Corrosion protection of steel structures in industrial and marine atmospheres by waterborne acrylics DTM (direct to metal) paint system

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Abstract

Acrylics represent one of the heavy duty polymer technologies used in industrial maintenance protective coatings. Major generic coating types utilizing acrylic technology include two-component polyurethanes, which are frequently based on acrylic polyols for the excellent durability they offer, and waterborne acrylic latex coatings, which are often relied upon for their one-component ease of use. This article focuses on special waterborne acrylics DTM paint and describes its corrosion protection to steel structures in aggressive atmospheric conditions.

For more than 40 years, raw material suppliers and coatings manufacturers have continually made advances in the development of waterborne acrylic coatings for maintenance and protective applications. Some exciting improvements in performance have been searched in the last years, improving the corrosion resistance and durability of these systems to new high levels while pushing VOC levels down to 100 g/L and below. Several groups have reported on the use of functional monomers to improve both the adhesion and corrosion resistance of acrylic latex coatings on metals. Adhesion and corrosion resistance are intimately related, so improving adhesion it will often affect positively the protective qualities of a film. Optimizing the polymerization process has allowed the most effective use of the functional monomers, which is important because these specialty monomers are often more costly than the bulk monomers.

This work launches new waterborne acrylics DTM paint with excellent corrosion protection properties. The evaluation of anticorrosion properties was performed by following ISO12944-6 [10] standard with results of 1440h in neutral salt spray test (ISO 7253)[18], 720h in water condensation test (ISO 6270)[28] and 3000 h of water immersion (ISO 2812-2)[22], 4200h in cyclic test (salt spray, UVB and freeze) (ISO 20340)[34] and following ISO 16773[33] for characterization of corrosion behavior with electrochemical impedance spectroscopy technique.

The results showed that just one layer of the proposed ecological waterborne acrylics DTM paint performs as a recommend paint system to be applied on steel substrate with high durability for C4, C5-M and C5-I equivalent atmospheric corrosivity categories (ISO 12944-2)[21] what indicates that it can substitute a classical epoxy primer and a PU top coating with lower thickness and only 50 g/L VOC.

Introduction

Waterborne acrylic latex coatings are a broad category that encompasses a wide variety of applications and performance requirements. The first acrylic latex house paint was developed 60 years ago in 1953 [2]. Since then, acrylics have captured a dominant position in the architectural coatings market, where they offer benefits such as excellent gloss and color retention and multi-substrate adhesion in exterior coatings, and good scrub and stain blocking resistance and DIY application properties in interior coatings. Some may be surprised that waterborne acrylics have been utilized in industrial maintenance painting for nearly as long, with coatings for metal and concrete substrates being first developed in the early 1960s [1-2]. During the 1970s, innovations in the polymers and other formulation additives (e.g.,anti-corrosive pigments) and a better understanding of how waterborne acrylic coatings can be best formulated to prevent corrosion, led to their continued improvement [3]. Greater industry acceptance of waterborne acrylics occurred in the 1980s due to the introduction of new products with improved corrosion resistance, as well as the introduction of acrylic direct-to-metal finishes, or DTMs, which were utilized as self-priming finish coats[4]. Much of the growth in waterborne acrylics has been at the expense of another one-component maintenance coating type, solvent-borne alkyds, and has been based on the acrylics' better environmental, health, and safety profile. Today, acrylics are heavily used in protective coatings for concrete and steel structures, typically in environments that would be considered light- to medium-duty service. They comprise approximately 15-20% by volume of industrial maintenance coatings in the U.S. [5] and are used in a variety or other industrial applications such as general industrial finishing of metal, wood and plastic substrates, traffic paints, and roof coatings [6].

Coating manufacturers and their raw material suppliers often have the hard job of providing coating technologies that offer multiple performance properties which may seem to be difficult to accomplish in a single coating. Attaining these contrasting properties can be even more complicated in a one-component thermoplastic waterborne coating such as an acrylic latex, where dense crosslinking is not available to build in properties such as chemical resistance or durability. New studies with acrylic polymers and derivations such acrylate vinylidene chloride [7] demonstrate excellent salt spray until 800hrs but after this ageing time the DTM system loss adhesion and it is very important to keep the metal integrity. The dichotomy between lower volatile organic compound (VOC) content and good hardness properties is another example which is actively being pursued in both the architectural and industrial coating markets, and is a particularly challenging target for waterborne acrylic latex polymers [8].

For heavy duty protection in aggressive environments like industrial and marine coating systems, primers rich in zinc, epoxy primer as intermediary coat and polyurethanes to finish as top coating is the best technology yet in using recommended for heavy duty application [1,9]. Environmental-friendly coatings were tested like waterborne epoxy paint, high solids and other systems with goods results for C4 and C5-M [9].

So, this work aims to study new waterborne acrylics DTM paint with excellent corrosion protection properties, evaluating the anticorrosion properties by following ISO12944-6 [10] standard with tests in salt spray chamber, water condensation and water immersion tests, cyclic tests and electrochemical impedance spectroscopy technique.

2 –Experimental

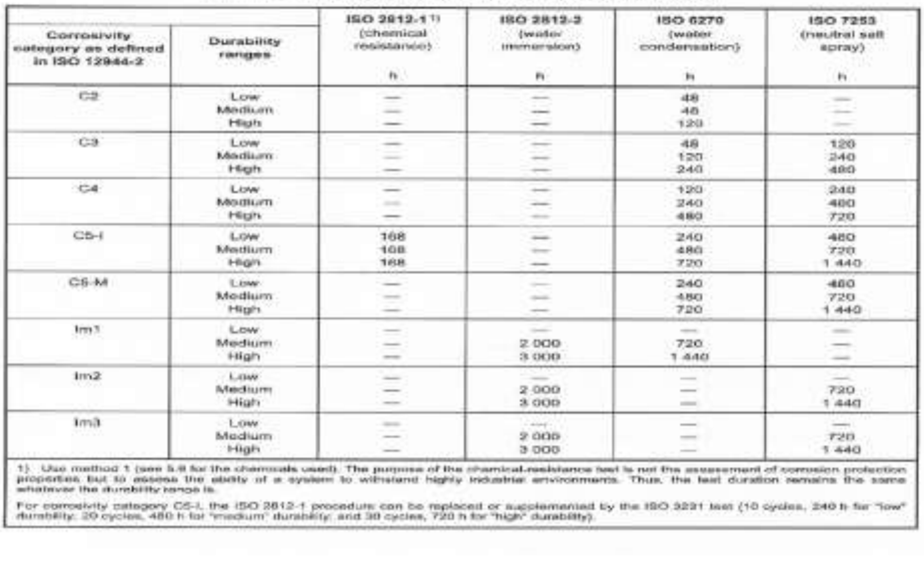
2.1- Materials

A Waterborne Acrylics DTM (Direct to Metal) paint system developed by Industria Eletrica Marangoni Maretti in Brazil was tested. The paint was applied onto the panel by spraying. Each coat shall be homogeneous in thickness and appearance and free from runs, sags, misses, pinholes, wrinkling, gloss variations, cissing particle inclusions, dry overspray and blisters. The dry film thickness was around200µm, measured in accordance with ISO 2808 [16] and shall not exceed 20 % of the specified value. The dry system condition for the coated test panels was four weeks in standard atmosphere (23±2) °C/(50 ± 5) % relative humidity or (20±2) °C/(65 **±** 5) % relative humidity, as defined in ISO 554 [17]**,** before ageing testing. The panels were cutted in the dimensions of 150 mm x 70 mm for UV test following ASTM G154 [11] and for other tests in the dimensions of 150mm x 100 mm. Their surface was prepared by blast-cleaning grade SA 2 ½ as defined in ISO 8501-1[11]. Three panels for each test condition were used.

2.2 - Laboratory performance test methods

The International Standard Collection — ISO 12944 — is intended to give information in the form of a series of 8 parts. It is written for those who have some technical knowledge. It is also assumed that the user of ISO 12944 is familiar with other relevant International Standards, in particular those dealing with surface preparation, as weIl as relevant national regulations. The part ISO 12944-6[10] specifies Laboratory test methods and test conditions for the assessment of paint systems for the corrosion protection of steel structures. The test results are to be considered as a help in the selection of suitable paint systems and not as exact information for determining durability. Certain tests in ISO 12944-6[10] are not applicable to many water-borne paint systems. Nevertheless, some water-borne paint systems are amenable to testing and evaluation using the procedures described herein, and their results could be taken into account. For this project the aim is characterizing this waterborne acrylics DTM (direct to metal) paint for corrosivity category C4, C5-I and C5-M and durability range "HIGH" as defined in ISO 12944-2 [21]. The tests and test durations given in Table 1 are intended for paint systems applied on steel substrates. For paint systems intended for corrosivity category C5—I the ISO 2812-1[20] procedure can be replaced or supplemented by the ISO 3231[29] test using the test duration, 240 h (10 cycles) for LOW durability, 480 h (20 cycles) for "medium" durability and 720 h (30 cycles) for "high" durability.

Table 1 ISO 12944-6 [10]– Test procedures for paint systems applied to steel



Corrosivity category as defined in ISO 12944-2	Durability ranges	ISO 2812-1 1) (chemical resistance) h	ISO 2812-2 (water immersion) h	ISO 6270 (water condensation) h	ISO 7253 (neutral salt spray) h
C2	Low	—	—	48	—
	Medium	—	—	48	—
	High	—	—	120	—
C3	Low	—	—	48	120
	Medium	—	—	120	240
	High	—	—	240	480
C4	Low	—	—	120	240
	Medium	—	—	240	480
	High	—	—	480	720
C5-I	Low	168	—	240	480
	Medium	168	—	480	720
	High	168	—	720	1 440
C5-M	Low	—	—	240	480
	Medium	—	—	480	720
	High	—	—	720	1 440
Im1	Low	—	—	—	—
	Medium	—	2 000	720	—
	High	—	3 000	1 440	—
Im2	Low	—	—	—	—
	Medium	—	2 000	—	720
	High	—	3 000	—	1 440
Im3	Low	—	—	—	—
	Medium	—	2 000	—	720
	High	—	3 000	—	1 440

1) Use method 1 (see 5.8 for the chemicals used). The purpose of the chemical-resistance test is not the assessment of corrosion protection properties but to assess the ability of a system to withstand highly industrial environments. Thus, the test duration remains the same whatever the durability range is.

For corrosivity category C5-I, the ISO 2812-1 procedure can be replaced or supplemented by the ISO 3231 test (10 cycles, 240 h for "low" durability; 20 cycles, 480 h for "medium" durability; and 30 cycles, 720 h for "high" durability).

2.2.1 Assessment before artificial ageing testing for the specified time

Before panels are put under the ageing or accelerated corrosion tests**,** the paint was characterized by its adhesion to the substrate. Before ageing testing, only adhesion classification obtained in accordance with ISO 16276-2 [32] X-cut testing **X_1Y_1 minimum is accepted**, although the thickness recommendation is to be greater than 250µm, X-Cut was used because it is more adequate for 200µm thickness.

2.2.2 Assessment after artificial ageing testing for the specified time

For assessment of defects on panels after artificial ageing, the standards collection ISO 4628 was used. ISO 4628 defines a system for designating the quantity and size of defects and the intensity of changes in appearance of coatings and outlines the general principles of the system used throughout ISO 4628. This system is intended to be used, in particular, for defects caused by ageing and weathering, and for uniform changes such as color changes, for example, yellowing. The other parts of ISO 4628 provide pictorial standards or other means or evaluating particular types of defects. Table 2 presents the requirements for evaluation tests after artificial ageing.

Table 2 – Assessment after artificial ageing, standards and requirements

Test	Assessment time	Standard	Requirements
Adhesion X-Cut	24 hours after ageing testing	ISO 16276-2[32]	X_1Y_1 minimum
Blistering	immediate assessment	ISO 4628-2 [24]	0 (S0)
Rusting	immediate assessment	ISO 4628-3 [25]	Ri 0
Cracking	immediate assessment	ISO 4628-4 [26]	0 (S0)
Flaking	immediate assessment	ISO 4628-5 [27]	0 (S0)
Rusting around scribe	immediate assessment	ISO 4628-8 [19]	1 mm maximum

Obs.: Any defect occurring within 1 cm from the edges of panels shall not be taken into account.

2.3 – Electrochemical Impedance Spectroscopy- EIS evaluation of paint performance ISO 16773 [33]

Electrochemical impedance spectroscopy measurements (EIS) were employed to evaluate the corrosion protection performance of coated samples with DTM acrylic paint in 3.5% NaCl solution. EIS measurements were performed at open circuit potential for different immersion times using a Gamry Reference 600 potentiostat/galvanostat/frequency analyser and controlled by Gamry Framework software. A frequency range from 100 kHz to 5 mHz with a sinusoidal potential amplitude perturbation of 10 mV rms was adopted.

2.4 Morphological characterization

Scanning electron microscopy (SEM) was performed on Philips XL 30 coupled with EDS (Energy Dispersive Spectroscopy) spectrometer. The coated samples after 48h of immersion in 3.5% NaCl were observed and were prepared by first depositing carbon by sputtering on samples to make them conductive and avoid image saturation. EDS analysis was performed in some particular regions.

3 – Results and discussions

3.1 – Salt Spray Measurements ISO 7253 [18]

Figure 1 presents the results obtained after 720 hours and 1440 hours. In these images one can see that the coated white panel (at left) with a scratch and at right the same area without paint (it was removed with a solvent) what make easy to calculate corrosion spread beyond the scratch. It is not possible to notice by visual inspection after 720 and 1440 hours any blistering, rusting, cracking or flaking on the coating. When calculating corrosion spread following ISO 4628-8 [25], corrosion products detected did not exceed 1 mm for both exposed times. The results show that the coating is approved to C5 category.

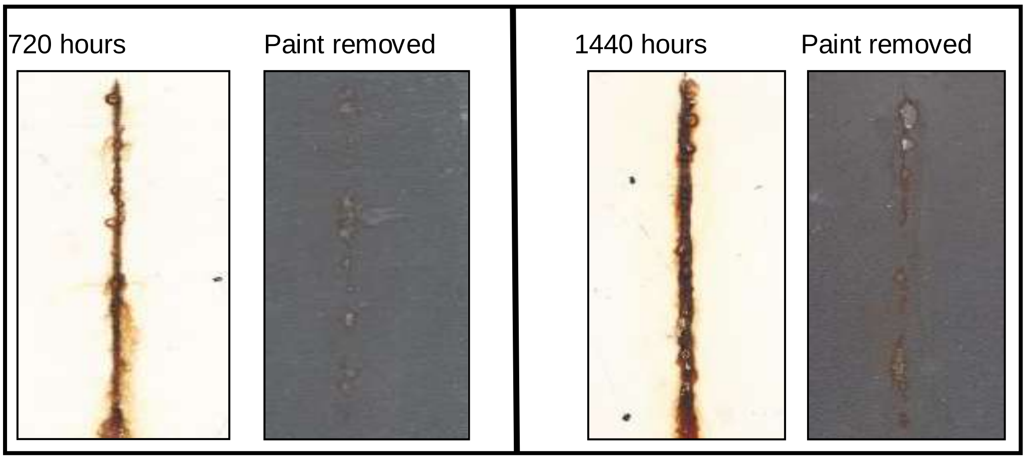


Figure 1 – Aspect of panels after 720h and 1440h of exposure in Salt Spray Chamber (coated - left and after paint removal - right)

3.2 – Water Condensation Measurements ISO 6270 [28]

Figure 2 represent the results obtained after 480 hours and 720 hours. In these images we can see the white panel (on left) and at right the same area without paint (removed). One cannot notice by visual inspection after 480 and 720 hours any blistering, rusting, cracking or flaking on the coating. The results show that the coating is approved to C5 category

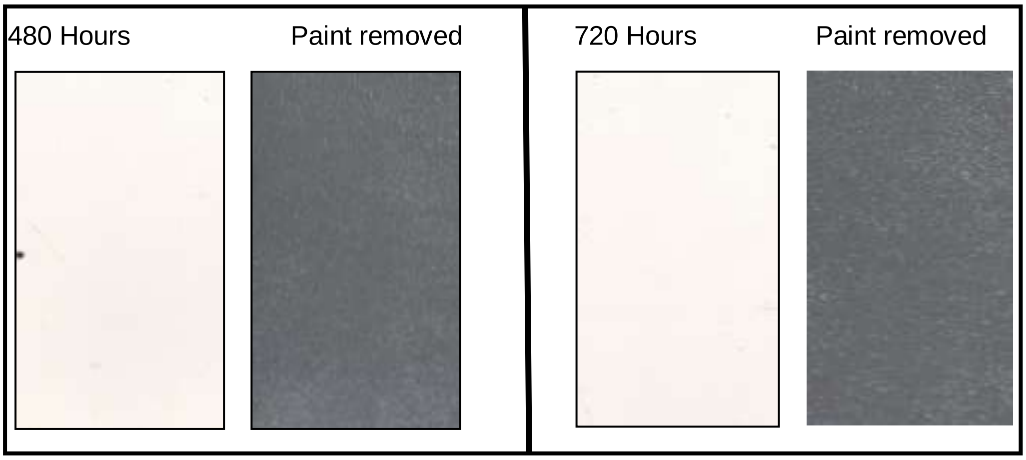


Figure 2 - Aspect of panels without a defect after 480h and 720h of exposure in Water Condensation Chamber (coated - left and after paint removal - right)

3.3 – Immersion in fresh water following ISO 2812-2[22]

Figure 3 presents the results obtained after 2000 and 3000 hours of immersion in fresh water. In these images one can see the white panel (at left) and the same area without paint (removed) at right. It is not possible to notice even after 2000 hours any blistering, rusting, cracking or flaking on the coating. Some blistering (small size) after 3000 hours can be seen. This test is very important to test metal structures immersed in lakes and rivers. The results show that the coating is approved to C5-M category

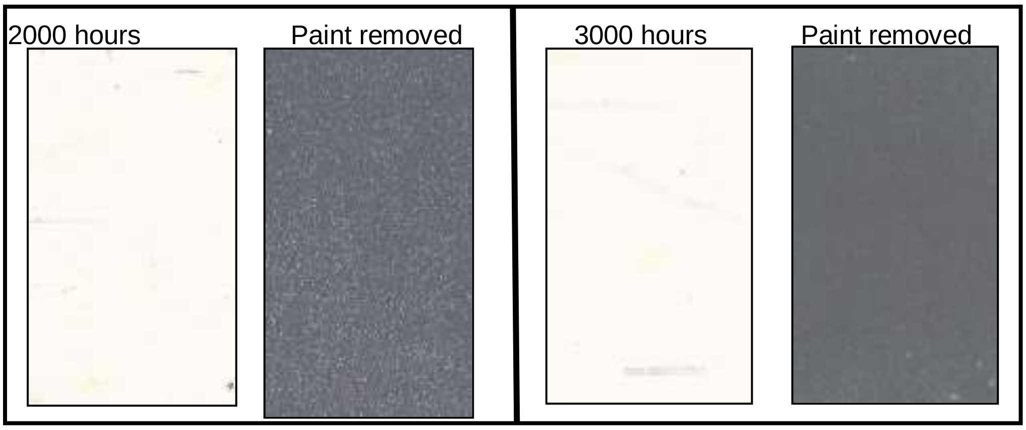


Figure 3 - Aspect of panels after 2000h and 3000h of immersion in fresh water (coated - left and after paint removal - right)

3.4 – Immersion in sea or brackish water according to ISO 2812-2 [22]

Figure 4 presents the results obtained after 2000 and 3000 hours of immersion in brackish water. In these images the white panel (at left) and the same area without paint (removed), any blistering, rusting, cracking or flaking of the coating can be observed after 2000h. After 3000 hours some blistering (medium size) appears but no corrosion products can be seen on coating. This test is very important for testing metals of structures immersed in sea like offshore plants. The results show that the coating is approved to C5-M category.

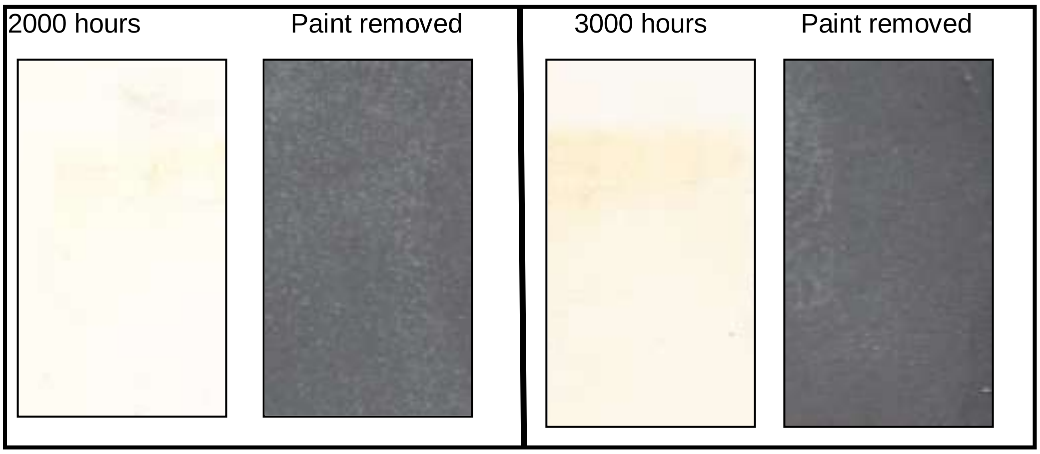


Figure 4 - Aspect of panels after 2000h and 3000h of immersion in brackish water (coated - left and after paint removal - right)

3.5 – Immersion to assess chemical resistance following ISO 2812-1[20]

Chemical stress tests for C5-I category employing *NaOH 10% (m/m) aqueous solution and H_2SO_4 10% (m/m) aqueous solution were performed on coated panels.*

Figure 5 presents the results of chemical stress tests in both solutions, alkaline and acidic, after 168 hours of immersion. In these images the white panel (at left) and the same area without paint (removed). By visual inspection after 168 hours, any blistering, rusting, cracking or flaking is observed. These tests are important to test metals for structures that will be in contact with chemical agents. The results show that the coating is approved to C5-I category.

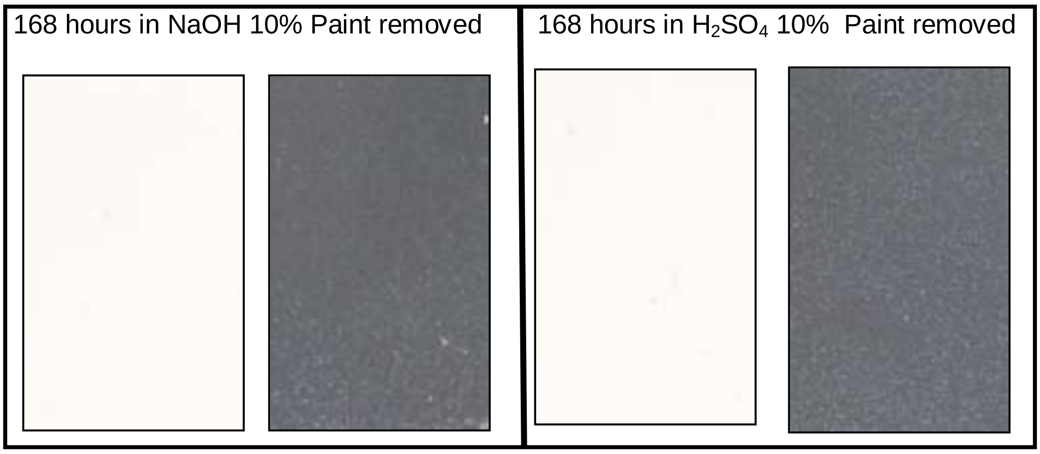


Figure 5 - Aspect of panels after 168h immersed in NaOH 10% and 168h immersed in H_2SO_4 10% (coated - left and after paint removal - right)

3.6 – Chemical Stress in atmosphere containing sulfur dioxide ISO 3231[35]

Chemical stress test for C5-I category exposing coated panels in an atmosphere containing 17067 ppm of SO_2 was performed.

Figure 6 presents the results of exposure in an atmosphere containing 2L of sulfur dioxide in a total volume of 300L, after 240, 480 and 720 hours. In these images we can see the white panel (at left) and at the right the same area without paint (removed). It is not possible to see after 240 hours of exposure any blistering, rusting, cracking or flaking on the coating. After 480 and 720 hours one can see corrosion products (brown color). Sulfur compounds were detected by EDS in the carbon steel surface. These tests are important because represents polluted areas like in big cities and industrial complexes and have confirmed the good performance of the coating deserving C5-I category.

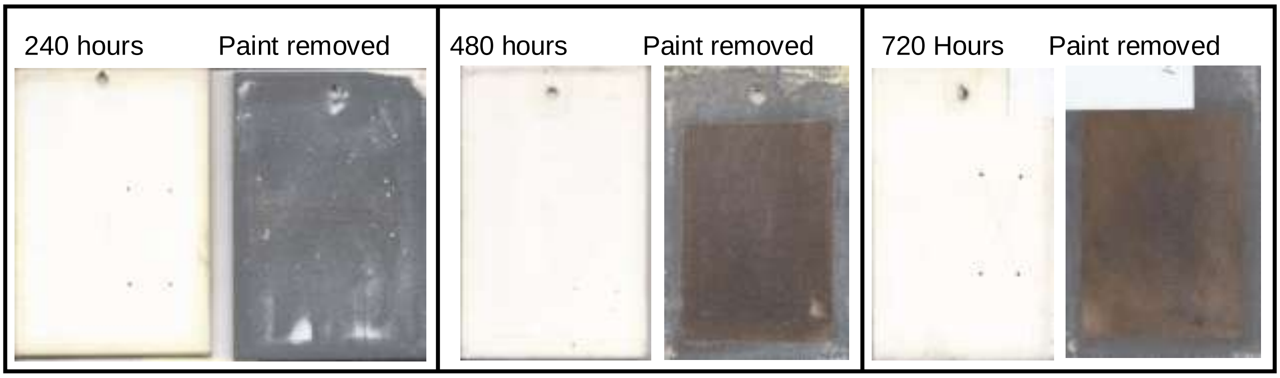


Figure 6 - Aspect of panels after 240, 480 and 720 hours exposed in atmosphere with 17067 ppm of sulfur dioxide (coated - left and after paint removal - right)

3.7 – Additional performance tests – UV Radiation Stress ASTM D 4587-11 [31]

It was considered necessary to assess the ability of the paint system to provide corrosion protection been challenged by a cyclic test using ultraviolet (UV) radiation and condensation. The cyclic test was performed following ASTM D 4587-11 [31] (8 hours UVA Radiation at 60°C and 4 hours in condensation at 50°C for industrial coatings). Figure 7 presents the results after 500, 1000 and 1500 hours of exposure. The white panel (at left) and the same area with paint removed in the right. In all the cases, one can notice gloss loss, but the paint film didn´t present chalking and kept excellent adherence. No blistering, rusting and flaking were detected. Despite this test isn't categorized as an assessment method for corrosion performance in ISO-12944-6 [10] the results showed a coating film with good integrity because chalking wasn't detected.

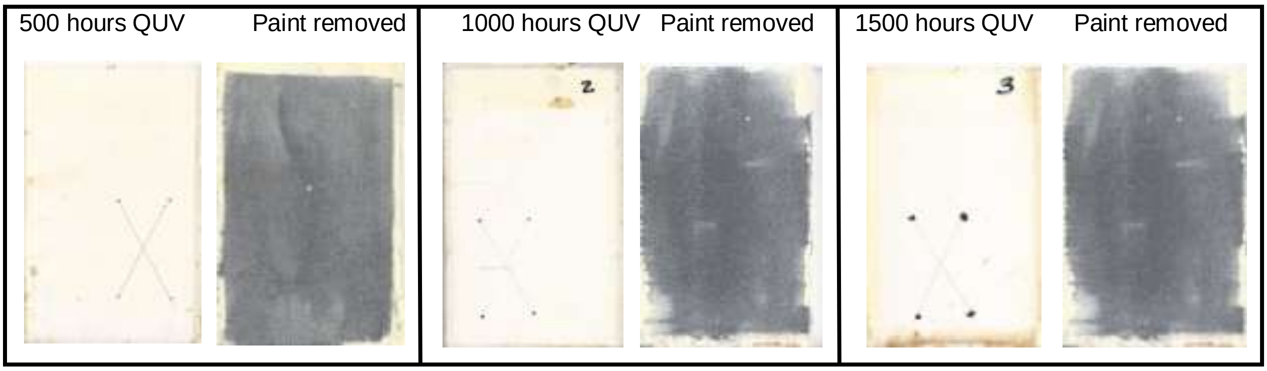

500 hours QUV Paint removed 1000 hours QUV Paint removed 1500 hours QUV Paint removed

Figure 7 – Aspect of panels after 500, 1000 and 1500 hours exposed in UV Radiation cyclic test (coated - left and after paint removal - right)

3.8 – Additional performance tests – Severe Corrosion Stresses ISO 20340[34]

DTM Acrylic paint was tested for severe corrosion stresses normally performed for paints that will be applied on offshore structures. It is known that for these conditions the paint system needs to use cathodic primers as zinc rich primers and the NDFT (nominal dry film thickness) must be larger than 280µm. The question is "What's happening with a DTM Acrylic paint with 200µm in severe corrosion stresses condition? To answer this question the standard ISO-20340[34] was followed. The exposure to cyclic test lasted for a full week (168h) and included 72 hours in Salt Spray, 72 hours in UV/condensation (UVA 4h 60°C/4h condensation 50°C) and 24 hours of exposure in low temperature of -20°C. After been exposed for 25 cycles or 4200h the test panels show that the protection of edges was not enough to resist all cycles, so corrosion was detected in this areas. We can see some medium blistering near the edges. Analyzing the panels after paint been removed, the corrosion attack near the scratch was minor and in the rest of the panel surface, except in edges areas, the protection was good and pull off adhesion test after 4200h showed good results above the tolerance of 5 MPa.

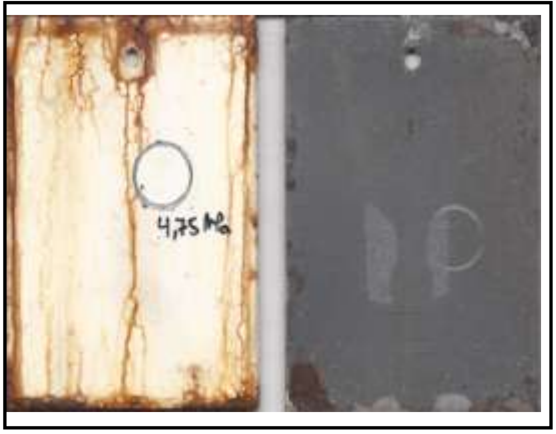
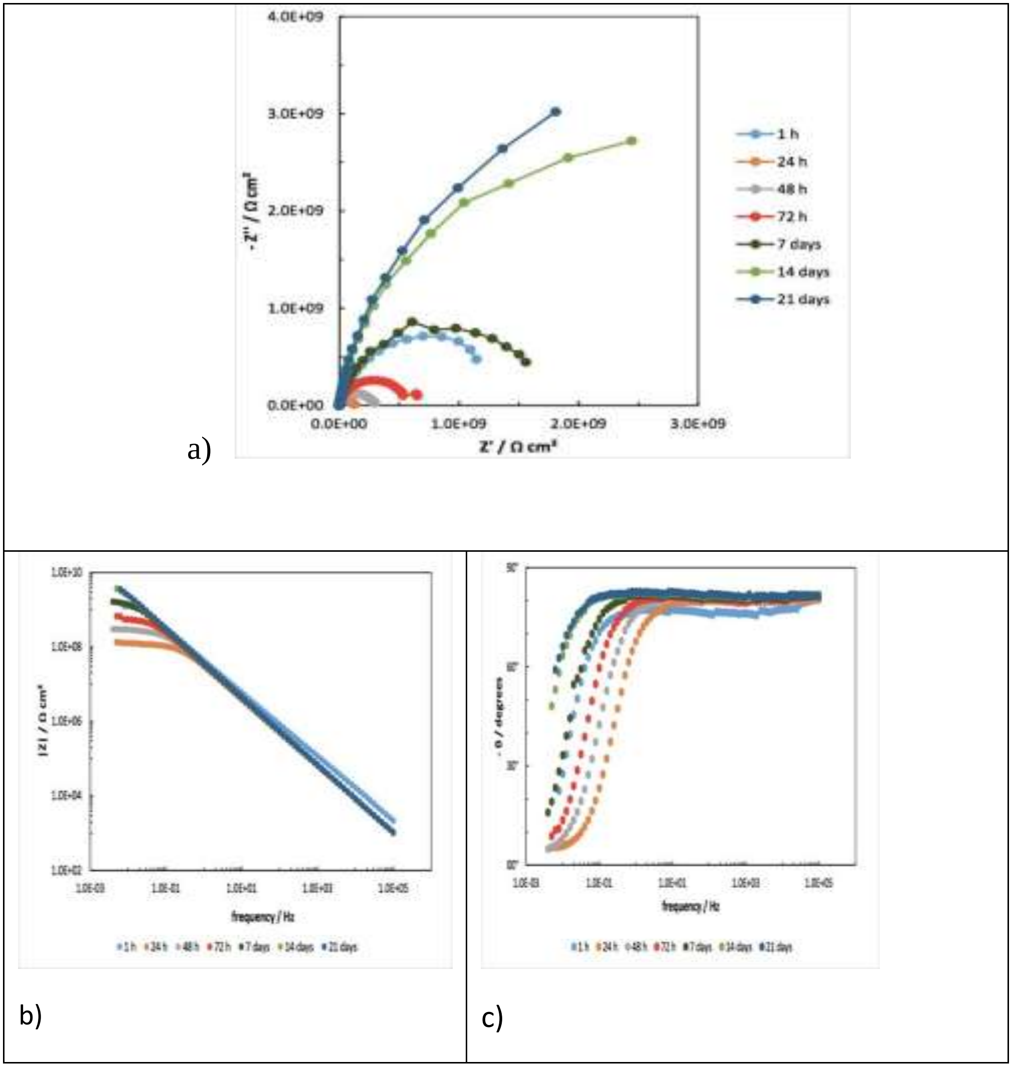


Figure 8 – Aspect of panels after 4200h exposed in cyclic test following ISO 20340 (coated - left and after paint removal - right)

3.9 – Electrochemical Impedance Spectroscopy- EIS evaluation of paint performance following ISO 16773 [33]

Figure 9 shows the EIS data for coated samples for increasing immersion time in the electrolyte. The Nyquist diagrams (Figure 9a) show that after 24h of immersion in the electrolyte there was a remarkable decrease in coating impedance modulus, due probably to establishment of preferential paths for water and ions in some local defects due to the presence of “so called” corrosion inhibitor particles, maybe those presented in Figure 10 a. After 48h of immersion the impedance modulus has increased again by the blocking effect of corrosion products and the impedance has increased progressively for longer immersion times, denoting that the paint is becoming more resistant, and this must be attributed to the occurrence of self-reticulation reactions in the polymeric matrix. EIS data is of very good quality without noise or fluctuations even at low frequencies. After 21 days of immersion one of the samples were withdrawn from the electrolyte and by visual inspection and by the optical microscope images no corrosion or blistering is observed following ISO 4628-2 [24] standard the grade is 0 S(0).



a)

b)

c)

Figure 9 – Nyquist (a) and Bode (b) and (c) diagrams for coated samples with acrylic DTM paint after different immersion times in 3.5% NaCl solution.

3.10 Optical microscope images

Figure 10 presents the aspect of coated sample before and after immersion in the electrolyte.

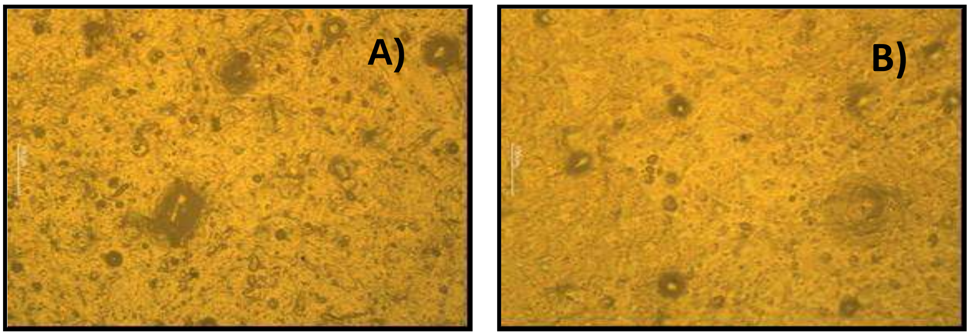


Figure 10 – Image of surface morphology obtained by optical microscope of panels coated with acrylic DTM coating – (A) panel without exposition (B) panel after 25 days immersed in 3.5% m/m NaCl.

The surface before immersion presents some particles embedded in the paint and after immersion part of the particles seem to have been dissolved. The presence of Fe in the spectra around these particles (see Figure 11 and Figure 12 for regions 1 and 5) indicates attack to the carbon steel substrate that was blocked by the presence of corrosion compounds. There is no evidence of attack to the substrate after 25 days of immersion in 3.5% m/m NaCl.

3.11 SEM- scanning electron microscopy of the coated sample surface

In order to understand what was happening with the coating that first decreased the impedance and after 48h of immersion in the electrolyte the impedance started increasing, the sample immersed for 48 h was cutted in 15mmX15mm dimensions and the images obtained are presented in Figure 11. A particle appears that by composition seen in Figure 12 is probably a phosphate of zinc, aluminum, calcium and silicon commercially known as a corrosion inhibitor.

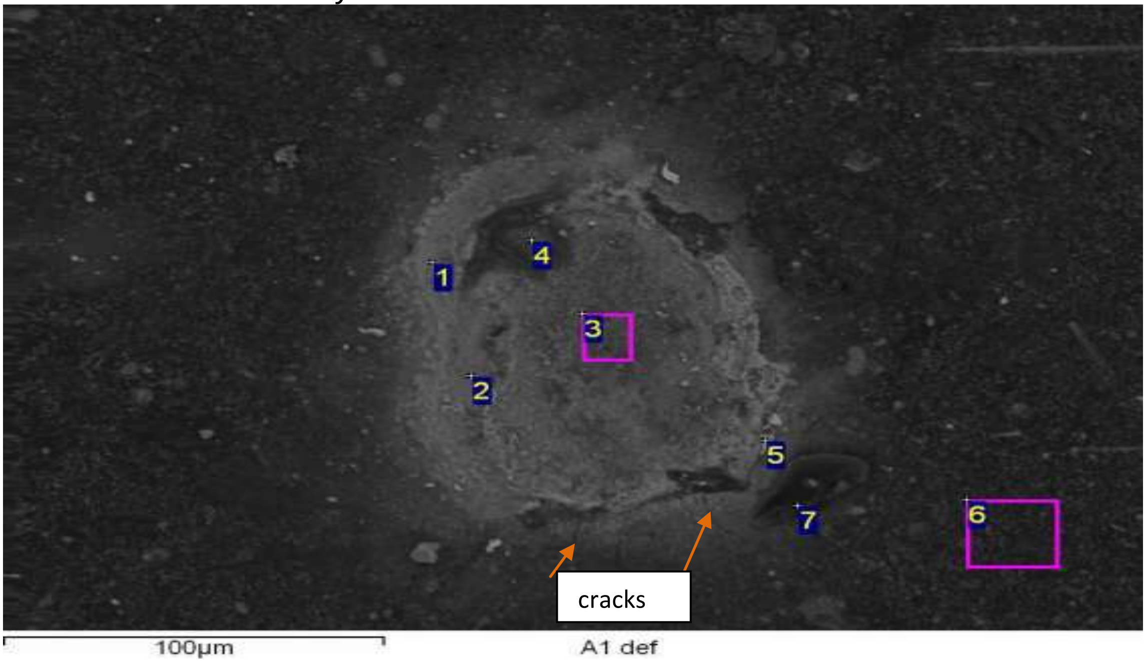
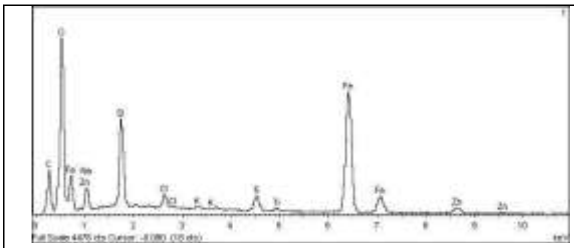
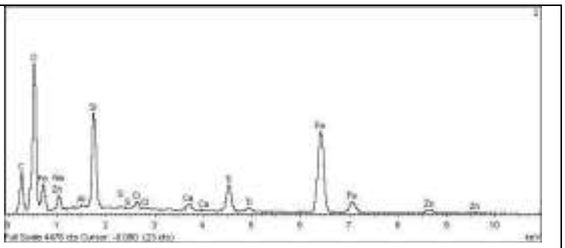


Figure 11 – SEM micrograph obtained from back scattered electrons of the coated sample surface after 48h of immersion in 3.5% NaCl solution.

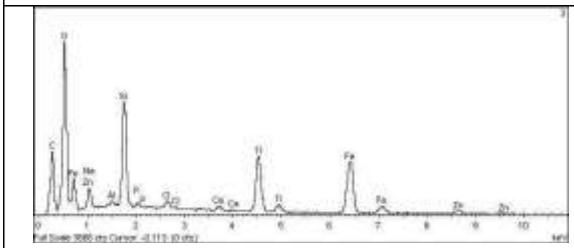
Seven regions indicated by numbers in the micrograph in Figure 11 were analyzed by EDS and the spectra are presented in Figure 12.



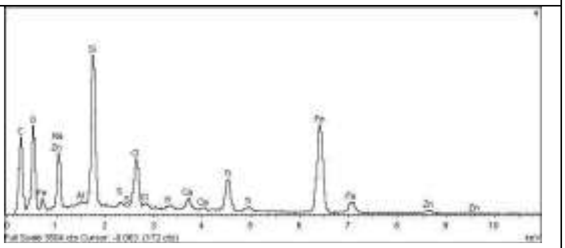
EDS spectrum from region 1 of Figure 11



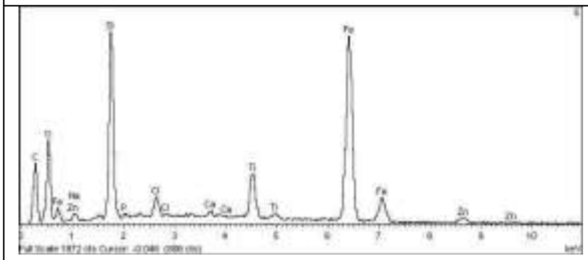
EDS spectrum from region 2 of Figure 11



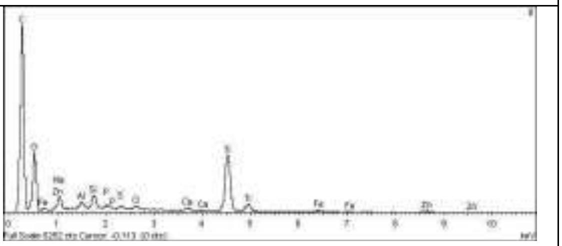
EDS spectrum from region 3 of Figure 11



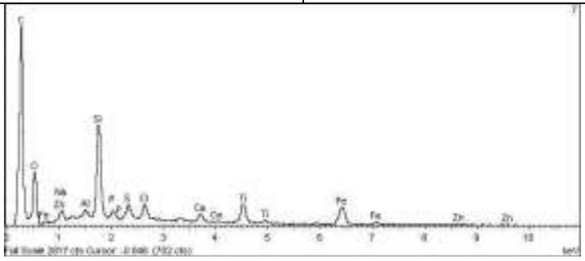
EDS spectrum from region 4 of Figure 11



EDS spectrum from region 5 of Figure 11



EDS spectrum from region 6 of Figure 11



EDS spectrum of region 7 of Figure 11

Figure 12 – EDS spectra from different regions marked b in Figure 11.

In the regions 1 and 5, in the border of the big particle (around 100µm) the peak of Fe is high and indicates that the particle provoked some cracks in the coating around the particle and this created paths to the substrate.

3.12 Tests after accelerated or cycling tests

The results of some adhesion, blistering, cracking and flaking tests after accelerated tests are presented in Table 3

Table 3 – Performed Tests Results

Assessment TESTS	ISO 16276 Adhesion before	ISO 16276 Adhesion after	ISO 4628-2 Blistering	ISO 4628-3 Rusting	ISO 4628-4 Cracking	ISO 4628-5 Flaking	ISO 4628-8 Rusting around scribe	ASTM D523 Gloss Meter
Tolerances ISO-12944-6	Min X_1Y_1	Min X_1Y_1	0(S0)	Ri 0	0(S0)	0(S0)	Max 1mm	
ISO-7253 - 720h Salt Spray	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	0,5mm	
ISO-7253 1440h Salt Spray	X_0Y_0	X_0Y_1	0(S0)	Ri 0	0(S0)	0(S0)	0,75mm	
ISO-6270 - 480h Water Condensation	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	
ISO-6270 - 480h Water Condensation	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	
ISO-2812-2 2000h Fresh Water Immersion	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	
ISO-2812-2 3000h Fresh Water Immersion		X_0Y_0	2(S2)	Ri 0	0(S0)	0(S0)	NA	
ISO-2812-2 2000h Sea Water Immersion	X_0Y_0	X_0Y_0	2(S2)	Ri 0	0(S0)	0(S0)	NA	
ISO-2812-2 3000h Sea Water Immersion		X_0Y_0	2(S4)	Ri 0	0(S0)	0(S0)	NA	
ISO-3231 240h SO2 2L	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	0 mm	
ISO-3231 480h SO2 2L	X_0Y_0	X_0Y_0	0(S0)	Ri 5	0(S0)	0(S0)	0 mm	
ISO-3231 720h SO2	X_0Y_0	X_0Y_0	0(S0)	Ri 5	0(S0)	0(S0)	0 mm	
ISO-2812-1 168h H_2SO_4 10% Immersion	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	
ISO-2812-1 168h NaOH 10% Immersion	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	
ASTM D4587-11 500h UV/Cond Test	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	30i/5f
ASTM D4587-11 1000h UV/Cond Test	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	30i/5f
ASTM D4587-11 1500h UV/Cond Test	X_0Y_0	X_0Y_0	0(S0)	Ri 0	0(S0)	0(S0)	NA	30i/5f
ISO20340 4200h Cyclic test		X_0Y_1	2 (S4)	Ri 2	0(S0)	0(S0)	0,25 mm	

The results in Table 3 indicate that the paint is very resistant and can be specified for environment of C4 and C5 aggressiveness categories.

4. Conclusions

The salt spray, humidity chamber and immersions test results approve this DTM Acrylic Coating for C4 (high), C5-M very high marine and C5-I very high industrial following ISO-12944-6. In SO_2 test ISO 3231 standard it is not approved in 480h and 720h.
Offshore cyclic test by ISO 20340 demonstrate a very good metal protection. In electrochemical impedance spectroscopy technique (EIS) the impedance decreased after 24h of immersion but after 48h it has increased progressively for longer immersion times, denoting that the paint is becoming more resistant and this is a prove that the self-crosslinking proprieties works in the film formation system.
The results point out that this paint can substitute a classical epoxy primer and a PU top coating with lower thickness and only 50 g/L VOC.

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