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Durability evaluation of road cooling coating

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HIGHLIGHTS

- The cooling effects of different new road cooling coatings.
- Durability evaluation indexes under different composite operating conditions.
- Multi-objective grey target decision-making method.

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ABSTRACT

A comprehensive durability evaluation system for road cooling coating had not yet been constructed. Aimed at this objective, different new road cooling coatings were prepared based on a variety of selected raw materials, and the cooling effects of different road cooling coatings were determined by means of a field test. The complex coupling environment of temperature, vehicle load, and pollution in the practical application of road cooling coating was simulated. Durability evaluation indexes of road cooling coatings under different composite operating conditions were presented, following which the comprehensive durability of different road cooling coatings was evaluated using a multi-objective grey target decision-making method. Road cooling coatings with superior comprehensive durability were selected. The results demonstrate that various road cooling coatings can reduce the asphalt pavement temperature under the impact of the outside environment. The comprehensive durability of road coatings is obviously improved with the addition of cooling function materials.

1. Introduction

Significant heat is accumulated inside asphalt concrete pavements, which is difficult to release at high temperatures during summer [1], leading to high-temperature rutting diseases of the pavement and aggravation of the urban heat island effect [2,3]. In order to address this problem, road cooling coating has been studied by numerous road researchers [4–6]. A road cooling coating was prepared by Li et al., in which unsaturated polyester was used as bonding material and its road performance was evaluated comprehensively [7]. Uemoto et al. found that solar reflectance was mainly determined by the coating color and surface roughness [8]. Cao et al. prepared thermal reflection coating with titanium dioxide in order to reduce pavement temperature, and applied it to asphalt pavements with different grades. The influence factors of road performance and the cooling effect were determined [9,10]. Akbari et al. presented the use of thermal reflection materials for reducing pavement temperature to mitigate the heat island effect [11]. Zheng et al. used rutile titanium dioxide to prepare a thermal reflection coating, and the cooling effect of different color coatings on asphalt concrete was studied [12]. Kumar developed a new carbon nanoscale coating that can significantly increase the heat release rate [13]. Guntor et al. studied the influence of coating material on the asphalt pavement surface temperature under different environmental temperatures, and the results indicated that this coating material can decrease the asphalt pavement temperature by 4.4 °C [14]. Han et al. estimated the performance of cool coatings colored with a series of novel, environmentally benign and high near-infrared reflective inorganic pigments [15]. Sun et al. studied the high temperature stability of different cooling coatings, based on a road wheel-tracking test [16]. Waste tiles were used on asphalt pavement to reduce pavement temperature, owing to their effective reflectivity, by Anting et al., and the maximum cooling was 6.4 °C [17]. Wang et al. prepared a new road cooling coating based on the energy transformation principle, where road performance and the cooling effect of the road cooling coatings were analyzed systematically, and the microstructures and cooling mechanisms of the coatings were revealed [18,19].

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Overall, several road cooling coating technologies have been explored worldwide. Such research mainly focuses on the optimization of cooling function materials, coating preparation, and studies of the cooling effect, among others. Quality and durability evaluations of road cooling coatings have seldom been studied. However, existing road cooling coatings all exhibit the obvious shortcoming of lacking durability in practical applications. In particular, the durability of a road cooling coating will decrease sharply after being polluted to varying degrees in a complex environment. Therefore, it is significant to study durability indexes and a comprehensive durability evaluation method for road cooling coating, based on composite operating conditions.

In this study, various new road cooling coatings are prepared based on a variety of selected raw materials, and the cooling effects of different coatings are determined by means of a field test. The complex coupling environment is simulated, and durability evaluation indexes of road cooling coating under different composite operating conditions are presented. The comprehensive durabilities of various road cooling coatings are evaluated using a multi-objective grey target decision-making method. The road cooling coating schemes with superior comprehensive durability are selected scientifically and reasonably. This lays a solid foundation for improving the quality and durability of road cooling coatings, in order to promote their extension and application in the highway transportation field in China.

2. Test materials and methods

2.1. Raw materials

Three micro-powders of pyrite, spiegeleisen, and titanium dioxide were selected as cooling functional materials, based on the principle of charge transfer and the characteristics of existing cooling materials. The specific technical indexes are displayed in Table 1. Epoxy and polyphthalamine resins were used as film forming materials for the coating. Ethanol, pottery clay, and ferric oxide were used as additive, pigment, and auxiliary cooling materials, respectively.

2.2. Preparation of road cooling coating

According to previous results from our research group [20], the optimal dosage of cooling function and auxiliary materials was determined by cooling efficiency and road performance tests. According to the *Corrosion Resistant Powder and Coating for Highway (JT/T 600.1-2004), China,* the formulations and test schemes of the selected cooling function materials were designed to improve the quality and durability of the road cooling coating. The test schemes are displayed in Table 2. Following this procedure, different road cooling coating types were prepared.

The main preparation steps for the road cooling coating are as follows.

a. The contents of the cooling function materials, auxiliary cooling materials, and pigments were determined, and these powdery materials were placed into the mixing machine and removed for later use after full mixing for 30 min.
b. The film forming materials and additives were mixed at high speed for 10 min. Next, the powdery materials were added into the film forming materials. These were mixed at high speed for 30 min to ensure the uniform distribution of cooling function and auxiliary cooling materials in the film forming materials.
c. The mixed slurry was poured into the sand mill for milling to below 270 μm. At the same time, an appropriate amount of additives was added into the mixed slurry for mixing, and the mixed slurry was thoroughly combined. Finally, it was filtered with a stainless steel screen and the road cooling coating material was obtained.

2.3. Cooling effect test method

According to *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011), China*, an asphalt slab specimens with a gradation of AC-13 were made with SBS modified asphalt and basalt aggregates. Temperature sensors were buried at the surface, middle, and bottom positions of the specimens during the preparation process. Then, the prepared cooling coating material was applied evenly on the surface of the asphalt slab specimen with an amount of 0.8 kg/m^2. The optimal apply amount of coating materials was determined through previous research results [20]. Thereafter, the specimen was placed in the ventilation area for 24 h to dry. The prepared road cooling coating specimens were placed in an outside environment with direct sunlight. The sides and bottom of the specimens were covered tightly with clay to prevent heat loss, in order to ensure accuracy of the cooling effect test results.

2.4. Durability test methods

2.4.1. Anti-compression test

Anti-compression performance was tested according to *Pavement Marking Paint (JT/T 280–2004), China*. Firstly, the coating material was poured into the specimen mold. The outburst part of the specimen surface was cut off with a heated scraper when it was completely cooled, and the surface was smoothed with sandpaper (#100). Thereafter, the initial specimen height was measured after 24 h at an ordinary temperature, and the accuracy was 0.1 mm. Next, a clump weight with a quality of 2 kg + 20 g was placed on the specimen. The final specimen height was measured following a certain time at a set temperature. Finally, the anti-compression coefficient was calculated, for which the formula is as follows.

$$B = \frac{H_2}{H_1} \times 100\%, \quad (1)$$

where B is the anti-compression coefficient, %; H_1 is the initial specimen height before the test, mm; and H_2 is the final specimen height after the test, mm.

2.4.2. Anti-rolling test

Anti-rolling performance was tested according to *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011), China*. Firstly, a cement (rigid) plate was used as the coating carrier, and its thickness was measured. The coating material was coated evenly on the cement plate surface, and it was placed in the ventilation area for 48 h to dry. Thereafter, the initial specimen thickness was measured following a certain time at a set temperature. Next, the specimen was placed in the rutting instrument at an ordinary temperature. Two parallel positions of the specimen were rolled 1 h under the standard axle load, respectively. Finally, the coating surface appearance was observed and the final specimen thickness was measured. The anti-rolling coefficient was calculated, for which the formula is as follows.

$$WI = \frac{H_2 - H_0}{H_1 - H_0} \times 100\%, \quad (2)$$

where WI is the anti-rolling coefficient, %; H_0 is the cement plate thickness without coating materials, mm; H_1 is the initial specimen thickness before the test, mm; and H_2 is the final specimen thickness after the test, mm.

2.4.3. Anti-abrasion test

Anti-abrasion performance was tested according to *Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering (JTG E20-2011), China*. Firstly, the specimen was constructed using the specimen mold of the wet track

Table 1
Physical and chemical performance indexes of cooling functional materials.

Material	Color	Specification	Density/(g/cm^3)	Mohs hardness	Thermoelectric coefficient/(μV/°C)	Acid alkali resistance
Pyrite	Brown	Powder, aggregate	4.92	6.0–6.5	496–530	Stable at any concentration of acid, alkali substance
Spiegeleisen	Reddish brown	Powder, aggregate	5.06	5.5–6.0	602–681	Stable at any concentration of acid, alkali substance
Titanium dioxide	White	Powder	3.06	5.0–6.0	–	Stable at any concentration of acid, alkali substance
Ferric oxide	Reddish brown	Powder	5.24	5.5–6.5	–	Stable, dissolving in hydrochloric acid and dilute sulfuric acid to produce iron salts