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A STUDY OF PHOTOCATALYTIC CEMENTITIOUS MATERIALS COMPONENTS FOR SUSTAINABLE INFRASTRUCTURE OF CONSTRUCTION DEVELOPMENT

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ABSTRACT

Sustainable development implies effort in order to be able to improve and safeguard future environmental conditions, while improving actual quality of life. A key aspect of this approach is related to construction materials and technologies sustainability since development is strictly related to construction capacity, not only for housing but even and mainly for infrastructures. Within this frame the use of photocatalytic products has been promoted and exploited, due to their ability to abate organic as well inorganic air pollutants and keep surfaces clean with time. In particular, the photocatalytic activity of paint, mortar, render and concrete made with a photocatalytic cement has been considered when applied to road infrastructures, like pervious concrete pavements, concrete lining and coatings for tunnels and also road accessories like barriers and walls.

KEYWORDS: Photocatalytic Cement, Sustainable Infrastructure, Pervious Concrete, Concrete Lining, Tunnel Coating

INTRODUCTION

Sustainable and affordable technologies and structures are an important aspect of the environment, economy and energy efficiency. When used in partnership with each other, these can improve the quality of life for our communities. The environmental pollution in urban areas is one of the causes for poor indoor air quality in buildings, particularly in suburban areas. Moreover, gaseous emissions from daily traffic in the same areas are continuously increasing often exceeding the allowable concentration in the atmosphere, raising public concerns and problems to the traffic itself. Within this frame the development of photocatalytic construction materials, particularly when applied to infrastructural works, can contribute to clean the air and improve sustainability levels. As a matter of fact, photocatalytic cementitious materials represent a new frontier in air quality improvement, since photocatalysis is able to accelerate natural oxidation process, promoting a faster decomposition of pollutants, preventing them from accumulating and favouring their decay (Cassar, 2004; Cassar et al., 2007; Guerrini, 2010). Indeed, they actually represents one of the most promising solutions for reducing air pollutant concentrations in urban areas, proving to be really effective and showing a real eco-sustainable value.

The development of innovative, sustainable technologies for the environmental improvement is an absolute need. In this sense, photocatalytic cements represent a significant contribution which can be widely implemented in the construction industry (Figure 1). Many research activities are currently conducted on photocatalysis applied to the building industry and cement based solutions represent the largest market in terms of volumes already applied.

Figure 1 - Newly built bridge with concrete piles made using photocatalytic cement

RADIATION-ACTIVE SURFACE DESIGN: THE USE OF PHOTOCATALYTIC CONCRETE

New research into photocatalytic architectural cement offers building professionals a renewed opportunity to contribute toward sustainable goals while improving value. A team comprised of a faculty from Architecture and Environmental Engineering has developed a computer algorithm that utilizes data from site conditions as a means of optimizing surface geometry for maximum photocatalytic activity.Urban centers often have poor air quality due to high density industrialization, internal combustion vehicle traffic, and nearby power generation. This poor air quality can produce adverse consequences, such as photochemical smog, poor visibility, and a host of detrimental health effects. Volatile organic compounds (VOCs) and nitrogen dioxide are pollutants prevalent in cities, and are pre-cursors to photochemical smog. Photochemical smog is formed by a series of chemical reactions which require photons from sunlight, nitrogen dioxide, volatile organic compounds (VOCs), oxygen, and ozone. The effects of smog include eye and respiratory irritation, reduced visibility, ozone accumulation and exposure, as wellas damage to forests and agricultural produce. Remediating the precursors to photochemical smog offers one way that buildings can play an active role in improving the environment. An innovative technology that can help achieve this goal is photocatalytic cement - it uses daylight to react with and neutralize common air pollutants such as nitrogen and sulfur oxides, carbon monoxide, and VOCs; the reaction takes place on the surface of the concrete and the resulting inert nitrates can be washed off manually or by rain. On a bright and clear day the process can eliminate up to 90% of nitrogen oxides, aldehydes, benzenes and chlorinated aromatic compounds [1]. Research into the use of photocatalytic cements in building has been progressing for over ten years and this emerging technology is most commonly available in paving products.

Early work by Fujishima and Honda determined that titanium dioxide is a photocatalyst. As a photocatalyst, during exposure to UV-light TiO2 forms oxidizing holes and photogenerated electrons, which create highly oxidative and reductive constituents. Included in these oxidative constituents are hydroxyl radicals (OH●). When VOCs are exposed to hydroxyl radicals from a photocatalyst, the VOCs can be completely destroyed. Additionally, as long as the photocatalyst is exposed to UV light, it will remain an active air pollution remediator as the UV-light/TiO2 photochemical reaction continues to yield oxidative and reductive constituents in perpetuity. Titanium Dioxide is a non-toxic material widely used in personal care products and paints as a white pigment. When producing photocatalytic concrete, the conventional Portland cement, silica sand, crushed stone, and water are mixed – but the addition of titanium dioxide in levels reported between 3–5% gives the resulting concrete photocatalytic properties. This paper reports on the research methods, designs and conclusions of a collaborative project that incorporates environmentally derived data and innovative photocatalytic concrete into the design of a panelized building façade surface. In resulting computer simulations the team was able to show a substantial increase in photo catalytic reaction. Consequently, physical photo catalytic panels were fabricated, tested for photocatalytic activity, and the results compared to initial computer simulations.

PHOTOCATALYTIC CEMENTITIOUS MATERIALS

Photocatalysis represents a very exciting topic in order to make innovation in cement industry with sustainable solutions. These innovative products have been developed in order to provide an environmentally friendly solution in the building market and are becoming more and more widely recognized for green building constructions. The photocatalytic principle is the basis of the photoactive cements and binders, designed and patented by Italcementi, used for manufacturing a wide range of cementitious products - from paints to mortars and precast elements - with which pavements, plasters and any type of horizontal or vertical structure and coating can be made. Due to aesthetic qualities and environmental benefits, the photoactive cements and binders, based on titanium oxide, represents a good choice in order to meet a variety of objectives, first of all sustainability (Guerrini, 2011). Moreover, two important effects related to the nature of photoactive TiO2 coatings have been pointed out (Folli et al., 2012). Firstly, a self-cleaning effect due to redox reactions promotedby sunlight, or in general weak ultraviolet light, on the photocatalyst surface is evident (Fujiushima et al., 1999). Secondly, photo-induced hydrophilicity of the catalyst surface enhances the self-cleaning effect, since inorganics causing dirt and stains on surfaces can be easily removed due to rainwater soaking between the adsorbed substance and the TiO2 surface. Finally, photocatalytic cement-based materials could represent one of the most efficient solutions for the mitigation of urban heat island effect (Guerrini, 2011), a phenomenon that causes urban areas to be 2 to 4°C warmer than their surrounding areas (Akbari et al., 1995; Akbari et al., 2010). Indeed, the increase of temperature in cities is dramatically influenced by the presence of large percentages of black or dark surfaces, and this condition could be limited by the use of lighter roofs and pavements. The photocatalytic properties of this “cool” materials are a further added value, from the environmental point of view. For example, paved surfaces (such as highways, roads, runways, parking areas, sidewalks, and driveways) typically represent from 30 to 60% of developed urban areas, and could be transformed – in occasion of periodical maintenance or renovation works – into more environmental surfaces. In pavement structures, the topmost surface is the only layer which affects the solar reflectance (commonly known as “albedo”). Therefore, pavement type selection should also include a consideration of albedo, where heat generation is a concern. As widely explained in literature (Akbari et al., 2010), urban heat islands are not inevitable, since an effective use of white or light-colored pavements (roads, sidewalks, roofs and paints) could significantly contribute to temperature mitigation during sunny periods. A broad utilization of white photocatalytic materials in the cities could give a relevant support in the reduction of temperature, thereby saving energy for cooling buildings, keeping parking lots and roads cool and improving air quality. Further, if we consider that the formation of smog is highly sensitive to temperatures, a reduction of ozone formation during summer period is also possible (ozone is a highly oxidizing and irritating gas and is the main ingredient of urban smog). Besides, the kinetics rate for photochemical pollution reactions could be decreased, with a subsequently lower production of noxious substances.

SUSTAINABLE INFRASTRUCTURE CONSTRUCTION

Pervious concrete pavements

Photocatalytic cement-based products are increasingly used worldwide in the construction sector. Vertical applications, such as coatings and walls, and horizontal applications, such as pavements or roof coverings, are solutions that are typically used for air purification whenever large surfaces are available. Till now, the most common examples of photocatalytic pavement applications are represented by paving blocks and slabs: using these precast concrete elements, several parking lots, local roads, sidewalks, shopping centres, pedestrian areas have been completed (Guerrini, 2009; Guerrini, 2011). However, other solutions for roads and pavements are now available, suitable for medium and heavy load traffic road projects, among which pervious concrete for draining pavements, standing out for its environmental sustainability. Pervious concrete, possessing high water draining properties and sound-absorbing properties, is one of the most promising concrete solution which could be a valid alternative to open grade bituminous asphalt. Sustainable engineering practice can be obtained with this no-fine concrete, whose aggregate grading allows adequate drainage of recyclable rainwater, whose maintenance works are strongly reduced with significantly increased durability, and can bealso produced using recycled concrete aggregates, meaning complete recyclability at the end of the service life. In addition, future innovation could involve also tunnels, where fire damages caused by high temperatures reached during combustion of bituminous asphalt could be strongly reduced.

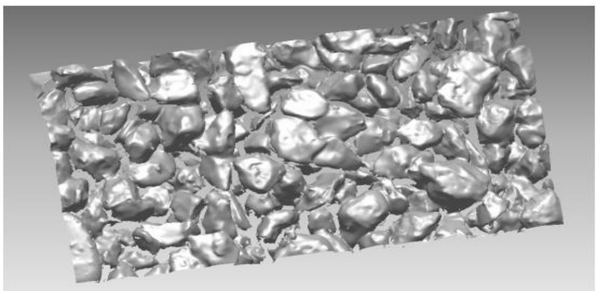

Figure 2. 3D scan of pervious concrete pavement surface

From the photocatalytic point of view, pervious concrete really offers high specific surfaces (Figure 2) and corresponding high depolluting performances (Guerrini et al., 2007; Guerrini et al., 2012), increasing its eco-sustainable value. However, a question arising from this new system is the assessment of its in-service photocatalytic performance depending on traffic, dirt deposits and weather conditions.

Two-lift paving

As part of the reconstruction of Route 141 in St. Louis between Ladue Road and Olive Boulevard, the Missouri Department of Transportation (MoDOT), in collaboration with the Federal Highway Administration, the National Concrete Pavement Technology Center at Iowa State University’s Institute for Transportation, the Essroc Italcementi Group, and Lehigh Hanson, Inc., has started an extensive research on the environmental benefits of using concrete made with photocatalytic cement-based products in the construction of highways (Guerrini et al., 2012).

The mainline pavement material is applied using a two-lift paving strategy, which involves the placement of two wet-on-wet layers of concrete instead of a single, homogeneous layer. The lower, base level layer is expected to be constructed with less expensive materials (e.g., a low cementitious-material content base lift) which is then overlaid with a thinner top wearing-course of concrete containing photocatalytic cement.The shoulder pavement element of this research effort involves photocatalytic cement, used in a previous (rather than conventional) concrete application. Together, this set of innovative mainline and shoulder paving materials, including both a two-lift photocatalytic mainline pavement and a photocatalytic pervious shoulder pavement, are believed to represent one of the most technically advanced and environmentally-friendly concrete pavement systems ever employed. This project was officially presented in occasion of the national two-lift concrete paving open house, hosted by the National Concrete Pavement Technology Center (NCPTC) in Chesterfield, MO - USA (September 2010). This experimental road was constructed in October 2011 (Figure 3) and the monitoring campaign lasted for one year at least, the. pervious shoulders were constructed in May 2012.

Figure 3. Two-lift technology for paving

Concrete Lining and Coatings for Tunnels

As already reported, photoactive cements and binders are used to prepare mortars, paints, renders and paving finish. Their resulting ability to oxidize pollutants induced by light radiation can be effectively exploited in tunnels illuminated by artificial ultraviolet light, obtaining a tunnel vault keeping clean much longer in addition to a significant abatement of the air pollution (Figure 4). Lighting systems specifically dedicated to these applications have been developed in order to provide maximum UV light and strengthen the anti-pollutant effect. For this aim, high pressure sodium vapor lamps mostly used in tunnels should be replaced by metal halide lamps, able to emit higher amounts of UVA rays. In order to achieve maximum photocatalytic effect, auto cleaning protective glass should be used in lamps. Advantages of this system applied to tunnels with a high traffic density clearly stand out. First of all, the higher achieved brilliance positively affects safety aspects as well as visual comfort. Moreover, the anti-pollutant action induced by photocatalytic paints can significantly reduce the maintenance as well as cleaning interventions, which constitute anonerous task in this type of tunnels. Finally, other aspects could be involved as energy consumption balance with savings resulting from lower maintenance need. The same advantages can be obtained by applying photocatalytic coatings, whose effect is activated by dedicated UV lighting systems. Smoothing cement-based coats, containing photoactive TiO2, can be effectively applied as final sprayed coating for wide vertical as well as horizontal surfaces, like walls, ceilings, tunnel vaults and multi-storey car parking. Photocatalytically activated, they show anti-pollution, bacteriostatic, anti-mold and auto cleaning properties, allowing clean surfaces for longer.

Figure 4. Application of photocatalytic coating to the internal surface of a tunnel

CONCLUSION

However, critical factors for the photocatalytic efficiency in abating NOx and PM from the air in road tunnels are wind direction and speed, influencing the percentage of air hitting the tunnel walls and ceiling, as well as other disturbing factors as jet stream at the tunnel exits, thermal influence, moving traffic and so on. Moreover, fluid dynamic computer models should be made in order to estimate the efficiency of the process with reference to the coming introduction of European norms for ultra-particular matter (PM 2.5) concentration under 25 µg/m3 . Cost-benefit analysis should also be performed to take into account reduction of cleaning costs and reduction of frequency in cleaning, as well as reduction of the energy bill for lighting and for ventilation against extra investment to prepare the tunnel tube to capture up as NOx as required. Lastly, the benefits of renovating the city tunnel tubes with photocatalytic technology are remarkably positive compared to the costs of the renovation with paint and UV lightingsystems, when considering that the exits of city tunnels are generally the most polluted spots in the city, and represent hazardous areas to the health of citizens living in the immediate vicinity of the tunnel exits. Photocatalytic cleaning of this spots could, indeed, prove to be the cheaper way to protect the health of citizens.

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