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Photocatalytic Active Surface of LWSCC Architectural Concretes

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***Abstract*—**Current trends in the building industry are oriented towards the reduction of maintenance costs and the ecological benefits of buildings or building materials. Surface treatment of building materials with photocatalytic active titanium dioxide added into concrete can offer a good solution in this context. Architectural concrete has one disadvantage – dust and fouling keep settling on its surface, diminishing its aesthetic value and increasing maintenance e costs. Concrete surface – silicate material with open porosity – fulfils the conditions of effective photocatalysis, in particular, the self-cleaning properties of surfaces. This modern material is advantageous in particular for direct finishing and architectural concrete applications. If photoactive titanium dioxide is part of the top layers of road concrete on busy roads and the facades of the buildings surrounding these roads, exhaust fumes can be degraded with the aid of sunshine; hence, environmental load will decrease. It is clear that options for removing pollutants like nitrogen oxides (NOx) must be found. Not only do these gases present a health risk, they also cause the degradation of the surfaces of concrete structures. The photocatalytic properties of titanium dioxide can in the long term contribute to the enhanced appearance of surface layers and eliminate harmful pollutants dispersed in the air, and facilitate the conversion of pollutants into less toxic forms (e.g., NOx to HNO_3). This paper describes verification of the photocatalytic properties of titanium dioxide and presents the results of mechanical and physical tests on samples of architectural lightweight self-compacting concretes (LWSCC). The very essence of the use of LWSCC is their rheological ability to seep into otherwise extremely hard accessible or inaccessible construction areas, or sections thereof where concrete compacting will be a problem, or where vibration is completely excluded. They are also able to create a solid monolithic element with a large variety of shapes; the concrete will at the same meet the requirements of both chemical aggression and the influences of the surrounding environment. Due to their viscosity, LWSCCs are able to imprint the formwork elements into their structure and thus create high quality lightweight architectural concretes.

***Keywords*—**Photocatalytic concretes, titanium dioxide, architectural concretes, LWSCC.

I. Introduction

WITH regard to the current development of surface finishes for concrete structures, the practical application of the photocatalytic form of TiO_2 to concrete is being promoted in the modern technology of concrete. The basic benefits of using photocatalytic active materials with a titanium dioxide (TiO_2) basis are in particular the reduction of pollutant emissions in the air, the reduction of bio-corrosion, the partial self-cleaning effect of its surface, and a reduction in cost pertaining to the additional maintenance of concrete structures [1].

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The surface of concrete, as an open porous silicate, has conditions for the functional effects of photocatalysis, in particular, self-cleaning surfaces. One option may be the surface treatment of building materials with photocatalytically active TiO_2, which is added as an additive to the concrete mass. In addition to the self-cleaning effect, the photocatalytic properties of TiO_2 can partly contribute to the removal of pollutants such as NOx. These harmful oxides of nitrogen, which filter into the air, for example, from an increased concentration of vehicles, can be eliminated via the photocatalytic properties of TiO_2. Harmful pollutants dispersed in the air are converted into less toxic forms (e.g., NOx to HNO_3) [2]-[6].

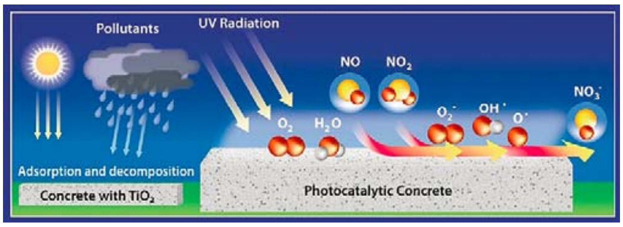

Fig. 1 Photocatalytic principle

The synergistic effects of photocatalysis and latently hydraulic admixtures are provided by new composite materials comprising a combination of natural clays and TiO_2. The application possibilities of these substances are expanded for specific concrete realisations in different modes of production.

Since long-term aesthetic performance is required from the production of architectural and visible concrete, the self-cleaning effect of adding TiO_2 to concrete is a beneficial solution. This article also shows the practical use of photocatalysts directly in wet-cast vibrated and LWSCC matrices. The resulting surfaces of photocatalytic concrete products are tested for their activity. The article presents a real construction of a self-supporting loggia made of LWCSS, with the addition of TiO_2.

II. Methodology and Results

A. Theoretical Assumptions about the Functionality of Photocatalysts in the Inorganic Environment of Silicates

TiO_2 is a relatively cheap and industrially feasible photoactive material which, according to a special production mode in the crystallographic modification of anatase under defined conditions, exhibits photocatalytic properties. Defined conditions in the natural environment of concrete structures are above all relative humidity and solar energy in the form of UVA components. Other aspects that affect the effectiveness of reactions are particle concentrations in the surface layer, and the shape and encapsulation of TiO_2 particles into the porous open surface. In general, these conditions are met by inorganic binder systems; organic binders generally do not meet these conditions, and there is a significant decrease or complete cessation of photocatalytic reactions [7].

Several different forms of TiO_2-based materials are currently used:

- Powder photocatalysts that exhibit roughly 75% of the colouring power over pigment types and are considered as admixtures in concrete.
- Composite materials such as metakaolin and TiO_2 composites, which not only exhibit photocatalytic activity, but also latent hydraulic properties [8]. In the water-cement system, such a material is substituted for any decrease in the strength caused by the penetration of a large quantity of the mixed water into the solvation of the very fine particles of the photocatalyst, and contributes to the formation of C-S-H II and C-S-H I [9].
- Photocatalytic suspensions

B. Testing Methods of Photocatalytic Activity and Their Principle

Together with the technical popularisation of photocatalysts in various applications, methodologies are also being developed to demonstrate the efficacy of these substances. In the following article, the two methods described below were used.

Decomposition of the Organic Colour on the Surface of the Sample

Testing is conducted according to Italian standards UNI 11259 (*Determinazione dell'attivita fotocatalitica di leganti idraulici – Metodo dellarodammina*). Testing is performed by monitoring the colorimetric evolution in time (four and 26 h) in samples of photocatalytic cement mortar, the surface of which was treated with organic dye and exposed to UV radiation. The selected organic dye was Rhodamine B, which was applied to the surface at a known concentration. The test allowed for evaluating whether the cement sample was photocatalytic by discoloration of the Rhodamine dye.

In view of the simplicity of this method, it can be applied in situ, directly on the surface of the building structure.

Degradation of Gaseous Components by Concrete Surface

Testing can be performed according to ISO 22197-1 – *Fine ceramics (advanced ceramics, advanced technical ceramics) – Test method for air-purification performance of semiconducting photocatalytic materials – Part 1: Removal of nitric oxide*. This is a procedure whereby the sample in the photoreactor is exposed to UV radiation and the test gas flows over it. This part is the most important in terms of the contribution of the sample. The procedure can be described as follows.

The test gas is prepared by enriching the air with NO to the desired level and the desired humidity. After stabilising the composition of the test gas, the test gas is dispensed into the reactor with the sample at the desired flow rate. For some time, the test gas is dispensed without UV radiation exposure to the sample in the reactor. During this step, the concentration of NO in the test gas is monitored. Due to adsorption to the surface of the sample, the concentration may decrease. After standard stabilisation, light exposure of the sample is started. If the sample is photocatalytically active, the concentration of NO in the test gas will decrease significantly. After a specified time, the exposure and dispensing of the test gas in the reactor is finished. A flow of clean air is fed to the reactor for a specified time, thereby finishing the experiment.

C. Photocatalysis Testing of Cast Prefabricated Components

To determine photocatalytic activity, cast fence concrete panels from the LWSCC were made in two versions of the proposed formulations:

- Formula with 5% powder photocatalyst Pretiox PK-20A (PD5).
- Formula with 10% powder photocatalyst Pretiox PK-20A (PD10).

The photocatalytic effect according to the UNI 11259 methodology using the Rhodamine B test (UNI 11259 *Determinazionedell'attivitafotocatalitica di legantiidraulici – Metododellarodammina*) was tested on samples of concrete parts. The Rhodamine B photoactivity test results are illustrated in Figs. 2 and 3.

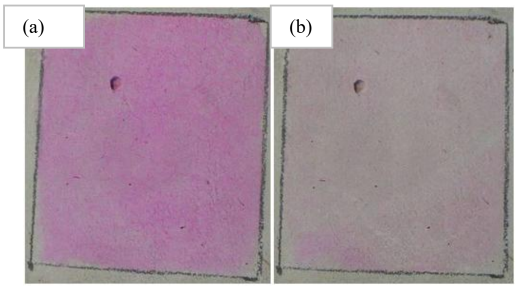

Fig. 2 Preview of the prepared samples PD5 prior to the test (a) prior to the test, (b) following the test

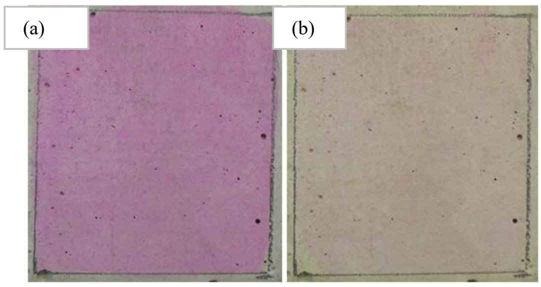

Fig. 3 Preview of the prepared samples PD5 prior to the test (a) prior to the test, (b) following the test)

A decrease in the intensity of the organic dye Rhodamine B

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is apparent to the naked eye. The mechanism of this reaction is the photocatalytic degradation in the dye, which is otherwise stable in the UV spectrum. When the dye was applied to the surface of the sample, staining was poor (up to 1.5 ml was applied compared to the standard 0.5 ml of dye in one sample).

Another test for measuring the photocatalytic effect was testing according to the UNI 12256 and ISO 22197-1 methodologies. In this procedure, the sample in the photoreactor is exposed to UV radiation and a test gas is passed over it, comprising a flow of air enriched with NO to the desired level and humidity. If the sample is photocatalytically active, the concentration of the NO in the test gas will be significantly reduced by exposure to UV radiation. The results of the experiments are summarised in Table I.

TABLE I
TEST EVALUATION ACCORDING TO UNI 12256 AND ISO 22197-1.

Sample	Average level of NOx conversion [%]
PD5	2.72
PD10	6.16

D. Model of Real Construction with Photocatalytic Matrix

In order to verify the practical behaviour of photocatalysis on the surface of the concrete, a model of real construction – a self-supporting loggia – was constructed. This is a combination of photocatalytic LWSCC and silicate surface treatment in the form of a coating (Fig. 4).

Fig. 4 Real construction of a self-supporting loggia

As part of the research project, TiO_2 – an anatase crystal modification – was applied with high specific surface area with a mesoporous surface structure, and to a small size of primary particles labelled Pretiox PK-20A. $TiO_2$was metered into a concrete prefabricate as a powder in the amount of 5% by weight of fines.

Description of Construction

A real-scale loggia built from flat panels; part of the prefabricate was built from LWSCC with a TiO_2 admixture, and part was built from reference concrete. One carrier wall was painted with a standard coating, the other with a TiO_2 admixture. The floor panel and the outer sides of the wall panels were embossed with a relief surface matrix to compare the effectiveness of TiO_2 on smooth and rugged surfaces (Fig. 4).

Light permanency, or resistance to sunlight, was assessed according to the results of colour measurements of the coloured concrete prefabricates exposed to weather and climatic events. Measurement wax carried out using a Hunter-Lab MiniScan XE spectrophotometer. The device was connected to a computer and the colour parameters were evaluated using the Universal software. The result was a comparison of colour variations in exposed and unexposed samples. The exposure time is given in days, and the overall light permanency evaluation can be performed at the earliest following two-year exposure [8].

Measurement Results

The largest colour change occurred in the luminance component dL*= -2.62 for reference concrete; the addition of TiO_2 in this case had a positive effect on brightness. For the reference construction darkens, the brightness component was lower, which may have been caused by surface soiling. For coatings, the values were almost identical, with differences within the allowed measurement error.

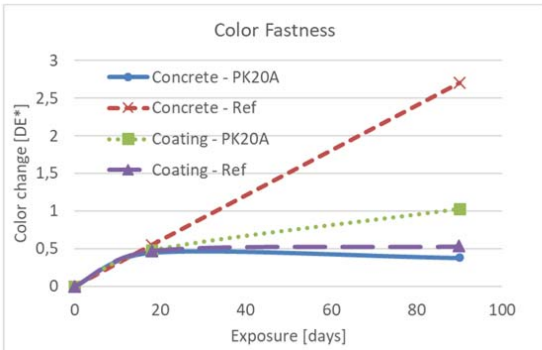

Fig. 5 Graphical representation of spectrophotometric measurements

The results demonstrate the positive results of the use of the photocatalytic effect of concrete with TiO_2 in prefabricated production. Concurrently, however, they indicate a second possible direction for the use of photocatalytic additives, i.e., for the production of paints for concrete structures. From a materials point of view, it is possible to adjust the coating, respectively, by spraying systems directly onto the technology, and having their industrial production effected in the form of photocatalytic premixes. These can easily be distributed on construction sites with technological water and applied according to conditions onto the base structure.

The loggia produced for this study has been developed into a real structure and the parameters of photocatalytic activity are being monitored long-term.

III. CONCLUSION

The results of the tests conducted in this study show the possibility of producing concrete with photocatalytic properties. If applied correctly, these concretes can help to ecologise concrete structures. As a result of the photocatalytic effect, such concretes can help in the destruction of air pollutants (NOx), particularly in densely populated urban agglomerations. Moreover, the surfaces of these concretes have a so-called 'self-cleaning' effect. In future, it will be possible to build concrete constructions with photocatalytic properties; however, production of prefabricated small parts such as interlocking and flat pavement will also be beneficial. This claim is based on the fact that large areas are already being constructed using these types of prefabricated concrete goods.

Based on the positive results of LWSCC production using a powder form of TiO_2, a real LWSCC construction was made, where no more than two surface types were compared, along with a TiO_2 admixture coating. Due to its thickness, the silicate coating is economically extremely motivating for the use of photocatalysts on building structures. Due to its non-load bearing/non-structural nature, and higher photocatalyst filling capacity, greater efficiency can be achieved. Research is currently underway involving silicate sprays. Using these techniques, it will be possible to make existing buildings or other concrete surfaces more ecological. Spectrophotometric measurement indicated a positive TiO_2 characteristic for maintaining the colour fastness and brightness of concrete surfaces.

TiO_2-based photocatalysts have proven their suitability for use in the environment of inorganic bonding systems. The application of these materials resulted in functional surfaces that contribute to a higher cleanness of the surfaces themselves, in addition to reducing the amount of pollutants in the vicinity. The economic aspect of the use of photocatalysts lies in reducing the cost of cleaning and maintenance of the visible surfaces of building structures, as well as the possible reduction of bio-corrosion.

Acknowledgment

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