C_5), which means that flaws will appear after a longer time of exposure. The thermal sprayed system with Zn/Al double layer without sealing, up to 36 months of evaluation, presented a good performance, without signs of corrosion at the surface substrate of the probe and with a good galvanic effect; it showed only a slight accumulation of environmental dust (Figure 5).

At 71 months of exposure, this coating began to surrender to the erosive attack, so some zinc corrosion products were noticed on the right edge (Figure 6), near the area of the border. This area, as it has been established in previous researches [6–9], is critical because coupons coated by the flame process presented an edge with a 90° angle which implies that the coating did not acquire the appropriate thickness as it was difficult to apply the product in that area; this opens the possibility for the aluminum fail to provide the necessary protection against the erosive effect and, therefore, to expose zinc, a material highly affected by the erosive action of the environment. The last inspection completed in this



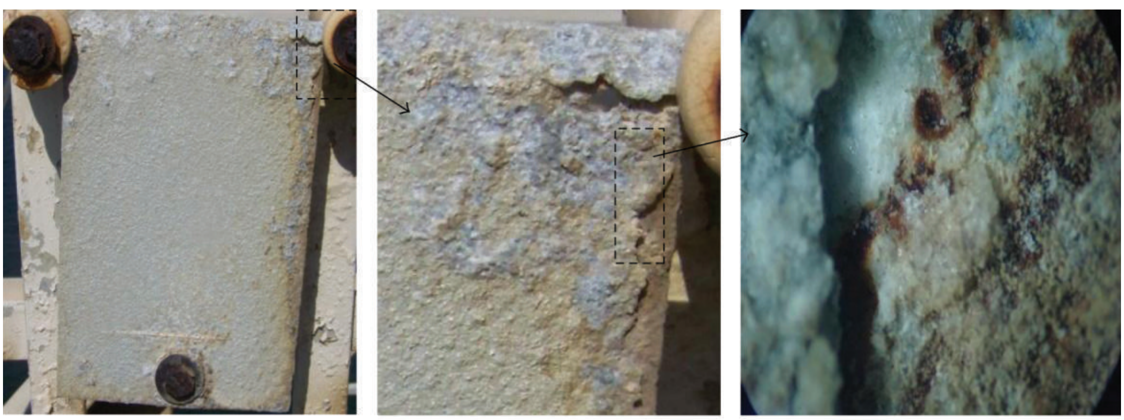
(a) (b) (c) (d)

Figure 4: Thermal-sprayed coating of Zn/Al by flame process, sealed with wash primer (445 μm). (a) 12 months of exposure. (b) 24 months of exposure. (c) 36 months of exposure. (d) 48 months of exposure.



(a) (b) (c) (d)

Figure 5: Thermal-sprayed coating of Zn/Al by flame process (318 μm) (a) 12 months of exposure. (b) 24 months of exposure. (c) 36 months of exposure. (d) 41 months of exposure.



(a) (b) (c)

Figure 6: Thermal-sprayed coating of Zn/Al by flame process (318 μm). (a) 71 months of exposure. (b) Delamination detail of the coating in the right edge. Notice the formation of corrosion products of Zn (white color) and the substrate corrosion (brown color). (c) A magnifying stereoscopic view 45x.

Table 4: Elemental analysis: wash primer sealer manufacturer 1 and 2.

Chemical analysis (Weight %)	
Wash primer 1	Wash primer 2
Al = 23.31	Na = 6.49
P = 13.52	Al = 30.36
Cl = 3.24	Si = 15.63
Ca = 1.45	P = 18.59
Ti = 4.84	Cl = 12.38
Cr = 11.54	K = 2.46
Fe = 9.66	Ca = 1.66
Zn = 32.42	Cr = 1.69
—	Fe = 6.21
—	Zn = 4.53

Table 5: Chemical analysis for thermal-sprayed Zn/Al, double layer, without sealer.

Chemical analysis (weight %)			
Area 1	Area 2	Area 3	Area 4
Al = 10.42	Al = 3.09	Mn = 0.46	Al = 98.85
S = 6.79	S = 3.18	Fe = 90.67	Fe = 0.58
Cl = 8.74	Cl = 3.46	Zn = 8.72	Zn = 0.57
Fe = 0.50	Zn = 90.52	Ga = 0.15	—
Zn = 73.23	Ga = 0.26		—
Ga = 0.33			—

Table 6: Chemical analysis of the right edge.

Chemical analysis (weight %)
Al = 13.03
Si = 6.37
Cl = 0.76
K = 0.44
Ca = 1.08
Fe = 1.42
Zn = 76.89

environment was almost after six years of exposure; some substrate corrosion was observed as the coating at the right border was slightly starting to delaminate.

3.3.2. Double-Layer System Sealed with Wash Primer. After 71 months of exposure, the probe was practically intact, with an excellent appearance and galvanic effect (Figure 7). Of all the systems evaluated in the project, this one has had the best performance, only a slight accumulation of environmental dust, a product of the last months of drought.

At La Voz Station, and just as previously explained, wash primer 1 drastically improved the resistance of the coating, as it helped it to face these very aggressive environments from the corrosion-erosion point of view.

Through the evaluation of this project, from the 5 studied samples of this system in this environment, only one presented an edge flaw at the lower-left corner after 13 months of exposition (Figure 8), the crack advanced to a longitude of 3.5 cm.

In spite of this, and similarly to the results of the previous station, the performance of the system was better than the one of the other systems of Zn and Al separately (Figure 9) [6–11].

3.3.3. Analysis by Scanning Electron Microscope (SEM). During the different phases of the project, some cuttings were made in areas which presented good or problem conditions (e.g., with flaws at the edges) to analyze through SEM the integrity of the coating, its microstructure changes, the penetration of polluting agents, the morphology of corrosion products, and their corrosion mechanisms. One of the analyses is presented below, specifically, the one done in a sample after 36 months of exposure (Figure 10) at the LMC Station; the area analyzed is localized at the right edge; it was chosen so that the integrity of the coating in the proximities of the edge of incidence could be verified.

The elemental analysis in zone 1 shows an attack to the zinc layer (corrosion products/light gray color). In this area, two things can be observed: first, a high concentration of pollutants (Table 5); and, second, a group of imperfections or interconnected pores that form a kind of channels, through which pollutants easily ingress toward the internal layers of the coating. On the other hand, in zone 2, there are high concentrations of chlorides and sulphur compounds. The high zinc content of the area suggests the presence of corrosion products of zinc. As observed in Figure 10, these zinc corrosion products are over the aluminum layer, as they are deposited on their discontinuities. Zone 3 is located in the interface area of steel/zinc (the furthest zone), as seen in Table 5, without the presence of pollutants for that time of exposition. However, in Figure 10, some microcracks and discontinuities of the zinc layer can be detected in the proximities of the zone; through them, aggressive agents could possibly ingress when reaching the level of the interface aluminum/zinc. Finally, in zone 4, the aluminum remains intact (Table 5), as expected; this element has remained in excellent conditions up to now.

The microscopic analysis revealed important aspects such as (a) differences in the thickness of the layers, which gave as a result a considerable aluminum thickness (200 μm approximately), clearly higher than zinc (100 μm); (b) interconnected porosity: there were appreciated some areas with interconnected pores through which aggressive agents entered through the zinc covered zone; (c) changes in zinc microstructure and penetration of polluting agents.

In relation to the analysis done on the right edge of the coupon (Figure 11), contrary to the observed in the border, there are two not-well-defined layers of zinc and aluminum. The chemical analysis (Table 6) shows that there is a low percentage of aluminum in the area, but it is rich in zinc. This inequality, and just as it was observed in the visual inspection, is responsible for the border flaws in these areas. Also, as it has been previously explained, it would be different if there was a uniform layer with a sufficient quantity of

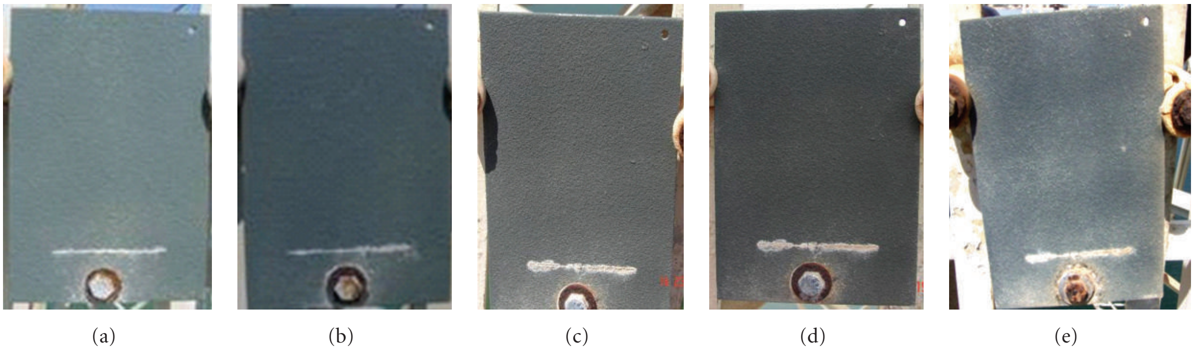


Figure 7: Thermal-sprayed coating of Zn/Al, sealed with wash primer 1 (345 μm). (a) 12 months of exposure. (b) 24 months of exposure. (c) 36 months of exposure. (d) 41 months of exposure. (e) 71 months of exposure.

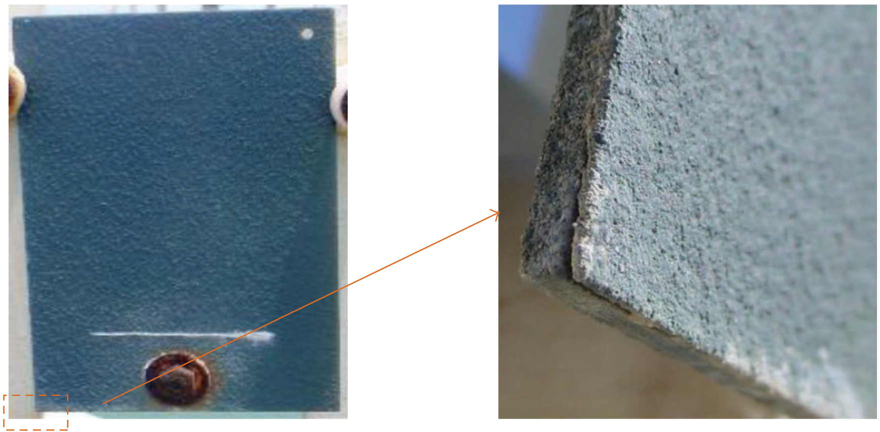


Figure 8: Thermal-sprayed coating of Zn/Al/wash primer 1 (325 μm). Notice the flaw at the edge on the left corner.

aluminum. Furthermore, the chemical analysis of the area reveals the presence of silicon, chlorine, and calcium (Table 6), suggesting deposits of environmental dust.

3.4. Analysis by X-Rays Diffraction (XRD). The XRD assays were carried out for the unsealed and sealed systems with wash primer (Figures 12 and 13). In relation to the double-layer system without sealing (Figure 12), Bayerite was found as a main component (α-Al(OH)$_3$), results that coincide with the ones reported by Pombo et al. [21], who affirm that if aluminum is thermal-sprayed by the flame process, the formation of this oxide will prevail (formed on the mouthpiece of the pistol) in the surface of the test probe. Additionally, the presence of SiO_2 was detected as a result of the accumulation of environmental dust during the period of exposure in the LMC station.

The obtained spectrum for the double-layer system sealed with wash primer 1 (Figure 13) showed phosphates formation as a product of the reaction of the coating with the sealer. It is important to highlight that the wash primer is a type of coating that is commercially used as a promoter of adherence, made up of two components: a component A which is a resin of polyvinyl butyral with pigment of Zn chromate; and a component B that is an alcoholic solution of phosphoric acid. When the latter is applied on zinc or aluminum, it reacts with them and forms a fine film of crystals of the respective phosphates, with the purpose of sealing the pores left by the application process. It is necessary to highlight that the formed phosphates contribute with a higher resistance to erosion and to the ingress of polluting agents from the environment; in contrast to the unsealed systems, it offers an additional protective barrier to the surface of the probe.

Titanium was also detected in wash primer 1 (Table 4), which is present as TiO_2 in paintings and sealers with the purpose of adding solids to confer them a better capacity to seal the pores. This element was not detected in the wash primer 2, which may be the reason why the wash primer 1 had a much better performance.

4. Conclusions

(1) Thermal-sprayed coatings with Zn/Al (double layer) sealed with wash primer extend the service life of this system, besides improving the physical appearance of the test coupon.

(2) Along the six years of studies, it was found that La Voz Station is a more aggressive area than Lake Maracaibo Crossing Station.

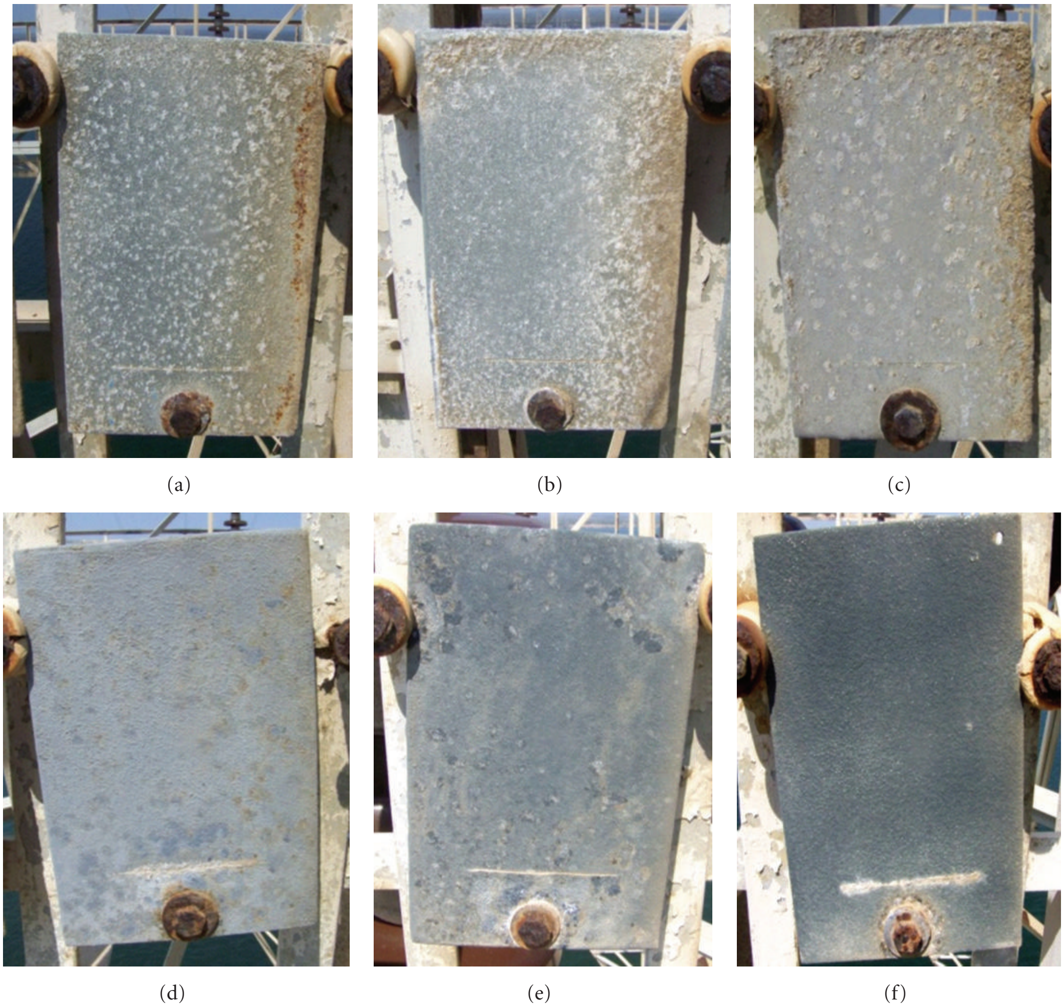


Figure 9: Comparison of different sealed systems used at the LMC Station, after 41 months of exposure (a) Thermal sprayed coating of zinc by flame process (wire), sealed with wash primer 1 (173 μm). (b) Thermal sprayed coating of zinc by the electric arch process, sealed with wash primer 1 (264 μm). (c) Thermal sprayed coating of zinc by electric arch process, sealed with phenolic (261 μm) (66 months of exposure). (d) Thermal sprayed coating of aluminum by electric arch process with phenolic (261 μm). (e) Thermal sprayed coating of aluminum by electric arch process, sealed with wash primer 1 (251 μm). (f) Thermal sprayed coating of Zn/Al by the flame process, sealed with wash primer 1 (345 μm).

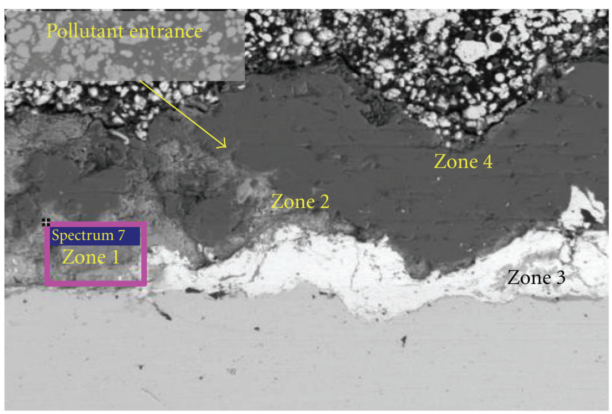


Figure 10: Thermal-sprayed Zn/Al double-layer, without sealer (thickness = 345 μm). View in the SEM. Area near the incidence edge.

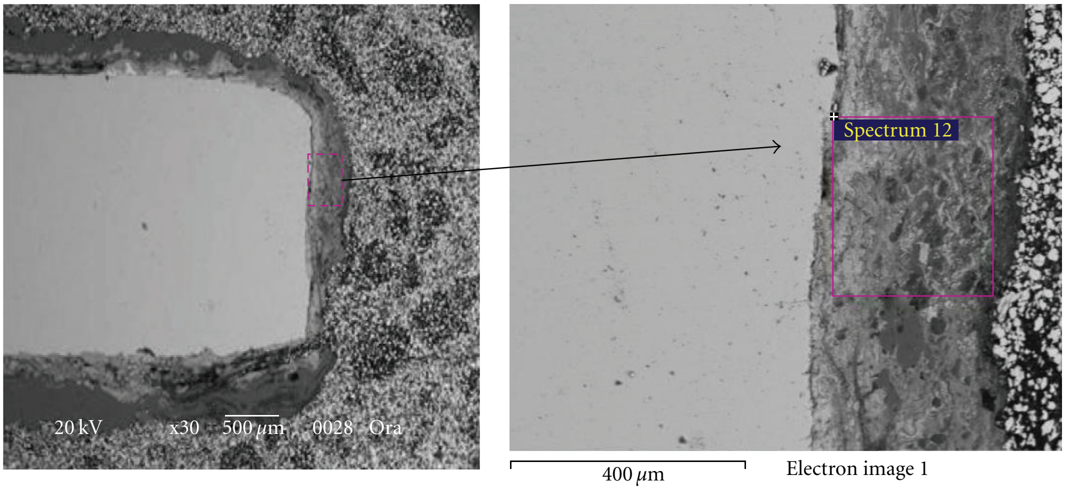


Figure 11: Thermal-sprayed Zn/Al double layer, without sealer. Thickness = 345.44 μm. View in the SEM. Right edge.

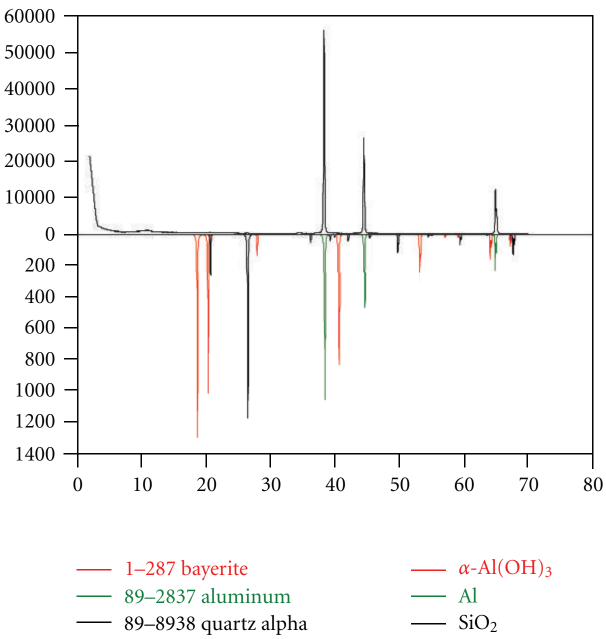


Figure 12: Spectrum of the double-layer system without sealer.

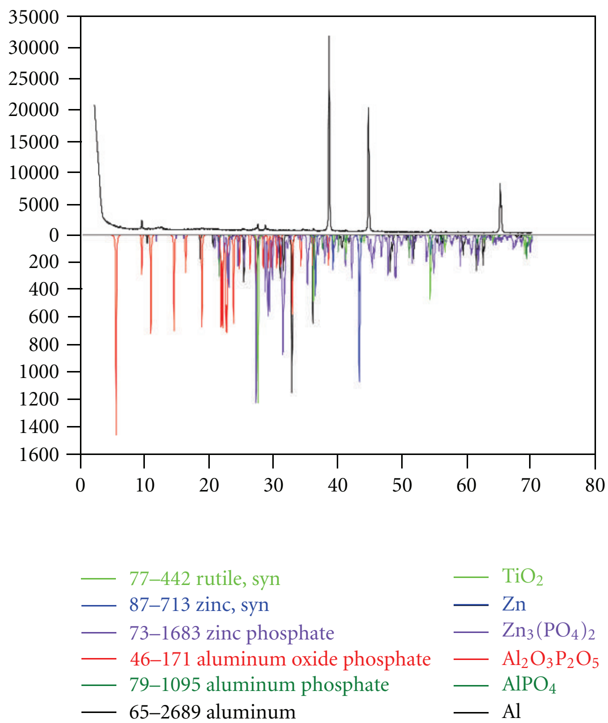


Figure 13: Spectrum of the double-layer system with sealer.

(3) The best performance in the sealed systems is due to the reaction of the wash primer with the Al (external layer of coating) of the test coupons, forming phosphates that contribute to a higher resistance to the polluting agents and erosive effects of the exposure environments; this resistance increases in the case of the wash primer 1, with the presence of TiO_2.

(4) The double-layer system with sealer represents a good protection option against the corrosion in marine and coastal marine environments with a high incidence of winds.

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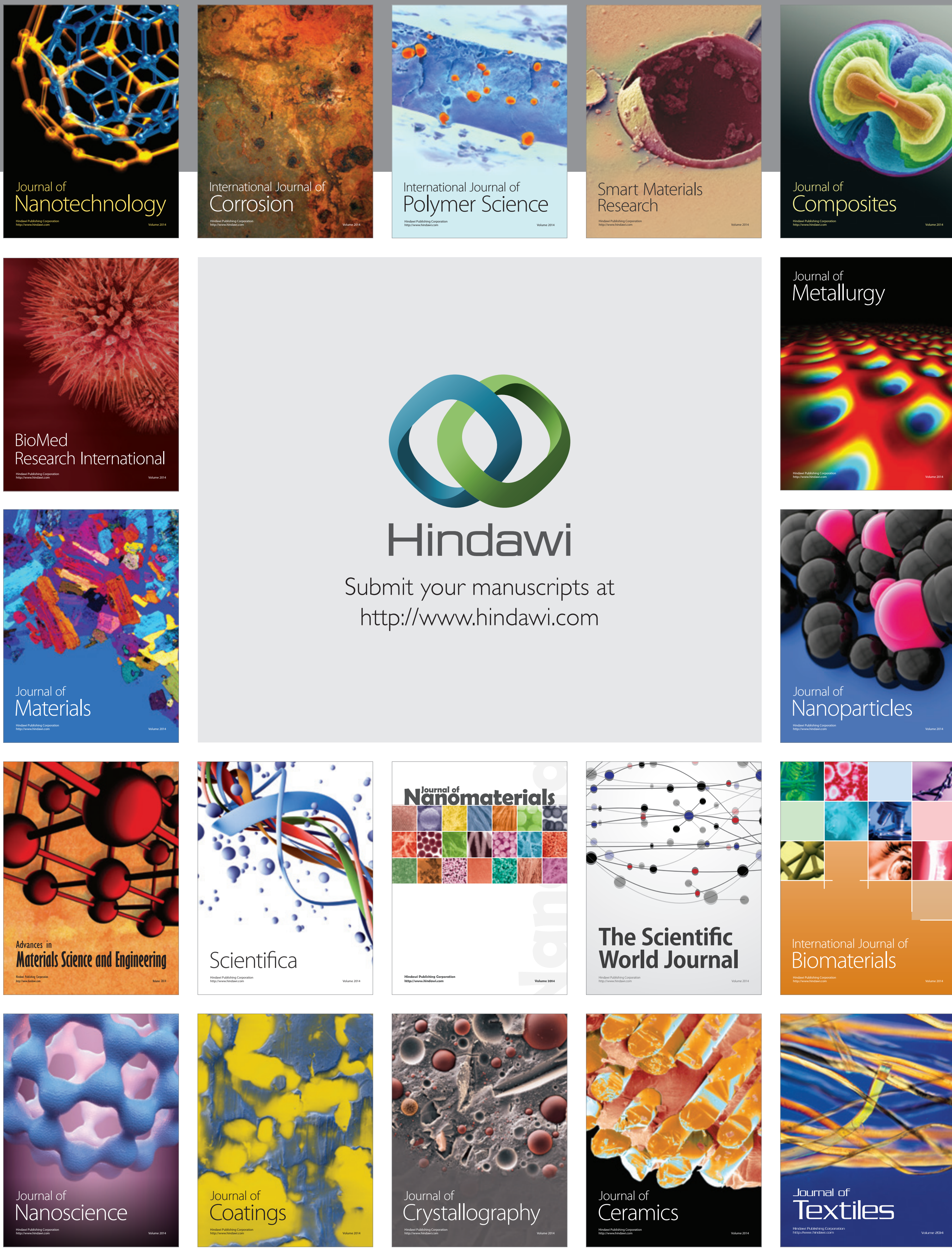
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