

## **Air purification by pavement blocks: final results of the research at the BRRC**

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### **Abstract**

The use of materials can influence to a large extent the environmental impact of traffic and of road infrastructure. Especially at urban areas, where the risk on smog formation during hot summer days is high, the use of photocatalytic pavement blocks can reduce the air pollution significantly.

A project on environmental friendly concrete pavement blocks is conducted at the Belgian Road Research Centre. The use of photocatalytic material in the surface of pavement blocks to obtain air purifying materials is investigated. In contact with light,  $\text{TiO}_2$  as photocatalyst, is able to reduce the  $\text{NO}$  and  $\text{NO}_2$  content in the air, caused by the exhaust of traffic. The efficiency is tested on pavement blocks, but the technique can as well be applied on other road elements (noise reducing walls, linear elements,...) or as a coating on new materials or existing structures.

At the previous TRA conference in Gotenborgh, the principle of photocatalysis is presented [1]. In this paper, emphasis will be put on the final results of the 4-year project obtained in laboratory as well as on site at the Leien of Antwerp (10.000  $\text{m}^2$ ). The results indicate a durable efficiency towards  $\text{NO}_x$  reduction, which is in favour for the diminishing of the risk on ozone formation. However, the precise translation from the laboratory towards the site is still in question. The results obtained during the project are discussed in this paper.

Keywords:  $\text{TiO}_2$ ; photocatalysis; air purification; surface treatment

### **1. Introduction**

Emission from the transport sector has a particular importance on the overall air quality because of their rapid rate of growth: goods transport by road in Europe has increased by 54 % since 1980, while in the past 10 years passenger transport by road in the EU has gone up by 46 % and passenger transport by air by 67 % . The main emissions caused by motor traffic are nitrogen oxides ( $\text{NO}_x$ ), hydrocarbons (HC) and carbon monoxide (CO), accounting for 58 %, 50 % and 75 % respectively of all such emissions [2].

These pollutants have an increasing impact on the urban air quality. In addition, photochemical reactions resulting from the action of sunlight on  $\text{NO}_2$  and VOC's lead to the formation of 'photochemical smog' and ozone, a secondary long-range pollutant, which impacts in rural areas often far from the original emission site. Acid rain is another long-range pollutant influenced by vehicle  $\text{NO}_x$  emissions and resulting from the transport of  $\text{NO}_x$ , oxidation in the air into  $\text{NO}_3^-$  and finally precipitation of nitrogen acid with harmful consequences for building materials (corrosion of the surface) and vegetation.

The European directives impose a limit to  $\text{NO}_2$  concentration of max.  $40 \mu\text{g}/\text{m}^3$   $\text{NO}_2$  (33 ppbV) averaged over 1 year and  $200 \mu\text{g}/\text{m}^3$  (163 ppbV) averaged over 1 hour. These limits gradually decrease from 50 and 250 in 2005 to the final limit in 2010 [3].

Heterogeneous photocatalysis is a promising method for  $\text{NO}_x$  abatement. As will be indicated in the last paragraph of this paper, different applications exist. Up till now, UV-light was necessary to activate the photocatalyst. However, recent research indicates a shift towards the visible light. This means that applications in tunnels and inside become more realistic. Especially the application in tunnels is worth looking at due to the concentration of air pollutants at these sites. Up till now, some applications of  $\text{TiO}_2$  at the mouths of the tunnels are known, like the application of  $\text{TiO}_2$  at the exits of the Göta tunnel in Göteborg, Sweden.

## 2. Heterogeneous photocatalysis, a process for air purification

A solution for the air pollution by traffic can be found in the treatment of the pollutants as close to the source as possible. Therefore, photocatalytic materials can be added to the surface of pavement and building materials. In combination with light, the pollutants are oxidized, due to the presence of the photocatalyst and precipitated on the surface of the material. Consequently, they are removed from the surface by the rain.

Heterogeneous photocatalysis with  $\text{TiO}_2$  as catalyst is a rapidly developing field in environmental engineering. It has a great potential to cope with the increasing pollution. The impulse of the use of  $\text{TiO}_2$  as photocatalyst was given by Fujishima and Honda in 1972 [4]. They discovered the hydrolysis of water in oxygen and hydrogen in the presence of light, by means of a  $\text{TiO}_2$ -anode in a photochemical cell. In the eighties, organic pollution in water was decomposed by adding  $\text{TiO}_2$  under influence of UV-light (wave length lower than 387 nm). The application of  $\text{TiO}_2$ , in the form of anatase, 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. 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.

In the case of concrete pavement blocks [5-6], the anatase is placed in the wearing layer of the tile which is approximately 8 mm thick. The fact that the  $\text{TiO}_2$  is present over the whole thickness of this layer means that even if some abrasion takes place by the traffic, new  $\text{TiO}_2$  will be present at the surface to maintain the photocatalytic activity. The application of the  $\text{TiO}_2$  in combination with cement leads to a transformation of the  $\text{NO}_x$  into  $\text{NO}_3^-$ , which is adsorbed at the surface due to the alkalinity of the concrete. It will be washed away by rain.

## 3. Laboratory results: parameter evaluation

Different test methods are developed to determine the efficiency of photocatalytic material towards air purification. An overview is given in [7]. A distinction can be made by the type of air flow. With the flow-through method (JIS TR Z 0018 / ISO TC 206/SC N), the air, with a concentration of 1 ppmV, passes over the sample, which is illuminated by a lamp with light intensity equal to  $10 \text{ W}/\text{m}^2$  in the range between 300 and 460 nm. The  $\text{NO}_x$  concentration is measured at the outlet. This test is used for this research. In the 'static'-method, the air is put into circulation into a closed circuit. The abatement of  $\text{NO}_x$  is measured over time. This method simulates the 'canyon effect' which can take place in smaller streets in urban areas.

The preparation of the samples is of great importance. Due to the photocatalytic activity,  $\text{NO}_3^-$  is deposited on the surface of the material and covers to a certain extent the  $\text{TiO}_2$  from the light and from the pollutants. By this the efficiency is lowered over time. By rinsing the surface, the initial efficiency can be reached again. The pre-treatment of the samples in the laboratory is important to obtain reproducible results. This effect is visible in figure 1, where a typical test scheme is applied to the sample: 0.5 hour at 1ppmV NO-concentration, no light – 5 h exposure to an air flow with 1 ppmV NO-concentration and illumination – 0.5 hour with illumination and no exposure. A small increase in time of the  $\text{NO}_x$  concentration is visible due to the deposit of the  $\text{NO}_3^-$  at the surface.

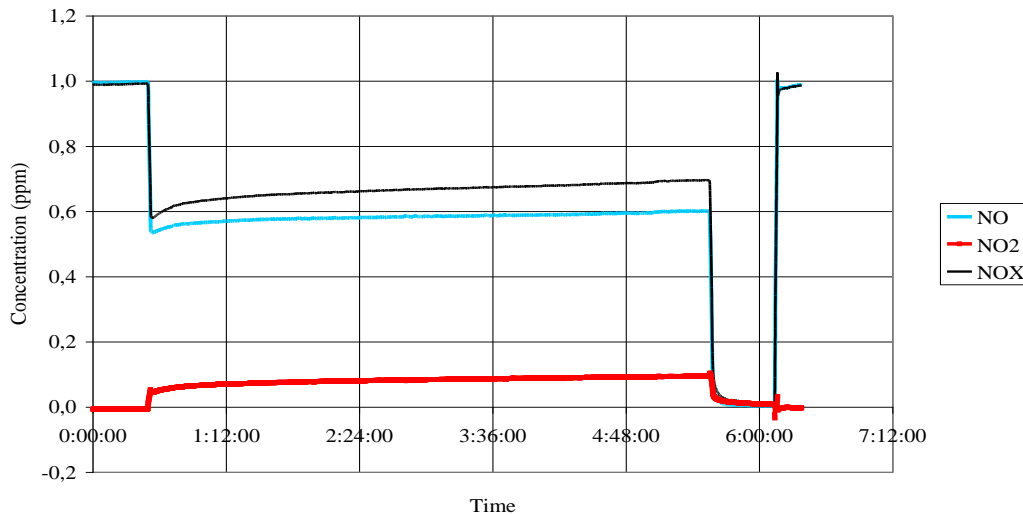


Figure 1 Results obtained in laboratory according to the standard test procedure

The laboratory research program consisted of the control of different parameters such as temperature, relative humidity, contact time (surface, flow velocity, height of the air flow over the sample,...). In general it can be stated that the efficiency towards the reduction of  $\text{NO}_x$  increases with a longer contact time (larger surface, lower velocity, smaller height of air flow, higher turbulence at the surface) and a lower relative humidity. These are the conditions at which the risk of ozone formation is the largest: high temperatures, no wind and no rain. At these days, the photocatalytic reaction will be more present.

#### 4. Pilot project in Antwerp

An important issue is the conversion of the results, obtained in the laboratory to real applications. In order to see the influence of the photocatalytic pavement blocks in real conditions, a test section of 10.000 m<sup>2</sup> photocatalytic pavement blocks as pilot project on the parking lanes of a main axe in Antwerp is constructed in 2004-2005. Figure 2 gives a view of the parking lane, where the photocatalytic concrete pavement blocks are applied. Only the wearing layer of the blocks contain  $\text{TiO}_2$ . In spite of the fact that the surface applied on the Leien of Antwerp is quite important, one has to notice the relative small width of the photocatalytic parking lain in comparison with the total street: 2\*4.5 m on a total width of 60 m.



Figure 2 Separate parking lanes at the Leien of Antwerp with photocatalytic pavement blocks

Two different types of tests were carried out. First of all pavement blocks were taken from the Leien after different periods of exposure. These blocks were measured in the laboratory without washing of the surface and with washing of the surface. The results are presented in figure 3. They indicate a good durability of the efficiency towards  $\text{NO}_x$  abatement. The deposition of pollutants on the surface leads to a decrease in efficiency which can be regained after washing.

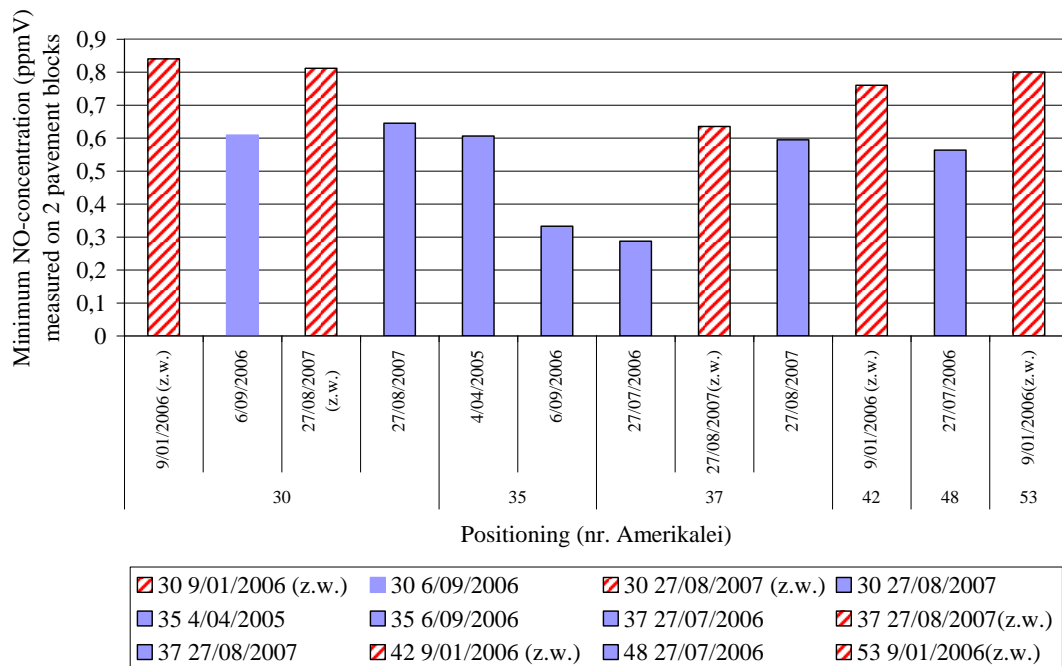


Figure 3  $\text{NO}_x$  concentration at the outflow, measured on 2 pavement blocks, before (z.w.) and after washing the surface

Besides the measurements in the laboratory, on site measurements are carried out. Since no reference measurements, without photocatalytic material, exist, the interpretation of these results is very difficult. Especially the influence of traffic, wind speed, light intensity and the relative humidity are playing an important role.

Figure 4 gives an overview of the measurements made on the 9<sup>th</sup> of June 2006 at 3 different places at the Leien of Antwerp. Consequently, measurements were made at house number 50, 108 and 38 of the Amerikalei. The parking lanes at number 50 and 38 contained photocatalytic pavement blocks, the parking lane at number 108 were placed with classic concrete pavement blocks. The measurements were carried out during 1 day. Parameters of the measurements are shown in table 1.

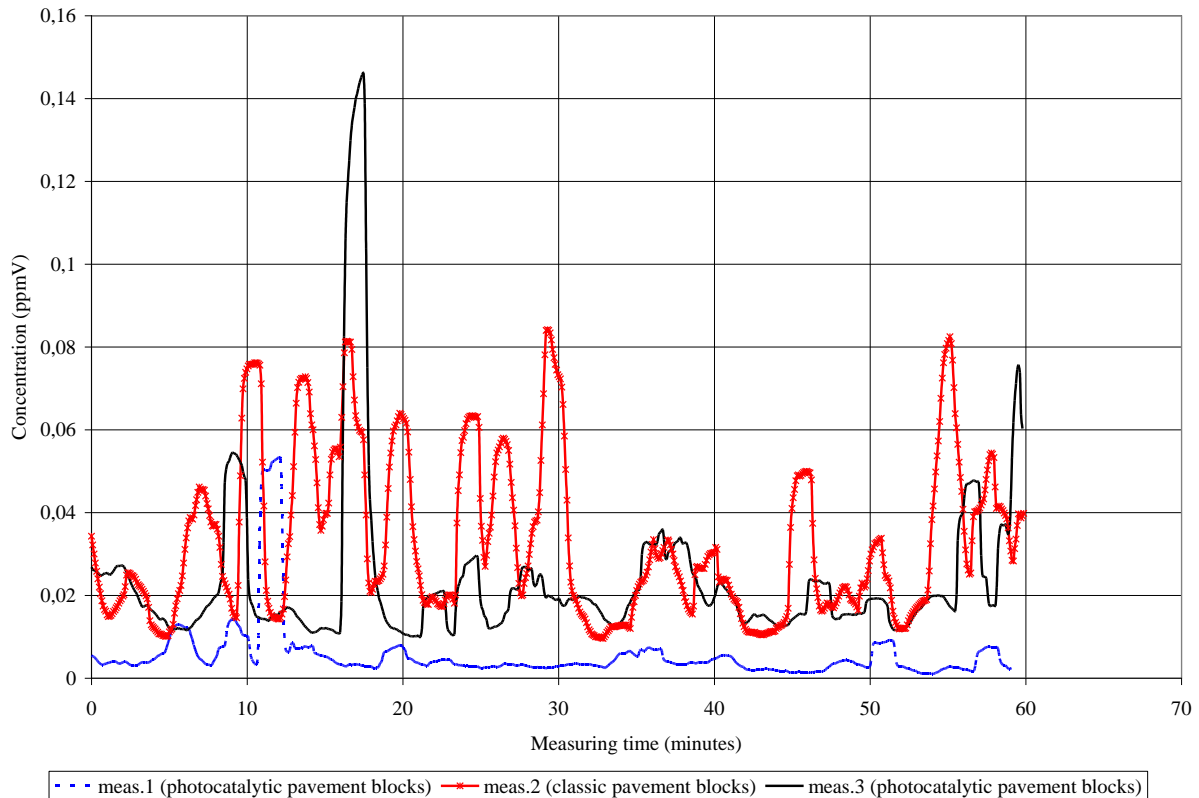


Figure 4 NO<sub>x</sub> measurements at the Leien of Antwerp

Table 1. Parameters of the measurements at the park lanes of the Leien of Antwerp

	Time	Vehicles/hour	R.H.	Temperature	Light intensity
1	10:32–11:32	1332	33 %	25°C	12 W/m <sup>2</sup>
2	11:41–12:41	1494	30 %	26,6°C	17 W/m <sup>2</sup>
3	14:10–15:10	1620	25 %	32,4°C	25 W/m <sup>2</sup>

The air was continuously taken at 5 cm above the surface at the side of the photocatalytic pavement blocks. The light intensity was measured parallel to the surface of the pavement blocks. The vehicles were counted manually on the main road of the Leien of Antwerp during the last 10 minutes of the measurement.

The results indicate a decrease in NO<sub>x</sub>-concentration at the sites with photocatalytic materials. A leveling out of the peaks is visible. The 3<sup>rd</sup> measurement is slightly higher than the 1<sup>st</sup> in spite of the lower relative humidity. Although the results presented in figure 4 give an indication of the efficiency of the photocatalytic material, precaution has to be taken since the results are momentary and limited over time.

## 5. Other field tests

More and more in situ applications are made in which the relation between the efficiency in laboratory and on site is established. A short overview is given in this paragraph.

One of the first large on site investigation is made in the PICADA project. In May-September 2004, a field experimental campaign is conducted in an artificially constructed street canyon in Guervill, Paris, which had a scale of 1:5. Statistics showing the depollution activity of the rendering versus  $\text{NO}_x$  were extracted from a three month measurement campaign. Important was the development of a numerical simulation tool to demonstrate and assess the depollution effect of the materials [8].

Towards horizontal applications different types may be distinguished: photocatalytic pavement blocks, as is applied in Antwerp, Belgium, in Bergamo, Italy [9] and in Japan; the combination of a hot mix asphalt and a cementitious mortar to which  $\text{TiO}_2$  is added [10], applied in Italy and in France or a concrete overlay as is newly applied in Paris, Portes des Vanves, France.

Vertical applications may be found in the Netherlands (as part from the IPL project) [11], in France [12], where photocatalytic materials are applied on noise barriers to achieve noise reduction as well as air purification.

Recent applications are realized in London, UK [13], where a school wall is covered with a  $\text{TiO}_2$  coating and extensive measurements are made. New applications can also be found in tunnels, where a combination of  $\text{TiO}_2$  and appropriate lighting is applied. In tunnels, due to the concentration of the pollutants, the actual abatement of  $\text{NO}_x$  can be much larger.

The translation from the laboratory results to the site efficiency is still a difficult factor. The best results can be achieved by modelling the environment, validating the model by measurements followed by an implementation of the different parameters. In the NR2C-project, the abatement of pollutants, by using photocatalytic materials in tunnels as well as on highways is investigated [14].

## 6. Conclusions

The use of photocatalytic materials to minimize the air pollution by traffic is applied more frequently on site in horizontal as well as in vertical applications. Laboratory results indicate a good efficiency towards the abatement of  $\text{NO}_x$  in the air by using photocatalytic materials. However, the relative humidity is an important parameter, which may reduce the efficiency on site. If the RH is high, the water will be adsorbed at the surface and prevent the reaction with the pollutants.

Measurements on site indicate a decrease of the peaks due to the presence of the photocatalytic material. Repeated measurements in the laboratory on the photocatalytic concrete pavement blocks confirm the efficiency over time. Although a reduction in efficiency is noticed due to the deposition of the  $\text{NO}_3^-$  on the surface, the original efficiency can be regained by washing the surface.

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