Preparation and performance evaluation of epoxy-based heat reflective coating for the pavement

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Abstract. According to the basic characteristics and composition of heat-reflective coating, combining with the functional requirements of road materials, the experiment selects the epoxy resin with good wear resistance and adhesive force as a film forming material, with TiO₂, SiO₂ and extinction powder as the main functional filler. The experiment gets a good formula with suitable viscosity, low glossiness and good cooling effect, optimizes by orthogonal experiment. The experiment evaluates the indoor and outdoor cooling effect of heat-reflective coating, and analyses the road performance of the coating. The results shows that the better heat-reflective coating formula included 12% of titanium dioxide, 4% of silica and 4% of extinction powder. When the dosage of coating is 0.8kg/m², the indoor specimen of heat-reflective coating decrease the temperature of 12 ~ 14°C, and the specimen under solar radiation can reduce the temperature of 7 ~ 9°C. The pavement of heat-reflective coating has good wear resistance, but the road slip resistance partly declines. Therefore, it needs to add the anti-sliding particles to meet the safe driving requirements.

1. Introduction
The characteristics of heat absorption and temperature sensitivity can easily lead to pavement rutting, cracks, loose, bleeding and other diseases to asphalt pavement. This has greatly limited the application of asphalt pavement, and the high temperature of asphalt pavement will aggravate the formation of urban heat island effect. At present, the main measures to solve the high temperature disease of asphalt pavement are adjusting the asphalt mixture gradation, improving asphalt grading standards, expanding the application range of modified asphalt, and adding modifier in asphalt mixture. These measures have improved the high temperature performance of asphalt pavement to some extent. But the problem of high temperature does not be solved radically. As a new mode of active cooling, the solar heat-reflective coating has received more and more attention. Many researchers tried to use Silicone-Acrylate Emulsion, Acrylic Resin and Unsaturated Resin as binder resin to make heat-reflective coating, and applied it to asphalt pavement. But due to the vehicle friction, the coating appears different degrees of damage after a period time of application. Based on this situation, the experiment makes a heat-reflective coating which has good wear-resisting performance and cooling effect. The main content of this paper is about epoxy resin has good wear-resisting and that adhesion as film forming material. Meanwhile, TiO₂, as the main reflective material and SiO₂ as material improves coating’s wear-resisting performance.

2. Experimental investigation

2.1. Experimental material
Table 1. Epoxy resin performance parameters

| Type          | Epoxy equivalent | Viscosity (Mpa*s) | Appearance     |
|---------------|------------------|-------------------|----------------|
| E51 Epoxy resin | 140              | 600±20            | Transparent liquid |

Table 2. Curing agent performance parameters

| Type             | Amine value (mgKOH/g) | Viscosity (Mpa*s) | Appearance     |
|------------------|-----------------------|-------------------|----------------|
| 107 Modified amine | 300±20                | 45±10             | Transparent liquid |

Table 1 shows the performance of E51 modified epoxy parameters. 107 modified amine curing agent. Table 2 shows the performance of parameters.

2.2. Experimental method

Low viscosity modified Epoxy Resin as film forming matter, TiO$_2$, SiO$_2$ and Extinction powder is main functional material. Orthogonal test selects out the coating formulation that has suitable viscosity, low glossiness and good cooling effect. The coating is brushed on the rutting plate. The rutting plate is made of 15cm × 15cm × 5cm asphalt mixture of dense gradation (AC). And it tests the indoor cooling effect of the coating by self-made sunlight simulation box. Test outdoor cooling effect of the coating by putting the coating specimens on the sunlight perpendicular incidence open area at the same time. The sliding resistance and wear resistance of epoxy thermal reflective pavement specimens were studied by pendulum friction tester and accelerated polisher.

3. Research and analysis

3.1. Confection of epoxy heat-reflective coating

3.1.1. Design of basic formula

3.1.1.1. Design orthogonal test. Filler is main functional material of Heat-reflective Coating. The ratio of filler also has great influence on the performance of Heat-reflective Coating, viscosity and construction time of coating. This test uses orthogonal design to filtrate the mixture ratio of filler quickly, so that we can select out the best ratio of filler which can make the Heat-reflective Coating have better synthetic performance.

L$_9$(3$^3$) orthogonal test, Table 3 shows design orthogonal table. In test, resin dosages are 100 copies. The dosages of the fillers and the resin are in proportion.

Table 3. L$_9$(3$^{3}$) filler orthogonal design table

| Factor | TiO$_2$ | SiO$_2$ | Extinction powder |
|--------|---------|---------|-------------------|
| 1      | 8       | 2       | 4                 |
| 2      | 10      | 4       | 6                 |
| 3      | 12      | 6       | 8                 |

Nine tests are carried out according to the design table. Every test repeats three times. Record the values of cooling, viscosity and glossiness of coating after curing, and calculate the average values respectively. Test results are shown in Table 4.

Table 4. Filler orthogonal test result

| Test number | a | b | c | Filler (filler+resin) | Cooling value(℃) | Viscosity values(mm/s$^2$) | Glossiness values |
|-------------|---|---|---|-----------------------|------------------|---------------------------|------------------|
| 1           | 8 | 2 | 4 | 12.3%                 | 14.3             | 144.4                     | 33.4             |
3.1.1.2. Orthogonal design range analysis

1) Viscosity range analysis
Coating’s viscosity range analysis and viscosity factors effect are shown in Table 5 and Figure 1.

Table 5. Viscosity range analysis

| Factors | TiO₂ | SiO₂ | Extinction powder |
|---------|------|------|-------------------|
| Average 1 | 178.7 | 179.3 | 156.8 |
| Average 2 | 181.5 | 183.0 | 168.9 |
| Average 3 | 187.2 | 195.4 | 217.6 |
| Range | 9.5 | 16.1 | 60.2 |

Figure 1. Viscosity factors effect
From Table 5 and Figure 1, the order of three fillers significant on coating viscosity: Extinction powder > SiO₂ > TiO₂.

2) Value of cooling range analysis
The coating’s cooling value and cooling factors effect are shown in Table 6 and Figure 2.

Table 6. Cooling value range analysis

| Factors | TiO₂ | SiO₂ | Extinction powder |
|---------|------|------|-------------------|
| Average 1 | 14.9 | 15.6 | 15.1 |
| Average 2 | 15.8 | 15.6 | 15.5 |
| Average 3 | 16.1 | 15.5 | 16.1 |
| Range | 1.20 | 0.14 | 0.97 |
From Table 6 and Figure 2, the order of three fillers influence on coating cooling effect: TiO$_2$ > Extinction powder > SiO$_2$.

3) Glossiness range analysis

The coating cooling value range analysis and cooling factors effect are shown in Table 7 and Figure 3.

**Table 7. Glossiness range analysis**

| Factors | TiO$_2$ | SiO$_2$ | Extinction powder |
|---------|---------|---------|-------------------|
| Average 1 | 28.2    | 34.4    | 29.8              |
| Average 2 | 26.7    | 27.7    | 21.6              |
| Average 3 | 25.6    | 25.5    | 19.7              |
| Range    | 2.6     | 8.9     | 10.1              |

From Table 7 and Figure 3, the order of three fillers influence on coating glossiness: Extinction powder > SiO$_2$ > TiO$_2$.

3.1.1.3 Orthogonal design optimized formulation and performance parameter. This test design hopes to get coating with high cooling value, low viscosity and low glossiness. However, the dosage of influencing factors changed will improve some functions of coating while some functions may be decreased. So it needs to take comprehensive balance method to analyze and choose the most optimal proportion. By the range analysis of orthogonal design, it finds that using 12 parts TiO$_2$ will get better cooling effects. While the dosages of SiO$_2$ increase from 2 parts to 4 parts, the glossiness of coating decreases rapidly. It shows great ability of extinction. But when the dosage increases from 4 parts to 6 parts, the glossiness of coating hardly changes. When the dosage of extinction powder is 4 parts, the
glossiness of coating has already been lower than 30, completely in full matte state. It meets the needs of driving safety. While the dosage of extinction powder increases from 4 parts to 6 parts, the viscosity of coating increases rapidly. It goes against the painted coating. In conclusion, the most optimized proportion is 100 parts resin, 12 parts TiO₂, 4 parts SiO₂ and 4 parts extinction powder.

3.1.2. The confection of color coatings
Coating’s heat-absorptivity will be increased after adding dark pigment. But the cooling effect will decrease. This test chooses the iron oxide red as color pigment. The coating’s temperature with different pigment content were compared and tested. And the result shows that white coating is the control group. The cooling effect with different pigment content is calculated. Figure 4 shows the result.

![Figure 4](image1.png)

**Figure 4.** Influence of color pigment content on cooling effect

From Figure 4, the addition of iron oxide red will increase the temperature of specimens. When the adding amount of iron oxide red is 1%~3%, the cooling effect decreases a little, when over 3%, the temperature difference changes a lot, the cooling effect obviously drops. When the adding amount of iron oxide red reaches to 5%, the temperature difference with white specimens almost reach to 4℃. So the best amount of iron oxide red is less than 3%.

3.2. The cooling research of epoxy heat-reflective coating

3.2.1. The influence on the cooling value of coating dosage
The surface of AC-13 asphalt concrete specimens are brushed the epoxy reflective coating. Then the specimens are packed well with tin foil. The tin foil plays the role of heat insulation. It will make the test results more representative. The 500W iodine tungsten lampas is used as the simulating indoor solar radiation to test the temperature of specimens with different dosage of coating. The temperature difference between two specimens were calculated when the black specimen’s temperature reaches 60℃. Figure 5 shows the results.

![Figure 5](image2.png)

**Figure 5.** Influence on the cooling value of coating dosage
From Figure 5, with the increased use of coating, the coating specimens show the tendency of gradually gentle after increasing. And the maximum of cooling value can reach to 12°C. Consider all aspects, the suitable dosage of coating is 0.8kg/m2 for AC asphalt mixture specimens.

3.2.2. The influence of specimen temperature on the cooling effect
Take the temperature of the asphalt concrete surface 2 cm depths as the object of study. Calculate the cooling value of specimens under different surface temperature. Figure 6 shows the result.

![Figure 6](image_url)

**Figure 6.** Contrast of indoor cooling evaluation

From Figure 6, cooling value increases with the specimens temperature increasing. So the heat-reflective coating cooling effect will be more obvious when the pavement temperature is higher.

3.2.3. The evaluation of the cooling effect under solar radiation
To further evaluate the cooling effect of heat reflective coating on asphalt concrete in natural environment, two AC-13 asphalt concrete rutting specimens are selected as test specimens. One of them is brushed with nothing. The surface of another is brushed 0.8kg/m2 coating. We put them in the place which is open and also can be exposed to radiation of sunlight. Temperature sensors are embedded in 2 cm away from the surface of specimens. Testing and recording the changes of temperature in a day. The highest temperature that day is 35°C. Figure 7 shows the result.

![Figure 7](image_url)

**Figure 7.** Change of Asphalt concrete specimens temperature

From Figure 7, two asphalt concrete specimens’ temperature increased at the same time. The temperature reached the highest at about 2:30 p.m. At that time, the one’s temperature reached to 59.6°C without coating. Another brushed with epoxy heat-reflective coating, its temperature is 51.8°C. The cooling value reaches 7.8°C.

4. The wear-resisting research of epoxy heat-reflective coating
The heat-reflective coating on pavement will be repeatedly rolling by vehicle. The wear-resistance is an important performance of heat-reflective coating. But so far, there isn’t a unified evaluation
criterion for pavement coating’s wear-resistance. In this experiment, asphalt mixture accelerated polishing apparatus (developed by Chongqing Transportation research and Design Institute) is used to simulate the friction effect of traffic load on the surface of coating. As shown in Figure 8. Each wheel load is 0.7 MPa, the wheel acceleration run time is 8h.

![Asphalt mixture accelerated polishing apparatus](image)

**Figure 8.** Asphalt mixture accelerated polishing apparatus

The experiment tests the epoxy heat-reflective coating’s wear-resisting performance before and after put anti-skid. The surface condition before and after the abrasion test is shown in Figure 9.

![Surface condition before and after abrasion](image)

**Figure 9.** Surface condition before and after the abrasion

In the Figure 9, a is the heat-reflective coating specimen without anti-skid before abrasion, b is the heat-reflective coating specimen with anti-skid before abrasion, c is the heat-reflective coating specimen without anti-skid after abrasion, d is the heat-reflective coating specimen with anti-skid after abrasion. Figure 9 show that after wheel runs for 8h, no anti-skid heat-reflective coating specimen surface stays well. Only a little coating falls off. A small part of spreading anti-skid pellets reflective coating specimen surface falls off. It is in good condition in general. The result shows that the epoxy reflective coating has better wear-resisting performance.

5. The siding resistance research of epoxy heat-reflective coating

The anti-sliding performance of pavement is the key factor affecting road traffic safety. The coating on asphalt pavement will decrease the anti-sliding performance of pavement. So we must research the
anti-sliding performance of specimen with heat-reflective coating. AC-13 asphalt concrete slabs are chosen as specimens (30cm×30cm×5cm), which is brushed with different amount of the coating on the surface. And then, we spread a certain amount of anti-sliding on the surface of specimens. We evaluate the anti-sliding performance of asphalt specimens with different amount of coating by pendulum tester, and compare the results of different performance of anti-sliding. Figure 10 shows the result.

![Figure10. Pendulum value of different dosage of coatings](image)

From Figure10, anti-sliding performance of asphalt specimen obviously decreased after putting coating. When the dosage of coating is 0.8kg/m2, pendulum value is lower than 40BPN. After spreading anti-sliding on the surface, the pendulum value raises from 38 to 60, increased over 60%. Anti-sliding performance is improved obviously and it meets the requirement of the traffic safety.

6. Summary
1. By orthogonal test, the best formula of epoxy heat-reflective coating is 12% TiO2, 4% SiO2 and 4% Extinction powder.
2. White epoxy heat-reflective coating has the best cooling effect. Adding colour coating will affect the cooling effect slightly. Colour coating quantity added is less than 3% for the best.
3. The cooling effect of epoxy heat-reflective coating increases with the thickness through comparing the temperature of specimens with different thickness coating. But when it reaches a certain thickness, the cooling effect tends to be stable. The dosage of coating is 0.8kg/m2.
4. Use solar simulator method measure epoxy heat-reflective coating can reduce the temperature 12~14℃ indoor. When the outside temperature is 35℃, the highest cooling value is 7.8℃. The pavement with epoxy heat-reflective coating has good wear-resisting performance.
5. The pavement’s wear-resisting performance decreases with the increasing dosage of epoxy heat-reflective coating. The wear-resisting performance of epoxy heat-reflective coating meets the requirement of the traffic safety after spreading anti-sliding particles on the pavement.

References
[1] Zhao Y Q and Huang D X, “Viscoelastic Behavior of Asphalt Mixtures with Damage Stage,” China Journal of Highway and Transport, 21(2008)1, 25-28.
[2] Chen Y R, “Research on Relationship Between the Thermal Characteristic of Underlying Surface and Urban Heat Island,” Beijing University of Civil Engineering and Architecture, Beijing, China, 2008.
[3] Tian W Q, Zhou B and Cong L, “High Temperature Stability of Modified Asphalt Mixture and Evaluation Method,” Journal of Building Materials, 12(2009)3, 285-287.
[4] Ang J, Yu L M, Wen, et al., “Rutting resistance of asphalt mixtures in the middle course,” Journal of Southeast University, 22(2006)2, 270-272.
[5] Song X F, Ling J M and Zhu F H, “The Thermal Reduction property and Effect of Porous Asphal Pavement,” Shanghai Highways, 1(2007)1, 18-20.
[6] Feng D C and Zhang X, “Development of Heat Reflection Coating and Observation of Road Performance,” Journal of Highway and Translation Research and Development, 27(2010)10, 17-20.

[7] Wang H, “Asphalt Pavement Light Thermal Reaction Mechanism and Heat-reflection Coating Engineering Research,” Harbin Institute of Technology, Harbin, China, 2013.

[8] Zhu X J and Lin A, “Study on Solar Heat Reflection Coating,” Equipment Environmental Engineering, 3(2006)2, 29-32.

[9] Cao X J, “Research and Performance Evaluation of Asphalt Pavement unsaturated polyester heat-reflective coating,” Chongqing Jiaotong University, Chongqing, China, 2011.