Enhanced air pollutant removal efficiency of photocatalytic concrete with waste glass

ENHANCED AIR POLLUTANT REMOVAL EFFICIENCY OF PHOTOCATALYTIC CONCRETE WITH WASTE GLASS

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Abstract

This study investigates the air pollutant removal efficiency of photocatalytic concrete with incorporated waste glass. Concrete samples are prepared with two different TiO_2 photocatalysts applied at different dosages. Subsequently, the photocatalytic oxidation (PCO) degradation efficiency of air pollutant is tested and compared between the reference concrete samples with normal aggregates and samples with waste glass particles. The obtained results indicate that the utilization of glass as concrete aggregate can enhance the PCO efficiency of concrete. The highest PCO efficiency improvement by glass particles application reached over 52% compared to the reference sample.

Key Words: *concrete, waste glass, air pollutants, photocatalytic oxidation (PCO)*

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1. INTRODUCTION

The photocatalytic oxidation (PCO) technology is becoming more commonly applied in building materials to provide the materials with self-cleaning and/or air-purifying properties. The most commonly used photocatalyst – TiO_2, is proven to perform well in concrete exposed to the outdoor environment. Recently, a full scale demonstration project in Hengelo (the Netherlands) has shown that a significant air pollutants (e.g. NO_x) removal in the urban area environment can be achieved by photocatalytically active concrete [1]. The reported results show that an average NO_x concentration reduction reached over 19% during the entire day length, reaching even 28% when considering only the afternoon, when the UV-light intensity is the highest. Under the ideal weather conditions, the NO_x concentration reduction could reach over 45% compared to the control street paved with standard concrete stones. Besides the UV-active TiO_2 used in outdoor applications, new types of modified TiO_2 (e.g. by doping) that can be activated by the visible light are also becoming widely available. Thus, this type of photocatalyst can be used also in indoor applications. Nevertheless, as TiO_2 is still considered as a relatively expensive additive compared to traditional building materials (e.g. concrete), it is wise to apply it in an optimal and efficient way.

Waste glass can be utilized in concrete as a partial or complete replacement of fine/coarse aggregates. Previous studies show that it is possible to overcome all the related issues e.g. lower mechanical properties, workability problems or alkali-silica reaction [2-5]. Besides the sustainability benefits of the usage of waste glass in concrete, some additional features of the material can be created, including translucency or aesthetically attractive surfaces with exposed aggregates [2,5].

The purpose of this study is to evaluate the effect of glass aggregates applied in the photocatalytic concrete on its air pollutants degradation efficiency. The light transmittance and reflection properties of glass particles are considered as main factors for a potential enhancement of the PCO efficiency, as the transferred light could be better scattered within the concrete matrix and activate the TiO_2 particles more effectively.

2. MATERIALS AND TEST METHODS

Following the previous study on the development of translucent concrete based on waste glass [2], one self-compacting concrete (SCC) mixture was selected for analyses. Two types of concrete were produced with the incorporation of TiO_2, one with fine and coarse waste glass particles and another one with conventional sand and aggregates, with the same volumetric proportions as the control mixture. This was done in order to analyse the enhancement of the air pollutant removal efficiency by waste glass particles. Two different types of TiO_2 slurries are used in this study with different dosages, to investigate their effects. Evonik TiO_2 - AERODISP W 740 X, is a water-based dispersion of fumed TiO_2. KRONO Clean 7404 is a carbon-doped TiO_2 also in a slurry form. The properties of both TiO_2 additives are summarized in Table 1. The particle size distributions of the materials used in this research are presented in Fig. 1. The reference concrete mixtures (no glass particles additions) are prepared with 3 different dosages of both TiO_2 types (i.e. 3, 5 and 7% by mass of cement). Similar TiO_2 dosages are also applied in the concrete samples containing waste glass, in which the glass particle replaced volumetrically all the sand and gravel from the reference concrete.

Table 1: Properties of the TiO_2 photocatalysts

Product name	AERODISP W 740 X	KRONO Clean 7404
TiO_2 type	Anatase	Anatase
TiO_2 content in the slurry [%]	40	40-50
pH	6.0 – 9.0	7.0 – 8.0
Viscosity	≤ 1000 mPas	≤ 800 mPas
Density (slurry)	1.43 g/cm^3	1.40 g/cm^3
Appearance	Milky liquid	Brownish-slurry
Particle size	40–300 nm	10–200 nm

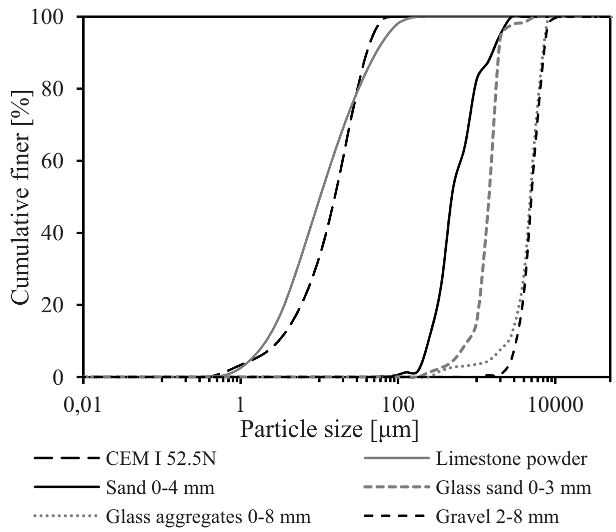

Fig. 1: Particle size distributions of used materials

Therefore, 12 different mixtures are prepared in total in this study (6 reference mixtures and 6 mixtures with waste glass). The base recipes for the reference concrete and concrete with waste glass are given in Table 2. The TiO_2 is added to the mixtures by replacing an equivalent volume of limestone powder, in the dosages of 3, 5 and 7% by the mass of cement. The water present in the TiO_2 slurry is subtracted from the total mixing water amount. Two samples are cast for each mixture (dimensions of 100mm × 200mm × 20mm) for the photocatalytic oxidation tests. One day after casting, the samples are demoulded and water-cured until the age of 28 days. Subsequently, the top surface of the samples is polished using a wet grinding device, in order to expose the embedded aggregates/glass, and dried in an oven. Finally, the PCO experiments are performed following the ISO 22197-1:2007. Fig. 2 shows a concrete sample mounted in the reactor prior to the PCO experiments.

Table 2: SCC mixture proportions

Reference SCC	CEM I 52.5 N	Limestone powder	Sand 0-4 mm	Gravel 2-8 mm	Water
Dosage [kg/m^3]	460.8	132.9	813.5	734.6	206.9
SCC with glass	CEM I 52.5 N	Limestone powder	Glass 0-3 mm	Glass 0-8 mm	Water
Dosage [kg/m^3]	460.8	132.9	770.7	703.7	206.9

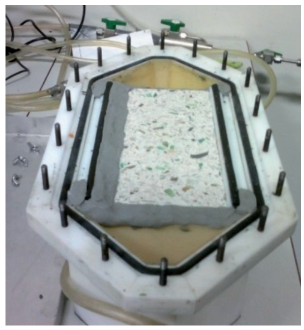

Fig. 2: Concrete sample in the PCO reactor

After the concrete sample is inserted into the reactor (see Fig. 2), it is tightly sealed with a borosilicate glass plate, allowing light to pass. Then, the reactor is connected to the PCO set-up (see Fig. 3) and the pollutant (NO) is mixed with synthetic air to get an initial concentration of 1ppm and a volumetric flow rate of 3 L/min. After reaching stable conditions inside the reactor, the concrete sample is exposed to the irradiating light. The applied light source consists of three cool ultraviolet lamps of 25 W each, emitting an ultraviolet radiation (UV) in the range of 300-400 nm. The light intensity is measured with a UVA radiometer. The schematic diagram of PCO set-up is presented in Fig. 3.

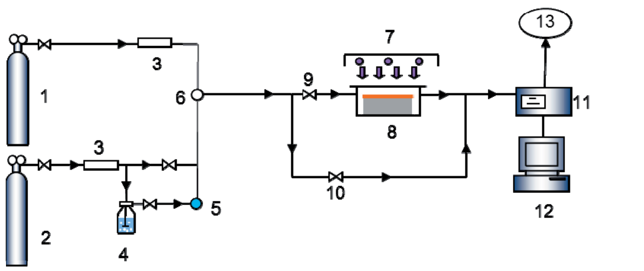

Fig. 3: Schematic diagram of PCO set-up [6]. 1. NO gas supply; 2. Synthetic air; 3. Mass controller meter; 4. Humidifier; 5. Humidity controller; 6. Temperature and RH sensor; 7. Light source; 8. Reactor; 9 and 10 Valves; 11. NO_x analyzer; 12. Computer; 13. Vent

The experiments are performed at a room temperature (20 ºC). The air stream is humidified by flowing into a demineralized water-filled bottle to ensure a steady 50% relative humidity during the measurements. The needed pollutant concentration is adjusted by mass control meters to ensure the appropriate proportions of the gases. The PCO reaction takes place immediately once the sample is exposed to the UV-light. The stream of the outlet reactor gas is directed to the NO_x concentration analyzer, where the outlet concentration of air pollutants is measured (including the unreacted NO and generated NO_2 as intermediate). To determine the efficiency of the pollutant degradation (conversion), the difference between the inlet and outlet concentrations in the reactor is determined, taking into the account also the NO_2 concentration. Two samples are tested for each developed concrete mixture and an average PCO conversion of NO_x is then computed.

3. RESULTS

Fig. 4 presents the concentration development of nitrogen oxides in the reactor due to the photocatalytic oxidation reaction for the reference SCC with 5% addition of AERODISP W 740 X. It can be observed that the PCO reaction cause a significant reduction of the nitrogen oxides concentration.

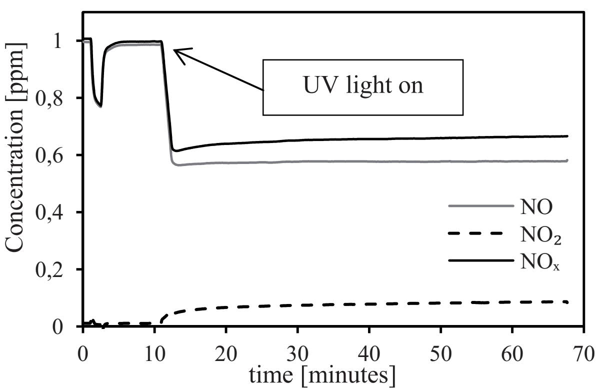

Fig. 4: NO_x concentration change during the PCO test

Fig. 5 presents the average NO_x conversion rates of the developed SCC reference and waste glass samples with Evonik AERODISP W 740 X TiO_2 photocatalyst. For the reference concrete samples, the conversion rates hold in the range of 20-30%. The NO_x conversion rate in the samples containing fine and coarse glass aggregates is significantly improved, especially in the samples containing 3 and 5% TiO_2 additions (52 and 41% higher conversion than the control samples, respectively). Therefore, it can be stated that for a reasonable air pollutant removal, a 3% dosage of this TiO_2 type can be recommended.

Fig. 6 presents the NO_x conversion rates of the SCC reference and waste glass samples with KRONO Clean 7404 TiO_2 photocatalyst. Again, a noteworthy NO_x conversion improvement can be observed for the samples containing waste glass particles (17-38% improvement). Hence, it can be concluded that glass particles, due to their light transmittance and scattering properties, can help the UV-light to activate the TiO_2 photocatalyst applied in concrete in a more efficient way, improving its overall PCO efficiency.

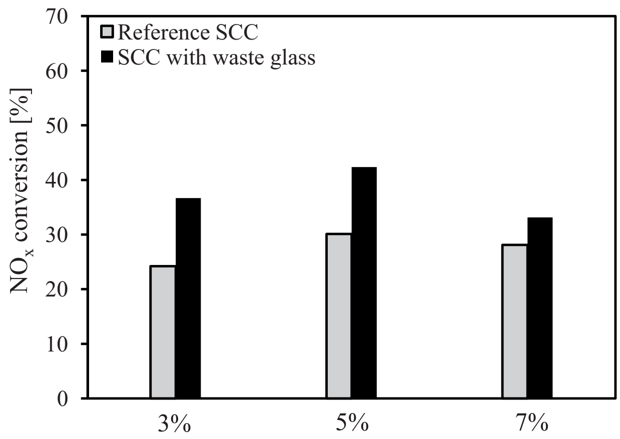

Fig. 5: NO_x conversion efficiency of SCC with different additions of AERODISP W 740 X TiO_2

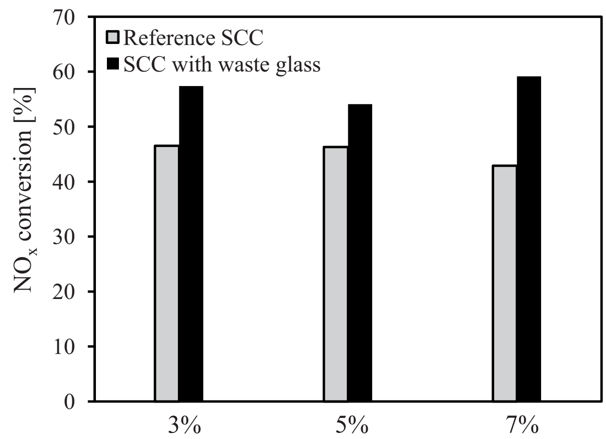

Fig. 6: NO_x conversion efficiency of SCC with different additions of KRONO Clean 7404 TiO_2

Analyzing the results shown in Fig. 6, it can be noticed that there is no significant NO_x conversion improvement for the TiO_2 dosages higher than 3%. Also, as shown in Fig. 5 for the other TiO_2 type, the highest TiO_2 dosage does not correspond to the highest NO_x conversion. This could be explained by agglomeration of TiO_2 particles when applied in larger quantities, which could occur as this material is very fine (see Table 1). Likely, if the agglomerates would form, an inhomogeneous distribution of TiO_2 particles in concrete matrix would decrease the PCO efficiency as the surface area of larger particle clusters is lower. Another possible explanation for this phenomenon is the experimental conditions (e.g. the air flow rate through the reactor), which can limit the amount of the NO_x or H_2O particles adsorbed on the TiO_2 active surface. Therefore, even for an increased number of TiO_2 particles in the system, the global PCO efficiency could remain at similar levels.

CONCLUSIONS

- Glass aggregates applied in photocatalytic concrete improve its air pollutants removal efficiency. All the samples prepared with waste glass show higher NO_x conversion rates compared to the reference samples with conventional aggregates. The highest NO_x conversion improvement due to the glass additions reached over 52% compared to the control samples;
- There is no significant NO_x conversion increase in the samples with higher TiO_2 additions. Therefore, a 3% TiO_2 addition can be recommended based on the results shown in present study..

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BIOGRAPHIES

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