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PHOTOCATALYSIS – A PROMISING TECHNOLOGY FOR SUSTAINABLE ROADS[1]

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Abstract

The design, construction and maintenance of roads will face a number of challenges in the coming decades. So, bearing in mind the environmental, economic and social trends, there is a need for creation of user – friendly transport system, as a combination of intelligence, low carbon energy and adaptable services.

Photocatalytic air cleaning is based on the use of titanium dioxide in building materials, on roads, freeway sound walls, in tunnels. This new techniquehas the potential for removing nitrogen oxides(NO_x) and volatile organic compounds(VOCs), as well as reducing concentrations of toxic and irritating ozone from polluted air.

The possibilities for its application have been researched in Japan, there are some applications in Europe,(Belgium, Italy,France,and Netherlands), but it is obvious that there is a need for additional investigations oriented towards:better technology deployment, catalytic activity of available materials, the occurrence of adverse environmental consequences.

Key words – sustainable roads; concrete roads; T_iO_2; photocatalysis; photocatalytic air cleaning; surface treatment

[1] Professional paper

INTRODUCTION

Bearing in mind the global trends, (changes to weather patterns, population growth, urbanization, security issues), it is obvious that the pressure to move towards a sustainable society is growing rapidly.

Transport system has a significant role in the process of realizing the sustainability, through so called triple bottom line. It's a question of solutions that should ensure a balance between economic efficiency of the system, socialneeds and environmental components.As a road is an integral part of transport systems, there is a need for itsadaptation and improvement, as a reaction to the above mentioned global changes.So, the use of the best practices, (new technologies and processes), on road planning, construction and management is one of the ways to achieve it.

This paper is focused on the application of photocatalytic oxidation air purification technology in the process of construction the roadway pavements. The main goal isto present the potential of this new technique when it is introduced in highway engineering, (on highly trafficked sites, in road tunnels, concrete pavement of road sections), having in mind that perspectives for its application depend ona lot of parameters involved on-site application.

PHOTOCATALYSIS IN HIGHWAY ENGINEERING

In accordance with the relevant literature, photocatalysis is defined as acceleration of a chemical reaction by light, while photocatalysts are materials that are able to produce, in the presence of sunlight, chemical transformation of the reaction participants. Additionally, using of photocatalytic substances is one of the waysfor reduction or elimination of polluted components in the air, such NO_x and volatile compounds.

T_iO_2 (titanium dioxide) has the most efficient photoactivity, the highest stability, and the lowest cost.It is harmless and have no absorption in the visible region. Its chemical stability exists only in dark and it is active under UV light irradiation. Because of the mentioned characteristics, it is added to different materials, (particularly in building materials), in order to produce the photochemical reaction and convert pollutants into less harmful products, under actinic irradiation (UV – range).

The results of various researches have shown that applications of T_iO_2 in concrete mix designs increase its natural photocatalytic ability. So, concrete is primary substrate for photocatalytic materials and it is used for creation of socalled photocatalytic pavements, road sound barriers, sidewalks.A

minimum mixture of cement to aggregate ratio of 1:3 has been recommended, in order to achieve the necessary mechanical strength for the surface layer.

The photocatalytic effect of T_iO_2 is presented on Figure 1. So, the essence of the process is in degradation of vehicle pollutants as a result of reaction between T_iO_2 (which is introduced in the concrete pavement) and ultraviolet light. The reaction products can be adsorbed at the surface and washed away by rain.

Generally speaking, there are two methods of application the photocatalysts in a concrete road:

- adding of T_iO_2 through the process of cementitious-based ultra-thin coating,
- spraying of T_iO_2 on the fresh concrete pavement surface.

Each of these methods has its advantages and also negative characteristics. So, the action undertaken in first method is more durable, because the added T_iO_2 is present before and after abrasion and wearing of the top layer. However, as compared with the second one, the initial costs are higher, the spray coating application has anadvantage of being more easily constructed, but the longevity of the action is questionable.

In accordance with the relevant literature and experiences from practical applications of photocatalysis in highway engineering, it can be concluded that the main influential factors on photocatalytic efficiency, are:

- ✓ pollutant types –nitrogen oxides - NO_x, carbon monoxide - CO, sulphur dioxide - S_iO_2, carbon dioxide – CO_2, volatile organic compounds – (VOC_s);
- ✓ the rate of photo catalytic degradation which depends on the pollutant;
- ✓ quantity of pollutants impact on photo catalytic efficiency;
- ✓ climate characteristics;
- ✓ UV light intensity as an energy provider for degradation of pollutants.

When it comes to the environmental impactof T_iO_2, it can be said that the appearance of the negative effect on the health is noted for workers exposed to nanoparticle T_iO_2.

But, relating to the quality of photocatalytic results, practical application indicates that the best conditions for the process are related to: larger surface area, higher temperatures, light intensities greater than 300nm, low relative humidity in the atmosphere, no wind.

On the other side, bearing in mind the results of previous applications, it's obvious that there is a need for additional activities oriented towards:

- ✓ providing of various demonstration projects that include state agencies, industrial companies,research organizations;

- ✓ market development;
- ✓ enhancing of photocatalitic activity, taking into account its costs;
- ✓ improving of catalyst durability;
- ✓ avoiding any environmental consequences.

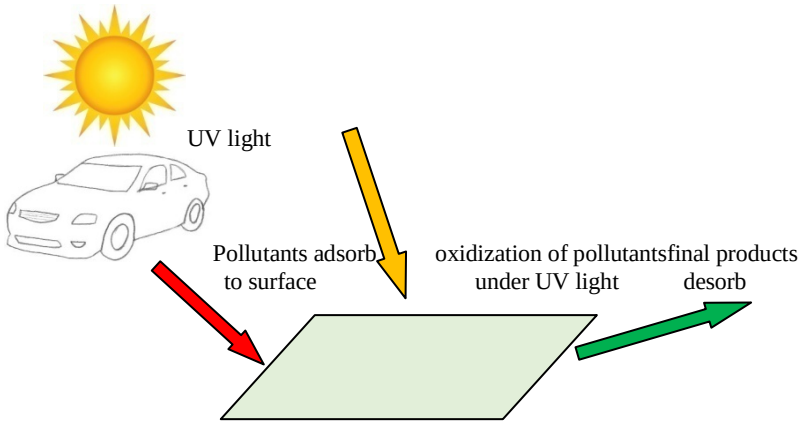

Fig.1.Ilustration of the photocatalytic process
Source: Prepared by the authors

SOME EXAMPLES OF PHOTOCATALYTIC APPLICATION IN TRANSPORT INFRASTRUCTURE BUILDING MATERIALS

Applying of T_iO_2 into building materials, in order to get the photocatalytic effect, has become a real practical technology after the middle of the 1990s. So, photocatalytic paving, air purification panels, as well as sound – proof walls are used for decomposing of nitrous oxide in the vicinity of transport infrastructure.

One of the examples of applying the photocatalytic process in highway engineering, is in city of Antwerp, Belgium, in 2004 and 2005. It's a question of the construction of a test section of 10 000m^2photocatalytic pavement blocks on the parking lanes, where only the upper layer of the blocks, (5mm – 6mm), containsT_iO_2. The results of laboratory analysis carried out on the used blocks with and without washing of the surface, demonstrated a good durability according to NO_x reduction. These tests were repeated in 2010, and the obtained results indicated that this characteristic is re-noted.

When it comes to the analysis of the obtained results on site measurements, it can be said that there is a need for their careful interpretation because of the absence of data prior of the application of photocatalytic material. So, the obtained results showed a 20% decrease in photocatalytic efficiency after one year of exposure to traffic.

Using of concrete made with photocatalytic cement – based products in the construction of highways, is also investigated in USA. The primary goal of one of theapplications was verification of the efficiency of photocatalytic concrete mainline pavement, as well as a photocatalytic pervious concrete shoulder pavement.

The essence of the first solution is in placement of two wet–on–wet layers of concrete. The lower, base level layer is built with less expensive materials,(low cementitious-material content base), while a thinner top layer consists of concrete containing photocatalytic cement. Second solution which is related to shoulder pavement element, presents using of photocatalytic cement in a pervious, (rather than conventional) concrete application. (Figure 2).

One of the activities that were undertaken relating to the renovation of the tunnel Umberto I in Rome, was the application of the photocatalytic cement based material on the vault, as well as on the remaining surface. (Figure 3). In accordance with the obtained results, the reduction of 88% to 90% of NO_x after 60 minutes under UV – lights, is noted.

Fig.2. Application of photocatalytic – technology on Route 141 in Sent Louis,USA[4]

Fig.3. Internal surface of the renovated Umberto I tunnel in Rome,[5]

Photocatalytic cementitious materials were applied on side walls and roof in Leopold II tunnel in Brussels in 2011. (Figure 4). The main goal was to investigate the effect of photocatalytic process on the air pollution inside the tunnel. For that reason, 100m long part of the tunnel, (as a test section), was equipped with installation, in order to measure the air quality. The UV – lighting system that was set up for inducing the reaction, as well as simulations of the air flow in the tunnel, were aimed for investigation of the impact of different influencing parameters (traffic flow, concentration profiles, ventilation…), on the air purification. Under the best conditions,(proper level of UV light intensity higher than $4W/m^2$, relative humidity below 50%, and limited pollution), reduction of the NO_x may be expected to reach ±12% for the entire tunnel, if not affected by ventilation.

Fig.4. Leopold II tunnel equipped with testing equipment,[6]

In order to built innovative and energy efficient road in the industrial zone "Den Hoek 3" of Wijnegem, (near Antwerp), double layered concrete for the road construction,with T_iO_2 in the top layer is used. First of all, for the purpose of analysis the characteristics of this technique, laboratory testing, (focused only on the air purifying performance), was conducted. In accordance with the obtained results, the use of T_iO_2 into cement, and its spraying on the surface, were used in the construction of trial sections of 30m long and 3m wide. (Figure 5). The obtained very promising results point to the conclusion that there is a need for further investigation of the photocatalytic efficiency under the impact of ageing, traffic and weather.

Fig.5Trial section in industrial zone of Wijnegem, [7]

In order to reduce the air – pollution around the Port of Los Angeles and make it environmentally friendly seaport, Buffer project is initiated. It is based on T_iO_2 application,which is, according to the southern California climate, very suitable solution. So, the site of 55 000 square, face – foot, stepped, pre - cast concrete retaining system abutting Harry Bridges Boulevard, for two options of T_iO_2 application, (mixing a T_iO_2 into the

paint for pre-cast panels, or painting the panels and covering the surface with a clear coat of T_iO_2), was analyzed. It was noticed that first option will increase the longevity of the paint and its adhesion to the panels, while the second one, although requires more labor, optimizes the pollution – reducing capacity of the T_iO_2.

The photocatalytic T_iO_2 is applied in Metro Rail Transit Guadalupe in Manila, on a total of more 6 000m. The measured NO_x reduction in the vicinity of the painted walls showed that each treated square meter removes up to 80g of NO_x per year. The total surface coated with depolluting photocatalytic materials is able to decompose more than 300kg of per year.

PHOTOCATALYTIC ROADS – POSSIBILITIES FOR APPLICATION IN MACEDONIA

The road network in Macedonia consists of roads with asphalt concrete pavements. Despite the positive qualities of cement concrete pavements, (evenness, roughness, durability), their use is limited on toll plazas and runways at the airports.

Several road sections, (Demir Kapija – Smokvica, Kicevo – Ohrid, Miladinovci – Sveti Nikole - Stip), are currently under construction. So, building of test road sections with T_iO_2 in cement concrete pavementswill be useful, in order to monitor the effect of photocatalysis on the environmental cleaning. Perhaps, the obtained results willbe a good base for possibility for reorientation of investors and professionals in civil engineering for construction of so called photocatalytic roads in our country.

CONCLUSIONS AND RECCOMENDATIONS

Photocatalysis is a natural reaction occurring in presence of light, water and oxygen. The reaction is accelerated by a catalyst, titanium dioxide, and is activated by the energy of the UV light.

Degradation of NO_x and VOC_s by concrete pavement containing T_iO_2, (photocatalytic oxidation), is a new kind of technology for solving the near-road pollution problems. The essence of the mentioned novel approach is that the T_iO_2, (as photocatalyst), when it is exposed to sunlight, generates nitrate compounds as a result of oxidation reactions. That species of nitrate are water soluble and can be flushed from the concrete pavement surface by rain.

A growing number of studies and applications of this promising solution around the world have demonstrated a positive impact on cleaning the environment. But it's clear that there is a need for improving the efficiency of the process in order to obtain an optimal surface for the photocatalysis of

air pollutants, deeper analysis of the methods for greater longevity, as well as analysis of the environmental and transport impact factors, (light wavelengths and intensity, relative humidity, temperature, wind, speed of traffic).

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