A Novel Method of Coating Titanium Dioxide onto Asphalt Mixture Based on Breath Figure Process for Air-purifying Purpose

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Abstract: Titanium dioxide (TiO_2) is a photocatalyst that has the capability of accelerating the oxidation of nitrogen oxides (NO_X) and other pollutants under ultraviolet (UV) radiation. A number of studies have been conducted on applying TiO_2 onto pavement surface to purify exhaust emissions from vehicles. However, it remains a challenging task to effectively coat TiO_2 to asphalt pavements to achieve durable air-purifying performance. This study aims to develop an innovative method, based on breath figure (BF) process and Pickering emulsion effect, to coat TiO_2 particles onto asphalt pavement surfaces. With this method, asphalt binder with micro pores filled with TiO_2 particles can be coated to asphalt pavement surfaces. The micro porous structure of the coating material helps to provide larger contact area between TiO_2 and UV, thus enhancing NO_X degradation efficiency. Microscopic analysis on the coating material prepared using the new method demonstrated that TiO_2 particles distributed well on the pore walls of the coating material, indicating that UV can reach TiO_2 to activate the

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photocatalytic process. The nitric oxides (NO) removal efficiencies of the asphalt mixture specimens coated using this new method and the traditional water-solution based method after various numbers of surface abrasions were also measured by a custom-designed environmental test setup. It was found that this new coating method provided not only better NO removal efficiency but also improved durability to maintain the degradation efficiency after tire abrasion, compared to the traditional method.

Author keywords: Photocatalytic process, Coating material, Micro pores, Breath Figure process, NO removal efficiency

Introduction

Emerging functional pavements have been extensively reported by recent studies (Stempihar et al. 2012; Losa. et al. 2013; Ballari and Brouwers 2013). These pavements provide not only smooth riding surfaces to vehicles, but also various additional functions, such as mitigating traffic noise, decreasing road surface temperature, and degrading harmful vehicle gases. Among these emerging pavements, the air-purifying pavement, which helps alleviate pollution due to vehicle emission, has gained rapidly increasing interest.

The main hazardous substance from vehicle emission is nitrogen oxides (NO_X), which is also the major precursor of particulate matter (PM) 2.5, the representative air pollutant of photo-chemical smog and haze (Atkinson 2000). Although various types of gas-cleaning equipment have been installed to vehicles, the NO_X concentration in traffic environment is still unsatisfying, especially in urban areas with high traffic densities. To further improve the traffic environment, attempts have been made to build pavement surfaces that have the function of degrading NO_X. So far, the most common and effective technology is to add titanium dioxide (TiO_2) to road surface, since TiO_2 is able to accelerate the photocatalytic activity of NO_X under ultraviolet (UV) radiation. Besides, properties such as high-chemical stability, super-hydrophilicity, and relatively low cost make TiO_2 an ideal photocatalytic purifier (Agrios and Pichat 2005) to be incorporated into pavement materials. A number of studies have verified the feasibility of this technology to decrease NO_X concentration (Chen and Liu 2010; Dylla. et al. 2010; Shen. et al. 2012; Hassan. et al. 2011; Hassan. et al. 2012).

To add TiO_2 particles onto road surfaces, the simplest way is to apply a thin TiO_2 coating layer. In order to activate the photocatalytic process, the TiO_2 catalysts should have direct contact with UV and pollutants. Previous studies have shown that TiO_2 coating layers worked well on concrete pavements, but not so successful on asphalt pavements (Venturini and Bacchi 2009; Dylla et al. 2010; Shen et al. 2012). On one hand, the pollution removal efficiency of asphalt pavements with TiO_2 coating was not so satisfying. On the other hand, the ability of asphalt pavements with TiO_2 coating to maintain NO_X removal efficiency was relatively poor. One of the possible contributing factors to such phenomenon is the porosity of the coating layer (Li and Qian 2009). The porous microstructure on the rigid pavement surface helps to provide larger interaction area between TiO_2 and UV, leading to higher degradation efficiency. Moreover, TiO_2 particles inside the micro pores are not easily removed by tire actions, resulting in better durability.

However, most urban roads in the world are surfaced with asphalt mixture. Thus, it becomes very meaningful to enhance the performance and durability of TiO_2 coating on asphalt pavements. The main objective of this study is to develop a novel TiO_2 coating method, based on breath figure (BF) process, for asphalt pavements, which is able to provide improved performance in terms of both pollution removal efficiency and durability. To achieve this objective, the following tasks have been conducted by this study:

- Prepare TiO_2 coating solution by using the novel method based on BF process;
- Conduct microscopic analysis on the coating material using Scanning Election Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) to

evaluate the distribution of TiO_2 on the coating material;

- Assess the NO_X removal efficiency of the asphalt mixture specimens coated with TiO_2 using the novel method;
- Assess the durability of the coating material by measuring the NO_X removal efficiencies of the asphalt mixture specimens with TiO_2 coating after various numbers of lab-simulated tire abrasions.

Research Background

Photocatalytic NO_X Oxidation

The photocatalytic oxidation property of TiO_2 was discovered by Fujishima in 1972 (Fujishima and Honda 1972). This discovery marked the beginning of a new age of using photocatalytic process for the purpose of self-cleaning.

It has been well demonstrated that both organic pollutants and oxides such as nitric oxide (NO), nitrogen dioxide (NO_2), and sulfur monoxide (SO), can be oxidized by TiO_2 under UV irradiation (Agrios and Picha 2005). The photocatalytic oxidation begins with the irradiation of light over TiO_2 particles. When TiO_2 absorbs a photon containing the energy larger than or equal to its band gap, 3.2eV, an electron will be promoted from the valence band to the conduction band, leaving a hole behind and creating electron-hole pairs, which are also known as excitons (Zhao and Yang 2003; Chen and Poon 2009). This process can be illustrated by Eq. 1.

$$TiO_2 \xrightarrow{hv} h^+ + e^- \quad (1)$$

In the above reaction, h^+ and e^- are powerful oxidizing and reducing agents, respectively. The strong oxidation power of h^+ enables it to react with water to generate the highly active hydroxyl radical (OH^-), which is also a powerful oxidant. In addition,

the power of the electrons can induce the reduction of molecular oxygen (O_2) to superoxide anion (O_2^-), which also has the strong capacity of degrading pollutants (Chen and Poon 2009). These two processes can be described by Eq. 2 and 3, respectively.

$$h^+ + OH^- \rightarrow OH^* \quad (2)$$

$$e^- + O_2 \rightarrow O_2^- \quad (3)$$

The superoxide anion can further react with H^+ dissociated from water to generate the HO_2^* radical, as Eq. 4 shows.

$$H^+ + O_2^- \rightarrow HO_2^* \quad (4)$$

Most organic air pollutants can be degraded completely by either the OH^- or the holes themselves to innocuous final products. For example, NO can be oxidized to NO_2, and then both the hazardous gases (NO and NO_2) can be degraded to water soluble nitrates, as Eq.5 and 6 show (Agrios and Picha. 2005; Zhao and Yang 2003; Chen and Poon 2009; Dylla et al. 2014):

$$NO + HO_2^* \rightarrow NO_2 + OH^* \quad (5)$$

$$NO_2 + OH^* \rightarrow HNO_3 \quad (6)$$

After the above reactions, the final product, nitric acid (HNO_3), can be easily washed away by rainwater.

It is worth noting that for the photocatalytic oxidation process described above, both TiO_2 and UV radiation are essential. As a result, it is necessary and important to provide enough contact area between TiO_2 particles and sunlight to ensure an efficient photocatalytic process.

Current Methods to Coat TiO_2 Particles onto Road Surfaces

Various studies have been conducted on appropriate approaches to incorporate TiO_2 particles into pavement surfaces (Li and Qian. 2009; Hassan et al. 2011; Hassan et al. 2012; Ramirez et al. 2012; Shen et al. 2012). An ideal method should be able to provide both high pollutant removal efficiency and good durability to maintain the efficiency under vehicle tire abrasion.

Researchers from Louisiana tried various methods to coat TiO_2 onto concrete pavement surface, including cement-water coating with TiO_2 and mineral fines, a commercial product named PURETI, and directly spreading TiO_2 particles to fresh concrete before curing (Dylla et al. 2010; Ramirez et al. 2012). It was reported that the cement-water coating method performed the best, which achieved 26.9% and 20% NO removal efficiency before and after abrasion, respectively, in a specific testing environment. A study conducted at Washington State University investigated various promising surface coating methods, such as cement/aggregate/TiO_2 mix (CATM), TiO_2 in water (TIW), and driveway protector mix (DPM), to apply TiO_2 coating to pervious concrete pavement. The durability of the coating material was also measured by actual weather exposure (Shen et al. 2012). It was found that the driveway protector mix (DPM) treatment performed the best in pollution removal test and the sample with DPM treatment also maintained a relatively high level of pollution removal efficiency after four months of weathering.

Relatively few studies have been conducted to apply TiO_2 to asphalt pavements. Venturini and Bacchi (2009) added TiO_2 particles into pervious asphalt pavements by sprinkling water-based emulsion onto pavement surface. The NO_X reduction efficiency was found between 20% and 57%, depending on the type of TiO_2 (rutile, anatase and

brookite), and anatase TiO_2 performed the best. After successfully applying TiO_2 onto concrete pavements, the researchers from Louisiana further attempted applying water-based TiO_2 spraying coating onto asphalt pavements (Hassan et al. 2011; Hassan et al. 2012). Satisfactory results were obtained when the TiO_2 coating was in the original state, but it was also pointed out that the durability of TiO_2 coating required further study. Li and Qian (2009) mixed TiO_2 particles with both cement concrete and asphalt mixture. They found that the pollution removal efficiency of cement concrete was much better than that of asphalt mixture. They believed that the porosity of concrete surface enabled TiO_2 to be stored inside the surface pores, which made positive impact on both the NO removal efficiency and the durability of air-purifying function.

It is worth noting that the NO_X removal performance of TiO_2 coating is dependent on the area of TiO_2 exposed to sunlight and pollutants. A larger contact area between TiO_2 and sunlight will provide better NO_X removal efficiency if all the other conditions are the same. Previous studies have proved that the porous surface of cement concrete is a potential factor that leads to the satisfied air-purifying performance of concrete pavements (Dylla et al. 2010; Shen et al. 2012; Hassan et al. 2012; Li and Qian 2009; Poon and Cheung 2007). To enhance the performance of air-purifying asphalt pavements, it is very promising to fabricate highly ordered micro pores in asphalt pavement surfaces. The micro pores can be achieved by various physical and chemical treatments, such as lithography, colloidal crystal, and self-assembled block copolymers (Li et al. 2010). Among these treatments, the one based on Breath Figure (BF) process has been investigated in this study because it is relatively inexpensive and easy to implement (Bunz 2006; Li et al. 2010).

Breath Figure Process

BF process is essentially a common and unimpressive process that happens every day. For example, the process of forming fog by breathing onto a cold surface is a BF process (Bunz 2006). BF had long been considered as an annoying natural phenomenon till 1994, when Widawski discovered the formation of an ordered porous film by casting a polymer solution onto a substrate (Widawski et al. 1994). Since this discovery, the BF approach has been developed into an amazing self-assembly strategy for the fabrication of porous structures, with the pore sizes ranging from hundreds of nanometers to hundreds of micrometers (Li et al. 2010).

In the BF process, the porous surface is achieved by water droplet condensation during fast solvent evaporation under a humid flow. The mechanism of forming a porous structure on a typical polymer surface can be described as follows: 1) the polymer is dissolved in a low boiling point solvent, and then cast onto a solid substrate in a high-humidity environment; 2) water droplets nucleate on the surface and grow subsequently due to the evaporative cooling; 3) driven by the surface convection and capillary force, the condensed water droplets self-assembles into hexagonal arrays; and 4) templated by the formed droplet arrays, micro pores are formed on the polymer film surface as soon as the solvent evaporates (Li et al. 2010).

In this study, BF process has been applied to build micro pores on the surface of asphalt, which is essentially a type of polymer, to enlarge the contact area between the sunlight and TiO_2 particles embedded into the micro pores and enhance the air-purifying performance.

Experimental Program

Preparation of Coating Solution

According to the mechanism of BF process, Tetrahydrofuran (THF) was selected as the solvent of asphalt binder due to its ability to dissolve asphalt and its low boiling point (66°C). The evaporation cooling effect of THF can decrease the solution surface temperature and accelerate the condensation of vapor nearby quickly. SBS modified asphalt with the performance grade of PG76-22 was selected as the coating binder.

During the trial experiment, it was found that the porous structure could not be formed with THF and asphalt only. As asphalt has a low glass transition temperature, its relatively high mobility makes the micro structure very easy to collapse, leading to irregular bulking without micro pores on surface (Fig.1a). To solve this problem, polystyrene (PS) was added to assist maintaining the formed microstructures. The difference in micro feature between the samples with various PS-asphalt weight ratios (total weight in THF: 60mg/ml) is shown in Fig.1. It can be seen that with the increase of the amount of PS, more and more regular pore arrays can be observed. When the PS-asphalt ratio reaches 10/10, clear honeycomb structure can be observed. Thus, the PS-asphalt weight ratio of 10/10 was selected to prepare the porous TiO_2 coating solution. The diameters of the micro pores as shown in Fig.1 d are approximately 10μm.

The coating solution was prepared under room temperature (20±3°C) and a humidity of 60±5%. The porous coating (PC) solution with TiO_2 particles was prepared by mixing all solutes, i.e., asphalt, PS and TiO_2 into certain amount of solvent (THF). Two porous coating solutions with different weight ratios of TiO_2, asphalt, and PS, i.e., 0.5/1/1 and 2/1/1, were prepared. The one with higher percentage of TiO_2 is labeled as H-

PC, while the one with lower percentage of TiO_2 is labeled as L-PC. Concentrations of all solutes (including asphalt, PS and TiO_2) were 75mg/ml for L-PC and 120mg/ml for H-PC.

Substrate Preparation

To measure the NO_X removal efficiency and durability of TiO_2 coating, standard Marshall Specimens (diameter=101.6mm and height=63.5±2.5mm) were prepared as substrates to simulate real asphalt pavement surfaces. The asphalt mixture used to prepare the specimens was a gap-graded mixture with a design air void content of 4.4%. PG76-22 asphalt binder was used and the asphalt content was 6.1%. All substrate specimens were compacted by a standard Marshall Compaction machine according to ASTM D6926.

L-PC and H-PC solutions were sprayed onto Marshall Specimen surfaces evenly using a water sprayer. The spraying was conducted in a highly humid environment to ensure the occurrence of the BF process. The dosage of both emulsions applied to each Marshall specimen was 7ml. As a result, there were approximately 0.1g and 0.4g of TiO_2 on each specimen with L-PC and H-PC, respectively. To compare the NO_X removal performance of the BF method with the traditional method, a water-based coating solution (named as WC) was also prepared and applied. The dosage of TiO_2 coated on each specimen using the traditional method was controlled at 0.4g, which is equal to that of the specimen with H-PC. Table 1 shows the detailed information of the test specimens for NO_X removal efficiency tests. For all groups except for OM, three replicate specimens were prepared and tested to ensure the reliability of the test results (Fig. 2).

Micro Analysis

For the purpose of microanalysis, L-PC and H-PC were dropped on both planar and non-planar substrates. An opaque coating covering the substrates formed after the evaporation

of solvent. SEM JSM-6490 with EDX detector manufactured by JEOL Inc., US, was employed to evaluate the morphology of the coating surface. Before observation, a thin layer of gold was pumped onto the samples to obtain clear and reliable images.

NO_X Removal Efficiency Test

A custom-designed environmental test setup was used to evaluate the NO_X removal efficiency of the test specimens. The test system mainly consists of NO_X and zero air cylinders, a reacting chamber, light source (UV lights), a NO_X data analyzer, and a data recorder. Fig. 3a is a diagram of environmental test system, and Fig. 3b shows the specimen inside reacting chamber during the testing process.

The reacting chamber is equipped with air inlet and outlet so that continuous flow stream inside chamber can be maintained. The cover of the chamber was fabricated of transparent glass rimmed with stainless steel, which allows UV light to reach the testing specimen surface. Two fluorescent lamps were placed upon the chamber and their distance to the chamber was adjusted till the required intensity was achieved (in this study, the UV intensity was set as 10 W/m^2). The wavelength of the UV light emitted from fluorescent lamps was 365nm, which is very close to that of the UV from sunlight. The temperature and humidity inside the reacting chamber were controlled at 20°C and 10%, respectively.

The NO_X data analyzer was able to record the amount of both NO and NO_2. In this study, as the concentration of NO_2 remained a low level (<50ppb) during all tests, the photocatalytic ability of the specimens was characterized by NO removal rate. At the beginning of test, the gas streams were adjusted by the flow controllers to obtain the initial NO concentration ($X_{initial}$), which is approximately 1200 ppb, and a flow rate of

3L/min inside the chamber. After around 30 minutes, the NO concentration inside the chamber reached equilibrium, and then the degradation test was started by turning on the UV lights. During the photocatalytic reaction, the concentration of NO was continuously recorded by the analyzer. After another 30 minutes, the NO concentration (X_{stable}) in the chamber reached another stable status. Based on the values of $X_{initial}$ and X_{stable}, the NO removal rate (R%) can be calculated by Eq. 7. A higher NO removal rate indicates a better pollutant removal efficiency.

$$\%\ \text{NO Removal Rate}(R\%) = \frac{X_{intial} - X_{stable}}{X_{intial}} \times 100\% \quad (7)$$

Durability Test

Since the TiO_2 coating is vulnerable to tire abrasion, especially in wet condition, it is necessary to evaluate the pollutant removal efficiency of TiO_2 coating not only in its original state but also its ability to maintain the pollution removal function under tire actions.

In this study, the British Pendulum Skid Resistance Tester was employed to simulate tire abrasion. Before applying abrasion, the Marshall specimens with TiO_2 coating were first immersed in water for 3 minutes to produce the wet surface condition. Then the Marshall specimen was fixed on ground, and the pendulum slider was positioned barely in contact with the wet surface of the specimen according to ASTM E303. The abrasion test was started by raising the pendulum to the lock position. Then the pendulum was released, allowing the rubber slider to make contact with and pass by the specimen surface. After the abrasion process was repeated for 50 and 200 times, the NO_X removal ability was calculated by Eq. 8.

$$\%\ \text{Residuary NO removal ability}(RA\%) = \frac{R_0 - R_x}{R_0} * 100\% \quad (8)$$

Where R_X is the NO removal rate after x times of abrasion and R_0 is the NO removal rate when the TiO_2 coating is in the original state, i.e., without abrasion. A higher residual rate indicates a better durability of the TiO_2 coating.

Results and Discussion

Micro Analysis Results

Fig. 4a and Fig. 4b present the SEM microscopic images of L-PC and H-PC on planar glass substrates. The micro features in these two images indicate that the incorporation of TiO_2 nanoparticles has little impact on the porous structure (in comparison to Fig.1d). Regular pores can be observed on the surfaces of both L-PC and H-PC samples. In addition, it can be observed from the close-up views (insets in Fig. 4a and Fig. 4b) and the cross-sectional view (Fig. 4c) that TiO_2 particles are distributed inside the pores. During the BF process, the TiO_2 particles tend to coat the pore walls because of the Pickering emulsions effect, which is emulsion can be stabilized by solid particles adsorbed onto the interface (Binks and Lumsdon 2001).

To further evaluate the coating effect of BF treatment, millimeter-sized aggregate particles with irregular shapes were employed as non-planar substrate. Similar to the results of the TiO_2 coating on planar substrates, highly ordered porous structure can be observed on most part of the aggregate surface (insets in Fig. 5a and 5b). Compared to the original aggregate, honeycomb structure can be observed on the surface of aggregate particles treated by the BF process. Along with the SEM images, the EDX results also demonstrate the existence of titanium on the sample surfaces (Fig. 5a and 5b). Multiple locations were analyzed and the EDX results from different locations indicate that

300 titanium distributed evenly on the aggregate surface. The satisfying results of TiO_2
301 coating on non-planar substrates indicate that such porous structure can also be formed on
302 pavement surface.

303 ***NO Removal Efficiency Test Results***

304 Fig. 6a presents the variations of NO concentration inside the chamber for four specimens
305 during the testing process. Each of the four curves represents one typical specimen in
306 each group shown in Table 1. As Fig. 6a shows, initially the NO concentration inside the
307 chamber was relatively constant at approximately 1200ppb. Then, after the UV lights
308 were turned on at 30 minutes, there was a rapid drop of the NO concentration for all
309 groups except for OM. A few minutes later, the second equilibrium state was reached
310 inside the chamber. At 45 minute, the UV lights were turned off and a sudden increase of
311 the NO concentration occurred.

312 Fig. 6b shows the NO removal rate of all test specimens. It can be seen that the
313 NO removal rates within each group are relatively close to each other, indicating good
314 testing repeatability. The NO removal rate of the OM specimen, which does not have any
315 coating, is almost zero. Among the three groups of specimens with TiO_2 coating, H-PCM
316 has the highest average removal rate, which is 16.4%, followed by WCM and L-PCM,
317 which have the average removal rates of 9.5% and 7.7%, respectively. It is worth noting
318 that H-PCM and WCM actually have the same amount of TiO_2 on the specimen surface,
319 which is four times of that of the L-PCM specimens. Therefore, by introducing the
320 porous structure to the coating material, much better NO removal efficiency can be
321 achieved when the same amount of TiO_2 is applied. In other words, the BF treatment

significantly improves the photocatalytic performance of the TiO_2 coating on the asphalt mixture specimen.

The enhanced effect of pollution removal ability is mainly attributed to the micro porous features of the coating surface. According to the mechanism of photocatalytic activity, only TiO_2 particles exposed on the surface can be in contact with UV and provide the catalytic effect. The micro porous structure enables TiO_2 to be distributed evenly inside the micro pores, providing larger contact area among TiO_2, UV, and NO, which helped accelerate the degradation of NO.

Durability Test Results

Fig. 7 and Table 2 present the results of the durability tests. In Fig. 7, the columns show the average NO removal rates (R%), and the curves describe the residuary NO removal ability (RA%) after various numbers of abrasion. It can be seen that compared to the original state, i.e., the state with no abrasion, there were obvious decreases in NO removal efficiency for all test samples after 50 times of abrasion. However, there were only minor drops after 200 times of abrasion, compared to after 50 times of abrasion. The possible explanation is that after 50 times of abrasion, the amount and distribution of TiO_2 particles on the specimen surfaces became relatively stable, leading to only slight variation in the pollution removal efficiency.

The results also indicate that the specimens with porous coating had better abrasion resistance or durability. As Fig.7 and Table 2 illustrate, H-PCM specimens had an average NO removal rate of 7.92% after 200 times of abrasion, which is much higher than that of WCM specimens (i.e., 2.95%). In addition, although L-PCM specimens performed worse than WCM specimens in the original state, they performed better after

200 times of abrasion due to better abrasion resistance. The residuary NO removal abilities of H-PCM and L-PCM are 47.5% and 48.3%, respectively, while that of the WCM is only 31.1% after 200 times of abrasion. In other words, the porous coating method provides better abrasion resistance than the traditional water-solution based coating method. The enhancement of the durability can be attributed to the porous structure, which protects the catalyst from direct abrasion by the rubber. Meanwhile, the TiO_2 particles inside the pores are not easily be pushed inside the asphalt binder.

Summary and Findings

In this study, a novel coating method was proposed to incorporate the TiO_2 particles onto pavement surface. This method was inspired by the BF process and Pickering emulsion effect. By using this method, uniform porous structure can be fabricated on the coating surface, which allows more TiO_2 to be exposed to UV lights. The photocatalytic efficiency and durability of the asphalt mixture specimens coated with this new method were investigated. Based on the results of this study, the following findings have been obtained:

- By BF treatment, honeycomb microstructures can be introduced to asphalt binder surface, and the incorporation of TiO_2 particles into asphalt binder does not affect the shape of porous morphology.
- Compared to the specimens coated with the traditional water-solution based method, the specimens with porous TiO_2 coating performed better in terms of removing NO pollution.
- The porous coating method also provided the coating material better durability to maintain the NO removal efficiency after tire abrasion.

With the promising findings of the laboratory testing in this study, future work will be conducted to further investigate how to implement the porous coating method in the field. In addition, the performance of alternative low-boiling-point solvents of asphalt binder for the BF process will be studied.

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List of Table Captions

451 **Table 1.** Description of test specimens for environment test

Group ID	Description
OM	Original Marshall specimen without TiO_2
WCM	Marshall specimen with water-based TiO_2 coating
L-PCM	Marshall specimen with L-PC coating
H-PCM	Marshall specimen with H-PC coating

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453

454 **Table 2.** The mean values and standard deviation values of removal rates

	R_0%		R_{50}%		R_{200}%	
	Average Value	Standard Deviation	Average Value	Standard Deviation	Average Value	Standard Deviation
OM	0.093	-	-	-	-	-
WCM	9.520	0.59719	3.194	0.49487	2.956	0.54501
L-PCM	7.730	1.02587	3.737	0.27538	3.676	0.50533
HPCM	16.408	1.85565	8.517	0.46608	7.923	0.41633

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