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The Experimental Evaluation of Parameters Contributing to the Durability of Coating Materials for Colouring and Protecting External Plastered Surfaces

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ABSTRACT

Building components and products durability is a high topical issue for the evaluation of built systems efficiency. It's also relevant about the theme of durability certification and constructions insurability. From the market comes the need to promptly determinate the performances of new products, often innovative, which are not testable through observations on site in real-time.

The paper reports a performances evaluation test of outdoor coating materials based on accelerated aging processes on natural and artificial samples.

The test, 3 years long, was directed to the evaluation of durability of 7 different systems, polymer-based, normally found on the market, applied on expressly prepared supports.

Physical durability tests, after different intervals of time, consisted in water absorption, steam permeability, adhesion, colorimetric values tests and surfaces observation at macro and micro scale of the products.

Experiment evaluated not only the tested systems behavior but also some critical aspects of the artificial ageing processes in weather chamber, mainly due to excessive severity of the cycles.

Natural ageing outdoors has produced good results showing general good performances of the tested systems.

KEYWORDS

Durability, Varnishes, Artificial ageing, Outdoor coating materials.

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1 INTRODUCTION

The longevity of components and products for the construction industry is a highly topical issue for the role it plays in the overall assessment of the reliability of systems built in relation to the theme of insurability of the works, and then increasingly in the interests of producers and users.
Durability of a product in construction means the ability to maintain the levels of performance and functional requirements over time (i.e. those planned) under the impact of foreseeable actions [1].

The evaluation of the behaviour of materials based on time has become an established and shared tradition just like the measurement or observation tools and methods. However, it still needs to be appropriately adjusted to the unique characteristics of each product and their use in specific environmental conditions.

In a market with constant product development, the assessments of durability provide reliable results only when performed over long periods of time and when based on statistically significant samples. Thus, the need to respond to the question of performance assessments in a decidedly more content remains strictly because of rapidly changing technology industry. From the market comes the need to promptly determine the behaviour of new products to commercialize. Based on their innovative nature, it is not possible to observe their functional behaviour in real-time.
For this reason, methods have been introduced to evaluate the performance of products over time. These methods are based on accelerated aging processes in natural or artificial environment. The tested samples are adequately prepared in order to simulate the main critical conditions due to exposure or use.

2 THE EXPERIMENT

The surface protection systems for surfaces plastered on buildings are generally made of polymer-based paints and varnishes (p.v.). It is well known that the aging and subsequent degradation of these systems are caused by water permeability, defects in adhesion and embrittlement of the polymer film upon exposure to UV.

To evaluate the durability of the p.v. it is possible to use outdoor exposure methods with accelerated natural aging and testing with accelerated aging in a weather chamber.
The experiment presented here was carried out in the experimental laboratory in the BEST [2] department of the Politecnico of Milan. Both of the abovementioned methods were activated also to verify if there is a significant possibility of comparison.

The experiment involved the evaluation of the durability of seven different systems normally found on the market[3]:

- System 01A - ACRYLIC PAINT
- System 02A - ACRYLIC QUARTZ PAINT
- System 01B – SILOXANE PAINT
- System 02B - SILOXANE PAINT
- System 02C – ELASTOMETRIC SYSTEM
- System 02D – HYDROPAINT
- System 02E – PLASTER FINISH[4]

2.1 Exposure to accelerated natural aging conditions

The experimental evaluations, the parameters of exposure of the samples to the outdoors that maximize the action of the weather agents using the most critical conditions in terms of where, how and when they are exposed were identified. The criteria defined by UNI 2810[5] provide that at our latitude, the samples should be placed on a stand with an inclination of 45° from horizontal plane and are oriented towards the south. These criteria increased the degradation rate of material by 4-6 times in the experimental tests. In fact, this method maximizes solar radiation, which is the main case of degradation of products with polymer-based coatings, just like those covered by this experiment. Furthermore, it is clear that the climatic and weather conditions of the exposure period directly influence the ageing results, and that is why an exposure period of at least 3 years is considered sufficient. The rate of air pollution in the area where the exposure takes place and local conditions are other parameters that significantly affect the exposure effects.

7 systems were tested and for each of these systems 2 samples were produced. The samples were made up of brick tables (100 x 25 x 6 cm) that were plastered on one of the two main facades and on the two long sides. This allowed to also evaluate the behaviour of the product at the corners. This is especially critical because of the reduced thickness of the protective film that is inevitably linked to the application technique.

The samples were exposed to the outside, on a galvanized steel support specifically designed and protected above by a steel flashing to prevent water seepage from the upper edge.
The exposure was based on normal parameters and started from the summer solstice of 2006 on the flat cover of a building of the Politecnico of Milan (Fig. 1). From an exposure and concentration of polluting agents point of view, this is a particularly stressed area. The evaluation of the performance behaviour of the samples was carried out through direct observations to consider the changes in surface characteristics and possible colour change of systems with colorimetric measurements.
In regards to the evaluation of surface characteristics, visual observations were made with optical instruments at different zoom factors.

Figure 1. The exposure of the samples on the flat cover of a building of the Politecnico of Milan.

The samples were then photographed with a macro lens at a close range, with a magnification factor of approximately 2:1 and with detailed photos with the help of an optical digital microscope (Fig. 2), able to record images with magnification factors of 50 x, 100 x and 200 x. The use of this sophisticated instrument allowed us to observe and document the evolution of the morphological characteristics of the surface of the samples.

The variations in the chromatic characteristics were registered with the use of a reflectance colorimeter[6]. To make the measurements taken with this instrument as reliable as possible. 20 measurements were taken for each sample, within a defined area of 25 cm^{2}, to avoid the risk non-significant local conditions for the whole sample.

The observations were performed on samples each year for 4 consecutive years and with intermediate readings (every six months) during the first and second year to evaluate the most significant variations that could be verified during the most critical period corresponding to the break-in period.

Figure 2. Observation by the optical digital microscope.

2.2 Outdoor exposure: results of the experiment

Following the colorimetric measurements, it was possible to observe how all the products had responded well to the aging process. In fact, all of them had undergone a normal surface greying process and yellowing of the colour trend caused by the exposure to UV rays that at the storage of atmospheric particles accumulated over time. These results, which were predicted because of the environmental characteristics of the exposure area, can be traced back to physiological degradation products.

Compared to the average behaviour, only one product (02D) showed to be more stable while, for some other products after the initial overall chromatic variation, the colour tended to be closer to the original. Thus, we can hypothesize that there is a kind of physiological colour change in the first phase of product life during the first year. In some cases this tends to stabilize at lower lees than those registered at the first threshold measurement. In this regard, an important variable with respect to the results of the observations is that of the effect of weather and rain in particular. In fact, if the observations and the colorimetric measurements are carried out after a rainfall, it is possible that this is removed due to the washing effect. On the contrary, if the observations are carried out after a long dry spell, the accumulation of dirt on the sample surface could be greater.

The chromatic variations of the surface, especially regarding the greying phenomenon, are reflected in the observation of microscopic samples. In fact, the gradual deposit of atmospheric particles and the consequent appearance of dark spots are visible with high magnification factors (superior to 50x). These phenomenon, which are almost invisible to the naked eye, contribute to the overall darkening of the surface. The use of the microscope allows us to fully appreciate the phenomena that contribute to the greying of the surface. In some cases, it has been seen that localized spots tend to form in areas where dirt particles accumulate on a small scale. In other cases, brown spots interpreted as oxidation of iron particles probably deposited from atmospheric dust have been observed.
The use of the microscope also allowed for very efficient observations on the surface morphology of the tested products. Some of these products (01A, 01B, 02A and 02B) showed a change in the surface at the microscopic level. This change was caused by the large number of micro-cracks and varying pore sizes (Fig. 3).

A micro erosion phenomenon of the product’s binder component highlighted the aggregated granules of the product. This micro degradation was very clear and in particular on sample 02E, which was already characterized by a particularly pronounced physiological graining. The sequence of observations allowed to evaluate the progressive dynamics of this phenomenon that led to put more light on the granular structure of the aggregate. If the surface covered with the binder component of the product was uniformly covered at the beginning of the observation, after 3 years of exposure the angular grains of the aggregate were apparent.

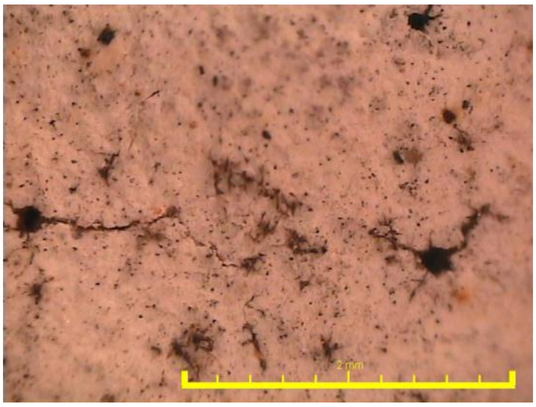

Figure 3. The surface morphology observed by the microscope (200x) after 2 years.

It is believed that these surface decay phenomena may only impair the functionality of the tested system only after very prolonged exposure.

2.3 Exposure in accelerated aging conditions in a weather chamber

In parallel, other samples of the same products were subjected to a process of accelerated aging in a weather chamber [7].

The samples destined for the weather chamber were made up of small tiles (40 X 25 X 3 cm). Only the tops of these tiles were covered with plaster and they were suitably protected on the backside with a siloxane water repellent product and sealed on the edges with the application of a epoxy resin based coating.

The correct preparation of samples is critical for the success of the experiment. In fact, treatment in a weather chamber could subject the samples to very harsh stress and thus making it crucial to protect all of the weak points that could distort the result. In fact, if the samples were not well sealed on the back and on the sides, infiltration may occur between the layers constituting the substrate. This infiltration would cause obvious consequences.

As is known, the weather chamber is an apparatus capable of simulating the main agents of weather and climate such as rain, solar radiation, frost, dry and humid climate and cold and hot climate:
- The relative temperature and humidity of the air inside the climatic chamber can be respectively regulated between -40 and +180 °C and between 10% and 98% RH;
- The facility that simulates the rain has four full-cone spray tips that are radially oriented at 90° intervals and with a spray angle of 120° able to create a round cover jet and with uniform distribution.

Based on previous experience, the equipment was programmed with the following sequence of agents, duration of action and number of cycles:
- precipitation stage: duration of 60 minutes, the test samples are uniformly hit by a water jet with a temperature of 20°C. The air within the compartment is constantly kept at a temperature of 20°C and a relative humidity equal to 95%.
- 30 minutes to pass from 20 °C to -16 °C
- frost phase: duration of 60 minutes, the wet samples and the air of the compartment are kept at 16°C for the whole duration of this phase.
- hot and humid climate phase: duration of 60 minutes, the air within the compartment is kept at a constant temperature of 55°C and 95% of relative humidity. This phase is preceded by a

transitional period lasting 80 minutes required to adjust the temperature from -20 °C of the earlier stage to 55 °C of this phase.

- Hot dry climate phase: duration of 80 minutes, the air of the compartment is at a temperature of 30°C and at a relative humidity equal to 35%.

During the exposure to ageing, the operation data of the equipment was measured according to defined methods and time intervals in order to monitor the proper performance of the test procedure. The use of the weather chamber to accelerate the ageing processes of the test pieces has the advantage of significantly reducing the experiment times but results in some very critical issues. The first thing to consider is the difficulty in compare the relationship between the natural aging, in normal operating conditions and the accelerated ageing in the weather chamber; secondly, as already mentioned, the sharp acceleration of the processes of atmospheric agents submit the samples to stresses that may be too stressful. Test criteria that are truly effective in relation to the nature and size of the weather chamber and that enable an effective assessment of the durability of products and systems still have to be developed.

In the case presented here, the test samples were forced into a horizontal position in the weather chamber. The result of the thermal cycles led to the stagnation of a film of water on the surface that plays an important mechanical action on the tested product. Additionally, this position is insignificant compared to the most common operating conditions for these systems that are used to protect vertical wall surfaces.

The fact that a protective product requires application to a support during testing is also worth consideration. During the test phase, this support is also stressed by the weather conditions and this has a more or less significant impact on the overall performance of the system (product + support). Surely, the more efficient the protective action of the tested product, the more contained the phenomenon, but the complexity of the data related to the characteristics of the support inevitably introduce variables that must be taken into account.. Therefore, in this sense, the support should be simplified (characteristics, functional layering) with the aim of limiting the possible disturbance factors on the test results.

Before introducing the samples in the weather chamber, characterization tests of physical performance were carried out on the comparison samples (T_0). These tests were designed to assess the degree of vapour and liquid water absorption and the ability to adhere to the support. As for permeability of liquid water, it is carried out by measuring the degree of capillary absorption of the protective systems in question.

The tests were carried out on cylindrical test pieces (Ø 50 mm) obtained by coring. These were protected on the lateral edges with an epoxy resin based varnishing product; the upper surface of the core is immersed in water and subsequently the test pieces are weighted with a digital scale every 10 minutes, 20 minutes, 1 hour, 2 hours, 3 hours, 4 hours and 24 hours. The obtained data is processed and systematized in appropriate tables containing the partial Δt values calculated for the samples of each test piece (Fig. 4).

Figure 4. The cylindrical test pieces immersed in water for permeability of liquid water test.

Subsequently, the amount of water absorbed (Kg) in one square meter of surface (W) and the coefficient of liquid water permeability, in kilograms per square meter and on the square root of the hour (w) were calculated. Both of these were calculated after a period of 6 and 24 hours[8].

The assessment of behaviour in terms of permeability to water vapour[9] was carried out on three test pieces with a diameter of 100 mm obtained with the use of coring. The test was carried out by applying the disk test piece obtained by coring, like a cap, to an special capsule containing a volatile liquid (Fig. 5). The capsule was then weighed at predetermined time intervals. The weight change is indicative of the amount of vapour that goes through the test piece[10].

Figure 4. A capsule for the test of permeability to water vapour.

The adhesion test is carried out by applying an axial traction to a plaque affixed to the sample surface. Its aim is to calculate the tensile strength value (adhesion to the support) and the break point of the tested system.

Based on legislation, three test areas with a diameter of 50 mm were delimited through milling. These three areas were delimited for each product and round metal plates were applied with the use of an epoxy for testing. We were able to record the tension value measured at the time of the break and the point in the test when rupture happened.

In the majority of the test pieces, the fracture of the test piece happened within the occurred within the mortar plaster of the support state. Even though this does not provide a tensile strength value indicative of the adhesion of the product to the support, this shows that the latter exceeds the tensile strength of the mortar. The tests described above were repeated on test pieces after exposure in the weather chamber.

3 CONCLUSIONS

In conclusion, it may be noted that the tests conducted on samples that naturally aged outdoors have provided intriguing indications on the ageing mechanisms. Over all, these mechanisms showed superior performance of the tested systems in terms of durability. On the contrary, the process of artificial ageing in the weather chamber demonstrated several critical points due primarily to the severity of the cycles. In this case, it was impossible to determine the correlations between the accelerated natural ageing and artificial ageing in the weather chamber.

Furthermore, from the findings of this and other trials it does not seem possible to define standardized ageing cycles in the weather chamber. In fact, we believe that the specifications of these cycles must be evaluated each time (probably with a distinctive pre-experimental phase) and calculated based on the risk factors of each system or, at least, risk factors that are specific to uniform system categories.

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[1] Regulation UNI 11156-1:2006 Evaluation of the longevity of construction components. Part 1: Terminology and definition of evaluation parameters

[2] Building Environment Science and Technology (B.E.S.T.)

[3] All by applicator technicians of the manufacturer with a plain white colour in order to replicate the actual conditions of use on construction sites as closely as possible. The supports were carried out by technicians commissioned by the BEST and under the supervision of the researchers in order to have a uniform support for all systems using widely available commercial products and applied in accordance with normal construction practices.

[4] System 01A - ACRYLIC PAINT: 1 layer of cement mortar component, fibreglass mesh, 1 coat of acrylic primer diluted in water, 1 layer of acrylic CONTINUOUS APPLICATION PLASTIC COATING, 2 coats of acrylic resin, quartz flour and pigmented based paint. System 01B - SILOXANE PAINT: 2 layers of mono-component cement mortar, 1 coat of siloxane primer diluted in water, 1 layer of siloxane CONTINUOUS APPLICATION PLASTIC COATING. System 02A – ACRYLIC QUARTZ PAINT: 1 coat of Pigmented solvent-based fixative, 1 coat of an acrylic base coat, 2 coats of acrylic resin, quartz flour and pigmented based paint. System 02B - SILOXANE PAINT: 1 coat of Impregnating siloxane-acrylic binder based primer, 1 coat of siloxane-acrylic binder and quartz flour based fixative base, 2 coats of mineral, organic and aggregate mixed matrix acrylic and siloxane based paint. System 02C - ELASTOMETRIC SYSTEM: 1 coat of Pigmented solvent-based fixative, 2 coats of acrylic resin, quartz flour and pigmented based paint. System 02D – Hydro-pliolite based mural hydropaint: 1 base coat of product diluted with 10% water, 1 top coat of white coloured product diluted with 10% water. System 02E – PLASTER FINISH: 1 coat of xiloxane-acrylic binder based Impregnating primer, 1 coat of siloxane-acrylic binder and quartz flours based primer.
2 layers of acrylic-siloxane resin, balance grained quartz flour and special lamellar filler based top coat.

[5] Regulation UNI EN ISO 2810:2005 Paints and varnishes. Natural aging of coatings. Exposure and evaluation.

[6] CR200 Minolta Colourimeter, able to detect and store three pieces of information: the L component, luminosity or light components, the "a" value that varies from green to red and the "b" value that varies from blue to yellow. In terms of the application field, the formulas and the CIELAB colour difference, reference was made to regulation UNI 8941-3:1987 "Coloured surfaces – Colourimetry, Calculation of colour difference".

[7] For the record, an Angelantoni Industrie CH 1200 model weather chamber was used at the Experimental Technical Laboratory at SUPSI (University of Applied Sciences and Arts of Southern Switzerland) in Lugano

[8] Classification of the degree of liquid water transmission kg/($m^2 \cdot \sqrt{h}$): I [high] if > 0.5; II [medium] from 0.1 to 0.5, III [low] if< 0.1 Refer to UNI EN 1062-3:2001 Paints and varnishes – Varnishing products and systems for external brick and concrete works - Determination and classification of the degree of transmission of liquid water (permeability)

[9] According to UNI EN ISO 7783-1:2001

[10] Classification of the degree of water vapour transmission according to EN 1062-1 g/($m^2 \cdot d$): I [high] if> 150, II [medium] from 15 to 150, III [low] if< 15