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BACK TO 4.0:

RETHINKING THE DIGITAL CONSTRUCTION INDUSTRY

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RETHINKING
THE DIGITAL CONSTRUCTION INDUSTRY

A cura di

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BACK TO 4.0: RETHINKING THE DIGITAL CONSTRUCTION INDUSTRY

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DICATAM, Università degli Studi di Brescia
Presidente ISTeA

4.0 is a paradigm which is tremendously featuring the Manufacturing Industry. Its meanings need to be debated and realized within the Construction Industry, too, without any undue and hastened translation, of course.
However, the Fourth Industrial Revolution is featured by Connectivity and Cognitivity.
It entails that both the Built Assets and the Construction Sites must be looked as a System of Systems, a networked entity which is on real time connected to other entities and which is capable of learning from the behaviours of its own agents/workers and users/occupants.
The Man-To-Machine relationships need to be deeply investigated either whenever machineries and gangers are acting over the construction sites or whereas the built asset's occupancy is concerned.
It is, undoubtedly a fascinating challenge, depending on telemetry, because each connected asset continously exchanges data and information.
Such Connectivity and Cognition imply that a digital doppelganger enables the flows coming from sensors and sentiments: anyway, the paradigm change appears as disruptive where the connected and cognitive building component, as well as the built asset, causes a shift from the ownership to the servitization.
The Untangible Value of the Building Components or the Built Assets transforms the nature of the Industry of the Built Environment: providing tailored services to geo-localized customers seems to be the core business, indeed.
Which are the Forms and Shapes of a Servitized Built Asset? Which are the ultimate Liabilities and Identities of the Players?
It is a challenging question involving some unanswered aspects and topics.
Cognitive Buildings & Infrastructures and Cognitive Construction Sites call forth a mid- and long-termed Vision: how many traditional competitors would be able to adopt such an unusual point of view?

The effects of a saline environment on the durability of commercial photocatalytic paints

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Topic: Life Cycle Management

Abstract

The use of photocatalytic products for surface coating of buildings ensures the reduction of certain air pollutants and greater duration of color over time, due to the reduced attitude of air particulate to adhere to the treated surfaces. The world market is producing a wide range of coatings, transparent and opaque, high initial performance, but there is a lack of data on their durability. The knowledge of performance over time of these new products is at the basis of the Regulation (EU) no. 305/2011, which repealed Council Directive 89/106/EEC and introduced the seventh requirement regarding the sustainability and particularly durability of construction works. This study focuses on the assessment of the durability of photocatalytic commercial paint, in three hues: white, red and yellow, based on TiO2 dispersion into inorganic resins. The methodology is based on the ISO 15686 and consists in the comparison of the most significant parameters considered, monitored during accelerated aging tests, into saline environment, by means of dry corrosion test cabinet, and natural aging in the atmospheric environment of the city of Palermo, characterized by marine aerosol. The monitored parameters were: surface morphology, by means of SEM and optical microscopy; color by means of spectrophotometer; photocatalytic activity, by means of isopropyl alcohol degradation. Chemical characterization test by means of diffractometer were also performed. The results obtained allow carrying out useful correlations to define the performance limits of photocatalytic paint over time. Monitoring was carried our for six months to the effects of degradation agents of atmospheric environment and for four steps of accelerating aging into dry corrosion test cabinet, according to the standardised natural stone test method of UNI EN ISO 14147:2005, adopted for coatings.

1. Introduction

The worldwide interest to the multiple applications of heterogeneous catalysis in the field of construction, has led to substantial investments towards the development of building products for surface coating. In the last two decades, photocatalytic products (plasters, coatings, paints, blocks, tiles, etc.) have attracted a broad market segment thanks to the contribution given for the mitigation of environmental problems, in a context of sustainable development. The use of nano-photosensitive materials, mixed according to the formulations of building products, provide substantial reduction of harmful substances in the various areas of application: reduction of air pollution, water and air purification (Choi, 2006; Cassar, 2004). Activation of these nanometer and/or micrometric size semiconductor materials is based on the absorption of light energy, resulting in the oxidation of harmful substances. Titanium dioxide (TiO_2) is, among the solid semiconductors, the most efficient and used in the construction sector due to its wide availability, low cost and high photo-activity. The monitoring of the initial performance of these materials, conducted by public and private research institutions[1], demonstrates high attitude in the reduction of air pollutants, organic and inorganic, and self-cleaning properties. The requirement of durability, is still barely known, although growing interest, due to the Regulation no. 305/2011 of the European Parliament laying down harmonized conditions for the marketing of construction products and repealing Council Directive 89/106/EEC[2]. The regulation, in fact, reiterating the need to apply sustainability criteria in the design of construction works, has introduced, among the basic requirements, "the sustainable use of natural resources", which requires, among other aspects, the durability. This paper deals with the performance monitoring over time of photocatalytic commercial paint, formulated and supplied by AZ TECH Ltd, whose commercial name is FosBuild 310L, according to the codified methodology of the ISO 15686.

2. Methodology, materials and monitored parameters

This study intends to contribute to national and international research on the evaluation of the durability of building products and components, according to the methodology of ISO 15686 and UNI 11156, based on the assessment of building materials service life by means of correlations between laboratory accelerated aging tests and in outdoor natural aging. The preparatory phase concerns the identification of potential stressing agents, potential degradation effects and most significant parameters to be measured. In this case, the studied product is an external surface coating, being part of coatings that do not modify the conformation of the substrate,

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[1] Information on http://www.picada-project.com
[2] Information on http://www.eur-lex.europa.eu

denominated "Paint systems" (UNI 8752:1985), applied to a thickness of about 300 microns. This kind of paint showed photocatalytic attitude and was tested in three hues: white, yellow and red, applied on cement mortar substrates, 1 cm thick and 10x10 cm size. The most significant parameters considered were: color, photocatalytic activity and surface appearance. X-ray diffraction analysis was carried out for the detection of chemical variations in the composition of the samples due to accelerated aging effect. Based on the tests carried out, we proceed to the time rescaling, to compare the results of the selected parameters monitoring, after artificial and natural aging.

2.1 Measurement of color

The measure of the surface color was performed, in accordance with the specifics of the UNI 8941:1987, by means of a spectrophotometer with numerical gloss control providing simultaneous measurement with specular component included (SCI) and excluded (SCE). Observations were made by means of CIE Standard Illuminant D65 and 10° observer. The chosen color space was the CIELAB[3], based on brightness, L*, and on the two chromaticity coordinates: a* and b*. Starting from the coordinate values of non-aged samples (time zero), we calculated ΔC_{ab}*, ΔE_{ab}*, ΔH_{ab}*, allowing evaluating the evolution of color over time. Color measurements[4] represent the average of five points.

2.2 Measurement of photocatalytic activity

Samples underwent non-standardized testing to evaluate photocatalitic activity based on isopropyl alcohol or 2-propanol degradation (Amadelli et al., 2013) and the measure of degradation products quantity: acetone and water, due to exposition cycles to UV lamp. The oxidative process, due to UV radiation, leads to oxidation of acetone adsorbed from the treated surface with titanium dioxide, TiO_2, and therefore to the mineralization of the acetone and to the formation of CO_2 and H_2O, according to the process in Fig. 1.

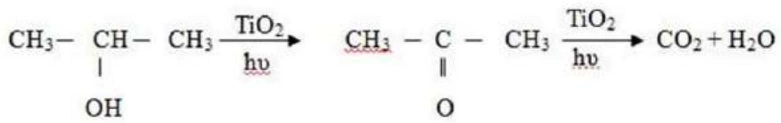


Fig. 1 The photocatalytic oxidation reaction of 2-propanol

During the test, the sample is placed inside a Pyrex reaction chamber (D=125 mm, V=0.9 dm^3) exposed to 400W UV lamp, the system works in batch (closed system), no incoming and outgoing flows, after the saturation of the chamber with oxygen (Fig. 2a). The test is conducted by injecting 1.5 µL of 2-propanol in the liquid phase with a gas tight syringe within the reactor, so as to obtain a mixture of known concentration of 20 µM. After 15 minutes the lamp is turned on to activate the reaction (Fig. 2.b).

[3] Information on http://www.cie.co.at
[4] Experimental activity was carried out at the "Laboratorio di Edilizia", University of Palermo


a

b

Fig. 2 The test system, before the beginning of the test (a), and during the test (b)

To cut infrared radiation and prevent overheating of the sample inside the reactor, a bowl full of water is interposed, at a constant level and continuous change. Samples of 500 μL were withdrawn at fixed intervals (30 minutes), using a gas tight syringe, and analyzed in the gas chromatograph in order to detect the amount of 2-propanol, acetone and CO_2 indicative of the degradation capability of the photocatalytic paint on the surface of the sample. Aiming at the measurement of the photocatalytic activity, from each sample, four 5x5 cm samples were obtained, by means of dry cutting.

2.3 Surface appearance measurement

The monitoring of surface degradation due to aging, was carried out by means of Leica MS5 optical microscope, at different levels of magnification, from 6.3x to 40x. The microscope is equipped with Leica DFC camera which allowed creating, editing and archiving digital images. For each sample, the two most representative points were observed and for each point four observations were made with increasing magnification (6.3x, 10x, 25x and 40x). The possible forms of alteration, for paints and varnishes, are described in the UNI EN ISO 4618:2007. The description of the amount of defects, the size and the intensity listed in the above-mentioned standard, in tabular form, allowed the classification for these three indicators of defect on a numerical scale, from 0 to 5. The assessment of the effects of aging on the surface appearance of samples was also performed by SEM.

3. The artificial aging

The artificial aging cycle performed in the Dry Corrosion Test Cabinet (DCTC 600) by Angelantoni® was derived from the UNI EN ISO 14147:2005 - Test methods for natural stone. Determination of resistance to aging by salt spray - in order to simulate an aggressive environment with high content of sodium chloride, typical of a climatic context of the coast of the Mediterranean basin, such as the city of Palermo (Alaimo et al., 2011; Alaimo et al., 2014). The basic cycle is shown in table 1.

BASIC CYCLE	Theoretical cycle (Minutes)	T (C°)	RH (%)	Percentage(%)
Salt spray environment	240	20	95	33.3
Hot humid environment	480	35	50	66.6
Total	**700**			**100**

Table 1. Values of the parameters of the artificial aging cycle

Each aging step consists of 15 basic cycles, for 180 h overall (Fig. 3). The accelerated aging ended with the 4th step, lasting 720 h (30 days). For each step a couple of samples were taken from the cabinet for the evaluation of the photocatalytic activity.

Fig. 3 The samples arranged in the DCTC 600

4. Natural aging

A series of four samples for each hue have been exposed to weather conditions, for a period of six months, to South orientation and inclination of 65° (Fig. 4).

Fig. 4 The samples exposed outdoor on the terrace of the 8th building of the Polytechnic School

5. Results

5.1 Color

In Fig. 5 the results of the monitoring of the color difference variation, at the end of the 4th step of accelerated aging are showed. The measurements of the colorimetric coordinates are reported in SCI mode.

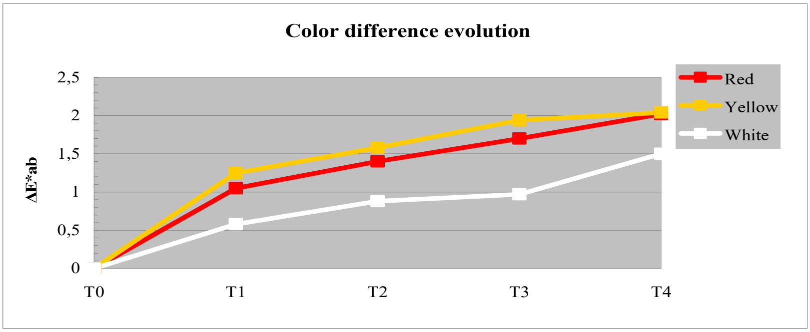


Fig. 5 The evolution of the color difference of the artificially aged samples

The color difference variation shows higher initial increase to the 1st step for the yellow and red samples, approximately 1÷1.2 points, while for the white ones is about 0.5 points. The trend of the curves for the following 3 steps is almost linear, with similar increases and color difference reaching 2 points for the yellow and red samples and 1.5 points for the white ones. According to the classification of the UNI EN ISO 3668:2002, at the end of the 4th step, the red and yellow samples showed "modest" color difference, while the white ones "very light". Chroma variation shows decreasing trend for the red and yellow samples (Fig. 6). Negative values of $\Delta C_{ab}*$ indicate the samples turned to opaque. Different is the behavior of the white samples, showing nearly constant value of zero for the chroma difference, indicating maintenance of the initial condition.

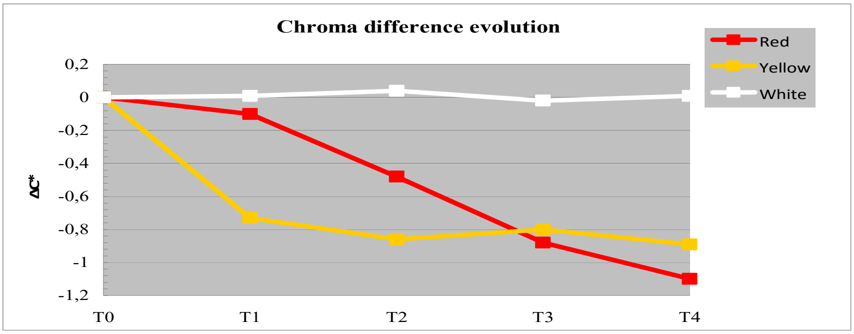


Fig. 6 The evolution of the chroma difference of the artificially aged samples

The hue's difference evolution shows ascending trend for yellow samples, while for white and red ones there is initial increase up to the 1st step, then a substantial maintenance of the hue to the 2nd step and a further increase for the 3rd and 4th step. The increase in hue shows progressive yellowing of the samples, whose trend in the chromaticity diagram are gradually closer to the axis of the positive b* coordinate. Samples set outdoor underwent the influence of the weather conditions of Palermo, data referring to a period of 6 months of outdoor exposure, starting from August 2015. From these early measurements, significant increase of the color difference on exposure in early winter was registered. The procedure of time rescaling, as codified first by ISO 15686 and UNI 11156 later, consists of comparing the accelerated aging data, obtained in laboratory, with the data measured on the same products subject to external natural agents. From the comparison of the line graphs in Fig. 7, 4 steps of accelerated aging correspond to about 2 months of natural aging for the red and yellow samples. For white samples 4 steps correspond to about 3 months of natural aging. These evaluations may be more detailed after at least one year of natural exposure.

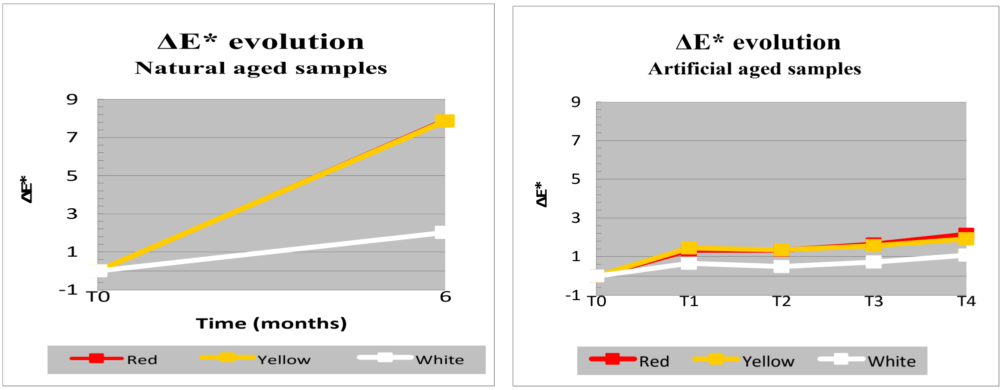
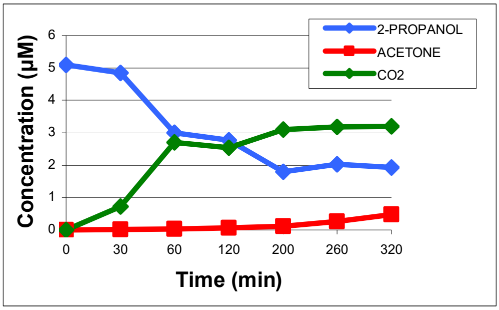


Fig. 7 Comparison of the evolution of the color difference for artificial and natural aging

Samples exposed to natural aging for 6 months, particularly the yellow and red ones, underwent greater variation in brightness when compared to samples having completed 4 steps of accelerated aging. The white samples exposed outdoor for 6 months have almost constant brightness, unlike the red and yellow ones showing variations respectively of 7 and 3 points, indicating tendency to clearing.

5.2 Photocatalytic activity

From the analysis of concentrations by gas chromatograph, on the non-aged red samples and on the 4 steps artificial aged red samples, it was initially observed, in both cases, a quantity of 2-propanol adsorbed on the surface, not participating to the reaction. In the non-aged samples, the concentration is 14.91 μM, while for aged samples the concentration is 17.31 μM. In fact, Fig. 8 shows in the first case the initial concentration is equal to 5.09 μM, in the second case is 2.69 μM. The amount of non-adsorbed 2-propanol, due to UV light radiation, reacts to form acetone and carbon dioxide. In both cases, total oxidation is more favoured than partial one, indicating 2-propanol is mineralised almost completely into CO_2+H_2O, resulting in low amount of acetone. From the comparison between the two graphs, in the case of aged samples lower amount of carbon dioxide and acetone is formed, showing decrease in photocatalytic activity. Probably, as is known in the literature, this is due to chloride ions reducing photocatalytic activity (Krivec et al., 2014). The photocatalytic activity data related to one year of natural aging are not yet available; therefore, it was not possible to proceed to the comparison procedure with the accelerated aging data, as provided by standard ISO 15686.



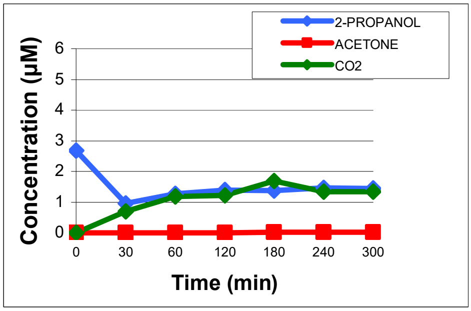


Fig. 8. Photocatalytic degradation of 2-propanol of non-aged (a) and aged (b) red samples

5.3 Surface appearance

The assessment of the effects of artificial aging on the surface appearance was conducted by means of SEM (Fig. 9). Morphological analysis at 100X shows nearly smooth and homogenous surface. The presence of small number of micro-cracks is observed in non-aged samples, while the aged yellow samples show 10 mm "crow's feet" microcracks. At 2000X, homogeneous surface is observed, almost identical to non-aged and aged samples, with reduced presence in the aged ones of few millimetres irregular shaped particles. Chemical analysis shows substantial invariance in the composition of the chemical elements. Chlorine is present in trace amounts, in the aged samples, due to exposure to salt spray, and the presence of iron in the red and yellow samples, due to ferric oxide pigments, and absent in the white ones.

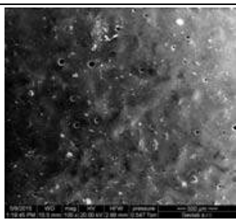
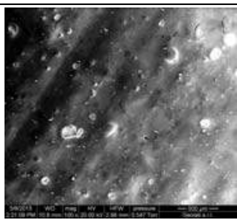
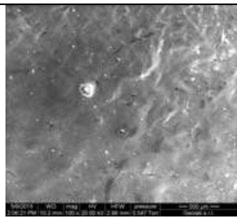
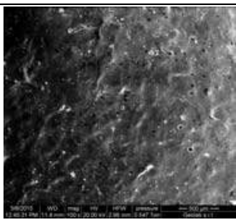
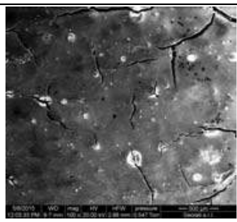
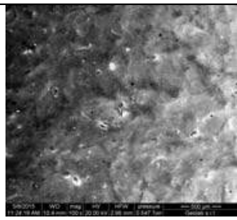
	FG	FB	FR
T_0			
T_4			

Fig. 9 Magnification of 100x SEM of 3 types of samples

According to the methodology of evaluation of the surface degradation of painted surfaces (UNI EN ISO 4628-1:2016), the evaluation of the detected degradation was performed (Table 2). Some of the most significant images in Fig. 10, obtained by optical microscopy, show the monitoring carried out during artificial aging.

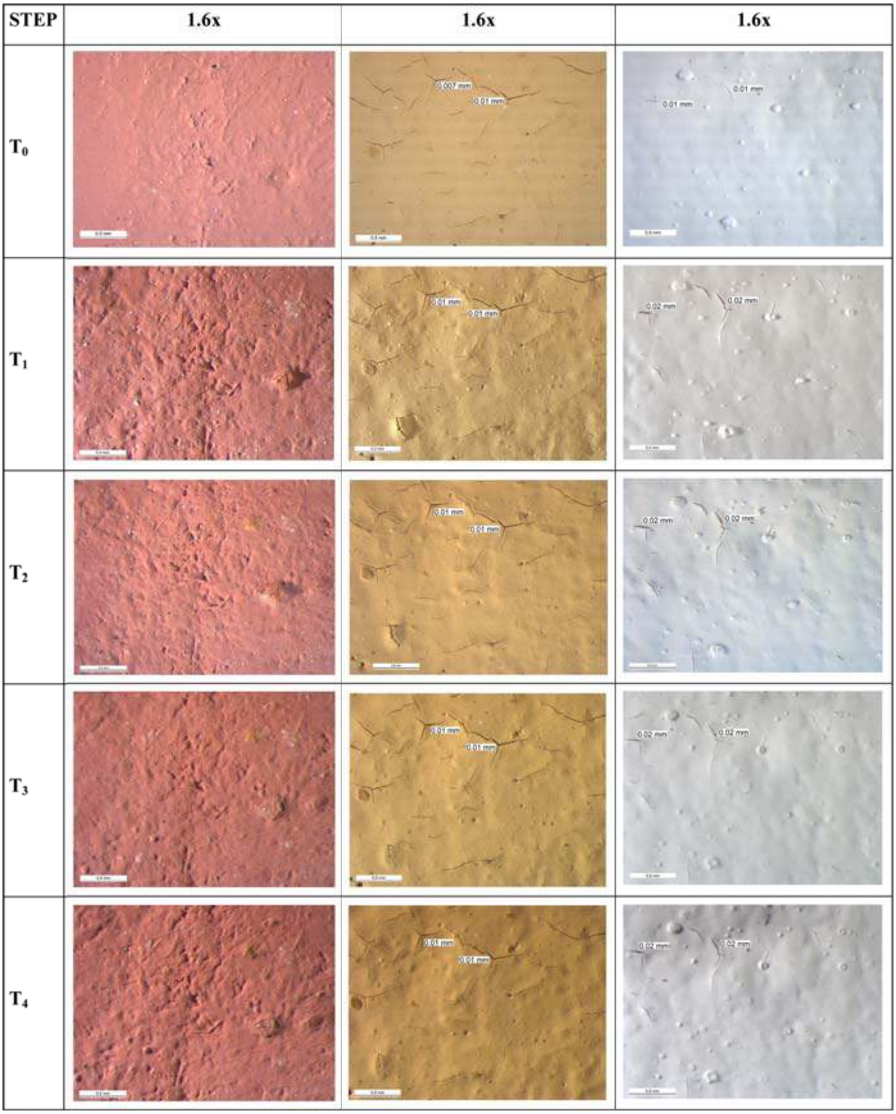


Fig. 10. Magnification at 16x of the samples surface

Degradation	T_0		T_4	
	Craze	Micropores	Craze	Micropores
Yellow	4 (S3)	2 (S2)	4 (S3)	2 (S2)
White	4 (S3)	2 (S2)	4 (S3)	3 (S2)
Red	2 (S5)	2 (S2)	2 (S5)	2 (S2)

Table 2. Classification of degradation (UNI EN ISO 4628-1:2016)

Observations allow us to determine the effects caused by the exposure to stressing agents (hygro-thermal stress by means of salt spray). In all the samples, at T_0, the presence of spread craze, typical "crow's feet" shape. Also there is a limited presence of micropores, average size of 0.30 mm. At the end of the artificial aging, it was observed general maintenance of the diameter of the micropores, while 0.40 mm craze have shown reduced increase. Some significant differences, the presence of microbubbles, average diameter of 0.25 mm, can be seen especially between the samples at T_0 and T_1, maintaining almost unaltered up to the 2nd step, denoting lifting of the paint layer, and then flattening out in the subsequent, 3rd and 4th step.

6. Conclusions

The time rescaling results for color show 4 steps of accelerated aging corresponding to about 3 months of natural aging, for white samples, rather than to the yellow and red ones, for which correspond to about 2 months. Additional data may clarify the actual product decay. The samples' surface, at the morphological level, does not show significant variation. The presence of spread micro-cracks, typical "crow's feet" shape, in non-aged samples is due to internal tensions that are determined during the drying stage, because of low elasticity of the paint, with respect to the substrate. General maintenance of micropores' diameter and amount of micro-cracks was observed.

7. Aknowledgements

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