Characterization of durability and photocatalytic properties of TiO_2 cement-based materials

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ABSTRACT

The issue of maintenance is steadily emerging in the framework of the built environment, with a specific focus on durability and service life planning and sustainability evaluations, as the definition of a maintenance plan for building components requires a preventative assessment of durability.

The aim of the experimental campaign here presented is to evaluate the durability of different cement based materials containing TiO_2 (anatase). Accelerated aging tests were conducted in a climatic chamber to evaluate the performance decay and physical degradation over time, in order to study the effect of composition and surface finishing on the durability and photocatalytic properties. Results achieved constitute a starting point for predicting the service life of building components, granting the transfer of information from materials to systems, in this case the cement based building envelope. Information promotes wise planning of maintenance interventions and control of the global costs.

Keywords: Durability; TiO_2 based materials; photocatalysis; self-cleaning

1 INTRODUCTION

The purpose of the research is to investigate durability aspects of photocatalytic materials for built environment. Knowing the behavior of materials over time, and consequently of building components, is the optimal way to predict the dynamics of their performance decay.

The combination of these concepts with the increasingly development of photoactive materials led to the research field of this work. Durability knowledge completes the concept of maintenance, which cannot be properly planned without such essential information and whose costs cannot be properly controlled, within a Life Cycle approach. By forecasting performance decays of materials, there is a chance to act in a preventative manner. Knowledge about the dynamics and the contexts in which such events occur allows operators to make choices during design stage that maximize the material functionality and enhance its properties.[1]

Anatase phase titanium dioxide (TiO_2) is the largest used photocatalyst, with increasing applications. Its addition to the mixture in the production of mortars allows exploiting its photoactivated depolluting and self-cleaning properties, which reveal their effects by means of the contribution of solar energy (UV radiation), able to activate the photocatalysis through chemical reactions. [3-8]

The paper presents the results of experimental tests, intended to be the starting point for predicting the service life of building components. Tests consist of accelerated aging in the climatic chamber set-up to evaluate the performance decay and physical degradation over time, also in relation to colorimetric variation, and photocatalysis tests which aim to evaluate the decay of photocatalytic properties with the progression of aging cycles.

Self cleaning samples performance was evaluated after 50, 100, and 150 aging cycles. In each cycle samples were subjected to UV radiation, rain, freeze-thaw and thermal cycles variations. The aging cycles on samples in the climate chamber are programmed in terms of humidity, temperature, exposition to UV radiation.

2 EXPERIMENTAL

The whole experimental campaign was set for 144 samples which differ for composition and finishing. 12 different series of materials were considered. The samples differ in terms of surface properties and compositionfinishing and (bare surface, paint, paint + primer). For the sake of simplicity, only some of them will be described. In Figure 1 part of the list of samples is presented, labelled according to their composition and finishing.

SERIES	COMPOSITION	DESCRIPTION
M-TX	photocatalytic mortar	photocatalytic mortar TX: mortar CEN sib Rezzato 3% TiO2 PC 105
M-P	mortar + photocatalytic paint	mortar CEN with cement-based photocatalytic paint without primer
M-PP	mortar + primer + photocatalytic paint	mortar CEN treated with cinfix primer and with cement-based photocatalytic paint
GRC-P	glass reinforced concrete (GRC) + photocatalytic paint	GRC with cement-based photocatalytic paint without primer

Figure 1: Samples description.

Accelerated aging tests were conducted in a climatic chamber (Figure 2) to evaluate the performance decay and physical degradation over time.
Accelerated ageing tests, recreating particular environmental conditions and reproducing the effect of the aggression of atmospheric and chemical agents, allow the assessment of degradation level, duration and resistance of materials.

Figure 2: Climatic chamber for accelerated aging tests.

Test were set up according to different ageing cycles, such as T1: 50 ageing cycles, T2: 100 ageing cycles, T3: 150 ageing cycles. Each ageing cycle is composed by two sub-cycles, A and B, in each of which the different atmospheric conditions take place. The ageing cycles on samples in the climate chambers are programmed in terms of humidity, temperature, exposition to UV radiation (Figure 3).

SUB-CYCLE A				
phases	**T_{air} [°C]**	**T_{H2O} [°C]**	**UR [%]**	**Duration [min]**
1 Rain	20	15-20	-	60
2 Freezing	-20	-	-	90
3 Wet heat	55	-	95	60
4 Dry heat	70	-	40	80
SUB-CYCLE B				
phases	**T_{air} [°C]**	**T_{H2O} [°C]**	**UR [%]**	**Duration [min]**
1 UV irradiation	30	-	40	80

Figure 3: Scheduling of sub-cycles A and B.

3 RESULTS

Degradation phenomena of different entity were detected on all typologies. A chromatic alteration was observable on all typologies of samples, together with the occurrence of aging effect. Degradation analysis pointed out some types of degradation phenomena: colouring variations, microcracks, detachments, spot appearance, characterized by different intensity of occurrence. The most evident degradation phenomena are exfoliations on painted mortars, whose painting layer detached (Figure 4.

For each sample, greying and yellowing effects increased progressively and proportionally to the number of ageing cycles (being no pollutants inside the climate chamber, the changes are due solely to the action of the simulated atmospheric agents). Neither of them appeared predominantly since tappearance and developmenet was simultaneous.

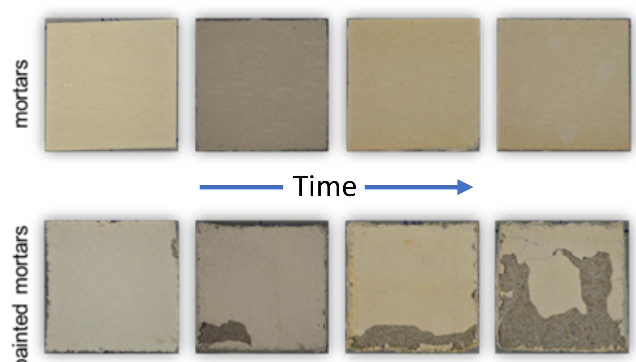

Figure 4: TiO_2 based materials surfaces after increasing number of cycles.

In order to compare different samples, five different degradation levels (DL) have been defined that range from 1 (negligible degradation) to 5 (very high degradation).

Results are based on arrays between the initial status T0 and those detected at the end of each time period T1, T2, T3.

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The most significant failure observed during the experimental campaign refers to painted mortars (Figure 5), with and without primer, and painted GRC.

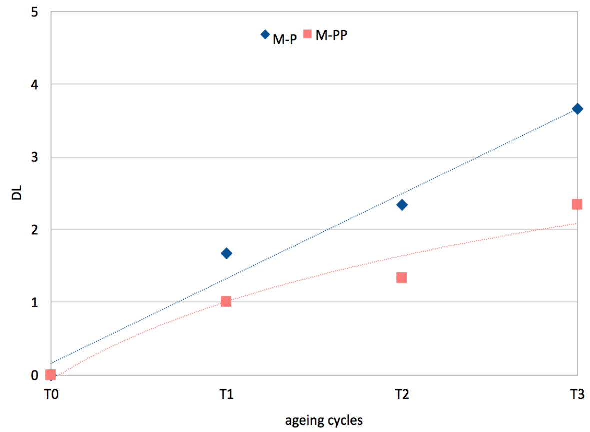

Figure 5: Comparison of degradation level (DL) trends between typologies M-PP (red) and M-P (blue).

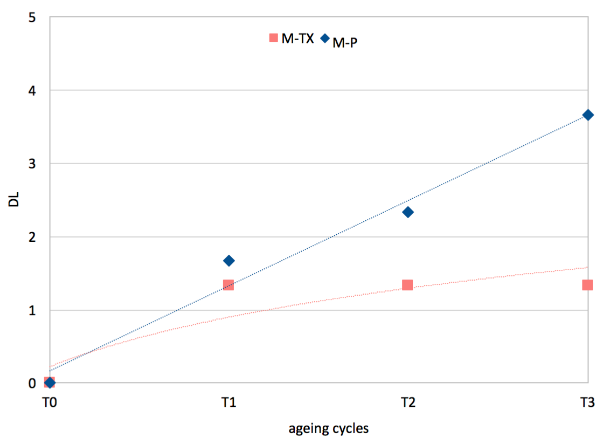

Figure 6: Comparison of degradation level (DL) trends between typologies M-TX (red) and M-P (blue).

The photocatalytic mortar M-TX present a better behavior than painted mortars with primer as it tends to stabilize its degradation trend after the second ageing cycle, (Figure 6). Painted mortars show light chromatic alterations and clear detachment, mainly detected at the end of the third ageing cycle until a degradation level higher than 3/5. A similar behavior is apparent on painted GRC, where detachments on the painting layer are localized on the bottom.

Further evaluations were set up in order to assess the decay of photoactivity on samples which underwent different aging cycles. Photocatalytic activity was determined through the application of Rhodamine B (Rh-B) solution on samples and the periodic monitoring of their change of colour in time during the exposition to UV radiation. Rh-B solution (10^{-5} M 0,05 g/l), a pink organic dye, was used as a model substance for studying photocatalytic efficiency of the different materials. Tests have been performed according to the Italian standard UNI 11259; after applying the dye on the surface, the sample is UV illuminated and the surface colour monitored using spectrophotometer (Konica Minolta CM-2600d). The parameter to take into account is R defined as follow:

$$R_4 = \frac{a*(0) - a*(4)}{a*(0)} \text{ x } 100 > 20\% \qquad (1)$$

$$R_{24} = \frac{a*(0) - a*(24)}{a*(0)} \text{ x } 100 > 50\% \qquad (2)$$

Where a* is, according to CIELab model, the colour cohordinate that ranges from red to green.

According to the standard, a material is considered photocatalytic if the following equations are satisfied: $R_4 > 20\%$; $R_{24} > 50\%$. Evaluations are based on the achievement of these thresholds, which determine in qualitative terms the photoactivity of samples.

	Time	$R_4 > 20\%$	$R_{24} > 50\%$
M-TX	T_0	**34%**	**64%**
	T_1	19%	34%
	T_2	17%	27%
	T_3	11%	38%
M-P	**Time**	**$R_4 > 20\%$**	**$R_{24} > 50\%$**
	T_0	15%	41%
	T_1	6%	23%
	T_2	5%	30%
	T_3	11%	44%
M-PP	**Time**	**$R_4 > 20\%$**	**$R_{24} > 50\%$**
	T_0	**26%**	**57%**
	T_1	-2%	24%
	T_2	9%	40%
	T_3	15%	46%

Figure 7: Comparison between R values of typologies M-TX, M-P and M-PP (red: meet threshold; pink: almost meet threshold; black: do not meet threshold).

Almost all typologies of sample show decreasing photocatalytic properties proportionally to ageing progresses. The more the sample is young, the greater are the values of R_4 and R_{24}. None of them meets threshold values of R at T3, since none of them is able to completely self-clean its surface.

Moreover, accelerated ageing tests should be compared with outdoor exposure, in order to apply a time rescaling of data. Information processed within accelerated tests must be validated by those revealed in natural exposure. The compared analysis would lead to relative equivalence between real and accelerated durations. The results of a previous experimental campaign allows a time rescaling since ageing cycles are equal. Conforming to the results achieved so far, it appears that some samples have reached state of non-performing their original functions. Reporting the cycles performed at a real-time scale, specimens should probably reach these damages within 4 years (corresponding to 3 ageing cycles). [2, 5]

It would be recommended to study the photocatalutic and self-cleaning behaviour by exposing the same types of samples to real climatic conditions, in order to compare the actual degradations with those found so far.

4 CONCLUSIONS

This research aims to provide basis for durability evaluation for planning of building maintenance, with reference to methods of prevision and control of service life and reliability of investigated materials. In order to plan maintenance, it is necessary to have access quantitative data on duration, service life and probabilistic value of reliability, i.e. the durability of complex building components. Knowing the way and the time according to which the decay of technological functions and properties occurs, is the best way to achieve planned conservation and restoration of initial performances. These data give information about non-functioning conditions and their occurrence probabilistic forecast, allowing intervention scheduling to prevent them to happen. In this field lies the concept of sustainability of the construction process, in terms of reasonable allocation of economic resources within the global cost in the life cycle.

The possibility of predicting the end of service life of the specimens is difficult because there are no references based on the functional and performance limits of these. The first step, in order to have an overview on the total useful life, will be surely going on with further accelerated aging cycles in the climatic chamber to examine their behavior.

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