Influence of dust and oil accumulation on the effectiveness of photocatalytic concrete surfaces

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Abstract

The day to day negative effect of contaminating substances on the NO_x removal effectiveness of photocatalytic surfaces and their recovery capacity after undergoing cleansing is of real academic and practical interest. This study deals with the analysis of the NO_x removal effectiveness of two different types of photocatalytic concrete surface layers incorporating nano-TiO₂ particles. Both types of surfaces were examined before and after being subjected to dust accumulation and oil impregnation. In addition, the recovery of their NO_x removal capacity after undergoing various cleansing processes was also evaluated. The results were compared to those of their respective reference samples. The results showed that the high NO_x removal capacity of the spray coated samples was partially maintained even after a high concentration of dust accumulation. However, the water cleansing process employed was sufficient enough to recover the

lost NO_x removal capacity. It was also discovered that the nano-TiO₂ particles lost nearly all their photocatalytic capacity after being subjected to oil impregnation, and that the cleansing processes, either by an alkaline detergent or using a n-hexane solvent, failed to recover the initial NO_x removal capacity.

Keywords: concrete surface; nano-TiO₂; photocatalytic, NO_x removal; dust accumulation; oil impregnation

1. INTRODUCTION

The use of photocatalytic building materials to reduce atmospheric pollutants, which have a negative effect on health, particularly amongst children and the elderly, is becoming increasingly more necessary. Vehicle traffic emissions, as well as contaminants caused by housing and industry, are the main sources of atmospheric pollution in dense urban areas. Many organic compounds and air pollutants including nitrogen oxides and sulfur dioxide can be decomposed by ultraviolet (UV) radiation. However, this process is extremely slow. Photocatalytic materials such as nano-titanium dioxide (TiO₂), in the presence of UV light (sunlight), can accelerate this process through the decomposition of organic and inorganic substances, including air pollutants such as NO_x, SO₂, and VOC's (Hodgson et al., 2007; Hassan, 2009).

Over the last twenty years there have been numerous studies dealing with ways of improving the quality of urban air through the incorporation of nano-TiO₂ into concrete block production (Murata et al., 1999; Poon and Cheung, 2007; Chen and Poon, 2009a; Chen and Poon, 2009b; Hüsken et al., 2009; Ballari et al., 2010; Guo and Poon, 2013; Ballari et al., 2011) as well as the manufacture of surface treated stone and rendering materials (Franzoni et al., 2014; Munafo et al. 2015). However, as yet there has been no in depth evaluation of the durability of the nano-TiO₂ surface coating. According to Hassan et al. (2010), there was a small decrease in the NO removal efficiency during the wearing down of the samples that had 5% TiO₂ incorporation. Results of the SEM-EDS analysis also confirmed that when compared with the original samples the relative concentration of Ti on the worn out specimens did not substantially change. However, Guo et al. (2013) found that TiO₂-dip-coated mortars almost totally lost the bactericidal ability after being subjected to a harsh weathering process.

Olabarrieta et al. (2012) presented an analysis of the effect of chemical and physical transformations associated with water flow on two intrinsically different photocatalytic coatings. Their work highlighted the deactivation of the active sites of TiO_2 upon prolonged immersion in water, which was found to reduce the performance of the photocatalytic materials. They hypothesized that sodium chloride and UV light somehow modified the TiO_2 - TiO_2 and TiO_2 -glass substrate interaction, resulting in facilitating the release of the TiO_2 nanoparticles into the surrounding water. According to De Melo et al. (2012), external agents such as dirt and abrasion are determinant in the efficiency loss of the NO_x removal capacity on the concrete block surfaces. Rainwater or the simple water cleansing (without pressure) of the block surfaces is not sufficient to ensure recovery of the photocatalytic activity, and thus periodic maintenance cleansing of the surface is required by means of employing a water jet.

In this research work, the influence of dust and oil accumulation on the NO_x removal capacity of the photocatalytic nano- TiO_2 based concrete surfaces as well as their recovery to NO_x removal after cleaning process are presented. Two separate types of photocatalytic concrete surface layers were produced. One set of samples was produced using TiO_2 as an addition (in 5% by cementitious materials weight), whereas, the other set was spray coated with a nano- TiO_2 solution. The effectiveness of the NO_x removal capacity of the two types of samples before and after being subjected to dust accumulation and oil impregnation was determined. The recovery of their respective NO_x removal capacity after treatment by a myriad of cleansing processes was subsequently evaluated.

2. MATERIALS AND SAMPLE PREPARATION

2.1 Materials

A commercially available nano- TiO_2 powder (P25, Degussa) was used as the photocatalyst in all the experiments. The particle size of the TiO_2 was 20-50 nm, with a specific BET surface area of $50 \pm 15 \text{ m}^2 \cdot \text{g}^{-1}$. ASTM Type I Ordinary Portland cement (OPC, Green Island Cement Limited, Hong Kong) and fly ash (FA) were used as the cementitious materials. FA was added as a pozzolana to control the alkali-silica reaction (ASR) between the silica-rich glass cullet (used as aggregate in preparing the photocatalytic cement mortar) and the alkali in the cement. Their physical and chemical properties are listed in Table 1. The nano- TiO_2 -based concrete surface layers were prepared by employing fine aggregates obtained from crushed recycled glass (RG)

cullet derived from post-consumer beverage glass bottles. The post-consumer beverage glass used was sourced from a local Hong Kong based eco-construction material company. Prior to their experimental use, all the discarded glass bottles were washed and then crushed by a mechanical crusher before being finally sieved to obtain the desired particle size. The particle size distribution of the RG used in the experiment is shown in Table 2.

2.2 Mix proportions and production process

The mix proportion (by weight) for the two types of concrete surface layers was 0.75:0.25:3.0:0.3 (OPC: FA: RG: water).

The procedures for the preparation of the concrete surface layers were as follows. First, all the proportioned materials were mixed uniformly for approximately 5 minutes using a mechanical mixer (nano-TiO₂ particles were added in the Intermixed-type 1 mixture). Then, the steel moulds (an internal dimension of 200×100×5 mm) were filled to maximum capacity (about 250 g) and the resulting mixture was then hand compacted before undergoing two further mechanical compacting stages of 500 kN and 600 kN at a rate of 500 kN·min⁻¹

The TiO₂ sprayed coated samples (SP-Type 2) were produced via the use of a suspension of methanol and P25 (30 g·L⁻¹) which was sprayed on to the mortar surface. A detailed explanation of the procedure employed is as follows. The mortar mixtures (without TiO₂) were first placed in the prepared steel moulds where they were hand compacted before being spray coated 10 times with the TiO₂-solution. The mixture was then subjected to mechanical compacting similar to that previously mentioned, before undergoing a further 10 spray coatings. All spray coating was carried out within the first 20 minutes after the surface layer material was introduced into the moulds.

The prepared surface layers were removed 24 hours later from their moulds and then tightly wrapped in plastic film during curing until further testing.

2.3 Properties of concrete surface layers

The physical and mechanical properties of the two types of concrete surface layers produced (intermixed-Type 1 and SP-Type 2) were determined using cubic test specimens of 70×70×70 mm according to ASTM C642-06. The specimens were produced by compacting the concrete specimens in three layers. The first two layers were compacted manually using a wooden rod. The third layer was compacted

mechanically via a press in the same manner as described in Section 2.2. Table 3 shows the properties of intermixed-Type 1 and SP-Type 2 samples. It is well-known that the use of nano-TiO₂ particles can have an impact on reducing the fluidity of the intermixed-Type 1 mixture and consequently reducing also the homogeneity of the prepared samples, thus leading to slightly reduced compressive strengths, a fact also detected by other researchers (Lucas et al., 2013; Jimenez-Relinque et al., 2015).

3. METHODOLOGY

3.1 Photocatalytic conversion of NO_x

The photocatalytic conversion of NO_x was tested through the use of a continuous flow reactor which was constructed in the laboratory in accordance with JIS R1701-1 specifications. The reactor (length: 300 mm, width: 150 mm and height: 100 mm) was completely sealed and free of all leakage. The test samples were placed on a rack in the centre of the reactor. A schematic diagram of the experimental setup is shown in Figure 1. Detailed information on the reactor and the required equipment employed to carry out the photocatalytic NO_x conversion test can be found in our previous studies (Guo et al., 2015). The entire experiment was carried out at the ambient temperature of 25±3 °C. The flow of the testing gas (1000 ppb NO) was adjusted by two flow controllers at a rate of 3 L·min⁻¹ and the relative humidity (RH) was controlled at 30±5%. The UV intensity at the centre of the reactor was 2 W·m⁻². All photocatalytic conversion processes were carried out by first introducing the testing gas stream into the reactor in the absence of UV radiation for a minimum of half an hour. The reason for this was to ensure that both the desired RH and the gas–solid adsorption–desorption equilibrium was reached, after which the UV lamps were turned on for the photocatalytic process to begin. The NO removal test took 1 hour per sample, during this time period the concentration changes of NO and NO₂ at the outlet were recorded. Every sample was tested three times and the average value together with the standard deviation was noted. The details of the calculation of the amount of NO_x removal have been described previously (Guo et al., 2015) and are expressed as a subtraction of the NO₂ generated from the NO removed. The calculation of the amount of NO_x removal, following the instructions detailed in JIS R 1701-1, is shown below:

$$Q_{NO_x} = \left(\frac{f}{22.4} \right) \{ \int ([NO]_0 - [NO]) dt - \int ([NO_2] - [NO_2]_0) dt \} / A \times T \quad \text{Eq. 1}$$

where Q_{NO_x} ($\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) is the amount of nitric oxides removed by the test sample, $[NO]_0$ and $[NO_2]_0$ (ppm) are the inlet concentration of nitrogen monoxide and nitrogen dioxide, respectively, $[NO]$ and $[NO_2]$ (ppm) are the outlet concentration of nitrogen monoxide and nitrogen dioxide, respectively, t (min) is the time of removal operation, f ($\text{L} \cdot \text{min}^{-1}$) is the flow rate converted into that at the standard state (0 °C, 1.013 kPa), A (m^2) is the surface area of cement paste samples, T (1 h for all experiments) is the duration of the photocatalytic process, and 22.4 represents the volume of 1 mole ideal gas at the standard state, which is 22.4 L (ideal gas law).

3.2 Worsening and recovery of photocatalytic activities

The effectiveness of the NO_x removal capacity of the intermixed-Type 1 and SP-Type 2 samples after the surfaces were subjected to dust accumulation and oil impregnation was determined. After which, the samples were subjected to several cleansing processes, and the recovery of their NO_x removal capacity was then evaluated.

3.2.1 Dust accumulation process and its assessment

Dust characterization

A fine dust (ISO 12103-1 A2) provided by Powder Technology Inc. was employed in order to simulate the effect of natural dust. Table 4 describes the grading size distribution of those dust particles (the data was provided by Powder Technology Inc.).

The specific weight of the dust was $2.65 \text{ g} \cdot \text{cm}^{-3}$, and SiO_2 and Al_2O_3 were the main chemical components. The compositions of the dust (by weight) are given in Table 5.

Dust accumulation and cleansing process

The photocatalytic effectiveness of concrete surface layers could be affected by dust accumulation on their surface. Although it is not easy to simulate the real situation during application in the laboratory, in this work a chamber designed and constructed for that purpose was used. The test chamber ($1 \times 0.6 \times 0.6 \text{ m}$) was made with ESD acrylic plates which were both transparent and antistatic. The test dust was injected by the dust generator (RBG 1000, PALAS) into the test chamber and mixed with air via means of a

fan. Dust was deposited slowly and naturally on the surface of the samples, which were positioned in the centre of the chamber (Figure 2). The amounts of dust accumulated on both the surfaces of the intermixed-Type 1 and SP-Type 2 samples were 0, 10, 18 and 37 gr·m⁻². Figure 3a shows several samples subjected to the dust accumulation process. Figure 3b shows, the samples (1) and (2) with 10 and 37 gr·m⁻² of dust accumulation on the surface, respectively. The NO_x removal capacity of the intermixed-Type 1 and SP-Type 2 samples with different weight of dust accumulation on their surfaces was immediately evaluated. Then, the cleansing processes were carried out in order to evaluate the recovery of the NO_x removal ability of the samples. Two cleansing processes were applied on each sample. First, slow flowing tap water, with an approximately flow rate of 6.25 cm³/s, was applied to the surface of the samples. Second, besides the water cleansing (under the same conditions), an electric brush was also employed to clean the samples' surfaces. Immediately after the cleansing process, all the samples were oven-dried (60 °C for 24 h) until NO_x removal testing. The photocatalytic activity of each sample was evaluated and the obtained results were compared to those of the reference samples (without dust accumulation).

3.2.2 Oil accumulation process and its assessment

Oil accumulation and cleansing process

A synthetic motor oil of 15W-40 viscosity was employed to impregnate the surfaces of the intermixed-Type 1 and SP-Type 2 samples. The surfaces of the concrete layers were impregnated by separately using two types of oil-solvent mixtures. Firstly, a low viscosity oil-solvent mixture consisting of 50% weight of oil and 50% weight of ethanol (with ratio of 1:1) was prepared. This low viscosity mixture was then applied on the samples in a dose of 200 g per m² of concrete surface. Secondly, 400 g of undiluted motor oil per m² of concrete surface was also used to contaminate the surface of the samples. A 3 mL pipette dropper was employed, the oil-solvents being distributed drop by drop in order to guarantee their homogeneous accumulation on the surface. 5 pipettes were employed to disperse all the oil-solvents on each concrete sample over a fixed area of 20×10 cm². The capacity of degradation of NO_x via the intermixed-Type 1 and SP-Type 2 samples after oil accumulation was determined. Several cleansing processes were used in order to remove the oil from the samples. The oil contaminated samples were separately cleaned by adding two oil removing products to the surfaces; an

alkaline industrial detergent and an organic solvent (n-hexane). The spray SP-Type 2 samples were cleaned by means of adding the n-hexane solvent to the surface as well as submerging the samples in hexane for another 12 hours (named as cleaned-hexane-2).

4. RESULTS

4.1 Photocatalytic NO_x removal of intermixed-Type 1 and spray SP-Type 2 samples

Figure 4 illustrates the NO_x concentration profiles when the reference intermixed-Type 1 and SP-Type 2 samples after undergoing the photocatalytic NO_x removal test. The SP-Type 2 samples showed a greater reduction of NO_x capacity. This finding proved to be consistent with our previous work (Guo et al., n.d.). The elimination rate of NO_x by the intermixed-Type 1 and SP-Type 2 samples were 136.5 $\mu\text{mol}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ and 255.0 $\mu\text{mol}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$, respectively. Thus, the SP-Type 2 sample proved to be 80% more effective than the intermixed-Type 1 samples. This far superior NO_x photocatalytic removal performance of the SP-Type 2 samples can be attributed to a much higher amount of TiO₂ particles on the sample's surface (supported by the following SEM-EDX analysis). As a result, most of the TiO₂ surface particles were able to gain easy access to the UV light irradiation. In contrast, a high percentage of nano-TiO₂ surface particles of the intermixed-Type 1 samples were completely enveloped by the hydration products, and hence were not in direct contact with the UV-light, as was previously described (Guo et al., 2013).

SEM and EDX were employed to analyse the two types of samples. Figure 5a and 5b clearly illustrate the morphological differences of the intermixed-Type1 and SP-Type2 samples studied, respectively. And the EDX analysis revealed that the percentage of titanium element presented on the surface of intermixed-Type 1 and SP-type 2 samples was 3.3% and 26.4%, respectively. Figure 5a and 5b also illustrate that some nano-TiO₂ particles in the intermixed-Type 1 samples were completely enveloped by the surrounding cement hydrated products, which more than likely impaired the NO_x removal capacity. Whereas, most of the spray-coated TiO₂ particles were free from the accumulation of the hydration products, and thus could be fully exposed to UV light. Therefore, the SEM-EDX results are well validated by the aforementioned explanations with respect to the observed differences in the photocatalytic NO_x removal.

4.2 Influence of dust accumulation on NO_x removal capacity and recovery by two cleansing processes

4.2.1 Influence of dust accumulation

Figure 6 shows the NO_x removal profiles of the intermixed-Type 1 and SP-Type 2 samples after being subjected to different amounts of dust accumulation on the surface. In general, the samples with a higher volume of accumulated dust displayed less ability to remove NO_x, regardless of the sample types. For example, the 37 g·m⁻² of dust accumulation significantly reduced the NO_x removal ability of both types of samples tested (from 136.5 to 39.5 μmol·h⁻¹·m⁻² for intermixed-Type 1 and from 254.9 to 148.7 μmol·h⁻¹·m⁻² for SP-Type 2 samples, respectively). However, it must be pointed out that even after 37 g·m⁻² of dust accumulation, the SP-Type 2 samples were still able to deliver a high photocatalytic NO_x removal ability. This can be explained by the fact that the dust accumulated on the surface was not densely compacted (no external force was applied to the dust covered surface), thus the light blocking effect was not so significant. Moreover, taking into consideration that the size of nano-TiO₂ particles used in this study was far smaller than that of the dust particles (see Table 4), the UV light was still able to penetrate through those dust particles to reach the TiO₂ particles underneath, some of which were still able to produce the photocatalytic activity. More interestingly, it was clearly observed that the dust accumulation noted had less influence on the SP-Type 2 samples than on those of the intermixed-Type 1 samples. This fact was consistent with the previous NO_x removal results of the reference samples (section 4.1). For example (see Figure 6), the SP-Type 2 samples still retained a relatively higher capacity of NO_x removal after exposure to 37 g·m⁻² of dust accumulation, (above 145 μmol·h⁻¹·m⁻²), which proved to be even higher than that of the intermixed-Type 1 samples without any dust accumulation (136.5 μmol·h⁻¹·m⁻²).

4.2.2 Rejuvenation of NO_x removal by the cleansing processes

Figure 7 shows the surface appearance of the samples after they were subjected to different cleansing processes. The surfaces of all the intermixed-Type 1 samples were similar in appearance to those of the reference sample after the application of the two different cleansing processes. However, for the SP-Type 2 samples, the intensity of the white colour on the surface (an indication of the TiO₂ amount) was slightly decreased after the cleansing process due to the washing away of some nano-TiO₂ particles from the surface.

Figures 8a and 8b demonstrate the removal capacity of NO_x on the two types of samples after being subjected to the two cleansing processes. It was observed that both the intermixed-Type 1 and SP-Type 2 samples recovered their initial NO_x removal capacity. According to the test results of the intermixed-Type 1 samples, a comparative study of the additional use of brush cleaning (Fig. 8b) with that of samples only cleaned with water (Fig. 8a) showed that there was no further improvement in the capacity of NO_x removal. This indicates that just washing with water is sufficient enough to recover their initial photocatalytic NO_x removal ability. Unexpectedly, the process of cleansing improved the NO_x removal capacity of the intermixed-Type 1 reference sample. The samples subjected to a higher dust accumulation achieved a higher NO_x removal capacity. The reason for this could be the abrasion action of the cleansing process, which led to more nano-TiO₂ particles (previously embedded) being exposed to the air, thus facilitating an increase in the available active TiO₂ sites on the surface (Jimenez-Relinque et al., 2015). The cleansing process resulted in an increased surface roughness and exposure of active surface particles, resulting in a slight increase in the NO_x removal capacity (De Melo et al., 2012; Sugrañez et al., 2013; Jimenez-Relinque et al., 2015).

A comparison study of the reference samples with that of the SP-Type 2 samples showed that the brush cleansing (Fig 8b) slightly reduced the NO_x removal capacity. The use of brush cleansing caused the removal of a certain amount of nano-TiO₂ particles from the surface of the samples, thus contributing to a decrease in their NO_x removal capacity.

4.3 Influence of motor oil accumulation on NO_x removal capacity and recovery via cleansing process

4.3.1 Influence of motor oil accumulation

Figure 9a illustrates the NO_x removal activity of intermixed-Type 1 samples and their corresponding reference samples after being impregnated with different concentrations of oil. Motor oil concentrations of 200 g·m⁻² and 400 g·m⁻² on the sample surfaces resulted in a complete loss of the NO_x removal capacity of the intermixed-Type 1 sample. Similarly, (Fig 9b) shows that the SP-Type 2 samples suffered a loss of 80-90% in their NO_x removal capacity.

It was also observed that when 10% of the surface of both the intermixed-Type1 and SP-Type 2 specimens were impregnated with oil, approximately 10% of the original

NO_x removal efficiency was lost. Apparently, the presence of oil on the surface of the nano-TiO₂ particles completely isolated them from contacting with air and light, and the effect of the localized contamination did not spread out to other parts of the concrete surface.

4.3.2 NO_x removal recovery by different cleansing processes

Figures 10a and 10b illustrate the NO_x removal capacity when the samples were impregnated with the motor oil and after undergoing different cleansing processes. Both cleansing methods were found to be inefficient in removing the motor oil. For example, the SP-Type 2 sample did not fully recover its NO_x removal capacity after being cleaned or treated with the n-hexane solution.

As mentioned in section 4.3.1, the samples which had 10% of their surface impregnated with motor oil lost approximately 10% of their NO_x removal capacity. However, applying the cleansing agents extended the spread of the oil to cover the entire sample surface. Consequently, the samples having 10% of their area impregnated with motor oil experienced a decrease of NO_x removal capacity from 219.8 to 188.9 $\mu\text{mol}\cdot\text{h}^{-1}\cdot\text{m}^{-2}$ when the samples were cleaned by the n-hexane solution. This demonstrates the very serious detrimental effect of oil contamination on the photocatalytic activities of the concerned samples.

A SEM-EDX analysis was undertaken to examine the surface morphology of the samples in order to identify changes of the nano-TiO₂ particles before (Figure 11a) and after (Figure 11b) applying the oil contamination. The morphology of the nano-TiO₂ particles presented on the surface of the contaminated samples was quite similar to those of the reference sample. However, an EDX analysis revealed that the titanium content was much lower. This in all probability was due to the presence of the oil envelope surrounding the surface of TiO₂ particles. Being oleophobic, the TiO₂ nanoparticles could have tried to stay apart from the oil and thus pushed themselves toward the bottom (i.e. toward the sliding surface), where they deposited themselves on the bottom surface due to gravity (Ingole et al., 2013).

Probably, the most effective method for cleaning the oil contaminated samples would be to leave them for a sustained period of time under UV light, as the photocatalysis of the nano-TiO₂ particles can decompose the adsorbed organic molecules due to a light-induced self-cleansing and antifouling function (Li et al., 2015). Longer term studies are required to ascertain such effects.

5. CONCLUSIONS

The following conclusions can be made based on the results of this study:

- According to the original samples:
 - The concrete surface layers spray-coated with nano-TiO₂ particle solution were more effective in NO_x removal than the concrete surfaces produced using 5% nano-TiO₂ as intermixed additive. The main reason for this was that the major part of the spray-coated TiO₂ particles had a higher accessibility to UV light irradiation.
- According to dust accumulation and the corresponding cleansing process:
 - A high amount of dust accumulation on the 5% TiO₂ intermixed concrete surface layers severely impaired their NO_x removal capacity. However, the spray coated samples were able to partially maintain their initial NO_x removal capacity.
 - The water cleansing process was sufficient to recover the initial NO_x removal capacity of both types of samples. The spray coated samples lost a small quantity of nano-TiO₂ particles upon being subjected to water and brush cleansing, resulting in a slight decrease in the NO_x removal capacity.
- According to the effect of oil impregnation and the corresponding cleansing process:
 - Oleophobic and high specific surface nano-TiO₂ particles were confined below the oil, thus losing their photocatalytic capacity. The samples produced by employing nano-TiO₂ as additive resulted in a complete loss of NO_x removal capacity. While the samples coated by spraying nano-TiO₂ solution suffered a loss of 80-90% reduction of their initial NO_x removal capacity.
 - The cleansing processes, either with an alkaline detergent or with a n-hexane solvent were not effective in recovering their respective NO_x removal capacity.

Overall, the spray coated samples were much more effective in NO_x removal than the intermixed samples in any mode of the sample tested (reference, contaminated or cleansed samples).

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Table 1. Chemical compositions and physical properties of OPC and FA

	OPC	FA
Chemical composition		
SiO ₂	22.18	48.14
Al ₂ O ₃	5.95	17.81
Fe ₂ O ₃	3.37	11.63
CaO	62.46	12.66
MgO	1.56	4.59
K ₂ O	0.48	1.26
Na ₂ O	0.24	-
TiO ₂	0.37	0.98
Sulphur content as SO ₃	2.25	2.64
Loss in ignition	0.64	3.90
Physical properties		
Specific surface (cm ² g ⁻¹)	3660	3960

Table 2. Particle size distributions of recycled glass cullet

Sieve size (mm)	Recycled glass (% passing)
5.0	99.8
2.36	90
1.18	57.9
0.6	32.1
0.3	10.6
0.15	7.5
0.075	4.7

Table 3. Properties of intermixed-Type 1 and SP-Type 2 concrete surface layers after 28 days curing

Type of samples	Dry density (g/cm ³)	DS	Accessible pores (%)	DS	Compressive strength (MPa)	DS
Intermixed-Type 1 (5% TiO ₂ by weight of binder)	2.05	0.11	18.30	5.5	28.2	7.2
SP-Type 2 (without TiO ₂ addition)	2.11	0.05	14.62	3.5	35.7	6.2

Table 4. Volume dust Particle distribution

	Dust size (µm)										
	1	2	3	4	5	7	10	20	40	80	100
Vol(%)	3.5	9	9.5	7.5	6.5	10	8	20	17	9	0

Table 5. Chemical compositions of dust

Component	% in weight	Component	% in weight
SiO ₂	68-76	CaO	2-5
Al ₂ O ₃	10-15	MgO	1-2
Fe ₂ O ₃	2-5	TiO ₂	0.5-1
Na ₂ O	2-4	K ₂ O	2-5

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Intermixed-type 1			SP-type 2		
Reference	Cleaned with water after 37 g/m ² of dust	Cleaned with water plus brush after 37 g/m ² of dust	Reference	Cleaned with water after 37 g/m ² of dust	Cleaned with water plus brush after 37 g/m ² of dust

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