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Full Length Article

Physical, rheological and chemical characterization of aging behaviors of thermochromic asphalt binder

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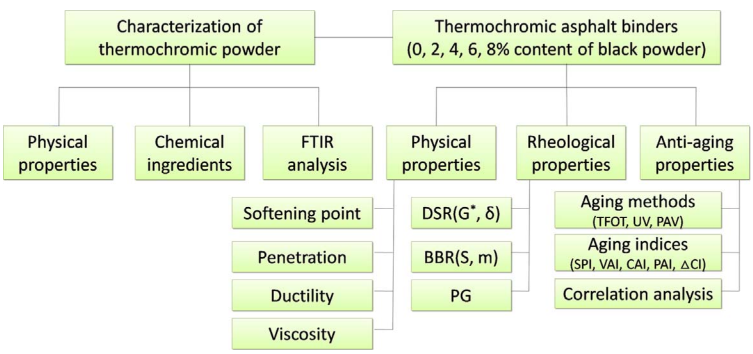
GRAPHICAL ABSTRACT



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ABSTRACT

As an innovative road material, thermochromic asphalt binder has great effect on keeping the surface temperature of pavement within relatively reasonable range. The objective of this paper was to investigate the anti-aging properties of asphalts containing 0, 2, 4, 6, 8% content of black thermochromic powders (named as blank sample, 2, 4, 6, 8% BTP binder for convenience). Three aging methods, including thin film oven test, pressure aging vessel test and ultraviolet radiation, were applied to simulate thermal and photo oxidation aging of asphalt, respectively. Physical and rheological properties of binders with and without thermochromic powders were measured before and after three aging methods. The results show that the introduction of black thermochromic powders could improve thermal stability and low-temperature cracking performance of asphalt binder. After three aging methods, all of thermochromic asphalt binders exhibit better aging resistance than blank sample by physical, rheological aging indices, and 4% is the optimal content in which thermochromic asphalt binder synthetically exhibits the best aging resistance. In addition, based on grey relational analysis (GRA), the aging indices of complex modulus aging index (CAI) and viscosity aging index (VAI) are more reliable in aging evaluation.

1. Introduction

Asphalt, a viscoelastic material with mechanical and rheological properties appropriate for its performance as road paving binder, is broadly applied in pavement construction [1]. However, the black appearance of asphalt binder brings about substantial solar absorption, which leads to high surface temperature of asphalt pavement, and hence results in acceleration of various high-temperature pavement

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Fig. 1. Color of thermochromic powder below and above transition temperature: left is below 31 °C, right is above 31 °C.

diseases (i.e., rutting, shoving, aging, fatigue damage) and environment-unfriendly issues (i.e., heat island effects, volatile gas emission) [2,3].

Developed by using materials with fixed high reflectivity and emissivity to solar radiation, cool pavements can indeed reduce surface temperature of asphalt pavement in summer, while the cooling effect on pavement also aggravates the distress of low-temperature cracking during the cold weather, which compromises the service life of such pavement in general [2,4–8]. To compensate for the weakness of cool pavement, an innovative thermochromic asphalt binder, which implies adding thermochromic materials into conventional asphalt binder, has been gradually investigated in recent years. Thermochromic materials are substances that can reversibly change their colors in accordance with temperature. Above certain temperature, they predominantly reflect solar energy (mainly infrared radiation); conversely, under that temperature, they mainly absorb solar energy by lowering reflectivity [9]. Thermochromic materials have been widely used in building materials due to its change of optical and thermal properties in such a dynamic way [10–13]. Hu et al. made pioneering researches on thermochromic asphalt binder as a road material. They discovered that in comparison with conventional asphalt binder, the surface temperature of asphalt concretes containing thermochromic asphalt binder are much lower during a typical summer and higher under cold weather conditions [14]. Besides, they analyzed the mechanisms by optical and thermal properties, the results showed that compared with conventional asphalt binder, thermochromic asphalt binder possessed higher reflectance in the near-infrared range and heat capacity and lower thermal conductivity [15,16]. Although thermochromic asphalt binder has great effect on keeping the surface temperature of pavement within relatively reasonable range that could mitigate the high- and low-temperature distresses of pavement, aging of asphalt is one of the key factors causing the deterioration of pavements [17], so it's necessary to further investigate the anti-aging behaviors of thermochromic asphalt binder for its comprehensive application.

The aging of asphalt can be categorized into two types: thermal oxidation and photo oxidation aging (the latter mainly refers to ultraviolet irradiation) [18,19]. Short-term thermal oxidation aging occurs when asphalt is exposed to heat and air in the process of asphalt mixture production and paving, which is primarily due to the oxidation and loss of volatile components at high temperatures. Long-term thermal oxidation aging proceeds in the time of service life of pavement as a result of continuous oxidation [20]. In terms of ultraviolet irradiation aging, the structure of asphalt molecule changes with the absorption of ultraviolet energy that induces the cleavage of chemical bond and produces the oxidation components, and finally causes the increment of stiffness and brittlement of asphalt binder [21]. Generally, thin film oven test (TFOT), pressure aging vessel (PAV) test and ultraviolet (UV) radiation are adopted to simulate short-term, long-term thermal oxidation and photo oxidation aging of asphalt, respectively.

In present paper, physical and rheological properties of asphalts containing different contents (0, 2, 4, 6, 8%) of black thermochromic powders were analyzed. Anti-aging properties of thermochromic asphalt binders were evaluated by variation amplitude of physical, rheological properties and carbonyl index before and after three aging methods. Additionally, correlations between chemical aging index and various physical and rheological aging indices were also discussed.

2. Materials and methods

2.1. Materials

The 60/80 pen grade asphalt was used as base asphalt. And its measured physical properties are shown as follows: penetration, 64.2 dmm at 25 °C; softening point, 45.5 °C; ductility, 56.8 cm at 10 °C; viscosity, 436 mPa·s at 135 °C. Black thermochromic powder with transition temperature around 31 °C was chosen for this research. The specific gravity and average particle size of powder are 0.25 (water = 1) and 3-10um, respectively. Below the transition temperature, powder exhibits black color, while powder becomes colorless above the transition temperature, which can be seen in Fig. 1. Its chemical ingredients and Fourier transform infrared (FTIR) spectrum are presented in Table 1 and Fig. 2, respectively. As shown in Table 1, black thermochromic powder contains ingredients of melamine-formaldehyde resin, bisphenol a, methyl stearate and 3-diethylamino-6-methyl-7-2,4-xylidinofluoran which can be demonstrated by FTIR spectrum. The appearance of absorption bands centered around 3355 cm^{-1} and 1509 cm^{-1} corresponds respectively to hydroxyl (−OH) and benzene skeleton vibration derived from bisphenol a. The characteristic peaks of methyl stearate lie in 2925 cm^{-1}, 2850 cm^{-1} and 1740 cm^{-1} indicating methyl ($-CH_3$), methylene ($-CH_2$) and

Table 1
Chemical ingredients of black thermochromic powder.

Ingredient	Melamine-formaldehyde resin	3-Diethylamino-6-methyl-7-2,4-xylidinofluoran	Bisphenol A	Methyl stearate
Content (%)	1–5	2–10	5–15	50–80