Study on Mix Proportion Optimization of Nano-TiO₂ Composite Photocatalyst for Pervious Asphalt Pavement

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Abstract: By using exhaust gas concentration tester, the degradation efficiency and mechanism of asphalt pavement coated with nano-TiO₂ composite photocatalyst (TCP) has been analyzed. The results showed that the addition of dispersant greatly reduced the amount of TCP under the condition of similar degradation efficiency. When the optimum coating amount of TCP is 500g/m², the degradation efficiency reaches 76.39%. As shown by scanning electron microscope, the TCP without dispersant will aggregate and exhibit uneven dispersion, while the TCP containing dispersant does not have this phenomenon, which indicates that TCP have a better exhaust gas degradation effect after being mixed with dispersant.

1. Introduction
Automobile exhaust is mainly composed of CO, CO₂, CH, SO₂ and solid particles. How to effectively deal with the automobile exhaust pollution is a hot topic for researchers. Lei Yuzi¹ and Li Zhenhao² gave guidance on the selection of TiO₂ and other photocatalyst. Salarian³ and Xie Jieguang⁴ systematically studied the effects of different factors, such as pH value, initial pollutant concentration, light time and humidity, on the degradation efficiency of TiO₂. Huang Qingli⁵ mixed the same amount of photocatalyst into the asphalt mixture samples with different porosity, the results show that the correlation between the degradation efficiency of automobile exhaust and the porosity of the asphalt mixture was not significant. Zhang Hua⁶ added nano-TiO₂ to PAC-13 asphalt mixture and found that the water stability of the test piece was improved to a certain extent. Liu Jianxin⁷ applied nano-TiO₂ modified asphalt to drainage asphalt mixture preparation, which can degrade automobile exhaust effectively. Sun Li⁸ investigated the photocatalytic efficiency, durability and antibacterial properties of modified nano-TiO₂.

The existed studies have shown that nano-TiO₂ photocatalysts used in the preparation of pavement materials can effectively degrade automobile exhaust gas⁹ and the optimal concentration of TiO₂ in the photocatalyst solution is 30%. However, Due to the poor dispersion of TiO₂ particles, the amount of photocatalyst is large, which is not only uneconomical, but also affects the apparent quality of pavement. In this paper, nano-TiO₂ composite photocatalyst (TCP) is prepared by adding binder,
dispersant, pigments and fillers, which is suitable for asphalt pavement with the function of degrading automobile exhaust gas. The degradation efficiency and mechanism of asphalt pavement coated with nano-TiO$_2$ composite photocatalyst (TCP) has been analyzed.

2. Experiments

2.1 Materials
TiO$_2$ is anatase type produced by Zixilai Co. Ltd. Dispersant is made of 5040 dispersant and sodium hexametaphosphate with equal proportions. The pigments & fillers is made of calcium carbonate and talc. Binder is silicone acrylic emulsion, which can improve the weather resistance, water resistance, washing resistance and toughness of the nano-TiO$_2$ coating film.

2.2 Preparation of Nano-TiO2 Composite Photocatalyst (TCP)
The preparation process of TCP is as follows: (1) Adding water and dispersant to the grinding tank and stir for 15 minutes at 500 rpm; (2) Adding nano-TiO$_2$ to the grinding tank and disperse at high speed for 20 minutes at 2500 rpm; (3) Adding the pigments and fillers to the grinding tank, and disperse them at high speed for 10 minutes at 2500 rpm; (4) Adding the silicone-acrylic emulsion under stirring at 2500 rpm for 5 minutes, and then discharge. The mix proportion is shown in Table 1.

| Concentration | TiO$_2$ photocatalyst | Adhesive | Dispersant | Pigments & fillers | Water |
|---------------|-----------------------|----------|------------|-------------------|-------|
| 0%            | 0                     | 80       | 1+1        | 5+5               | 908   |
| 1%            | 10                    | 80       | 1+1        | 5+5               | 898   |
| 3%            | 30                    | 80       | 1+1        | 5+5               | 878   |
| 5%            | 50                    | 80       | 1+1        | 5+5               | 858   |
| 7%            | 70                    | 80       | 1+1        | 5+5               | 838   |
| 9%            | 90                    | 80       | 1+1        | 5+5               | 818   |

2.3 Preparation of Pervious Asphalt Mixture Specimen Coated with TCP
The OGFC-13 pervious asphalt mixture was selected as the reference sample, and the prepared TCP was coated on the surface of the asphalt mixture samples. Compared with the asphalt mixture sample coated with nano-TiO$_2$ without dispersant, the dispersant has better wettability, thereby improving the hydrophilic and lipophilic properties and dispersing the pigments & fillers in the coating system, as shown in Figure 1.
2.4 Pollutant (NOx) degradation test
The adopted exhaust gas degradation efficiency equipment is shown in Figure 2, which mainly includes gas supply device, gas reaction decomposition device and gas concentration tester[10]. The test procedures are as follow: turn on the ultraviolet light, record the test date once every 3 minutes, when the concentration no longer changes, record the final reading and turn off the equipment.

![Figure 2. Test equipment](image)

3. Results and discussion

3.1 Analysis of pollutant degradation efficiency
The degradation efficiency of pervious asphalt mixture coating with different concentration of TCP is shown in Figure.3. After the photocatalyst TiO2 is added to the binder base material and coated on the surface of the asphalt mixture according to the relevant ratio, the photocatalytic performance of specimens is still high. The carrier binder used in the test can reduce the usage of TiO2, which helps to reduce costs. The nano-TiO2 powder is fully dispersed to confirm the stable degradation effect of the photocatalyst. With the increase in the amount of photocatalysis incorporated in the carrier base material, the efficiency of degrading NOx also increases. The concentration of TCP between 0% and 5% has a greater impact on the degradation efficiency of NOx, and the degradation efficiency varies by about 20%. When the concentration of TCP great than 7%, the final degradation efficiency is not greatly improved. When the concentration of TCP reaches 7%, the degradation efficiency reaches 73.74%, while the concentration of TCP reaches 9% and the degradation efficiency is 74.5%, which indicates that 7% concentration of TCP is the optimal value.

![Figure 3. Effect of TCP concentration](image)  ![Figure 4. Effect of coating amount](image)

3.2 Design of coating amount
The coating amount of 7% TCP on the surface of asphalt mixture is designed to be 350g/m², 400g/m², 450g/m², 500g/m² and 550g/m². The degradation efficiency of different coating amounts of TCP is shown in Figure.4. Indeed, different coating amounts also affect the degradation efficiency of NOx.
With the increase of degradation time, the concentration of NO$_x$ decreased significantly in 0-75 minutes, and tended to linear relationship, while the reduction range of NO$_x$ concentration gradually decreased in 75-135 minutes. After 135 minutes, the NO$_x$ concentration tends to be stable, which indicates that the best degradation time for different coating amounts is 135 minutes. When the coating amount increases, the degradation efficiency gradually increases, while the increments is small. When the coating amount increases from 350g/m$^2$ to 500g/m$^2$, the degradation efficiency increases by 3.5%. When the coating amount is increased from 500g/m$^2$ to 550g/m$^2$, the degradation efficiency is only increased by 0.1%. The results show that the optimal coating amount is 500g/m$^2$, in which case, the degradation efficiency is 76.39%.

3.3 Mechanism analysis
The nano-TiO$_2$ composite photocatalyst material was analyzed by scanning electron microscopy (SEM). The microstructure of nano-TiO$_2$ without dispersant is shown in Figure 5, and the microstructure of nano-TiO$_2$ with dispersant is shown in Figure 6. It can be seen from Figure 5 and Figure 6 that nano-TiO$_2$ is uniformly dispersed in TCP with dispersant. While for the TCP without dispersant, nano-TiO$_2$ has obvious agglomeration.

![Figure 5. Microstructure of nano-TiO$_2$ photocatalyst material without dispersant](image-url)
Dispersant, which made of 5040 and sodium hexametaphosphate, is an intramolecular surfactant, which has two opposite properties: lipophilicity and hydrophilicity. The dispersant can uniformly disperse the solid and liquid particles of inorganic and organic pigments that are difficult to dissolve in liquids. The dispersant can also prevent the sedimentation and agglomeration of the particles to form the amphiphilic reagent required for stable suspension.

4. Conclusion
In this paper, the mix proportion optimization of nano-TiO$_2$ composite photocatalyst was conducted. The addition of dispersant can not only ensure the degradation efficiency of TCP, but also reduce the amount of nano-TiO$_2$. The optimal concentration of TCP is 7% and the optimal coating amount is 500g/m$^2$, in which case, the degradation efficiency of pervious asphalt pavement coated with TCP is great than reaches 74%. The microstructure of nano-TiO$_2$ with and without dispersant is analyzed by using SEM. The mechanism is attributed to the lipophilicity and hydrophilicity of the used dispersant.

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