

## TiO<sub>2</sub> coating on autoclaved aerated concrete both for self-cleaning and air-purifying purposes

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### ABSTRACT

Application of titanium dioxide photocatalysis on cement-based-materials has brought novel and environmentally friendly properties to construction materials, such as self-cleaning and air purification. Mixing TiO<sub>2</sub> based nano-powders with cement allows to obtain photoactive materials that have been able to degrade complex microorganisms which are common colonizers of building envelopes such as algae and fungi. Similarly, different air pollutants such as NO<sub>x</sub> and VOC's have been degraded when exposing these novel materials to light. Although these are important achievements, technical aspects still limit the broad application of this light-driven technology. In order to optimize the photocatalytic activity by exposing more TiO<sub>2</sub> to both pollutants and light than in other technologies (e.g. bulk mixing), development of different TiO<sub>2</sub> coating technologies provides an interesting approach. Therefore, the evaluation of a novel TiO<sub>2</sub> coating applied using a vacuum saturation technique, in relation to both its air purification and self-cleaning potential at laboratory scale is presented in this article. Self-cleaning is evaluated using *Chlorella vulgaris* as the algae specie in an accelerated algae growth test set-up. Although significant color changes were produced, results indicate a reduction of about 30 % in the area colonized with algae after 3 weeks of accelerated testing. Next to that, air purification is evaluated using toluene as the model pollutant in a flow-through UV-irradiated photo-reactor. Toluene removal efficiencies before and after the application of an accelerated weathering process on the coated samples kept constant at about 95 % (70 mg/m<sup>2</sup>.h) at an initial toluene concentration of 15 ppm<sub>v</sub> and a gas residence time of 3 min. Increasing the toluene load by applying higher toluene inlet concentrations (up to 35 ppm<sub>v</sub>) and lower gas residence times (1 min) did decrease the toluene removal efficiency to 32 %, but elimination rates up to 166 mg/m<sup>2</sup>.h were obtained. Both results indicate that using the developed coating promising air-purifying and self-cleaning properties can be obtained. However, the activity towards both effects is different indicating differences in the mass transfer and degradation kinetics of both types of reactants (air pollutants and microorganism cells) onto the catalyst surface.

**Keywords:** titanium dioxide; coatings; autoclaved aerated concrete; air purification; weathering; self-cleaning.

### 1. Introduction

Cementitious materials, especially those exposed to outdoor conditions, are directly and continuously exposed to many atmospheric pollutants (both gaseous organic and inorganic contaminants and particulate matter), microorganisms (e.g. algae, fungi, cyanobacteria) and different weather conditions. They suffer from accelerated deterioration which can produce in many cases important changes in the materials' properties, particularly regarding aesthetic properties. The color of a material belonging to a building facade, for example, has to offer a pleasant appearance that should project to the public an adequate perception of the quality

and maintenance of the building. However, serious color changes are produced on buildings and structures due to their relatively high porosity, roughness and rich mineral composition that enable the easy deposition of colored organic pollutants and particulate matter, and that facilitate microbiological growth [1]. In order to avoid and control color changes of cementitious materials, the use of additives, sealers, chemical cleaners, painting, restoration and repair works are common practices in buildings or structures. Nevertheless, this effort, though valuable, has not led to a complete elimination of the problem because the nature of atmospheric pollutants and micro-organisms on cementitious materials is not entirely known [2-3]. On the other hand, apart from the direct costs of these activities, indirect costs related to environmental and operational losses should be also considered in the selection of appropriate solutions. It is therefore important to tackle these problems by formulating efficient, innovative and more environmentally friendly cementitious materials. In this sense, thanks to the hydrophilic and degrading properties of titanium dioxide ( $\text{TiO}_2$ ) used in heterogeneous photocatalysis, it seems possible to develop an autonomic cleaning process (self-cleaning) on cementitious materials that only requires sun light as the energy source. Furthermore, considering that  $\text{TiO}_2$  photocatalysis also allows degradation of some organic air pollutants such as industrial or traffic related volatile organic compounds (VOCs) and inorganic air pollutants such as nitrogen oxides ( $\text{NO}_x$ ),  $\text{TiO}_2$  loaded cementitious materials have not only the potential to increase the life cycle of cement-based materials using their self-cleaning properties, but they could also contribute to a better air quality in densely populated areas (with high traffic rate) by their air-purifying properties.

In general, cementitious materials offer two important conditions to the  $\text{TiO}_2$  photocatalysis that make them ideal for the application of this light-driven technology. First, the air fouling substances and pollutants sources are close to the cementitious materials. Second, when cement based materials are applied outdoor, they offer considerable surface areas which experience sun exposure during the whole year.

Although already a small number of products using this technology is present in the construction market (mainly  $\text{TiO}_2$ -added cement products), their low observed efficiencies in situ (both regarding self-cleaning and air-purifying properties), have limited the broad application of this technology [4-5]. In order to optimize the photocatalytic activity by exposing more  $\text{TiO}_2$  to both pollutants and light compared to common  $\text{TiO}_2$  additions, the development of different  $\text{TiO}_2$  coating technologies provides an interesting approach. Therefore, the evaluation of a novel  $\text{TiO}_2$  coating applied using a vacuum saturation technique, in relation to both its air purification and self-cleaning potential at laboratory scale is presented in this article.

## **2. Experimental study**

### *2.1. Preparation of the $\text{TiO}_2$ coating on autoclaved aerated concrete*

A new  $\text{TiO}_2$  coating applied on autoclaved aerated concrete using a vacuum saturation technique (SVS) is evaluated in this research paper. The  $\text{TiO}_2$  nanoparticles used are ANX Type N100. This is an experimental nanocrystalline  $\text{TiO}_2$  obtained from Kemira Pigments Oy (Pori, Finland). An X-ray diffractometric analysis with a step size of 0.02 degrees and a step time of 1 s (Siemens D5000) on this  $\text{TiO}_2$  showed a pure anatase composition. Furthermore, determined by a volumetric  $\text{N}_2$ -gas adsorption method (Belsorp-mini II), a specific surface area of  $100 \text{ m}^2/\text{g}$  was measured for this nanomaterial. Information supplied by the manufacturer indicates a crystal size of 20 nm (TEM microscope) and a particle size ( $d_{50}$ ) of  $2 \mu\text{m}$  (laser diffraction). Additionally, according to the manufacturer, the content of sulphur (0.4 %; ICP-AES),  $\text{Fe}_2\text{O}_3$  (70 mg/kg; X-ray fluorescence) and sodium (150 mg/kg; AAS) make this  $\text{TiO}_2$  ideal for photoactive concrete due its low alkali metal and sulphur contents.

Autoclaved aerated concrete samples were provided by Xella and cut with the following dimensions (length  $\times$  width  $\times$  height): 100 mm  $\times$  80 mm  $\times$  10 mm and 160 mm  $\times$  80 mm  $\times$  10 mm for air purification and self-cleaning experiments, respectively. The open porosity of this material determined by vacuum saturation (ASTM C1202 Vacuum Saturation Method), and the roughness (Ra) measured using an automated laser measurement system (ALM), amounted 74.9  $\pm$  2.9 % and 70  $\pm$  27  $\mu$ m, respectively [6-7]. In order to have a better coating quality, the autoclaved aerated concrete samples were washed and dried in the oven (Vötsch – Industrietechnik) at 105°C during 48 h before coating. Afterwards, the 6 autoclaved aerated concrete samples (3 for air purification and 3 for self-cleaning experiments) were installed in a vacuum saturation tank at 100 mbar during 2.5 h. Later, a TiO<sub>2</sub>-ethanol suspension (0.05 g/ml) was injected into the vacuum tank to coat the samples. When all samples were covered with the suspension, the vacuum process was stopped and the samples were left in the open vacuum tank during at least 30 min, prior to drying at 105 °C during 48 h. For comparison, also a set of 3 uncoated autoclaved aerated concrete samples (REF) was prepared during the experiments.

## 2.2. Testing procedures

### 2.2.1. Self-cleaning experiments

Self-cleaning is evaluated stimulating the algae growth or algal fouling on the TiO<sub>2</sub> coated autoclaved aerated concrete samples and comparing this to that one produced on non-coated samples (REF). The accelerated algae growth on the samples was achieved by means of a water run-off test developed in house [8]. This modular test set-up designed to allow simultaneous evaluation of different strategies to minimize algal fouling on cement-based materials, consists of independent compartments where samples are placed (sample holder) and subjected to two daily (every 12 hours) alternate wet cycles with an algae suspension (6.5  $\times$  10<sup>8</sup> cells/L) lasting 1.5 hours. Furthermore, as algae are photosynthetic microorganisms, their growth is also stimulated by creating a 12 h day and night regime, which started simultaneously with the run-off periods. Day regimes were created by a combination of fluorescent tubes GroLux 30 W that are specially designed to assist algae growth (Sylvania). Irradiation peaks from this lamp type are at 365, 400, 550 and 580 nm. Complementary UV-A lamps type BLB TL-D 36 W (Philips) were adapted to this test set-up to activate the expected photocatalytic reaction. Irradiation peaks from this lamp type are at 352 and 368 nm. Measured by a UV radiometer with a sensor calibrated at 365 nm (UVP), irradiation level averages on all specimens at the test set-up ranged from 0.5  $\pm$  0.2 mW/cm<sup>2</sup> at the lowest part to 1.4  $\pm$  0.3 mW/cm<sup>2</sup> at the highest part. On the other hand, as darkness triggers other cell activities, algae need several hours of darkness a day. Therefore, during the night regime, all light systems were off. Finally, for creating a suitable environment for the algae growth process, the accelerated algae growth test set-up is placed inside a room with high relative humidity. By means of a thermo-hygrometer sensor (Logger Testo 175-H2) this parameter together with the temperature were continuously monitored during the whole test. Temperatures ranged between 24.2 °C (day) and 20.6 °C (night). Similarly, relative humidity ranged between 82.4 % (day) and 92.4 % (night).

Based upon representativeness and easy of liquid culture, *Chlorella vulgaris* var. *viridis chodat.*, was the algae specie selected in this research. The strain was obtained from the culture collection of algae and protozoa (CCAP) from Dunstaffnage Marine Laboratory (Scotland, UK) (accession number CCA 211/12). Batch cultures of the algae were grown under sterile conditions in Erlenmeyers containing 1 L of Walne medium with addition of 0.2 mg thiamine chlorhydrate and 0.01 mg vitamin B12. The Erlenmeyers were continuously exposed to light

by means of lamps GroLux 30 W (Sylvania) on a KS 501 rotary shaker (Ilka Werke) at 100 rpm. Air was provided by means of an Air plus 3 air pump (Project blue). For the preparation of the medium, 1 mL of sterile concentrated Walne and 0.1 mL of vitamin solution were added to 1 L autoclaved mineral water (Cristaline, natural spring water, Mériqnyies, France). Each week, new batch cultures were grown by transferring 150 mL of the one week old culture to 1 L of fresh medium. The remaining culture solution was used to inoculate the PET bottles used in the accelerated algae growth test set-up. The amount of cells per mL was determined by means of a Zeiss Axioskop II plus light microscope (Zeiss) and a counting chamber.

As the problem of algal fouling on cement-based materials has important consequences in the aesthetical properties of building materials, human visual inspection (images) should be enough to judge the strategies to avoid algal fouling (e.g. TiO<sub>2</sub> photocatalysis). However, in order to avoid human's eye subjectivity, two other quantitative criteria which are based on the CIE Lab color space (L\*, a\*, b\* coordinates) were used besides visual inspection. On one hand, as algal fouling on cement-based materials can be a localized or global problem on the materials surfaces, the area covered with algae or fouled area (%) on the specimens is determined by means of image analysis. In this, fouled areas are identified with white pixels while not fouled with black pixels based on a b\* threshold. From the latter, the percentage of area covered with algae can be calculated as indicated in Eq. (1).

$$\text{Covered area (\%)} = \left( \frac{\text{white pixels}}{\text{white pixels} + \text{black pixels}} \right) \times 100 \quad \text{Eq. (1)}$$

On the other hand, due to *chlorophyll* presence, algae growth quality is related with the green intensity of the colonized area. Therefore, analysis of color changes ( $\Delta E$ ) on the surface of the specimens is conducted by means of colorimetric measurements and using Eq. (2).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad \text{Eq. (2)}$$

with  $\Delta L = L_t^* - L_0^*$ ;  $\Delta a = a_t^* - a_0^*$ ;  $\Delta b = b_t^* - b_0^*$  and  $L_t^*$ ,  $a_t^*$ ,  $b_t^*$  color values after a specific time (t) and  $L_0^*$ ,  $a_0^*$ ,  $b_0^*$  color values before starting the test (samples not fouled). Based on computer simulations estimating the human perception of the color changes ( $\Delta E$ ) after the aesthetic rehabilitation of architectural concrete, the produced color changes on the paste specimens could be assessed following the parameters indicated in reference [9]. In this research, both monitoring data (color changes and area covered with algae) during the accelerated algae growth process on the test specimens were taken on a weekly basis. More details about these methodologies can be found in De Muynck *et al.* (2009) [8].

### 2.2.2 Air purification experiments

In this research work, the air purification potential of a TiO<sub>2</sub> coating applied on autoclaved aerated concrete samples was determined before and after the coated samples were submitted to an accelerated weathering process. For evaluating the air purification potential, the photocatalytic degradation of toluene (TOL) in air was investigated in a rectangular plexiglass flat-plate lab-scale photoreactor (length (L): 20 cm, width (W): 10 cm, height (H): 4 cm), operating in a flow-through mode [7]. Gas sampling points are provided at both the inlet and outlet of the reactor. A TiO<sub>2</sub> coated aerated concrete sample was put into the reactor, resulting into a free gas volume of 500 mL and a gas residence time of about 3 min. The geometric area of the TiO<sub>2</sub> coated top-side of each substrate amounted 80 cm<sup>2</sup>. UV irradiation was provided by a blacklight blue 18W UV lamp (340 <  $\lambda$  (nm) < 410; maximum emission at 365 nm, Philips Lighting, Turnhout, Belgium), covered by a half cylindrical reflector and positioned just above the 2.2 mm thick borofloat glass-plate closing the reactor. By means of potassium fer-

rioxalate actinometry, light intensity (I) at the catalyst surface was determined to be 2.3 mW/cm<sup>2</sup>. Toluene inlet concentrations amounted 14.9 ± 1.3 ppm<sub>v</sub>. The air relative humidity (RH, %) and temperature (T, °C) were monitored using a TESTO 110 sensor device (Testo NV) and were similar as observed in real ambient environment (RH = 53.9 ± 0.5 % and T = 23.6 ± 0.5 °C). Inlet and outlet air samples were taken by solid-phase microextraction (SPME) using a 100 μm polydimethylsiloxane fibre (Supelco) as the extraction phase. Chemical analyses were carried out with an Agilent 4890D Series gas chromatograph equipped with a flame ionization detector (FID). Equilibrated water-gas systems with a known toluene headspace concentration were used for calibration. Prior to all photocatalytic degradation experiments, humidified TOL contaminated air was passed through the reactor in the absence of UV irradiation for at least 12h to obtain the desired RH and TOL gas-solid adsorption-desorption equilibrium throughout the whole reactor, the latter being exemplified by TOL in- and outlet concentrations not significantly different from each other (t-test, significance level α ≥ 0.05). Afterwards, the UV lamp was switched on and photocatalytic TOL degradation was carefully followed for at least 30 h. Finally, the lamp was switched off and the TOL in- and outlet concentrations were measured for an additional period of approximately 4 h. Later, for evaluating the TOL degradation obtained with each TiO<sub>2</sub> loaded material, its removal efficiency (η<sub>removal</sub>), loading rate (LR) and elimination rate (ER) is calculated as presented in Equations (3) to (5). Afterwards, to estimate the effect of weathering on this material, samples are submitted to an accelerated weathering process which was divided in 2 stages (WI and WII). So, samples are installed again in the photoreactor for being re-evaluated in relation to the air purification potential after each weathering stage.

$$\eta_{\text{removal}} (\%) = \left( 1 - \frac{[\text{TOL}]_{\text{out}}}{[\text{TOL}]_{\text{in}}} \right) \times 100 \quad (3) \quad \text{LR (mgTOL/m}^2 \cdot \text{h)} = \frac{Q}{A} \times [\text{TOL}]_{\text{in}} \quad (4)$$

$$\text{ER (mgTOL/m}^2 \cdot \text{h)} = \frac{Q}{A} \times ([\text{TOL}]_{\text{in}} - [\text{TOL}]_{\text{out}}) \quad (5)$$

The weathering process applied on the TiO<sub>2</sub> coated concrete samples was produced by the same water run-off test operating in another mode as was used to produce the accelerated algae growth on the coated samples. In this case, this laboratory test set-up develops an accelerated weathering process that simulates in a fast way a typical façade abrasion. By creating every 12 hours rain-dry cycles and day-night coordinated periods the samples are weathered during 2 weeks (1 week ~ one weathering stage). Considering the simulated rain conditions (120 mm/h) at the test set-up and the Belgium average cumulative precipitation index (800 mm/year), this test duration represents 25 years of weathering. Rain cycles are produced in each compartment by pumping 1 L of mineral water during 12 h by means of a NW33 aquarium pump. For each compartment, mineral water is replaced after 3.5 days to have more similarity with the real rain process in which water is non-recirculating. Dry cycles as well are obtained by switching off the pumps during 12 h. Day-night stages last also 12 h each. The test set-up is placed in an air-conditioned room in which the changes in temperature and relative humidity during the daily cycles are measured using a thermo-hygrometer Logger Testo 175 – H2. During the weathering process, relative humidity values amounted 89.2 % and 93.6 % during day and night stages respectively. On the other hand, temperatures reached 21.7 °C and 20.9 °C also during day and night stages, respectively. In order to monitor the effect of weathering on the samples, the TiO<sub>2</sub> content of the coated and weathered samples was determined as the difference in mass between the non-coated samples and the coated samples at stage W0 (before weathering), WI, and WII. An analytical balance (Mettler Toledo AG04) with a precision of 0.1 mg was used. Secondly, in order to visualize the coating morphology changes and especially the thickness evolution because of weathering, coated samples were

cut in suitable sizes, and Scanning Electron Microscopy (SEM) equipped with Energy-dispersive X-ray spectroscopy (EDAX) analysis (Philips XL 30 ESEM) were taken before and after weathering. The coating thickness ( $t$ ) was then determined (when possible) by using a graphical measurement tool of the software (supplied by SEM producer) on at least 10 different points randomly distributed on each coated sample. Similarly, also in order to evaluate the coating removal, color changes ( $\Delta E$ ) produced by the weathering stages were measured as conducted during the accelerated algae growth experiments.

### 3. Results and discussion

#### 3.1. Self-cleaning properties

During these experiments, the self-cleaning effect produced on the  $\text{TiO}_2$  coated samples was not enough to avoid completely algal fouling. However, as can be seen in Figs. 1 and 2, a smaller fouled area and less intense color changes were observed on the  $\text{TiO}_2$  coated samples (SVS) compared to the non-coated samples (REF). The most significant result was obtained until the 3<sup>rd</sup> test week with a 30% reduction of the area colonized with algae compared to the non-coated samples (REF). Nevertheless, based on the scale of human perception of the color changes indicated in reference [9], it can be said that 'large' color changes were observed on the  $\text{TiO}_2$  coated samples as result of the algae growth.

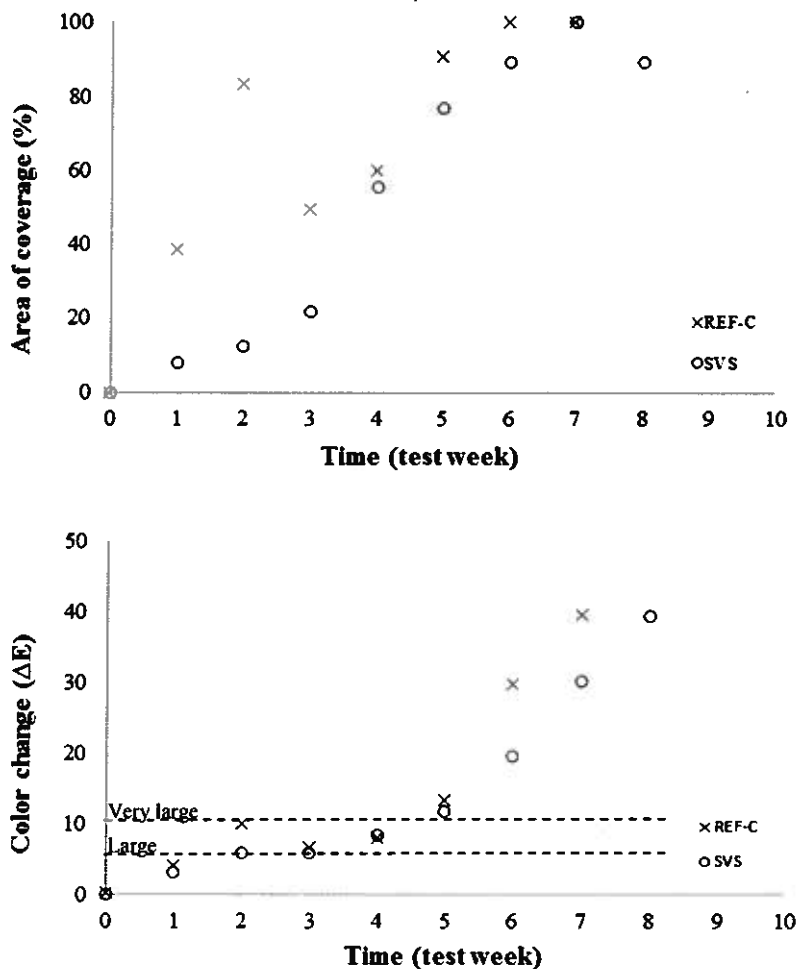
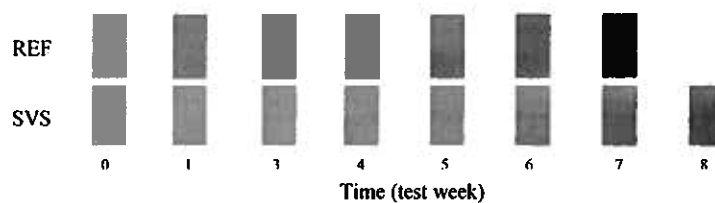


Fig. 1. Evolution of the area covered with algae (%) and color changes ( $\Delta E$ ) on the  $\text{TiO}_2$  coated auto-cured aerated concrete samples during the accelerated algae growth test.



**Fig. 2.** Evolution of the visual appearance during the accelerated algae growth test on one TiO<sub>2</sub> coated autoclaved aerated concrete sample and a reference sample.

Overall, the obtained results are in close agreement with those reported previously by Maury Ramirez and De Belie (2009) using the same coating applied on autoclaved aerated concrete samples but using a higher cell concentration ( $\sim 4 \times 10^7$  cell/mL) and fluorescent lamps (Gro-lux 30W, Sylvania) [10]. In the last case, a reduction in the fouled area of about 40% was observed after the 4<sup>th</sup> test week. Similar results were obtained by De Muynck *et al.* (2009) with a water repellent applied on autoclaved aerated concrete (fouled area  $\approx 40\%$ ) after the 4<sup>th</sup> test week. However, better results were obtained using two different pure biocides (fouled area < 20%) or two combined biocides with water repellents (fouled area < 40%) also on autoclaved aerated concrete samples at the same algae cell concentration used in this experiments ( $6.5 \times 10^8$  cell/L) [8].

Using other test methodologies, Linkous *et al.* (2000) reported that a coating based on a TiO<sub>2</sub> dispersion (10% on a weight basis) produced a photocatalytic inhibition of around 66% of the algae growth (*Oedogonium*) when applied on a cement substrate under a combination of fluorescent and UV-A lamps which gives in total an intensity of 12 W/m<sup>2</sup>. However, efficiencies about 87% were found when adding 1% of noble metals such as Pt and Ir [11]. Very recently, mortars containing TiO<sub>2</sub> or TiO<sub>2</sub> doped (0.5 wt%) with Fe<sup>3+</sup> (12 : 4 : 4 : 1 – sand: lime: anatase: Portland cement on a volume basis) were tested and compared against two commercial biocides and reference samples in relation to the antimicrobial effect on a mixed culture of two green microalgae (*Stichococcus bacillaris*, *Chlorella ellipsoidea*) and one cyanobacteria (*Gleocapsa dermochroa*). Results based on averages of *chlorophyll a* fluorescence emission measurements and *chlorophyll a* contents indicated that the TiO<sub>2</sub> antimicrobial activity from the mortars was effective after 4 months of exposure to outdoor conditions. Algae growth ratios after the test reached 0% (no algae) and 11.8% for the mortar containing TiO<sub>2</sub> and doped TiO<sub>2</sub>, respectively. Application of the same photocatalyst within coatings onto 2 wall surfaces of the Palacio Nacional da Pena (Portugal) showed promising results concerning the degradation of lichens and other phototrophic microorganisms after two weeks of color monitoring. However, long lasting effects of this application have still to be confirmed [12]. In a longer time frame, roofing tiles (red engobe, natural clay, black varnish) coated by a sol-gel technology were evaluated while exposed during more than 6 years to outdoor conditions in 6 different locations in Germany. Results based on monitoring of the phototrophic biomass by pulse amplitude modulation (PAM) fluorometry, image analysis, and visual evaluation indicated that photocatalytic surfaces did not affect phototrophic biofilms [13].

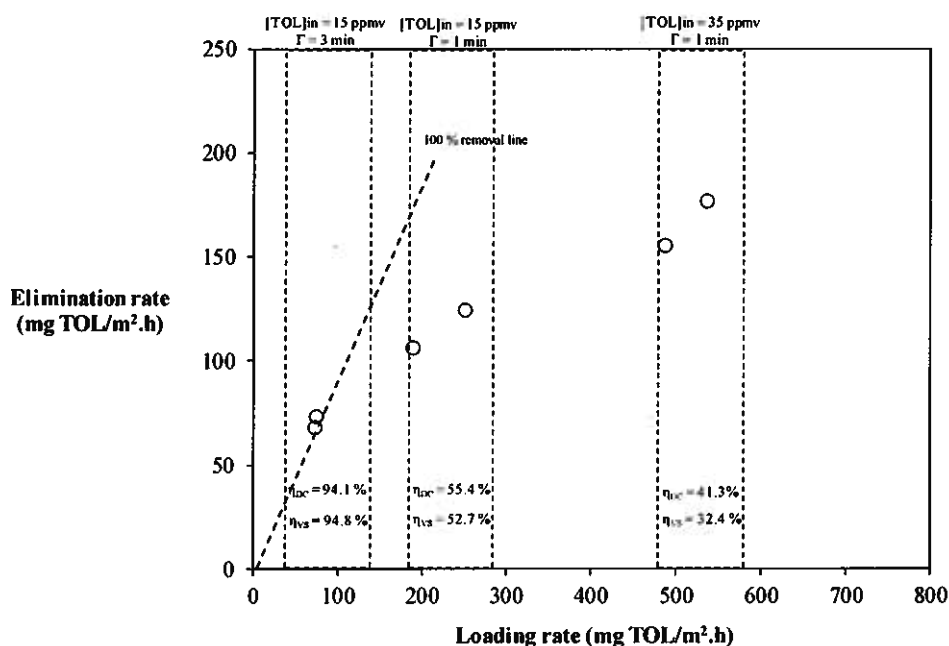
### 3.2 Air purification properties

Both before and after weathering stages WI and WII, highly reproducible toluene removal efficiencies of about 95% (corresponding to ER = 70 mg/m<sup>2</sup>·h) were obtained during UV-irradiation at TOL inlet concentration of 15 ppm<sub>v</sub>, 3 min gas residence time, 50% relative humidity and temperature about 25°C. In contrast, no significant difference between TOL in- and outlet concentrations was measured in the dark. In a similar experiment, toluene removal on a non-coated autoclaved aerated concrete sample (REF) was investigated at the same con-

ditions of inlet concentration, gas residence time, relative humidity and temperature. Results indicated that there was no significant toluene removal, as exemplified by toluene inlet and outlet concentrations averages of 12.0 and 12.6 ppm<sub>v</sub>, respectively, during UV irradiation. In the same test set-up and at similar conditions (12 ppm<sub>v</sub> toluene inlet concentration; RH = 41%; T = 25°C; τ = 3 min, I = 2.3 mW/cm<sup>2</sup>), Maury Ramirez *et al.* (2010) obtained toluene removal efficiencies from 41% to 86% (equivalent to toluene ER from 28 to 48 mg/m<sup>2</sup>h) using different dip-coated concrete types. When using a sol-gel method on the same concrete types, however, removal efficiencies did not exceed 4% (corresponding to a maximum toluene ER of 4.0 mg/m<sup>2</sup>h) [7].

Regarding the effect of the weathering process on the TiO<sub>2</sub> coated samples, the TiO<sub>2</sub> content (~11 g) dropped by 90% and 93% after WI and WII, respectively. Similarly, the coating thickness dropped from 1150 μm to 18 μm (98% reduction) after WI, corresponding well with the decrease in TiO<sub>2</sub> content. After WII, the coating thickness was no longer measurable. However, the presence of TiO<sub>2</sub> was confirmed by SEM-Edax analyses, so that is expected that these nanoparticles are responsible for the maintaining photocatalytic activity towards toluene degradation. Finally, color changes induced by the weathering stages WI and WII were 5.0 and 4.6, respectively.

In order to subject the coated samples to higher toluene loading rates (LR), both the gas flow rate and the inlet concentration were varied. Consequently, the toluene removal on the weathered TiO<sub>2</sub> coated samples (i.e. after WII) was measured at inlet concentrations up to 35 ppm<sub>v</sub> and gas residence times between 1 and 3 min, corresponding to loading rates between 65 and 540 mg/m<sup>2</sup>h. Results are given in Fig. 3.



**Fig. 3.** Elimination rates (ER), loading rates (LR) and toluene removal efficiencies ( $\eta_{\text{removal}}$ ) at different gas residence times ( $\tau = 1$  to 3 min) and toluene inlet concentrations ( $[\text{TOL}]_{\text{in}} = 15$  to 35 ppm<sub>v</sub>) using the TiO<sub>2</sub> coated samples.

By reducing the residence time by a factor of 3, the toluene removal efficiency dropped from about 95% to about 53%. Similarly, increasing the inlet concentration by a factor of 2 further decreased the toluene removal efficiency to 32%. Despite this decline in removal efficiency, the TOL elimination rates (ER) increased from 70 mg/m<sup>2</sup>h to 166 mg/m<sup>2</sup>h at increasing loading rate. Using TiO<sub>2</sub> containing roofing tiles and corrugated sheets, Demeestere *et al.* (2008)



obtained toluene removal efficiencies and ER up to 61% and 107 mg/m<sup>2</sup>h, respectively, at toluene inlet concentrations between 23-465 ppm<sub>v</sub>, RH = 50%, T = 25°C, τ = 2 min and I = 2.3 mW/cm<sup>2</sup> [14].

Other researchers like Strini *et al.* (2005) used TiO<sub>2</sub> nanopowder embedded in white Portland cement to degrade BTEX compounds from air at concentrations of 400 µg/m<sup>3</sup>, RH = 50%, T = 23°C, τ = 20 min and I = 1.36 mW/cm<sup>2</sup>. Removal efficiencies between 5% and 54% were obtained, corresponding to ER up to 120 µg/m<sup>2</sup>h [15]. Contrary, Chen *et al.* (2011) evidenced no toluene removal at different inlet concentrations (200-800 ppb), neither as single compound nor when mixing toluene with NO (400 ppb), using TiO<sub>2</sub> added concretes (5% and 10% on a weight basis). In this case, temperature, relative humidity, gas residence time and light intensity amounted to 25°C, 50%, 1.5-9.0 min, and 1 mW/cm<sup>2</sup>, respectively [16].

#### 4. Conclusions

Both the self-cleaning and air purification potential of the TiO<sub>2</sub> coating produced on autoclaved aerated concrete samples is reported in this article. The photocatalytic degradation of toluene produced by the TiO<sub>2</sub> coated samples is almost complete (95%) before and after the application of the weathering process. Furthermore, although increasing air flow and pollutant concentration decreases significantly the removal efficiency (32%), one of the highest toluene removal rates reported in literature (166 mg/m<sup>2</sup>h) was obtained with this photocatalytic material. Contrary, only a delay (30%) in the algal fouling was obtained with this photocatalytic material after three testing weeks. These different results concerning air purification and self-cleaning are a good indication that the photocatalytic oxidation occurring in the cement-based materials is a very complex interaction between the photocatalysts, the reactants and photons [16] and in this particular case, it can be assumed that the protective cell structures of the algae cell wall are more difficult to degrade than the toluene molecules (gas phase) using the same photocatalytic material at the studied conditions. Similar results have been recently reported by Folli and Macphee (2011) comparing the self-cleaning (measured by rhodamine B degradation) and air purification (measured by NO<sub>x</sub> removal) results of two different added TiO<sub>2</sub> cements [17].

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