

# Weathering in Coating Systems-A Bibliographic Study of Causative Agents, Tests and Performance

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**Abstract**-The present paper aims to carry out a bibliographic study to determine the main weathering factors and how they degrade coating systems, the most common tests applied, as well as the parameters evaluated and the performance of the coatings usually found in the Brazilian market.

The main factors of weathering found were solar radiation, humidity and temperature, each one causing degradation of the coating in different ways. To verify these damages, natural or laboratory exposure tests can be done, evaluating the parameters of interest. The combination of the two types of tests is recommended to estimate the durability of the coating. Regarding the performance of the coatings, it was possible to observe that ones with resins and epoxy primers have low resistance to UV radiation and good performance in high humidity situations. In most of the tests, paints with polyurethane resins presented high performance when exposed to UV radiation, except for epoxy polyurethane ones. It has also been observed that the possible addition of some components such as primers may be beneficial to improve the performance of the coatings in weathering conditions.

**Keywords**-*Natural Weathering, Accelerated Weathering, Coatings*

## I. INTRODUCTION

Coatings are a set of components applied to a certain surface in order to provide aesthetic and especially resistance and protection of the surface from the most varied aggressive situations. In order to reach this target, paints have been developed over the years and its composition is currently based on resins, pigments, additives and solvents [14].

A material or product may present adverse weathering responses and may present undesired and premature faults [33]. "It is the set of processes conditioned by the action of atmospheric and biological agents that cause physical destruction and chemical decomposition of materials" [18].

The three main factors of weathering are: solar radiation, temperature and humidity. They behave along with side effects,

such as pollutants in the air, biological phenomena and acid rain [33].

The degradation process caused by weathering occurs in two stages: first, the coating surface is deteriorated and swellings, cyclic shrinkage derived from retention and subsequent evaporation of water can be identified in it. Then, the surface begins to deteriorate and the substrates may suffer several consequences, such as rust on metal surfaces, rotting, cracking and warping on wood surfaces and cracks in masonry surfaces [22], [15].

The present paper aims to carry out a literature review on studies related to weathering factors and how they cause pathologies in paint coatings. It also discusses the most commonly performed tests for their verification, as well as the parameters evaluated and the performance of the paints usually found in the market.

It was verified that there are few works explaining the concepts regarding the performance of paints against weathering. In Brazil, for example, there are no specific standards for such an important control, directly related to the durability of the coating and therefore corrosion of the structure. Usually comparative studies between certain types of paints or between different exposure tests are found. Thus, the study presented on this paper expects to provide conceptual basis for further studies that address this property.

## II. METHODOLOGY

A paper review was carried out in different bibliographical references to understand the performance evaluation of paints when exposed to weathering. The results obtained were listed as follows:

### A. *Main weathering agents*

In this topic, the main causative agents of weathering were studied as well as the way they contribute to the degradation of coatings.

### B. Types of tests

The two different kinds of tests (natural and accelerated), their advantages, disadvantages, exposure conditions and parameters evaluated, as well as ASTM and ISO standards that help in this evaluation were explained.

### C. Performance of paints

The performance of some of the main paints found on the market, used to cover and protect metallic surfaces exposed to UV radiation and other forms of weathering, was evaluated based on experimental comparative studies carried out by other authors.

## III. REVIEW AND DISCUSSIONS

### A. Weathering agents

Durability can be defined as the ability of a painting to withstand degradation when exposed to adverse external conditions.

The degradation process includes changes in properties and aesthetic characteristics, such as loss of mechanical properties, chemical resistance, adhesion, reduction of gloss, discoloration, calcination, cracking, water spots, etc. [35].

The durability of a coating exposed to solar radiation is influenced by several factors, such as: the distribution of spectral radiation from sunlight associated with environmental conditions (e.g. temperature); the sensitivity of the material to this type of radiation; and the efficiency of photo stabilizers present in the composition of the materials, when exposed to radiation [1,2].

The main source of ultraviolet radiation to which organic materials are exposed is the sun. The composition of the solar radiation that reaches the earth's surface consists mainly of radiation in the wavelength range of visible, infrared and a small amount in the ultraviolet range. Although the sun emits radiation over a wide range of wavelengths, the one responsible for the degradative processes of organic coatings is between 280 and 400 nm [18].

The processes of photo degradation cause total or partial ruptures of the polymer chains and, as a consequence, the decrease of the polymerization degree and loss of properties [33]. Ranby and Rabick [34] showed a relationship between wavelength and the dissociation energy of different molecules, proving that the UV radiation at Earth's surface is sufficiently rich in energy to break the covalent bonds found in polymers. Only the absorbed light is capable of starting photochemical degradation processes.

Wicks, Jones and Pappas [40] presented several concepts on the initiation of photo-oxidation of polymers, explaining in stages the proposed mechanism for the process, as presented below.

During photo-oxidation initiation, the absorption of UV light by the polymer or another coating component occurs, producing a highly energetic excited state, which can result in the hemolytic cleavage of bonds, generating free radicals. In

the propagation stage, the formed free radicals react with O<sub>2</sub>, mainly to start the degradation of the polymer, creating hydro peroxides and peroxides. The products formed are unstable species in the photo-oxidation process, which, by the action of sunlight and moderate heating, dissociate, producing alkoxy and hydroxy radicals, thus rendering autocatalytic degradation reactions. These radicals are highly reactive during the abstraction of hydrogen with formation of polymeric radicals, continuing the polymer degradation [40].

The hydrogen atom abstracted from the macromolecule is not the one at the end of the chain, but any hydrogen atom present in it. The chain's susceptibility to hydrogen abstraction is based on the existing carbon-hydrogen bond type. Hydrogen atoms attached to tertiary carbons are more susceptible to abstraction than atoms attached to secondary and primary carbons. So, it is evident that the hydrogen abstraction from carbon atoms in the middle of the chain is easier than at the ends [34].

During the propagation process, the photo-oxidation of aldehydes and ketones can occur forming peracids, which are strong oxidizing organic agents, contributing to the autocatalysis of the degradation process [40].

As can be seen, radiation incident on earth's surface can affect chemical bonds, thereby inducing photodegradation processes, which cause the aging of such materials. Depending on the chemical bonds present in the polymer, each type of resin will have a specific behavior [18].

Even with all precautions concerning photodegradation, coating systems are still vulnerable to other external agents. Infiltration, for example, is an important factor of deterioration in coatings.

Water causes damage to materials by physical and chemical processes. The absorption of water into a material, from air humidity or surfaces, produces an expansion of its volume, causing stresses within it [29].

Water molecules, due to their relatively small size, can penetrate cracks, slits, holes and microscopic cracks inherent to any coating system. Water infiltrates the paint, filling the voids left by solvents and other materials that evaporate during application and cure. In addition, due to the slight polarity of the water molecule, it can be absorbed by the paint in the presence of polar solvents, polar groups or polar materials retained in the dry film. Thus, the presence of ester groups, ether linkages, carboxyl groups and other polar groups in the resin can contribute to the water's absorption by the paint. Finally, deposits of rust, dirt, salts and other contaminants remaining on a surface can prevent the paint from adhering and establish osmotic driving forces that further promote water infiltration [30].

The water molecule has the ability to penetrate between the molecular chains that make up the organic resin and the interstice between resin and pigment where the pigment was not completely encased by the resin. As it penetrates, it separates the bonds that hold the bound particles, such as the polar bonds, attracting and causing the molecules to swell in the regions of covalent bonds, which are polar. This swelling

forces the bonds to separate further, decreasing their force and breaking the bond. The coating expands due to the increased presence of water. Some paint films increase its volume from 20 to 50% when in contact with water [30]. The generated expansion can separate the polar bonds and other weak forces that keep the molecules adhered to the substrate. Thus, the polar attractions, necessary to adhesion and cohesion of the paint film, no longer occur [30].

Warming the paint layer increases molecular movement, allowing faster water penetration. On the other hand, cooling reduces molecular movement and retards water permeation [30].

## B. Tests

The weathering test can be performed in laboratory in different artificial atmospheres or by field tests under natural conditions [42]. Accelerated weathering tests are performed in the laboratory with exposure of specimens in special chambers that simulate the actual conditions of exposure of the material and have the advantage of being faster than the open-air tests [18]. Although the laboratory tests provide exposure conditions similar to the real ones, they must be complemented by the exposure test to natural weathering when there is a need to establish the coatings' lifespan [36], [39], [38]. Otherwise, possibly only comparative results will be obtained [18], [24].

### 1) Exposure test to natural weathering

The advantage of this type of test is the fact that the material is exposed to all types of aggressive factors such as humidity, sunlight, rainfall, pollution, temperature fluctuation and rainfall. Therefore, it is the most reliable way to evaluate coatings [3]. It also has disadvantages such as longer exposure time required to obtain satisfactory results [36], [18], [39], [3], struggle to isolate an aggressive factor to verify the effect it causes on the durability of the material and control difficulty, which prevents the reproduction of the assay [3].

### 2) Place of test

The results of this assay will be different depending on where it is performed. Valadez-Gonzalez [38] carried out tests of natural weathering in two different environments, one rural-urban and another marine-coastal, and verified that there is a significant difference in the photodegradation process when there is variation in climatic conditions.

For the precise characterization of a material, it must be exposed to different types of climates and at different times throughout the year [25], [9]. Hence, it is recommended that the natural exposure tests are performed in several places with different climates and in periods longer than one year [9].

The test site will be chosen depending on the actual conditions that the material will be subject to. Usually the tests are performed in places with high incidence of solar radiation, such as hot desert and subtropical or tropical areas. However, in some cases, the material will be exposed to different variations such as freezing and thawing, salty air or industrial pollutants. [9].

Florida and Arizona States, in the USA, are widely used sites, recognized worldwide, to carry out exposure tests to natural weathering. Arizona has high intensity sunlight (20% more than Florida), high temperatures and low humidity. Florida has high intensity sunlight, high temperatures and high humidity [36] [39]. A year of sunshine in Florida can represent the same of several years in other places. The climate found in these states provides extreme conditions of exposure to materials, and is ideal for companies to test products that cannot fail elsewhere in the world [37].

### 3) Exposure conditions

#### a) Plate height and ground cover

Exposure stands should be located in clean areas, with the lowest height positioned at least 0,45 m above the ground, and avoiding contact with the vegetation. In most cases, the ground cover should be low grass, except in desert areas, which should be gravel [9]. To intensify the effect of ultraviolet radiation, it is possible to use a natural sunlight concentrator [36], [9].

#### b) Plates position

The orientation of the plates also influences the assay. The pole-facing surfaces, for example, are less prone to degradation than those facing the equator due to less exposure to solar radiation, but remain wet longer, which is important for the evaluation of the effects of this variable, as a vulnerability to microbial growth [25].

The test specimens shall be exposed on a single test panel or adjacent panels so that all are given the same environmental influence. For comparison purposes, it is recommended to use two control materials, with known properties, one with good and the other with poor durability [9].

#### c) Exposure Angle

Exposure tests to natural weathering can be performed applying direct exposure techniques, using different angles and application methods to simulate diverse exposure conditions [36], [3]. The exposure angle directly influences the amount of solar radiation that the test specimen will receive and should represent the actual service condition that the material will meet. [3].

Different types of exposure angles may be used varying from 0° to 90° with the horizontal surface, the most commonly angle used is 45° [9], for general testing [29] or for testing materials that do not assume a specific position when in actual operating conditions [3].

In tropical regions, exposure at a 90° angle is considerably less severe than near-horizontal exposure [25]. This angle is commonly used for exposure of many construction products, such as coating materials [29].

The horizontal angle of 5° is used to test materials that would normally be used in horizontal or near-horizontal applications [9], such as automotive coatings [29], [3].

The 0° angle is used to test three-dimensional specimens and materials that will be used in water and civil construction collectors. It is rarely used for flat samples [2].



Figure 1. Specimens aging on 45° test racks. <www.q-lab.com>

#### 4) Accelerated weathering

These tests have the advantage of providing results in a short time, since they intensify the values of the parameters used as temperature, ultraviolet radiation and humidity, providing higher levels than those observed under natural conditions [38]. The comparison of accelerated weathering results with those obtained from natural test conditions is difficult to make because there is variability in both cases and the laboratory tests generally do not reproduce all the exposure variables that the coatings are actually exposed to [24].

Beyoda [11] conducted a study to find a relationship between laboratory and outdoor weathering tests with exposure time of two years, finding a coefficient of determination equal to 0.8. He also concluded that it is possible to carry out accelerated tests lasting from three to six months. Tests that, in natural conditions, would last more than five years.

There are several reasons why many studies do not find a significant correlation between laboratory and field trials, and it is possible to highlight one that has a great impact on this variation, which is the failure to define real environmental conditions. They often take into account few environmental variables or they do not simulate each specific environment (industrial, maritime, urban, rural, etc.) [13].

Deflorian [13] compared the natural trial for 10 months in Italy to quantify the meteorological data and the simple accelerated weathering and degradation analyzes estimated by the technique of electrochemical impedance spectroscopy (EIS). The environmental parameters were measured every few seconds. As a result, it was confirmed that the accelerated UV test is not sufficient for an accurate test. Furthermore, he concluded that thermal cycling and exposure to the salt spray chamber can achieve exposures very close to the actual in low thickness samples.

There are various types of accelerated weathering tests, each one ideal for simulating a particular environmental variable. No single laboratory exposure test can be specified as a total simulation of actual use exposures [24].

There are different types of exposure tests. Simpler chambers control only temperature and humidity, and other, more complex variables such as ultraviolet radiation, airflow,

and gaseous composition can be added. The degradation process can be quickened by including wetting and drying cycles in the test, as well as temperature and pH variations, and incorporation of salts and aggressive gases [3].

#### 5) Salt Fog

The sea air is one of the largest causes of corrosion by the sea. It acts as a strong electrolyte, favoring the electrochemical corrosion of metal surfaces [17]. The salt fog test simulates the conditions found in marine atmospheres, through the continuous mist of NaCl solution at a concentration of 4 to 6% by mass, with temperature control, which should be maintained between 33° C and 37° C (92° F to 98° F) and PH of the collected solution controlled between 6.5 to 7.2, and relative humidity of 100%. [3], [7], [17].

This test can be used to compare coatings if they are similar enough, but often it cannot be used for comparative long-term behavior, since corrosion stress conditions used in tests are significantly different from those found in practice. It is generally suitable for rapid analysis of discontinuities, pores and damage in organic and inorganic coatings [26].

#### 6) Wet Chamber

This test simulates a humid climate, with no pollutants [17]. The specimens are placed in a chamber with 100% relative humidity (RH) and maintained at generally 36 to 40° C (96 to 104° F). All changes such as color ones, bubbles, loss of adhesion, softening or embrittlement should be evaluated [8]. The formation of bubbles is more critical in this case than in the salt fog test environment due to the osmosis phenomenon [17].

In the chamber, the bottom water is evaporated and there is condensation of its vapor in the samples due to a small temperature variation [8], [17]. Corrosion tests may be introduced once the condensate that flows from the samples is not recirculated [8].

#### 7) Sulfurous Anhydride (SO<sub>2</sub>)

Sulfur dioxide (SO<sub>2</sub>) gas, which is generally generated by the burning of fuels, is present in the atmosphere of large urban centers and industrial agglomerations. In contact with certain metals, it can become SO<sub>3</sub>, which can form sulfuric acid (H<sub>2</sub>SO<sub>4</sub>) in the presence of moisture. It can also favor the deterioration of the substrate by its deposition as soot on the surface that may penetrate eventual discontinuities of the coating, establishing the corrosion [17].

Distilled water (1.8 to 2.2 L) and SO<sub>2</sub> (0.2, 1.0 or 2.0 L) are added to the test chamber. A liquid 99.9% pure SO<sub>2</sub> gas should be used. The chamber temperature should remain between 37 and 43° C (98.6 to 109.4° F). The assay is performed in 24 hour cycles and continuous or alternate exposure can be made. In the continuous exposure, the samples are exposed during 24 hours and in the alternate one, there is exposure for 8 hours followed by 16 hours of drying in environmental conditions without pollution and with temperature and humidity controlled [10].

#### 8) Ultraviolet (UV)

Exposure tests to UV radiation are performed in chambers where samples are exposed to lamps that simulate sunlight and

moisture [17]. For the sunlight simulation, Xenon-arc lamps, Fluorescent UV lamps or Open-flame carbon-arc lamps [28] can be used. For each type of lamp there is a specific test. The most commonly used sources of UV radiation are Xenon-arc lamps, because they have a radiation spectrum very close to sunlight, and Fluorescent UV lamps, which allow working with UVA and UVB radiation [19].

9) *Evaluation Parameters*

In order to obtain the results of the tests of weathering can be evaluated the chemical and visual changes. These changes can be evaluated with the naked eye or by optical microscopy, scanning electron microscopy (SEM), atomic force microscopy (MFA) or infrared spectroscopy or X-ray photoelectron (XPS) [22]. A variety of standards sets standards for evaluating each type of parameter. For this article, ASTM and ISO standards were selected for the most commonly evaluated parameters. The test specimens can be exposed on a single test panel or adjacent panels so that all are given the same environmental influence.

TABLE I. ASTM AND ISO STANDARDS ASSISTING THE EVALUATION OF THE VISUAL PARAMETERS OF THE TEST BODIES SUBMITTED TO INTEMPERISM TESTS

Visual parameter	ASTM	ISO
Gloss loss [ivonei][q-lab]	D 523	
Color change and fading [ivonei][q-lab]	D 2244	
Chalking [ivonei][q-lab]	D4214	4628-6
Mold, Mildew, and Fungus [ivonei][q-lab]	D3274	
Corrosion [ivonei][q-lab]	D610 D1654	4628-3
Blistering [ivonei][q-lab]	D714	4628-2
Delamination and loss of adhesion [ivonei][q-lab]	D3359	
Cracking and checking [ivonei][q-lab]	D 660 D661	4628-4
Erosion [q-lab]	D662	
Flaking/Scaling [q-lab]	D772	4628-5
Dirt Retention [q-lab]	D3274	
Gray Scale [q-lab]	D2616	

C. *Resistance of paints to weathering*

The epoxy paints are composed of epoxy resin, resulting from the reaction between epichlorohydrin and bisphenol [14]. They are characterized by their good adhesion resulting from their higher density of cross-links between the epoxy molecules [19]. Epoxy has lower water absorption and better performance in chemical resistance, abrasion, impact and it is characterized by strong hardness. In contrast, epoxy paints exhibit low resistance to UV radiation. Its main mechanism of protection is through the formation of a solid barrier, blocking water, oxygen and other aggressive agents [23]. The epoxy resins used alone do not exhibit interesting properties as coating, making it necessary to react with another resin, such as polyamide, polyamine or isocyanate [16].

Polyamide epoxy paints are characterized by flexibility, strong adhesion and high resistive performance at high

humidity. However, they can calcine when used as an external coating, fading or losing glare through exposure to UV radiation and rain. [21], [19], [20].

The acrylic paints have resin from polymers extracted from monomers of esters of acrylic and methacrylic acids. They exhibit good resistance to UV radiation without color fading or loss of brightness. They resist chemical atmospheres of medium aggressiveness and are indicated for rural, light industrial and urban environments, for external or internal seals [14], [20].

Polyurethane paints are composed of polymers extracted through the chemical reaction of condensation of hydroxylated compounds, called polyisocyanates polyols. The polyurethane paints are available in two components, the polyhydroxylated polyester resins, and the polyhydroxylated acrylic resins as first component alternatives and the curing agent, being aliphatic or aromatic polyisocyanates. They have excellent anti corrosion properties, hardness and impact and abrasion resistance. They are widely used in environments with high aggressiveness and are suitable for use in external fences because they have resistive properties to weathering and internal in chemical environments. However, the aromatic polyurethane paints do not present high resistance to UV radiation, these being indicated for internal environments [14].

The tests of the paints in relation to the resistance to UV radiation are based on the measurement of gloss of paints [4] and the evaluation of powderiness [27]. In his studies, Fragata [18] selected the aliphatic polyurethane, aliphatic acrylic polyurethane and epoxy polyamide coating as a coating of metallic substrates. The polyurethane coatings presented satisfactory results in this test and in the pulverulence evaluation test, but the aliphatic acrylic polyurethane coating excelled over the aliphatic polyurethane coating. The epoxy polyamide coating presented low resistance to UV radiation in both tests, showing a loss of brightness and color rapidly.

Hattori [22] also conducted tests with the intention of verifying the performance of coatings on exposure to UV radiation. He analyzed the polyurethane paint and epoxy paint both allied to a primer epoxy, applied on a metallic surface. The coatings were subjected to the accelerated weathering test using the equipment Suga Tests Instruments Co., Ltd. S80, through exposure to alternating cycles of wetting and drying under UV radiation. As a result, variations in the colors of the epoxy/polyurethane coating were found over time, acquiring a faded effect. In addition, in the scanning electron microscope (SEM) it was possible to observe micro cracks originating from exposure to UV radiation. The epoxy/epoxy coating also suffered fading over time and its surface considered soft, turned into rough. Even though the two coatings analyzed presented poor performance, the epoxy/epoxy coating presented inferior performance to the epoxy/polyurethane coating, presenting significant wear.

Gevaerd [19] developed the accelerated weathering test using the Bass UUV / 2010 and Comexim C-UV as equipment. The metal plates were epoxy coated, in order to evaluate fading and loss of gloss. It was found that the epoxy coating presented significant loss of color and brightness during the period of



exposure to UV radiation. Gevaerd [19] also carried out tests with the epoxy coating on exposure to the humid atmosphere, which showed a reduced loss of adhesion to the metallic substrate during the test period.

Another relevant test was performed by Yang [41], the primer coating being tested a primer epoxy polyamide in conjunction with high gloss polyurethane paint on an aluminum substrate. The tests were intended to evaluate the resistance in the coating against some weathering situations such as exposure to UV radiation and moisture associated with heat and chlorides. The exposure of the coated plates to the UV fluorescence lamp [6] and the vapor exposure test containing chlorides in alternating cycles with exposure to UV radiation [5] were performed for the UV radiation exposure test. Then, the coated plate was observed in the Illa Nanoscope, the Scanning Electron Microscopy (SEM) study was also used. Because of the experiment, the authors concluded that exposure to incessant UV radiation caused more damage to the coating than the alternating exposure of UV radiation and chloride containing vapors. The brightness of the coating significantly decreased in the test period, which was continuously exposed to UV radiation and decreased slightly over the same period of alternating exposure to UV radiation and chloride containing vapors.

Hu [23] developed a study using metal plates as a substrate to test the UV radiation resistance of a polyurethane acrylic coating. The authors performed two artificial weather tests, in the first the plates were exposed to wetting and drying cycles with periods of exposure to UV radiation followed by a period of vapor condensation. Already in the second test, the plates were submitted to exposure to the Xenon lamp (Xenontest). Fluorescent condensation (UV 2000 TM, USA), Xenotest Alpha High Energy (Xenotest Alpha High Energy) and Atlas Material Testing Technology (USA) equipment were used for the tests. After the period of exposure of the tests, the Scanning Electron Microscope (SEM) was used to identify the consequences of both tests on changes in the coated surface, and the initial smooth morphology became irregular and rough. However, the surfaces remained level without cracking. A reduction in coating thickness was observed, lower gloss loss at the end of the test period, revealing color retention and glossability by the polyurethane/acrylic coating. Thus, despite having been subjected to inclement weather conditions and having undergone some physical changes, the coating remained intact. The degradation of the coating was greater in thickness and gloss when subjected to Xenontest in relation to exposure to the UV / condensation cycle.

Gevaerd, [19] as well as Hattori [22], consider that epoxy used alone and used as primer and paint, respectively, does not present positive results in relation to the higher resistance to exposure to UV radiation, presenting accelerated color and brightness loss and Deterioration of the coating. The polyamide epoxy paint tested by Frigate also showed inferior results in relation to the resistance to UV radiation. Although they do not present resistive properties to the UV radiation, the epoxy-based coatings presented positive results in relation to the adhesion to the substrate after the tests of accelerated weathering, revealing that for situations of high humidity the

epoxy can be considered an effective alternative. The adhesion factor also provided protection to the metallic substrate, which was not damaged during the test period.

Fragata [18] and Hu [23] tested coatings on metal surfaces with polyurethane associated with other components and found positive results of UV resistance. The coatings tested by them were aliphatic polyurethane, aliphatic acrylic polyurethane, and acrylic polyurethane. The positive results reinforce the bibliography researched when it refers to the resistance to UV radiation and rainfall, characteristics of the paints with these compositions. In contrast, Yang and Hattori tested the polyurethane epoxy polyamide and epoxy primer coatings associated with the polyurethane paint, respectively, and evaluated the results of their assays as negative for UV radiation resistance. Therefore, even polyurethane being characterized as high resistance to UV radiation and rainfall, its association with epoxy does not bring positive benefits from the point of view of the authors who carried out the tests. Epoxy may not exhibit good resistance to UV radiation but its relevant substrate adhesion performance coupled with the excellent resistive performance of polyurethane inks to UV radiation renders performance in alternating cycles of positive moisture/drying.

#### IV. FINAL CONSIDERATIONS

There are a number of external agents that influence the durability of painting coatings. Degradation by solar radiation, humidity and temperature were discussed among the main causes of weathering. These factors were treated unconnectedly in the present article, but the combination of their action on coatings should also be considered. Thus, the evaluation of the environmental stresses considered in the analysis of coatings failure can increase its lifespan.

Weathering tests can be performed outdoors or inside laboratories. Natural weathering tests are safer because they represent a greater number of environmental variables in comparison to laboratory tests. However, its duration is significantly longer. The combination of the two tests is recommended to estimate the durability of coatings.

Regarding the performance of the paintings, based on bibliographic studies and from the authors' experiments, it was possible to prove the benefits of primers and paintings with epoxy resins for high humidity situations. On the other hand, it is observed that the epoxy resin paintings are not resistant to UV radiation. The authors who tested the painting with polyurethane resin in its composition allied to other components evaluated positive resistance, except for polyurethane coatings with epoxy. Finally, it can be concluded that the resins play a fundamental role of adhesion and resistive capacity in coatings, and two or more resins can be associated to achieve the desired performance. Some components such as primers, when added to paintings, add resistive capabilities to the final coating. It was also verified that the changes of the chemical and physical variations derived from the coatings' degradation when exposed to weathering are correlated to time.

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