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Self cleaning and depolluting glass reinforced concrete panels: Fabrication, optimization and durability evaluation

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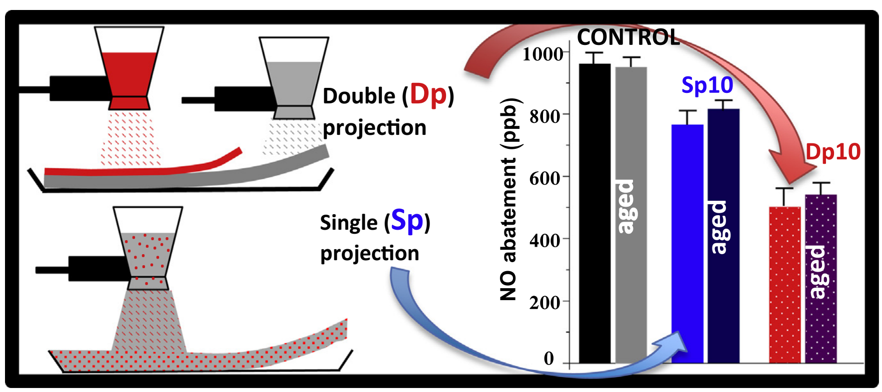
HIGHLIGHTS

- Photocatalytic glass reinforced concrete panels are fabricated and characterized.
- Micro-sized anatase (TiO_2) up to a 10% is included as photocatalytic agent.
- A double projection procedure allows to maximize the surface exposure of anatase.
- TiO_2 inclusion induces a mechanical loss but still over the standard minimum limit.
- This performance maintains over time as confirmed by an accelerated weathering test.

GRAPHICAL ABSTRACT



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ABSTRACT

The introduction of titanium dioxide within glass reinforced concrete panels is optimized in order to fabricate commercially affordable photocatalytic facades. A double projection method, easily scalable, that facilitates the concentration of the anatase on the surface, is developed. The so obtained materials show superior self-cleaning and NO_x degradation capacities to those samples prepared by a single projection starting from the same amounts of titanium oxide. TiO_2 percentages over a 5% ensure self-cleaning abilities that remain over the standardized thresholds even for aged panels, whereas their NO_x photocatalytic capacity slightly decreases as a consequence of the aging treatment.

1. Introduction

The use of titanium dioxide in the construction industry to improve the performance of different materials due to their self-cleaning and pollutant degrading capacities is continuously growing and extensively being applied [1–13]. In fact, several applications such as soundproof walls, tunnels coverings or pavements in the road constructions field, tiles, wallpaper, windows, paints or coatings as interior furnishing materials and glass, plastics films, paints or panels as exterior protective envelopes are already being tested under real conditions and even commercially employed [14–16].

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Titanium dioxide, traditionally employed as a pigmentary component of paints, paper, inks or plastics due to its non-toxic nature, brightness and high refractive index that confers opacity and whiteness, has gained new applications derived from its photocatalytic properties [17,18]. This photocatalytic capacity has been extensively studied and reviewed by several authors [19–23]; due to its band gap energy (3.23 V) anatase shows, apparently, the best photocatalytic efficiency among the different crystalline phases of this oxide. However, it must be taken into account that not only the crystal phase but also its microstructure and texture have a critical role on the capacity of degradation [24]. In this sense, high surface areas, which are definitively associated with low crystal size, improve the degradation capacity. Consequently, nanosized (nanocrystalline) anatase has flourished as the material of choice for any application related with the use of titanium dioxide as catalytic material [25,26].

In fact, several works are devoted to improve the photocatalytic performance by controlling the crystal phase and size through different synthetic routes including doping with different substances [20,27,28]. However, the use of such tailored products in the construction industry is limited by the scarce quantities available and, finally, by the high costs deriving from the amounts required for real scale applications. Moreover, the widespread use of nanoparticulate powders for different applications has become a serious concern for health and environmental reasons [29,30]. Indeed, the particular application of such nano-dispersed products critically affects the cement curing process and its ulterior performance [31–37]. Taking all these reasons into consideration some authors [2,18,38,39] have studied whether the benefits of using microsized powders compensate the expected decrease on the photocatalytic efficiency.

Another practical consideration is related to the maximum exposition of photocatalytic active agent, i.e. the titanium dioxide, to the substances to be degraded. In this sense, different strategies have been adopted to improve the exposition of the anatase particles by minimizing their masking within cementitious matrix, integration within an ordered structure [40,41], inclusion of aggregates [42,43] or increasing the porosity [44–46]. Another approximation, successfully applied for the preservation of the architectural heritage [35,47–49], consists on the creation of a TiO_2-rich layer onto the surface of the material through different spraying or painting techniques [5,26,50–57].

Considering the critical role of the surface exposition of these materials, glass reinforced concrete (GRC), a composite material worldwide employed to fabricate buildings facades [58–60], seems to be an excellent support to create self-cleaning and depolluting envelopes. Moreover, the reduced thickness and weight of GRC, i.e. less material is employed than other traditional precast equivalents, together with a maximum surface exposure in relation to the volume of cement employed, converts TiO_2 containing GRC into not only a green material [61,62], due to its minor environmental impact, but an active depolluting agent. However, the few attempts to convert GRC panels into a photo-degrading surface are based on their coating with a TiO_2/SiO_2 gel layer [63].

In addition to the pollutant sequestrating beneficial effect, understood as an active transformation and not merely storage, some authors have pointed out that the profits of the self-cleaning action are not only related to aesthetical effects but also to the preservation of a high solar reflectance and thermal emittance. The soot and stain removal from facades should ensure a more efficient reflection of the solar direct radiation towards the sky and not to other buildings, thus mitigating the generation of urban heat islands and the cooling requirements [64,65].

In this work a practical and easily implemented strategy to maximize the inclusion of a photocatalytic agent in GRC panels is proposed and evaluated in terms of durability. In such an affordable way the enormous surface to be covered by this type of reinforced concrete could convert into environmental-friendly facades capable of transforming and fixate pollutants while maintaining their functional and aesthetical properties.

2. Materials and methods

2.1. Materials

The raw components: sand, cement and plasticizer were the same as those routinely employed in the preparation of commercialized panels.

The titanium dioxide component was chosen among different chemical products suppliers as a function of the verification of anatase as a single phase, its crystallinity and economic cost. This last factor could not be discarded taking into account that this study was carried out in a factory at a real scale having the final objective of generating a competitive commercial product. In this sense the selected substance (Panreac-2021010914) could be indexed, after its characterization by XRD, as an anatase single phase with a crystal size of around 200 nm and a N_2 surface of 10 m^2/g, much different (<25 nm, 50 m^2/g, respectively) to one of the commercialized products as "nano" that cost 30 times more than the chosen anatase.

2.2. Panels fabrication

Different formulations (Table 1) based on the composition usually employed to fabricate commercial panels, i.e. $\approx$50 kg of cement (sulphate-Resistant Portland), 50 kg of sand (silica content >96%, particle size <1.2 mm), 16–18 L of water and 0.5 kg of a plasticizer, have been prepared in this work. These formulations were employed to prepare $50 \times 80 \times 1$ cm panels. An alkali-resistant fiber at a percentage of 3% was employed, being the fiber/mortar ratio adjusted between 4.67 and 5.00. The quantity of water varied as a function of the environmental conditions and the components' requirements. The casting of the panels was carried out by spray up; the concrete is sprayed out of a gun-like nozzle that also chops and sprays a separate stream of fibers. The concrete and fibers mix upon hitting the mold surface. Glass fiber is fed off of a spool in a continuous thread into the gun, where blades cut it just before it is sprayed. The so obtained panels were demoulded after 24 h and cured inside the factory at ambient temperature (Average Temperature, 15.4 °C, and degree humidity, 53%). This fabrication method carried out in the factory following the procedure to prepare the commercial panels has been termed as "Single Projection" in this work. The unique variation is the inclusion of the TiO_2 powder that is previously thoroughly mixed with the cement component; this mixture is added together with sand into the water volume.

In order to concentrate the anatase presence in the surface of the panels, a second production method named "Double Projection" has been optimized. This modification consisted on projecting, firstly, a slurry containing all the titanium dioxide followed by a second spraying of a paste containing the remaining amounts of the components (Table 1). Both routes are schematized in Fig. 1 including some photographs of the actual fabrication of the panels in the factory.

2.3. Components and panels characterization

In order to characterize the mechanical performance, the panels were cut and divided in coupons in accordance with the standards of UNE-EN_1170-5 [66] that rules the measurement of the bending strength. The slump test that gives idea of the plasticity of the mortar was carried out following the standard UNE-EN_1170-1 [67].