Design and Performance Research of Epoxy Thermal Reflective Coating on Asphalt Pavement

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Abstract. In order to reduce the temperature of the asphalt pavement, determine the coating viscosity and curing time at different temperatures, in this paper a set of road heat reflection coating schemes is designed. Through the self-developed indoor coating cooling test box, brinell viscometer and other test instruments, the coating amount, cooling effect, curing time and coating viscosity analysis test were carried out. The coating scheme with the best cooling effect is determined, and the problem of explosion reaction of coating in the process of high-temperature construction is solved. The anti-skid performance of the coating under the optimal ratio of coating additives was evaluated. The results show that the reflectivity of the coating can be improved by the addition of functional material titanium dioxide, and the best mixing value is about 30% of the quality of epoxy resin, and the maximum cooling range of the coating reaches 7.35℃. The cooling effect increases with the increase of the coating amount, but the cooling effect tends to be stable after reaching a certain degree and the recommended coating dosage is 0.8kg/m². The addition of 2-ethyl-4-methylimidazole can prolong the curing time and reduce the viscosity of the coating.

1. Introduction

Asphalt pavement has strong heat absorption, and high temperature in summer can easily induce rutting on asphalt pavement [¹] and aggravate the urban heat island effect [²]. Rutting is the cumulative permanent deformation of asphalt pavement in the vertical direction under the action of vehicle load at high temperature. At present, the factors affecting asphalt pavement rutting are usually divided into internal and external factors. The internal factors mainly include the properties of aggregate and asphalt, gradation and pavement structure[³]. Technical measures such as adding anti-rutting agents, using modified asphalt, adjusting the gradation of mineral aggregates, and using high modulus asphalt mixtures are usually used to solve the internal factors[⁴], but these measures passively accept the high temperature conditions of the asphalt pavement, and these effects are often not obvious. The external cause is the high ambient temperature in summer. At present, the methods adopted to actively reduce the temperature of asphalt pavement mainly include thermal resistance pavement [⁵-⁷], water-retaining pavement [⁸-¹⁰], pavement with phase change material [¹¹-¹³], and heat-reflective coating pavement [¹⁴].
Among them, the heat-reflective coating method is the simplest and most effective method. Therefore, the new environmentally-friendly heat-reflective coating pavement has been widely used. The heat-reflective coating applied to the asphalt pavement not only effectively reduces the pavement temperature, improves the high temperature stability of asphalt pavement, reduces the high temperature diseases such as asphalt pavement rutting, but also changes the heat radiation absorption characteristics of asphalt pavement and effectively relieves the urban heat island effect. Niu Jianfu [15] used epoxy resin and titanium dioxide as the main materials to prepare a heat-reflective coating, and used finite element software to analyze the feasibility of the heat-reflective coating to reduce the road temperature. Zheng Mulian et al. [16] made a heat-reflective coating with epoxy resin as binder and titanium dioxide as pigment and filler, focusing on the indoor and outdoor cooling effect and anti-skid performance of the coating. Feng Xirong [17] studied the heat reflection of asphalt pavement with polyurethane resin, acrylic resin, epoxy resin and other resins as the matrix, titanium dioxide as the functional material, and iron oxide red, iron oxide yellow, zinc oxide and other shading pigments, the temperature of the coating can be reduced to more than 7.43 °C.

However, in the existing research, only the proportion design and road performance research of epoxy resin heat reflective coating at a certain temperature have been carried out, and the curing time and viscosity comparison analysis of epoxy resin at different temperatures have not been compared and analyzed. In the construction process, especially in the high temperature environment, the coating material may have an explosive polymerization reaction with rapid increase of molecular weight and excessive local heat release. In view of this, in this article, the proportion of epoxy resin heat reflective coating additives is improved, the problem of explosion reaction that epoxy resin heat reflective coating is easy to produce under high temperature conditions has been solved, and the curing time of the coating is prolonged, and the scheme support is provided for the construction of thermal reflective coating.

## 2. Materials and Methods

### 2.1. Materials

#### 2.1.1. Coating material

The heat-reflective coating material are mainly composed of matrix materials, functional materials and additives. The matrix material is E-51 epoxy resin, which bears the main mechanical properties. It has the characteristics of strong adhesion, low viscosity, high toughness and small shrinkage force. It also has excellent mechanical properties and heat resistance. The main technical indicators are shown in Table 1. The functional material is mainly titanium dioxide, which is responsible for the main cooling effect. Its shading index is high and can strongly refract or scatter light. The main technical indicators are shown in Table 2. Functional materials also include floating beads and color pigments. The floating beads have a particle size of 60 meshes, which bear the secondary cooling effect. It is thin-walled and hollow, with small specific surface area, which can reduce the amount of resin, low viscosity of the floating beads, can improve the fluidity of the coating, and have good hardness and wear resistance. The color pigment is iron oxide red with a particle size of 60 mesh, which plays the role of coating coloring. Additives include curing agent, inactive diluent, water-based defoamer and SN-5040 dispersant, which respectively play the role of curing the coating, reducing the viscosity of the coating, improving the workability of the coating, eliminating the coating bubbles and evenly dispersing the filler [18]. The curing agent includes 593 curing agent and 2-ethyl-4-methylimidazole. The parameters of the two types of curing agent are shown in Table 3.

| Table 1. Main technical indicators of E-51 epoxy resin. |
|---------------------------------------------------------|
| **Epoxy value /mol** | **Volatile value /%** | **PH (25°C)** | **Inorganic chlorine /ppm** | **density /g/cm³** |
|----------------------|-----------------------|---------------|-----------------------------|-------------------|
| E-51 epoxy resin      | 0.512                 | ≤1.0          | 6                           | ≤220              | 1.18              |

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Table 2. The shading index of some commonly used pigments.

| pigment            | Shading index | pigment            | Shading index |
|--------------------|---------------|--------------------|---------------|
| Titanium dioxide   | 2.8           | Alumina            | 1.7           |
| Iron Oxide Red     | 2.8           | Barium sulfate     | 1.64          |
| Iron Oxide Yellow  | 2.3           | Magnesium Sulfate  | 1.58          |
| Zinc oxide         | 2.2           | Silica             | 1.54          |

Table 3. Main technical parameters of curing agent.

| Type of curing agent | Appearance               | Relative density | Molecular weight | Curing performance        |
|----------------------|--------------------------|------------------|------------------|---------------------------|
| 593 curing agent     | Colorless transparent liquid | 0.985            | 217.13           | Fast curing at low temperature |
| 2-ethyl-4-methylimidazole | Yellow thick liquid       | 1.026            | 110.16           | Fast curing at medium temperature |

2.1.2. Coating ratio

According to the amount of various materials, 9 coating ratios are designed in this paper. The main purpose of the first three proportions is to determine the optimal amount of functional material TiO₂, and the last six ratios mainly verify the effect of the two curing agents on the curing time and viscosity of the coating, therefore, appropriate construction ratios at different temperatures are recommended. The specific proportion is shown in Table 4.

Table 4. Coating ratio design.

| Coating number | TiO₂ dosage (%) | floating beads dosage (%) | Pigment dosage (%) | Dispersant dosage (%) | Defoamer dosage (%) | 593 curing agent dosage (%) | 2-ethyl-4-methylimidazole dosage (%) | Thinner dosage (%) |
|----------------|-----------------|----------------------------|--------------------|-----------------------|----------------------|-------------------------------|---------------------------------------|-----------------|
| 1°             | 10              | 10                         | 30                 | 0.6                   | 0.6                  | 12.5                          | 12.5                                  | 30              |
| 2°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | 12.5                          | 12.5                                  | 30              |
| 3°             | 50              | 10                         | 30                 | 0.6                   | 0.6                  | 12.5                          | 12.5                                  | 30              |
| 4°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | 25                            | -                                     | 30              |
| 5°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | 20                            | 5                                     | 30              |
| 6°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | 15                            | 10                                    | 30              |
| 7°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | 10                            | 15                                    | 30              |
| 8°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | 5                             | 20                                    | 30              |
| 9°             | 30              | 10                         | 30                 | 0.6                   | 0.6                  | -                             | 25                                    | 30              |

Note: the amount of the above-mentioned materials is the mass percentage of the amount of epoxy resin.

2.1.3. Coating preparation process

According to the coating ratio, first weigh the material according to the predetermined ratio, then add titanium dioxide, iron oxide red and floating beads into the epoxy resin and mix them evenly, then add dispersant and defoamer and use a magnetic stirrer to perform low-speed shearing dispersion stirring, the low-speed stirring rate is 500 r/min and the stirring time is 10 min, finally, add diluent and curing agent, and maintain high-speed shearing dispersion stirring, the high-speed stirring rate is 3000 r/min, and the stirring time is 2 min to prepare the reflective coating.

2.1.4. Asphalt

The gradation as shown in Table 5, the rutting specimens of AC-13, SMA-13 and OGFC-13 with specifications of 300 mm×300 mm×50 mm were formed. The asphalt is Karamay No. 70 asphalt, the coarse and fine aggregates are granite, and the mineral powder is ground from limestone.
### Table 5. Gradation of Asphalt Mixture.

| Gradation | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|-----------|----|------|-----|------|------|------|-----|-----|-----|-------|
| AC-13     | 100| 95   | 76.5| 53   | 37   | 26.5 | 19  | 13.5| 10  | 6     |
| SMA-13    | 100| 95   | 62.5| 27   | 20.5 | 19   | 16  | 13  | 12  | 10    |
| OGFC-13   | 100| 95   | 70  | 21   | 16   | 12   | 9.5 | 7.5 | 5.5 | 4     |

2.2. Test plan

2.2.1. Cooling performance test

The self-developed equipment is used for the cooling test of the coating. The main composition of the equipment is shown in Figure 1. The equipment is mainly composed of closed box, iodine tungsten lamp, temperature recorder and other components.

![Figure 1. Indoor coating cooling test equipment.](image)

Note: 1-Iodine tungsten lamp 2-Stabilizing device 3-Heat insulation layer 4-Elevating pulley 5-Temperature recorder 6-Closed box 7-Heating device 8-Fan 9-Humidity controller

The size of the test piece is 300 mm × 300 mm × 50 mm rut plate. Before the test, the 1³-3⁴ coating was coated on the surface of AC-13, SMA-13 and OGFC-13 specimens with different thicknesses along the rutting direction. After the coating was completely cured, small holes were drilled symmetrically along the rutting direction at 2.5 cm in the middle of the side of the test piece, and the temperature sensor was embedded in the drill hole and sealed with asphalt, two temperature sensors are symmetrically placed 5 cm from the center of the top surface of the board and parallel to the drilling position. Then put the test piece into the thermal insulation box on the test bench, as shown in Figure 1. Open the radiation environment box, set the initial temperature to 15°C, heat preservation for 1 hour, turn on the iodine tungsten lamp to radiate for 5 hours after the heat preservation time, the radiation intensity on the surface of the control panel is about 850 w/m² and turn off the iodine tungsten lamp after 5 hours to ensure that the temperature in the enclosed box drops freely, so as to simulate the temperature change in a day. During this period, use a temperature recorder to record a data every 10 minutes, and record the temperature rise and drop data of the test piece.

2.2.2. Curing time and viscosity change test

Due to the high curing temperature and short time required for E-51 epoxy resin, and the cured product has the problems of low heat resistance and low toughness \(^{[19]}\). In this paper, 2-ethyl-4-methylimidazole is added, the reaction degree is more complete, the heat resistance of the cured product will be improved, and the curing time will be prolonged. After the coating was completely
cured, small holes were drilled symmetrically along the rutting direction at 2.5 cm in the middle of the side of the test piece, and the temperature sensor was embedded in the drill hole and sealed with asphalt, two temperature sensors are symmetrically placed 5 cm from the center of the top surface of the board and parallel to the drilling position. Then put the test piece into the thermal insulation box on the test bench, as shown in Figure 1. Open the radiation environment box, set the initial temperature to 15°C, heat preservation for 1 hour, turn on the iodine tungsten lamp to radiate for 5 hours after the heat preservation time, the radiation intensity on the surface of the control panel is about 850 w/m² and turn off the iodine tungsten lamp after 5 hours to ensure that the temperature in the enclosed box drops freely, so as to simulate the temperature change in a day. During this period, use a temperature recorder to record a data every 10 minutes, and record the temperature rise and drop data of the test piece.

Epoxy resin is used as an organic polymer material, and its viscosity is measured by Brookfield viscometer. Separately dispense the 4#-9# coating and their respective curing agents in the sample container, place the sample container in the oven, and keep it at 20°C, 40°C, 60°C and 80°C for 30 minutes for standby. According to the T0625-2011 test procedure in JTG E20-2011 "Test Procedures for Asphalt and Asphalt Mixtures in Highway Engineering", the samples in the oven are fully mixed and place them in a Brookfield viscometer to test at 20°C, 40°C, 60°C, and 80°C respectively. The No. 29 rotor was selected for this test with a speed was 20 r/min to observe the viscosity change.

2.2.3. Anti-skid performance test
Based on the above tests, an optimal ratio is selected for the anti-skid performance test. In this paper, the pendulum value of rutting plate is measured by pendulum friction instrument for evaluation.

3. Results

3.1. Effect of brushing amount on cooling effect

Figure 2. The influence of the amount of brushing on the cooling effect.

It can be seen from Figure 2 that coatings of different thicknesses have cooling function for different types of specimens. The cooling effect on the upper surface and 2.5 cm inside of the specimen showed a trend of rising first and then gentle with the increase of the amount of brushing. When the brushing amount is 0.2 kg/m², the cooling effect of the coating on the surface and inside of the test piece is lower, which is due to the thin coating, less TiO₂ content and insufficient refractive ability, so the cooling rate is small. When the amount of brushing reaches 0.8 kg/m², the temperature drop on the surface and 2.5 cm inside the specimen reaches a larger value and tends to be gentle, because when the coating thickness increases to a certain extent, the distribution of functional material
TiO$_2$ tends to be stable and the refractive effect does not change much. Therefore, 0.8kg/m$^2$ is recommended as the best brushing amount in this paper.

### 3.2. Cooling performance

As shown in Figure 3, the cooling effect diagrams of 1$^{st}$-3$^{rd}$ coating on the upper surface of AC-13, OGFC-13 and SMA-13 specimens are (a), (b) and (c), respectively.

![Figure 3](image1.png)

Figure 3. The cooling effect of upper surface of test piece. As shown in Figure 4, the cooling effect of 1$^{st}$-3$^{rd}$ coating at 2.5cm from the upper surface of AC-13, OGFC-13 and SMA-13 specimens are (a), (b) and (c), respectively.

![Figure 4](image2.png)

Figure 4. Cooling effect at 2.5 cm of specimen.

As shown in Figure 5, the maximum cooling effect diagrams of the 1$^{st}$-3$^{rd}$ coating at the two positions of the AC-13, OGFC-13 and SMA-13 specimens are (a), (b) and (c), respectively.

![Figure 5](image3.png)

Figure 5. Comparison of the maximum temperature difference of the specimen.
Figure 6. Effect of coating on the anti-skid performance of asphalt mixture.

It can be seen from Figure 3 that the temperature on the upper surface of the three graded specimens shows a trend of first decreasing and then increasing with the increase of TiO2 content, of which the temperature at the upper surface of the 30% TiO2 content specimen is the lowest. It can be seen from Figure 4 that the temperature at 2.5 cm decreases with the increase of TiO2 dosage, but the cooling effect will stabilize after reaching a certain concentration, the cooling effect of the coating is equivalent when the TiO2 content is 30% and 50%. The possible reason is that when the TiO2 content exceeds a certain limit, the TiO2 particles are not uniformly dispersed, resulting in a decrease in the reflection efficiency of the coating. It can be seen from Figure 5 that when the TiO2 content is 30%, the cooling range of the three graded specimens is the largest. This is because when the content of TiO2 is small, the refractive ability of the coating is insufficient, so the cooling range is small, as the TiO2 content gradually increases, its distribution tends to be stable until saturation, and the coating refractive effect gradually becomes better until the final coating shading effect does not change or even decreases. The maximum temperature difference on the surface of AC-13, OGFC-13 and SMA-13 specimens reached 4.95℃, 4.9℃ and 7.35℃ respectively, and the maximum temperature difference at 2.5 cm is 5℃, 7.05℃ and 7.35℃ respectively. Considering the cooling effect, cooling amplitude and engineering cost and other factors, the recommended amount of TiO2 to be 30% of epoxy resin in this article.

3.3. Anti-skid performance

Based on the above tests, the anti sliding performance of 2# coating with a brushing amount of 0.8kg/m2 is analyzed in this paper. According to the T0964-2008 test procedure in JTG 3450-2019 "Highway Subgrade and Pavement Field Test Regulations", the anti-skid performance of the 2# coating was tested. The effect of coating on the anti-skid performance of the mixture is shown in Figure 6 (temperature has been corrected).

It can be seen from Figure 6 that the coating reduces the anti-skid ability of the pavement. Compared with the original road, it is reduced by about 30%, but it still meets the standard requirement of pendulum value BPN≥45.

3.4. Variation of coating viscosity

As shown in Figure 7, (a), (b), (c), and (d) represent the change trend of paint viscosity over time at 20℃, 40℃, 60℃, and 80℃, respectively.
Based on the fluidity requirements of construction spraying, 300 mPa·s is set as the best viscosity for coating spraying. Coatings with a viscosity lower than this value can be sprayed smoothly, and coatings with a viscosity higher than this value may block the nozzle and nozzle, causing damage to the instrument. The 30 min construction and spraying time is taken as the limiting condition, and the best coating ratio is recommended. As shown in figure (a), within 30 minutes, the viscosity of 4⁻⁹ coatings does not exceed the best viscosity required for spraying, and the coating can be sprayed, in order to open up traffic as soon as possible, it is recommended that the best coating is 4⁻ at 20°C. As shown in Figure (b) that within 30 minutes, 4⁻, 5⁻ and 6⁻ coatings have exceeded the optimum viscosity of coating spraying. In order to ensure the spraying quality and do not damage the construction equipment, these three ratios should not be used. The recommended best coating at 40°C is 7⁻. As shown in Figure (c), within 30 minutes, 4⁻, 5⁻, 6⁻ and 7⁻ coatings have exceeded the optimum viscosity of coating spraying, in order to ensure the construction quality and do not damage the construction equipment, these four ratios should not be used. The recommended best coating at 60°C is 8⁻. It can be seen from the figure (d) that at 80°C, the 4⁻⁻⁻⁻ coating reacts violently and the viscosity value changes drastically, exceeding the optimum viscosity of the coating spraying in 2 minutes, therefore, when the temperature is higher than 80°C, it is not suitable for coating spray construction.

4. Conclusions
(1) The incorporation of functional material titanium dioxide can increase the reflectivity of the coating, and the cooling effect will first increase and then decrease or become flat with the increase of the titanium dioxide content. There is an optimum value for the amount of titanium dioxide, the
proportion is about 30% of the mass of epoxy resin. The maximum cooling rate of the coating can reach 7.35°C.

(2) The cooling effect of epoxy resin heat-reflective coating on the test piece shows a trend of first increasing and then gradually flattening with the increase of coating thickness. The recommended optimal dosage is 0.8 kg/m².

(3) The coating will reduce the anti-skid performance of the road surface, but it meets the requirements of the specification.

(4) With the increase of the content of 2-ethyl-4-methylimidazole, the viscosity of the coating shows a downward trend in the same time period at the same temperature. This means that under the same temperature, the addition of 2-ethyl-4-methylimidazole delays the curing time of the coating, which is more conducive to the spray construction of the coating. The recommended spraying construction at 20°C, 40°C and 60°C are 4#, 7# and 8# respectively.

Acknowledgements
This article is the science and technology project of Shenzhen Longgang Transportation Bureau (220021160451).

References
[1] Zhao, Y.Q., Huang, D.X. (2008) Viscoelastic Behavior of Asphalt Mixture during Failure Stage. J. China Journal of Highway and Transport., 01: 25-28.
[2] Mohajerani, A., Bakaric, J., Jeffrey-Bailey T. (2017) The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. J. JOURNAL OF ENVIRONMENTAL MANAGEMENT., 197: 522-538.
[3] Li, J.Y. (2019) Analysis on Formation Mechanism and Control Factors of Rut Disease on Asphalt Pavement, D. Jilin University.
[4] Tian, W.Q, Zhou, B, C, L, et al. (2009) Journal of Building Materials., 12(03): 285-287+291.
[5] Li, C.X, Yang J.H, Zhang, K.(2019) Thermal insulation and cooling characteristics of thermal resistance asphalt mixture and evaluation of its pavement performance. J. Journal of Xi'an University of Architecture & Technology., 51(3): 375-382, 395.
[6] Wang, C.H, Fu, H, Fan, Z.T., et al.(2019) Utilization and properties of road thermal resistance aggregates into asphalt mixture. J. Construction And Building Materials., 208: 87-101.
[7] Qin, Y. H.(2015) A Review on the Development of Cool Pavements to Mitigate Urban Heat Island Effect. J. Renewable and Sustainable Energy Reviews., 445-459.
[8] Nakayama T, Fujita T. (2010) Cooling Effect of Water-Holding Pavements Made of New Materials on Water and Heat Budgets in Urban Areas. J. Landscape and Urban Planning., 96(2): 57-67.
[9] Li, H, Harvey, J, Ge, Z. S. (2014) Experimental Investigation on Evaporation Rate for Enhancing Evaporative Cooling Effect of Permeable Pavement Materials. J. Construction and Building Materials., 65: 367-375.
[10] Gao, Z. W, Liu, L. Q, Xiao, X. D, et al. (2020) Research progress of thermal resistance asphalt mixture. J. Journal of Chang’an University., 40(01), 125-134.
[11] Chen, M. Z, Wan, L, Lin, J. T. (2012) Effect of Phase-Change Materials on Thermal and Mechanical Properties of Asphalt Mixtures. J. JOURNAL OF TESTING AND EVALUATION., 40(5): 746-753.
[12] Anupam, B. R, Sahoo, U. C, Rath, P. (2020) Phase change materials for pavement applications: A review. J. Construction And Building Materials., 247.
[13] Ma, B. A, Wang, S. S, Li, J. (2011) Study on Application of PCM in Asphalt Mixture. J. Advanced Materials Research., 168: 2625-2630.
[14] Pan, S. P, Sun, B. X, Zhan, P. M, et al. (2019) Overview of Studies on Pavement Cooling Mechanism and Its Influencing Factors Based on Reflectance. J. Journal of Highway and Transportation Research and Development., 36(9): 14-23.
[15] Niu, J.F. (2019) Research on the Cooling Function of Colored Thermal Reflective Asphalt Pavement Coating. J. Journal of Liaoning University of Science and Technology., 42(05):397-400.

[16] Zheng, M.L, He, L, Gao, X, Wang, F, Cheng, C. (2013) Performance analysis of thermal reflective coating on asphalt pavement based on cooling function. J. Journal of Traffic and Transportation Engineering., 13(05):10-16.

[17] Feng, X.R. (2020) Study on Optimal Design and Performance of Coating Materials for Aspashphalt Pavement. J. Chinese and Foreign Highway., 40(03): 253-258.

[18] Zheng, N.X, Lei, J.A, Wang, S.B, et al. (2020) Influence of Heat Reflective Coating on the Cooling and Pavement Performance of Large Void Asphalt Pavement. J. Coatings., DOI: 10.3390/coatings10111065.

[19] He, X.W, Zhang J.J, Wang, H.X, et al. (2018) Study on bisphenol A epoxy resin/dicyandiamide / 2-methylimidazole. Transactions of the Chinese Society of Forestry Engineering., 3(03): 63-67.