PHOTOCATALYTIC CONCRETE – ENVIRONMENT FRIENDLY MATERIAL

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Summary: *The phenomenon of dirty facades and elements of infrastructural facilities such as roads and bridges is becoming more prominent with the increase of industrial air pollution, which has a detrimental effect on the quality of urban environment and structural life cycle cost. New construction material called photocatalytic concrete is self-cleaning, and in addition it is a filter for air pollution and it is used for construction of the aforementioned structures. Self-cleaning is a result of the capacity of photocatalytic concrete enabling the façades, bridges, roads and other structures to retain their color in time, and appear as new for decades. The primary catalytic ingredient of photocatalytic concrete is Titanium oxide (TiO_2), a white pigment. When activated by the energy in sunlight, TiO_2 creates a charge separation of electrons which disperses on the photocatalytic surface and reacts with external substances, decomposing organic compounds. Photocatalytic concrete reflects much of the sun's heat which reduces the heat gain of the structural surfaces during the summer seasons, reduces the air temperature in urban environments, and as a result, reduces the amount of smog. The paper presents the properties of photocatalytic cement, concrete and advantages of its usage as environment friendly material and its application on important structures in the world.*

Keywords: *photocatalytic cement, photocatalytic concrete, new environment friendly material*

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1. INTRODUCTION

Many cities around the world struggle with increasing car exhaust fumes, industrial smog and other forms of air pollution. Together they produce a mix of nitrogen oxides (NOx), volatile organic compounds (VOC's), carbon monoxide (CO), sulfur oxides (SOx), and particulate matter (PM). The deleterious effects of these pollutants may extend far beyond the original source of emission. NO_2 and VOC's react in the atmosphere to produce secondary pollutants, such as acid rain, smog, and ozone, which may impact areas far from cities and congested streets. The urban areas with the most air pollution are often called 'street canyons', where busy roads are flanked by tall buildings that hamper the dispersion of harmful Nitric oxides and other pollutants [1,2]. Air pollution poses a serious threat to human health and the environment. Pollutants from exhaust systems can cause unsightly blackening and costly degradation of walls and building facades [3,4,5]. Nitrogen dioxide is one of six criteria pollutants that the Environmental Protection Agency (EPA) set in the National Ambient Air Quality Standards[5]. It is becoming increasingly apparent that a number of human activities and development practices are negatively affecting the economic, environmental, and social well-being of the planet, putting future generations of humanity, as well as of other species, at risk [6]. By selecting appropriate building materials, architecture and landscape the negative impact of air pollution can be reduced [3]. One solution that received attention involves treating pollutants in close proximity to their source, in the city or on the street. The European Union has supported an international research consortium, PICADA (the Photocatalytic Innovative Coverings Applications for Depollution Assessment), that has investigated the use of building materials to reduce air pollution. Japanese research centers have also been involved, examining the pollution-reducing capability of photocatalytic compounds such as titanium dioxide (TiO_2). In the presence of sun or artificial light, photocatalytic TiO_2 reacts with air pollutants, converting them into small amounts of relatively benign molecules. Both laboratory and field experiments reveal that adding TiO_2 to the surface of pavement and building materials can significantly reduce air pollution, by up to 60% in some applications, figure 1 [3].

Figure 1. Introducing the Photocatalytic City: A Vision of the Environmental Future [7].

2. PHOTOCATALYTIC PROCESS

Photocatalysis - prefix **Photo** – defined simply as light, **Catalyst** – a substance that accelerates a process, increases the rate of a reaction, without being consumed in that process [8].

Photocatalytic reactions constitute one of the Advanced Oxidation Technologies (AOT) applied to water and air purification. This process involves a solid semiconductor catalyst, typically titanium dioxide (TiO_2, which is activated with ultraviolet light (UV) of certain wavelength, figure 2.

TiO_2 is a metal, which is multiply present in nature, figure 3a. The oxygen TiO_2 has three different molecule structures: rutile, anatase and brookiet [9]. Rutile is known as pigment in white paints, but demonstrated a low photocatalytic reactivity, figure 3b. Anatase is preferable if used as photocatalytic cell, figure 3c.

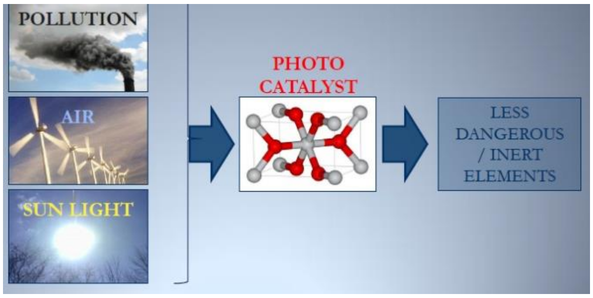

*Figure 2. In presence of **sunlight** and **air** Titanium Dioxide produces a significant **acceleration of natural chemical reactions** reducing pollutants (VOC - Volatile Organic Compounds, NOx, SOx) into inert elements [10].*

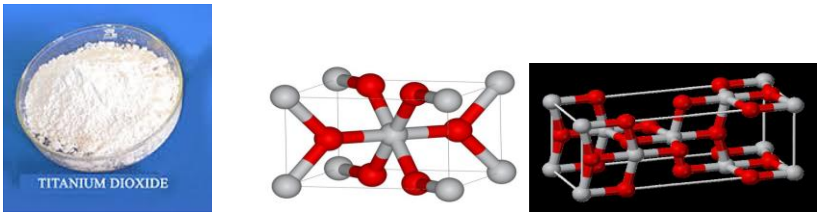

Figure 3. a) $TiO_{2,}$ b) crystalline structure RUTILE [10], c) crystalline structure ANATASE [10].

To use anatase in heterogenic photocatalysis, UV-light with a wave length lower than 387 mm has to be present. Also the intensity of the light is important to optimize the photocatalytic activity. Normal daylight can be used for the photocatalytic reaction. Research is focusing now on the application of nano-particles of TiO_2, active in the visible light range. Existing applications may be found in water purification, air conditioning (air purification), self-cleaning glazing, ceramic tiles (self-cleaning, antibacterial,…), textile (anti-odour), mirrors (anti-condensation), tunnel lightning, white tents,… Besides the air purifying and antiseptical action, where the pollutants are oxidized or reduced due to the presence of the photocatalyst, TiO_2 is also used to obtain a self-cleaning material.

The use of TiO_2 photocatalyst in combination with cementitious and other construction materials has shown a favorable effect in the removal of nitrogen oxides, figure 4. [11,12,13].

$$NO + HO_2\cdot \rightarrow HO\cdot + NO_2$$
$$NO_2 + HO\cdot \rightarrow HNO_3 \rightarrow NO_3^-$$

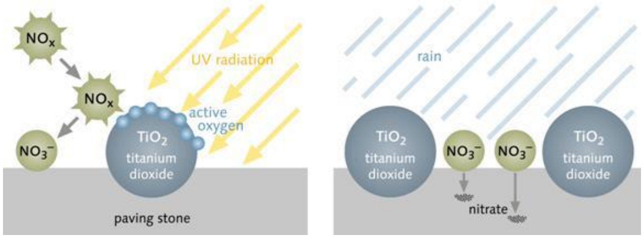

Figure 4. Nitrogen Oxides(NO,NO_2) are turned in to raw material,washed away by water without are levant pollutio naction,according to the photocatalytic oxidation mechanism [10].

3. PHOTOCATALYTIC CEMENT

TX Active® is the active agent, with photocatalytic properties, developed by Italcementi. The products containing TX Active® are able to abate air noxious organic and inorganic substances and they preserve over time the aesthetic quality of the finished products. TX Active® is an environmental friendly product for mortars, paints, precast elements and pavements plasters. TX Active**®**, with its self-cleaning and depolluting properties, is the seal of quality for photoactive cementitious products [13].

Concrete produced with TX Active will exhibit certain properties depending on the formulation used:

TX Arca - Self-cleaning - Concrete will resist most organic and inorganic pollutants that gather on the surface causing discoloration:

-Soot, grime, and organic particulates

-Mold, mildew, fungus, and their spores

-Algae, bacteria, and allergens

-Tobacco smoke and stains [14].

TX Arca with its self-cleaning effect, is the cement complying with the requirements set forth in European Standard EN 197/1 and is specifically designed for building prestigious architectural structures. The aesthetic qualities of the final concrete elements, regardless of whether they are prefabricated or cast on site, are enhanced and preserved for years. TX Arca® cement is the cement for striking, high-end architectural structures, in which quality of the construction material used and final appearance are equally important and significant [13].

TX Aria - Self-cleaning and Pollution Reducing - In addition to the self cleaning effect, that photocatalytic cement, will remove significant amounts of environmental pollutants deemed harmful to human health that are produced by human activities (industry, transport and residential heating units) [12,14]:

-Nitrogen Oxides (NOx) – major component in the formation of acid rain, ground level ozone (smog), certain toxic chemicals, and water quality deterioration.

-Sulfur Oxides (SOx) – component to acid rain and the formation of many harmful sulfates and other products.

-Volatile Organic Compounds (VOC's) – such as benzene and toluene.

-Ammonia – NH_3.

-Carbon Monoxide.

-Organic chlorides, aledehydes, polycondensated aromatics, among others [14].

In the United States, Gray or White Portland Cement Type I, II, and III complying with ASTM C 150 with the addition of nano-sized particles of titanium dioxide (TiO_2) specifically engineered for use in the manufacture of concrete and concrete products. In Canada, Gray or White Portland Cement Type GU, MS, MH, and HE complying with CSA A3001 with the addition of nano-sized particles of titanium dioxide (TiO_2) specifically engineered for use in the manufacture of concrete and concrete products [14]. Photocatalytic cements: short history shows on figure 5.

1995-1998	R&D program on photocatalysis in cement-based systems First (Italian) patent application (1996) First publications First concrete trials
1999-2001	First project: "Dives in Misericordia" Church, Rome "Cité de la Musique et des Beaux Arts", Chambéry Rhodamine-B (discoloration) test (CSTB, France)
2002-2005	Start of PICADA Project (2002-2005) Street canyon experience Pilot depollution tests in Segrate, Calusco, Bergame Launch of first version of photocatalytic cement (TX Millennium®) Development of Laboratory Test methods
2006-2011	Launch of TX Active® Cements (Italy, France, Spain, USA, ...) Publication of first UNI standards (Italy) "Umberto I" Tunnel (Rome) (2007) License agreement with Heidelberg Cement Group (2008) Projects: *i.lab*, Bergamo - Vodafone Village, Milan

Figure 5.Photocatalytic cements: short history [12].

4 PHOTOCATALYTIC CONCRETE

If using the appropriate industry guidelines, the quality of concrete in both the plastic and hardened state should not be compromized with the use of TX Active. Slump, air content, unit weight, set-time, workability, permeability, flexural strength, and compressive

strength should yield similar results. In general, concrete containing TX Active cements should be used in accordance with the standards that apply to ordinary Portland cement concrete and accepted industry practices [15].Concrete made with TX Arca® cement has the same physical & mechanical properties as traditional concrete. On top of that, it offers a selfcleaning benefit and extraordinary brilliance so that original beauty is retained for years. TX Aria® can be used for both horizontal and vertical structures as well as tunnels, where air quality and safety conditions are eventually improved. TX Aria® is the first active way in battle against accumulation of substances from smog [14]**.** Applications of **TX Aria®**: **Horizontal Structures:** concrete sidewalks, interlocking concrete pavers, pavement and road surfacing, cement-based tiles, concrete roof tiles. **Vertical Structures:** architectural precast panels, tilt-up concrete panels, stucco, exterior plaster, cladding elements,noise barriers for roads and highways, concrete median barriers [13].
The test showed that in the area covered by the TX Active® blocks the concentration of nitrogen oxides measured was clearly lower than in a comparable area. The reduction calculated on the basis of the average values recorded is around 45%.Photocatalysis is also possible for indoor structures treated with photocatalytic TX Active**®** cementitious materials, provided that diffuse solar radiation or artificial light is present. Also when it rains a TX Active**®** product maintains its photocatalytic effect [14].
This new photocatalytic cements can be used to produce concrete and plaster products that save on maintenance costs while they ensure a cleaner environment. Italcementi tests have demonstrated that a road paved with concrete made with the photocatalytic cement can reduce NOX levels by 20 to 80%, depending on atmospheric conditions. A building with photocatalytic precast concrete cladding can do the same [15]. In 2002, a first test on a photocatalytic TX Active**®** mortar was used to cover the asphalt surface of a section of Via Morandi in Segrate (province of Milan); a road which is 230m long and 10m wide, and which everyday sees traffic flow of around 1,000 vehicles/hour. Monitoring proved a reduction in nitrogen oxides on this urban road of around 60%. In 2003, TX Active**®** self-locking blocks were laid over 8,000 m^2 on an industrial site in the province of Bergamo. The test showed that in the area covered by the TX Active**®** blocks the concentration of nitrogen oxides measured was clearly lower than in a comparable area. The reduction calculated on the basis of the average values recorded is around 45% [16].

5 ENVIRONMENTAL BENEFITS

Sustainable Site
As the temperature of urban areas increase, the chemical reactions that produce smog and pollution also increase. The intent of this credit is to use materials that stay cool in sunlight and have a solar reflective index (SRI) of at least 29. Ordinary Portland cement has a SRI of around 35, and new concrete produced with white cement has an SRI of 86. It is likely that concrete produced with TX Active cement will maintain a higher SRI value for a longer period of time [17].

Energy and Atmosphere
Whole-building energy simulations using computer models can show the benefits of concrete’s thermal mass, along with the complex interaction between solar reflectance, emissivity, and thermal mass [17].

Innovation and Design
Exceptional performance in aged reflectance – due to the self-cleaning benefit, concrete produced with TX Active cements will remain clean and reflective reducing the heat island effect for a longer time.
Exceptional performance in air pollution abatement – the use of TX Active cement in concrete will reduce the organic and inorganic substances responsible for air pollution. Durability – the use of TX Active cement will tend to give concrete a longer life without the use of protective coatings [17].

6 PRODUCT LIMITATIONS

Due to the entire photocatalytic process being dependent on the sun's ultra-violet light, TX Active is not recommended for interior applications unless sufficient light with the appropriate wavelength is administered.
Concrete produced with TX Active cement cannot be labeled graffiti proof. Many paints are UV resistant blocking the sunlight to start the photocatalytic reaction. For the same reason, sealers or other coatings that may block the sun's UV light should not be used.
Essroc Italcementi Group reserves the right to limit the use of TX Active cements to projects that meet its quality control requirements. Due to the proprietary nature of the product it is imperative that Essroc remain informed and involved in all project applications.
Observing normal occupational health guidelines dealing with the handling of ordinary Portland cement and cement based products are believed to be sufficient to protect workers against exposure.
Most of the chemical components formed by the photocatalytic process are benign. However, by-products of certain chemical reactions may include calcium nitrates, carbonates, and sulfates, which are mostly simple salts washed away by rain. In addition, trace amount of carbon dioxide will be formed. These resultant products are in a much smaller quantity and pose a lower threat to the environment then that caused by the original compounds. [17].

7 PRODUCTS AND APLICATIONS FOR DEPOLLUTION

Among the main applications of photocatalytic materials produced by TX Active® let us recall:
• The self-locking block pavement laid in Borgo Palazzo Street, Bergamo. Tests results highlighted **an abatement of pollution between 30% and 40%.**
• The self-locking block pavement laid in Settemetri Street, Rome;
• The self-locking block pavement laid at the Cardinal Lambruschini School in Rome;
• The self-locking block pavement laid at the Maharishi Sathyananda Yoga Academy in Brescia;
• The self-locking block pavement laid at the Montichiarello Sports Center in Montichiari (Brescia);
• Indoor painting of the gym facility at the Scuola Media Statale, Ribolle Street, in Forlì.
• Reconstruction of a concrete footbridge by Mazzano (Brescia)

• Painting of tunnel Umberto I in Rome, figure 6.

There are many outstanding architectural works, the beauty of which is preserved thanks to the self-cleaning effect of TX Active®: the Dives in Misericordia church in Rome, figure 7, the new headquarters of Air France at Charles de Gaulle airport in Paris, the Cité de la Musique et des Beaux-Arts in Chambéry, the Hôtel de Police in Bordeaux, the Saint John's Court Montecarlo Bay residence in the Principality of Monaco [16].

Figure 6. Hospital in Mexico City (left)[18], Painting of tunnel Umberto I in Rome (right)[19].

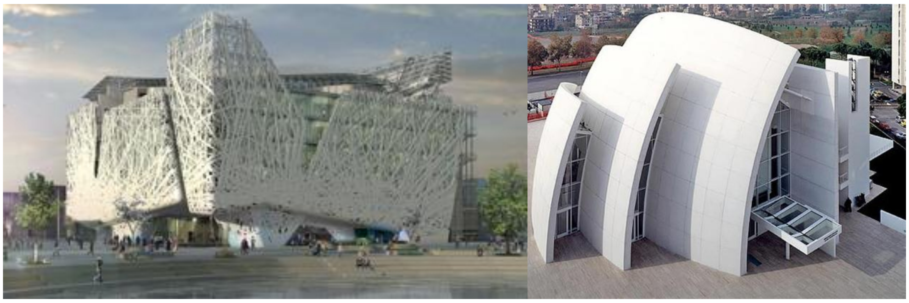

Figure 7. The Milan Expo 2015 - a pavilion with an air-cleaning facade designed by Roma studio Nemesi & Partners(left) [20]; the Dives in Misericordia church in Rome (right) [21].

8 CONCLUSIONS

A basic definition of sustainability is the capacity to maintain a process or state of being into perpetuity, without exhausting the resources upon which it depends nor degrading the environment in which it operates. In the context of human activity, sustainability has been described as activity or development "that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987 - World Commission on Environment and Development). One of the elements of sustainability, from the aspect of environment friendly materials in contemporary civil engineering is the photocatalytic concrete which is obtained through usage of photocatalytic cement Recently introduced formulations of cement are able to neutralize pollution, turning harmful smog into harmless compounds that can be washed away.

Anything made out of concrete is a potential application as these cements are used in the same manner as regular Portland cements. Self-cleaning buildings and pollution-reducing roadways: These may sound like futuristic ideas, but they are the realities of some of contemporary concretes.

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FOTOKATALITIČKI BETON – EKOLOŠKI MATERIJAL

Rezime: *Fenomenologija zaprljanja fasada i elemenata objekata infrastrukture kao što su putevi i mostovi je u porastu sa industrijskim zagađenjem vazduha što utiče na kvalitet urbanog okruženja i troškove životnog ciklusa objekata. Novi građevinski materijal pod nazivom fotokatalitički beton koji čisti sebe a pored toga je i filter za zagađivače iz vazduha primenjuje se za izgradnju napred navedenih objekata. Samočišćenje kao rezultat sposobnosti fotokatalitičkog betona omogućava da fasade, putevi, mostovi i druge konstrukcije zadrže svoju boju tokom vremena i decenijama izgledaju kao novi. Primarni katalitički sastojak fotokatalitičkog betona je titanijum oksid (TiO_2), beli pigment. Kada ga aktivira energija sunčeve svetlosti, TiO_2 stvara naelektrisanje koje se rasprostire po površini fotokatalitika i reaguje sa spoljašnjim supstancama razgrađujći organska jedinjenja. Fotokatalički beton utiče i na reflektovanje većeg dela sunčeve toplote čime se smanjuje zagrevanje površina objekata tokom letnjeg perioda, smanjuje se temperatura vazduha u urbanim sredinama, a kao posledica toga se umanjuje i količina smoga. U radu su prikazana svojstva fotokatalitičkog cementa, fotokatalitičkog betona i prednosti njegovog korišćenja kao ekološkog materijala kao i njegova primena na značajnim objektima u svetu.*

Ključne reči: *fotokatalitički cement, fotokatalitički beton, novi ekološki materijal*