The effect of TiO2 nanoparticles in reduction of environmental pollution in concrete structures

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Abstract. Heterogeneous photocatalysis is developed rapidly in the field of engineering of environmental. It has a good potential to tackle with the enhancing traffic pollution. Adding photocatalyst to usual building materials such as cement and concrete makes friendly environmental materials against the air pollution. TiO2 nanoparticles are a good item for concrete structures for diminishing the air polluting effect by gasses of exhaust. In specific, the transformation of NOx to NO3- is studied and the interaction of TiO2 nanoparticles and concrete is investigated here by experimental test. This paper presents an overview of the principle of photocatalysis and the application in combination with cement, as well as the results of the laboratory research, especially towards air purifying action. In addition, by the analytical models, the influence of TiO2 nanoparticles is studied on the stiffness of the concrete. The Results show that TiO2 nanoparticles have significant effect on the reduction of environmental pollution and increase of stiffness in the concrete structures

Keywords: TiO2 nanoparticles; concrete structures; environmental pollution; stiffness

1. Introduction

In modern civic environments, the quality of life, mobility and comfort are very important issues. In modern countries, the environmental requests are a significant objective in the projects. Applying TiO2 nanoparticles in the concrete is one of the new ideas which can leads to environmental pollution. However, we investigate this subject in this article based on experimental and analytical models.

Nanoparticles have good effects on the mechanical, environmental and chemical properties of structures (Babazadeh et al. 2016). The materials with self-cleaning properties based on photocatalyst were presented by some researchers. TiO2 is metal in nature. The oxygen of TiO2 has 3 molecules of anatase, rutile and brookiet. Rutile is in white tint with little photocatalytic reactivity until now. Anatase is superior for photocatalytic. For this purpose, a UV-light with wave length of 387 mm or lower than it is needed. In addition, the light strength is major for optimization the activity of photocatalytic. Researchers focused on the usage of TiO2 nanoparticles in air conditioning, water purification, ceramic tiles, selfcleaning, textile, tunnel lightning and etc. This is since to high surface hydrophilicity activatingTiO2 by UV-light. The layer of water is engrossed between the surface anddirt which wash off of the dirt particles.


To the best of author knowledge, no work has been presented on reduction of environmental pollution in concrete structures using TiO2 nanoparticles. However, we presented the effect of TiO2 nanoparticles on the mechanical properties and reduction of environmental pollution in concrete structures.

2. Laboratory tests

To obtain the air cleaning activity of TiO2 nanoparticles for building materials, the oxidation of OH and NO into NO2 is obtained. Matter is carried out for pollution induced by traffic and other subjects. The NO oxidation is written using below equations

\[
\text{NO} + \text{OH} \xrightarrow{hv, \text{TiO}_2} \text{NO}_2 + \text{H}^+ \tag{1}
\]

\[
\text{NO}_2 + \text{OH} \xrightarrow{hv, \text{TiO}_2} \text{NO}_3 + \text{H}^+ \tag{2}
\]

Other important items are high temperature and humidity due to water of atmosphere. At higher temperatures, the conversion will be better. The optimum condition is at hot summer days due to low humidity and
high temperature.

The experiment set-up is based on the Japanese standard of JIS TR Z 0018 consisting of metal container, pavement block and UV-transparent glass. Air with a NO-doping of 1 ppm over the surface is blown with flow rate of 3 l/min. The height for the free space is about 3 mm. The temperature is 24°C and the humidity is 51%. The light force is 15 W/m² in the range of 300 and 500 nm.

3. Analytical model

Various methods are used to obtain the average properties of a composite (Mori and Tanaka 1973). Due to its simplicity and accuracy even at high volume fractions of the inclusions, the Mori-Tanaka method (Mori and Tanaka 1973) is employed in this section. The matrix is assumed to be isotropic and elastic, with the Young’s modulus $E_m$ and the Poisson’s ratio $\nu_m$. The constitutive relations for a layer of the composite with the principal axes parallel to the $r$, $\theta$ and $z$ directions are (Mori and Tanaka 1973, Shi and Feng 2004)

$$
\begin{bmatrix}
\sigma_{11} \\
\sigma_{22} \\
\sigma_{33} \\
\sigma_{12} \\
\sigma_{13} \\
\sigma_{23}
\end{bmatrix} = 
\begin{bmatrix}
k + m & l & k - m & 0 & 0 & 0 \\
l & n & l & 0 & 0 & 0 \\
k - m & l & k + m & 0 & 0 & 0 \\
0 & 0 & 0 & p & 0 & 0 \\
0 & 0 & 0 & 0 & m & 0 \\
0 & 0 & 0 & 0 & 0 & p
\end{bmatrix} \begin{bmatrix}
\varepsilon_{11} \\
\varepsilon_{22} \\
\varepsilon_{33} \\
\gamma_{12} \\
\gamma_{13} \\
\gamma_{23}
\end{bmatrix}
$$

where $\sigma_{ij}$, $\varepsilon_{ij}$, $\gamma_{ij}$, $k$, $m$, $n$, $l$, $p$ are the stress components, the strain components and the stiffness coefficients respectively. Utilizing the Mori-Tanaka method the stiffness coefficients are given by Mori and Tanaka (1973)

$$
k = \frac{E_m[E_mC_m + 2k(1+p_m)(1+c_m, (1-2c_m))]}{2(1+p_m)[E_m(1+c_m, -2c_m) + 2c_mk(1-v_m,-2c_m)]}
$$

$$
l = \frac{E_m[C_m, C_m + 2k(1+p_m)(1+c_m, (1-2c_m))]}{(1+p_m)[E_m(1+c_m, -2c_m) + 2c_mk(1-v_m,-2c_m)]}
$$

$$
n = \frac{E_m^2c_m, (1+c_m, -c_m^2) + 2c_mC_m(k, n_m, -l_m)(1+v_m)(1-2v_m)}{(1+v_m)[E_m(1+c_m, -2c_m) + 2c_mk(1-v_m,-2c_m)]}
$$

$$
+ \frac{E_m^22c_m^2k(1-v_m) + c_m, n_m(1+c_m, -2c_m) - 4c_m, l_m, v_m)}{E_m(1+c_m, -2c_m) + 2c_mk(1-v_m,-2c_m)}
$$

$$
p = \frac{E_m[E_m, C_m + 2p_m(1+v_m)(1+c_m)]}{2(1+v_m)[E_m(1+c_m) + 2c_m, p_m(1+v_m)]}
$$

$$
m = \frac{E_m[E_m, C_m + 2m_n(1+v_m)(1+c_m)]}{2(1+v_m)[E_m(1+c_m, 4c_m, (1-v_m) + 2c_m, m(3-4v_m)]
$$

where the subscripts $m$ and $r$ are for matrix and nanoparticles respectively. $C_m$ and $C_r$ are the volume fractions of the concrete and the reinforcing respectively and $k$, $l$, $n$, $p$, $m$, are the Hills elastic modulus for the TiO2 nanoparticles (Mori and Tanaka 1973).

4. Numerical results

The result of the experimental is presented in Figs. 1-3, respectively for No, NO2 and NOx. The input concentration is 1 ppm. When the light is applied, the drop of concentration is 42%. After 5 hours, the NO is cut off for 30 minutes. Hence, the light is applied again and the NO concentration is calculated. The results show a little enhance in NO2 leads to reduction in NO (NO+NO2). The final reduction is depended to the surface exposed size, material, light intensity, NO concentration, ambient temperature and flow rate.
Based on Mori-Tanaka model, the elastic modulus of the concrete with respect to the volume percent of TiO2 nanoparticles is shown in Fig. 4. As can be seen, with enhancing the volume percent of TiO2 nanoparticles, the elastic modulus is increased significantly. In other words, reinforcing the concrete with 10% TiO2 nanoparticles leads to 65% increase in the elastic modulus. This is due to this fact that with enhancing the volume percent of TiO2 nanoparticles, the stiffness of the structure improves.

5. Conclusions

The reduction of environmental pollution by applying TiO2 nanoparticles for construction of concrete structure was studied in this paper based on experimental and Mori-Tanaka model. The effect of using these nanoparticles on the modulus of elasticity was investigated. Results show that after 5 hours, the NO was cut off for 30 minutes. Reinforcing the concrete with 10% silica nanoparticles leads to 65% increase in the elastic modulus. The final reduction is depended to the surface exposed size, material, light intensity, NO concentration, ambient temperature and flow rate. The results shows a little enhance in NO2 leads to reduction in NO (NO+NO2).

References


