Innovation materials for road construction: Photocatalytic road pavements

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1. *Foreword*

The development of technologies for the use of photocatalysts such as titanium dioxide in road pavements jobs has increased significantly in recent years thanks to the studies carried out by Universities and some industrial partners. Titanium dioxide (TiO_2) in its crystalline form of nano anatase is still the most used photocatalyst in major road applications both at research level and on a real scale. Due to its versatility, stability and its intrinsic ability to transform substances such as nitrogen oxides (NO_x) into inert substances (nitrates), titanium dioxide is very effective against air pollution caused by traffic in urban areas.

2. *Photocatalytic pavements*

The possibility of using a photocatalyst on most paved areas means that large areas can be potentially treated for reducing air pollutants [1].

The research conducted on the behavior of titanium dioxide (TiO_2) as photocatalyst in road pavements jobs allowed obtaining over the years several eco-sustainable solutions able to offer both the mechanical–functional performance required by a road surface and the photocatalytic effect of reducing pollutants (nitrogen oxides: NO_x) [1].

2.1. *Objectives and research tools*

One of the main targets of the research is the analysis of products with photocatalytic properties having a long-lasting and high depolluting effect [2] at a sustainable cost and which don't cause structural changes to the pavements structure [3]. In this sense, the research conducted at universities, in co-operation with the industrial partners of the sector, allowed meeting the market demands related to the use of photocatalytic products in the road construction sector (in terms of costs and reliability) by means of stringent tests carried out both in the laboratory and on the field [4-5]. At international level, Italy and specifically the research team of *Infrastrutture Varie* of the Politecnico di Milano, in co-operation with some industrial partners, is considered the leader in this sector. Research so far conducted at the Politecnico di Milano has been developed according to the following procedure [6]. Starting from the chemical composition of the product (based on titanium dioxide) the first steps concern laboratory tests on the photocatalytic effectiveness under controlled conditions, integrated by investigations into phenomena such as: shrinkage, consumption, bleeding etc. compared with established functional performance. Then one or more applications are carried out on test areas (or real road sections) in order to validate laboratory results and monitor the behavior of pavements under traffic conditions. The strictness and severity of the methods used by the Polytechnic of Milan, together with the test procedures in compliance with major European and International regulations, have always given high technical-scientific value to the results obtained, which are internationally recognized. To date the

research carried out by the Polytechnic of Milan has shown interesting results in terms of reduction of pollutants as well as high resistance to degradation [2-7]. The many scientific publications of recent years already widespread throughout the world testify that the results so far obtained by the research are very interesting for the scientific community and bodes well for the future development of photocatalytic technologies. The Infrastrutture Viarie Dept. of the Politecnico di Milano has many years experience in the certification of the properties of photocatalytic products and its laboratory is equipped with the proper instrumentation to measure and quantify pollutants reduction (NO, NO_2, NO_x).

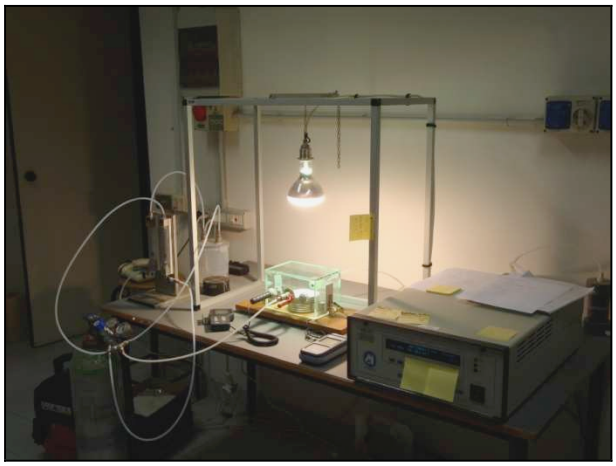

Figure 1: Experimental setup for depolluting measurements

Equipment calibration and setup and definition of test conditions were just some of the goals that the Politecnico di Milano set in the past before starting experiments on photocatalytic materials [8]. The stability of laboratory test conditions allowed monitoring the influence of each parameter (lightness, humidity, flow, temperature, etc.) on photocatalysis processes by establishing acceptability limits for the evaluation of results [8]. Furthermore, in an attempt to standardize test conditions, some test protocols were prepared in co-operation with public authorities (e.g. with the Municipality of Milan). The research activities carried out by the Experimental Laboratory of Infrastrutture Viarie Dept. concern not only photocatalytic properties but also the applicability and durability of said materials under traffic conditions as well as monitoring of several test areas on photocatalytic pavements [4]. Co-operation with industrial partners has also allowed the research to respect market timescales and to produce exploitable results [9-4].

3. The technologies

The road photocatalytic pavements developed in recent years can be classified as follows: bitumen-cement photocatalytic pavements and bituminous pavements sprayed with photocatalytic products.

3.1. Bitumen-cement photocatalytic pavements

The first road pavements were developed in partnership with Italcementi Group in order to use a cement matrix as durable support for the photocatalyst [3] (TiO_2). They are usually made of an open-grade wear layer of asphalt concrete clogged up with cement slurry with photocatalytic properties [10]. These slurries are solutions of water and cement which can leach into the voids of the draining layer without being subject to segregation or backflow phenomena. The water content is low due to the addition of admixtures that maximize the fluidity of the slurry during the filling process, however the cement matrix requires a minimum curing period (24 - 48h) for the paving to acquire the minimum mechanical performance necessary to withstand traffic loads [11-3]. Titanium dioxide is suspended in the cement matrix, but during the mixing process it tends to distribute on the paving surface due to its lower molecular weight compared with cement. At the end of curing, the bitumen-cement surface is light gray, which induces higher reflection of sun light (Figure 2).

Figure 2: Test field on bitumen-cement photocatalytic paving, 2011

This considerably reduces the absorption of UV rays by this surface (thereby increasing the “Albedo

effect") compared to a traditional "black" asphalt-concrete paving surface. The presence of titanium dioxide can also further reduce the effects of UV rays, as these are part of the photocatalysis reactions and are absorbed by the photocatalyst in order to induce oxidation processes [3]. This makes the bitumen-cement paving very efficacious in reducing both air pollutants and overheating phenomena of urban centers or UHI (Urban Heat Island). The photocatalytic properties of these pavements are closely related to the type of slurry used [10], because the amount of material applied, the type of dioxide and the performance of the slurry-titanium dioxide system are highly variable. Recent applications in urban areas carried out in co-operation with the Politecnico di Milano and some industrial partners are showing that bitumen-cement pavements are much more performing both in terms of durability with reference to fatigue and rutting and in terms of photocatalytic effectiveness (recording reductions up to 40% compared to the initial pollutant concentrations, [7-1]). In addition, durability and stiffness of the cement matrix remarkably increase the paving durability delaying phenomena such as: surface wear, detachment of aggregates, resistance to chemicals and ageing of the bituminous binder.

3.2. Sprayed photocatalytic pavements

Sprayed photocatalytic pavements unlike the bitumen-cement ones do not require any changes to the paving structure thereby reducing costs. This technology, developed in co-operation with the company Bacchi of Milan, is very versatile because the photocatalytic product can be applied either directly on the existing road surface or immediately after the road paving has been laid. In this sense, teachers at the Politecnico di Milano and industrial partners have co-operated with the objective of developing an emulsion with photocatalytic properties having also adhesive and durability characteristics able to withstand traffic wear and the action of atmospheric agents while maintaining their photocatalytic effectiveness [2].

The spray treatment is compatible with most road surfaces for traffic and pedestrian use and can be applied immediately after the wear layer (hot spay) or on existing paving surfaces after an appropriate cleaning (cold spray). This type of treatment also helps to preserve the surface characteristics of the asphalt concrete layer, whether it be a closed layer or a layer with draining features. Using an aqueous suspension or an emulsion, the photocatalyst is sprayed directly onto the road surface by means of spray bars placed on tankers. Usually the photocatalytic solution (or emulsion) evaporates quickly leaving on the surface a mixture made of a photocatalyst and a binder substance, able to make the titanium dioxide adhere to the paving while keeping it separated from the bituminous surface. In addition, the dark gray color of these pavements is not in conflict with the horizontal road signs and therefore does not reduce safety for the user. Other recent applications in areas with heavy traffic have shown that these pavements can also be successfully used in urban areas such as multi-storey car parks, parking areas, tunnels and urban tunnels (Figure 3).

Figure 3: An application of sprayed photocatalytic pavement, 2011.

Moreover, the rapid application and drying process (one to several hours depending on the season) of the sprayed pavements made it possible to minimize disturbance to traffic. A study conducted by the Politecnico di Milano has demonstrated that the surface film of titanium dioxide that covers the road surface after a spray application has a durability (in terms of photocatalytic effectiveness) equal to or greater than the average life of a traditional wear layer (3 to 5 years), thus ensuring product reliability [2].

The reduction in concentration of pollutants (NO_x) that can be obtained with sprayed photocatalytic pavements depends on the product used. However values equal to the ones obtained with bitumen-cement pavements have been recorded. To date, actually, no considerable difference has been noted between the two technologies from the photocatalytic effectiveness viewpoint.

4. *Conclusions*

Photocatalytic pavements can reduce the amount of pollutants in the atmosphere produced by vehicles (SOV, SO_x, NO_x) by using the same surfaces traditionally used only for vehicle transit. The use of this type of pavements comes under the more general aim of creating an environment in large urban centers that can support and convert some noxious substances produced by vehicular traffic. In this sense photocatalytic pavements, coatings and surfaces are tools which today research can offer to further reduce pollution. Specifically, because they have to come into contact with vehicle traffic and ordinary and extraordinary maintenance operations, pavements have to operate in very unfavorable environments. However continued commitment and co-operation between universities and industrial partners have already produced a huge step forward. Currently a research line is working side by side with air pollution experts at the Environment Dept. of the Politecnico di Milano in order to create synergies of expertise and to better identify the potential of these technologies.

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