Session 4 - Specific techniques and innovation

Paper :

Urban concrete paving and photocatalytic pavement blocks : environmental friendly solutions for the future ?

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Urban concrete paving and photo catalytic pavement blocks: environmental friendly solution for the future?

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SYNOPSIS

Following a short overview of the possibility of concrete as modular element as well as cast in place, this paper presents some ideas put forward in the European project NR2C, concentrating on photo catalytic pavement blocks.

The heterogeneous photo catalysis is a fairly new technique, which is developing rapidly in the field of environmental techniques. This method offers good perspectives to give a significant reduction in air pollution on a short term base, especially in that caused by traffic. The addition of TiO_2 to the surface of ordinary construction materials such as concrete, leads to environmentally friendly materials, which are able to purify the air.

This contribution presents the results of a study, conducted at the Belgian Road Research Centre and focusing on the air purifying action of photo catalytic pavement blocks. It briefly presents the working mechanism, the most important parameters and the first results, obtained in laboratory and in situ. In Antwerp, 10 000 m² of photo catalytic pavement blocks are being applied.

Résumé

Après un bref rappel de la palette des matériaux urbains qu'offre le béton tant sur le plan des éléments modulaires que du béton coulé en place, la présente communication traitera des réflexions menées au sein du projet européen NR2C dans ce domaine et présentera les pavés photocatalytiques.

En effet, en matière d'innovation, la photocatalyse hétérogène est une technique qui se développe rapidement dans les technologies de l'environnement. Cette méthode offre de bonnes perspectives pour donner un coup de pouce à court terme à la réduction de la pollution de l'air, en particulier celle causée par le trafic. L'ajout de TiO_2 aux matériaux de construction ordinaires tel que le béton conduit à des matériaux favorables à l'environnement parce qu'ils purifient l'air d'une part et restent propres en surface d'autre part.

Les résultats d'une étude portant spécifiquement sur l'action dépolluante des pavages photocatalytiques et dressant un aperçu du principe de fonctionnement, des principaux paramètres intervenant et des résultats obtenus seront présentés. L'article abordera également l'extension à une application réelle en Belgique.

1. Introduction

"Quality of life" is becoming a main issue in modern urban environments. Comfort, mobility, energy resources and respect for the environment are key points of interest in future developments. In the European project NR2C (New Road Construction Concepts), new developments and technical innovations are looked at and integrated in a global vision of the road of the future. The adaptation of the surface transport infrastructure in European countries to new societal and environmental demands is a major objective for the project.

Following the expression and derivation of new concepts for the roads of the future from a global perspective, a number of targeted innovations of special interest are developed. The application of TiO_2 at the surface of concrete pavement blocks is one of them and replies to the social demand of safe, comfortable and environmentally friendly road surface infrastructures.

Prior to the description of the photo catalytic process and of its the application in situ, an overview of the application of concrete in urban environment is given. The use of concrete paving blocks, with their various shapes, sizes and textures, offers designers a range of creative possibilities. Besides, coloured exposed aggregate concrete offers an interesting alternative to fulfil spatial and visual quality requirements. This technique has enjoyed a growing success in Belgium in recent years. A brief review of three recent applications is given.

The use of concrete leads to a durable road structure. The addition of TiO_2 to the surface of the structure, adds hereby the possibility to purify the air. In Belgium, air purifying concrete pavement blocks were placed on the parking side roads of the Leien, a main arterial road crossing through Antwerp. The mechanism, the properties and the experience in practice are described in this paper.

Heterogeneous photo catalysis is a rapidly developing technique. It offers good perspectives to give an extra impulse to the short term reduction of NO, NO_2 and VOC. On sunny days, these pollutants are important towards the ozone and smog formation. Since traffic is responsible for more than 50% of the NO and NO_2 in the air, the application of NO_x-reducing material is especially important in the near vicinity of the source, i.e. as paving or as noise reducing barrier. The photo catalytic process implies that the TiO_2 is at the surface of the material and can be reached by the UV-light and by the pollutants.

2. Coloured exposed aggregate concrete surfaces in urban environments

To fulfil spatial and visual quality requirements, coloured exposed aggregate concrete offers a good and durable solution for urban applications. Exposed aggregate concrete is characterised by a specific surface treatment. After the concrete is processed, a retarding agent is sprayed on the surface of the still fresh material to prevent the cement from hydrating. The non-hydrated layer is washed away afterwards, for example with a high-pressure cleaner. This procedure exposes the coarse aggregate, so that their appearance and colour can be appreciated. Moreover, the natural shades of these granulates can be highlighted by mixing a dye into the concrete. The procedure known as “chemical washing” is systematically used in Belgium as a surface finishing on motorways and major roads to reduce noise.

The use of coloured exposed aggregate concrete, possibly in combination with concrete pavement blocks, is most suitable for places where the public domain has to offer a certain number of functions. This can be seen as part of the translation of one of the conceptual innovations, presented in the NR2C-project. In this project, urban design models are elaborated, in which a relation is established between the function of the road and the applied structure and materials.

Three recent realizations are done in Belgium, where coloured exposed aggregate concrete is combined with other materials such as concrete pavement blocks and natural stone [1].

At the Sint-Jans Square in Antwerp, the renovation involved the construction of an underground car park and the construction of decorative concrete paving at ground level. A yellow decorative concrete was alternated with a dark grey decorative concrete. LAMORIVILLE 5/8 dolomite and granite 3/8 were respectively used as granulate. A yellow ochre ferrous hydroxide ALS and a black manganese dioxide were respectively added as dye. Polypropylene fibres were used to limit the risk of cracking due to plastic shrinkage. A discontinuous granulate distribution was taken: besides the coarse aggregate, a 0/2 colour highlighting sand was used. The concrete was placed in 2 layers, using a slip form paver. The surface was finished using a retarding agent for fresh concrete applied directly after concreting at a ratio of 4 m²/l. The actual washing was carried out the following day by brushing with a mechanical brush. Finally, 4 weeks after the concreting and before entry into use, an aqueous anti-stain waterproof sealing was applied at a ratio of 250 g/m².

The project at the Fays Square in Saint-Hubert was set up in order to develop a multifunctional space at a major junction in urban environment. Exposed aggregate coloured concrete was used for the road sections and the parking areas in combination with gravel-surfaced concrete paving stones for the pedestrian zones. A convivial aspect was developed, notably by creating a pergola with benches and beds of plants, and a small amphitheatre and by widening the pavements facing the housing. Moreover, the planned developments will not prevent the semi-annual installation of the fun fair.

The structure was sized to carry heavy traffic as well as that of exceptional convoys taking the reserved itinerary crossing the town. The surface layer consists of a 23 cm exposed aggregate coloured concrete. The structure has a total thickness of 68 cm. In order to limit any risk of cracking, the concrete surface is made up of 4 m-long non-reinforced slabs. As regards the development of the square itself and of the lateral parking areas, a 20 cm coloured concrete was placed on a base of 40 cm. Finally, concrete paving stones were reserved for the pedestrian areas and laid on a 10 cm thick porous lean-concrete sub-base resting on a 30 cm sub-grade of unbound crushed aggregate. As granulate for the concrete, a sandstone was chosen with yellow quarry sand and a brown colouring pigment.

Sint-Jans Square in Antwerp

Fays Square in Saint-Hubert

Arms Square in Dinant

In Dinant, a revitalisation project accompanies the construction of a major housing and social complex. In this project, the public domain had to offer a certain number of functions:

- motor vehicle traffic: regional and communal roads;
- slow user traffic: pavements, the square and RAVeL (Independent Network for Slow Roads) bordering the Meuse;
- parking;
- service for local residents, municipal infrastructure, the hotel, the casino, etc.;
- leisure, rest and games: Arms square and spaces bordering the towpath.

The public space was essentially designed using two types of materials: light-grey concrete French stone and natural stone (small granite, sandstone and dolomite). Concrete paving stones were used as surfacing for all of the important surfaces: light-grey 22x11x12 paving stones for most of the roadways and parking areas and French-stone-coloured architectonic 22x22x8 concrete paving stones for the pavements. Exposed concrete poured on site was placed at some locations. Its shade is natural grey for the RAVeL and French stone at the foot of the building on the Meuse side and in the basketball pitch. The concrete poured on site for the spaces located on the banks of the Meuse was selected to resist possible flooding. The combination of exposed concrete paving stones and exposed concrete poured on site ensures harmony while offering slightly different surface textures. Dolomite covers some leisure areas within Arms square. For its part, small granite was used in two different situations: as a surface for the pedestrian axis which crosses the square and for linear elements separating different materials or marking the layout geometry.

The applications of coloured exposed aggregate concrete in Belgium give innovative possibilities for urban design and multifunctional uses of public spaces.

3. Heterogeneous photo catalysis, a process for air purification

The addition of TiO_2 at the surface of the exposed aggregate concrete could lead to even more functional roads, since it would incorporate air purifying capacities in the road structure. Although the practical and especially the economical application of TiO_2 in concrete poured on site is not yet optimized, some promising results are obtained with photo catalytic concrete pavement blocks.

The impulse of the use of TiO_2 as photo catalyst was given by Fujishima and Honda in 1972 [1]. They discovered the hydrolysis of water in oxygen and hydrogen in the presence of light, by means of a TiO_2-anode in a photochemical cell. In the eighties, organic pollution in water was decomposed by adding TiO_2 under influence of UV-light. The application of TiO_2 as air purifier originated in Japan in 1996. A broad spectrum of products appeared on the market for indoor use as well as for outdoor use.

When TiO_2, a semi-conductor, is irradiated with UV light (λ < 380 nm), electrons and holes are produced in the conduction and valence bands respectively. The electrons have a highly reactive reduction potential, while the holes have a highly reactive oxidation potential, which together induce catalytic reactions on the catalyst surfaces. 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 photo catalyst, TiO_2 is also used to obtain a self-cleaning material. This is due to a very high hydrophilicity of the surface when TiO_2 is activated by UV-light. The water layer is attracted between the dirt and the surface resulting in the washing off of the dirt particles. This effect is more pronounced with smooth surfaces like glass and ceramic tiles. In the case of concrete surfaces, the self-cleaning effect will be more limited due to the physical anchoring of the dirt in the larger pores. In addition, due to photo catalytic working, a decomposition of the dirt particles, especially of the organic particles takes place, followed by the washing of the surface resulting in a cleaner surface.

TiO_2 is a metal abundantly present in nature. It is used as pure metal in high-tech applications, where it couples corrosion resistance and low density to high strength. It can also be used in powder form or as a colloidal solution. The oxygen TiO_2 has three different molecule structures: rutile, anatase and brookiet. The former is mostly applied as white pigment in paints, the second is preferable used as photo catalytic cel. The latter has few application forms.

Heterogeneous photo catalysis with TiO_2 as catalyst results in a total mineralization of a broad gamma of organic compounds (alkanes, alkenes, alcohol, pesticides,…) Further, it is possible to reduce NO_x, bacteria, viruses,… The speed at which these reactions take place depends on the intensity of the light, the amount of TiO_2 present at the surface and the adhesion of the pollutants to the surface. In the case of traffic, it is important that the exhaust gasses stay in contact with the surface during a certain period. The geometrical situation, the speed of the traffic, the speed and direction of the wind, the temperature, influence the final reduction rate of pollutants in situ.

4. Laboratory procedure and results

To determine the air purifying activity of TiO_2, applied in building materials, the oxidation of NO and NO_2 into NO_3 is determined. Emphasis is put on this pollutant, since it is one of the most important pollutant produced by traffic and plays a major role in the formation of smog and ozone. It is also one of the pollutants on which limits have been places by the Kyoto agreement.

The oxidation of the NO is simplified presented by the following equations:

$$NO + {}^{\bullet}OH \xrightarrow{h\nu, TiO_2} NO_2 + H^+$$

$$NO_2 + {}^{\bullet}OH \xrightarrow{h\nu, TiO_2} NO_3^- + H^+$$

The last reaction is slower than the previous one, which results in a low increase of NO_2 concentration. However, one has to take into account that the conversion of NO into NO_2 also takes place in nature under influence of the sunlight. The rate of conversion depends on the original concentration of NO. By decreasing this concentration, the natural conversion into NO_2 will be slowed down.

The NO_3^-, which is formed during the process, will precipitate on the surface of the stone. To retain the efficiency of the material, the deposit will have to be washed away by rain or by cleaning the surface with water.

The test set-up is based on the Japanese standard JIS TR Z 0018 “Photo catalytic materials –Air purification test procedure”, which is also adapted in a proposal for an ISO standard (2/2/2004): “Fine ceramics (advanced ceramics, advanced technical ceramics) – Test method for air purification performance of photo catalytic materials – Part 1: Removal of nitric oxide”, ISO TC 206/SC N. The test set-up consists of a metal container, in which 1 pavement block is placed, with a UV-transparent glass at the top. Air with a NO-concentration of 1 ppm is blown over the surface with a flow rate of 3 l/min. The height of the free space is 3 mm. The temperature is approximately 23°C and the relative humidity is 50%. The light intensity is equal to 10 W/m² in the range between 300 and 460 nm. The maximum is at 365 nm. The set-up is illustrated in figure 2.

Figure 2: Set-up of the test to determine the air purifying properties

The concentration of NO and NO_2 is measured at the outlet of the container. The test is executed during 5 hours. 30 minutes prior to the test, the concentration of the air is measured without illumination to ensure that there is no deposit of the NO on the surface.

A typical result of the test is given in figure 3. The inlet concentration is equal to 1 ppm. As soon as the light is put on, the concentration drops with approximately 40%. After 5 hours of illumination, the NO is cut off for 30 min. Consequently, the light is put off again and the NO is concentration is measured.
The results indicate a small increase in NO_2, but a significant decrease in NO_x ($NO+NO_2$). The final decrease depends on the material itself, on the size of the surface exposed, on the concentration of NO, on the light intensity, the ambient temperature and the flow rate.

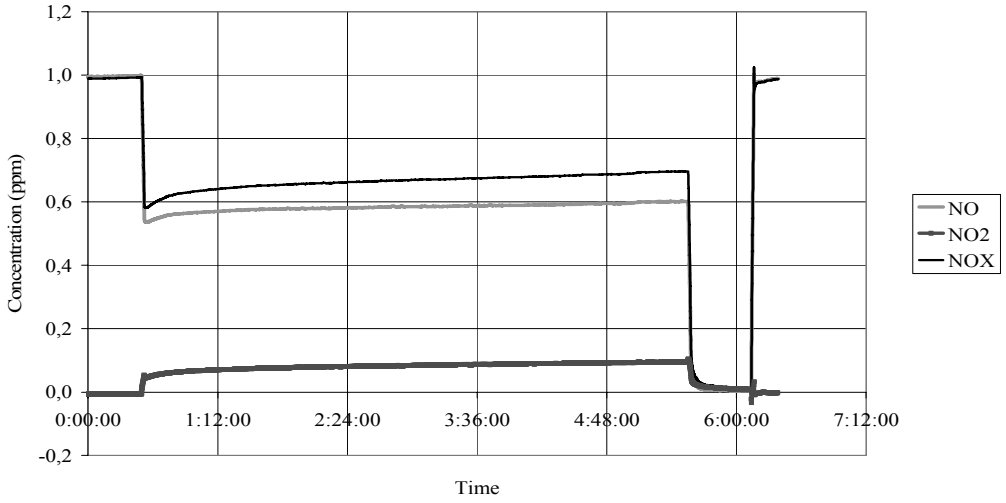

Figure 3: Results obtained in laboratory according to the standard test procedure

By increasing the surface by 6 (2 rows of 3 pavement blocks) for instance, a further reduction is obtained (up till 85%), which results in a NO_x concentration of 13.5% at the outlet. This is very promising for the extrapolation to the situation in situ. By increasing the time of contact and increasing the surface over which the air flows, the reduction will be even more significant.

5. Pilot project in Antwerp

An important issue is the conversion of the results obtained in the laboratory to real applications. The construction of a test section of 10.000 m² photo catalytic pavement blocks as pilot project on the parking lanes of a main axis in Antwerp allows us to search for answers on frequently asked question, like the amount of reduction of NO_x, the durability of the material not only for mechanical and aesthetical properties, but also for the photo catalytic efficiency, the minimum surface needed related to traffic density and the frequency of maintenance, i.e. washing off of the surface by rain or by artificial spraying.

Figure 4 gives a view of the parking lane where the photo catalytic concrete pavement blocks are applied. Only the upper layer of the blocks contains TiO_2.

Figure 4: Separate parking lanes at the Leien of Antwerp with photo catalytic pavement blocks

To obtain results towards the reduction of e.g. NO_x and on the durability of this reduction, different measurement techniques may be applied. The use of global measurement sites is not appropriate, due to the limited surface covered by the photo catalytic pavement blocks compared to the overall surface. Local continuous measurement of the NO and NO_2 concentration demands a long period during which the measurement has to be conducted to eliminate the influence of parameters such as wind, temperature, light intensity, traffic intensity and so on. Although the presence of a reference lane allows comparing measurements, the time needed to come to reliable results will be too long. Another method, which seems to be more suitable, is the measurement of NO_3-deposit on the surface of the blocks. The NO and NO_2 oxidizes into NO_3, which forms a deposit on the surface. By washing off the stones with distilled water and determining the amount of N in the water, an idea of the minimum amount of reduced NO_x can be obtained. Furthermore, a regular measurement in laboratory will be executed on blocks from the surface to measure the possible reduction of efficiency under controlled conditions.

The measurements on site have started during the summer of 2005. They will continue over 2 years and will be reported in due time.

6. Conclusions

In this paper, two different applications of concrete pavement are described: the coloured exposed aggregate concrete pavement and photo catalytic concrete pavement blocks. Both applications are very suitable in urban conditions. They contribute to a safe, comfortable, environmentally friendly interpretation of the urban design and roads for the future.

Coloured exposed aggregate concrete complies with the multifunctional demand of public spaces. The three examples briefly mentioned in this paper indicate that an aesthetical layout may be obtained without giving in on functionality and durability. The harmonization between concrete poured in place and other materials like concrete pavement blocks and natural stone allows for a well-considered design in which the different users of the public space are taken into account.

The addition of TiO_2 in building materials and more specifically in concrete pavement blocks, add an additional property to the road. Purification of the air, which is in contact with the surface, is obtained when the surface is exposed to UV-light (present in daylight). The preliminary results obtained in the laboratory are very promising. A pilot project of 10.000 m² is constructed in Antwerp. Measurements to reveal the air purifying efficiency in situ and the durability of this efficiency are programmed. The results will be published in due course.

7. References

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8. Acknowledgements

The author wishes to thank IWT-Flanders for its support to this project. (VIS-CO 020790).