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Effect of LDHs on the aging resistance of crumb rubber modified asphalt

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HIGHLIGHTS

- LDHs improved the ageing resistance of crumb rubber modified asphalt (CRMA).
- LDHs present significant influences on properties of CRMA after UV aging.
- Less carbonyl groups appeared in the aged LDHs/CRMA than in the aged CRMA.
- LDHs modified CRMA has a better performance at both low and high temperatures.

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ABSTRACT

Layer double hydroxides (LDHs), a kind of ultraviolet light resistant material, was added into the Crumb Rubber Modified Asphalt (CRMA) and its effects on the aging resistance of the CRMA were investigated in this paper. The short-term and long-term aging processes of asphalt were simulated by Thin Film Oven Test (TFOT) and ultraviolet (UV) radiation test, respectively. With Fourier Transform Infrared Spectroscopy (FTIR) measurements, it was found that LDHs can slow down the formation of carbonyl groups during the aging process. The conventional physical properties test and Dynamic Shear Rheometer (DSR) test were used to evaluate the properties of the asphalt. The results showed that the softening point increases and G^* ratios of CRMA decreases significantly, the ductility and the penetration retention rate increase after ultraviolet aging due to the introduction of LDHs. Besides, the results of both creep and relaxation test implied that the LDHs modified CRMA binder has a better UV aging resistance.

1. Introduction

With the development of motor transportation industry, the amount of discarded tires nearly reaches 10 million every year in the world [1]. A great number of waste rubber tires have caused serious environmental problems. Therefore, the utilization of waste rubber tires has attracted great interests of researchers in recent decades [2–4]. A lot of researches show that crumb rubber, made from waste rubber tires, can improve the temperature sensitivity, deformation resistance at high temperatures, crack resistance at low temperatures and fatigue resistance of asphalt as asphalt modifier. Therefore, the service life of crumb rubber modified asphalt (CRMA) pavement will be longer than unmodified ones [5–7]. In addition, CRMA can also reduce the traffic noise and improve the driving comfort [8]. So the utilization of waste crumb rubber as asphalt modifier is one of the most promising ways to solve the problems caused by waste rubber tires considering the benefits of economy and environment [9].

Some researches on interaction mechanism of crumb rubber and base asphalt indicated that crumb rubber swells in asphalt by adsorbing the light components of asphalt [10–12]. However, just like other asphalt materials, the aging of CRMA during active time can induce the change of proportion of the components in the asphalt, the light components of asphalt volatilize, and micromolecules convert into large molecular size fractions by oxidation and polymerization [13–15]. The components of asphalt determine its properties, and the properties of CRMA binder are degraded with the decrease of light components and the structure destruction of asphalt [16], as a result, the CRMA pavement diseases take place. Therefore, it is important to improve the aging resistance of CRMA binder.

LDHs have attracted a considerable attention as the UV light resistant materials to improve the properties of rubber, plastics, coating material in recent years. These layered materials are multi nestification layered structure. The inorganic layer sheets have the physical shield effect against UV light, and some metal elements of

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layer sheets and negative ions between layer sheets will chemically absorb UV light. This kind of multi chemical absorbability and physical shield effect of LDHs result in excellent UV aging resistance in the organic material [17–19]. Wu et al. studied the effect of LDHs on the aging property of the asphalt and found that the LDHs can enhance the aging resistance of asphalt [20]. So, LDHs, as a kind of UV aging resistant materials, has the potential to improve the aging resistance of CRMA. In this paper, LDHs, were added into the CRMA at 0, 3, 5 wt% mass ratio, and the impact of the LDHs on the aging resistance of CRMA was investigated. Thin film oven (TFOT) test and UV light accelerated aging process were used to simulate the short-term aging and long-term field aging of asphalt, respectively. The rheological properties of asphalt before and after artificial UV aging were investigated by using Dynamic Shear Rheometer (DSR) through temperature sweep, creep tests and relaxation test. FTIR test result, conventional physical properties, complex modulus ratio, creep and relaxation curve of asphalt were used to evaluate the chemical and physical characteristics of asphalt before and after artificial UV aging.

2. Materials and experimental

2.1. Materials

The CRMA used in this paper was provided by Hubei Guochuang Hi-tech Material Co., Ltd. The diameter of crumb rubber power modifier was smaller than 0.3 mm and the content was 15% by weight. The basic properties of CRMA are exhibited in Table 1.

Mg–Al layered double hydroxides complex metallic material was used to modify the CRMA. The LDHs was produced by Rui Fa Chemical Company Limited, Jiang Su, China. The density of the LDHs was 1.7 g/cm^3 and the moisture content was less than 0.3%.

2.2. Preparation of LDHs modified asphalt

Many researchers suggested the blending temperature of crumb rubber and base asphalt should be more than 160 °C and less than 200 °C [21]. In China, the most commonly used blending temperature for CRMA is 175–185 °C. Although this temperature range may lead to the degradation of base asphalt, it is good for the swelling process of crumb rubber. Therefore, LDHs was blended into CRMA binder using a shear blender at 180 °C in this research. The rotation speed of the blender was 5000 r/min and 60 min of blending was used to ensure a good distribution of LDHs. The CRMA without LDHs was also processed under the same conditions as the reference group.

2.3. Aging procedures

TFOT was employed to simulate the short-term oxidation that occurs during the hot-mix process according to Chinese standard test methods of bitumen and bituminous mixtures for highway engineering JTG E20-2011(T0609-2011) [22]. After TFOT aging, the asphalt samples with film thickness of 1 mm were prepared for further UV aging to simulate the photodegradation that occurs during the service life. The UV aging performed on the asphalt samples lasted for 10 days in a UV light accelerated aging oven, the radiation strength of the UV light was set at 26.5 W/m^2 with the wavelength of 360 nm, and the test temperature was controlled at 60 °C.

Table 1
Properties of base asphalt and CRMA.

Index		Base asphalt	CRMA	Specification
Penetration at 25 °C (0.1 mm)		72	51	T0604-2011
Ductility of base asphalt at 15 °C, CRMA at 5 °C (cm)	before TFOT	65	12	T0605-2011
	after TFOT	19	8.5	T0605-2011
Softening point (°C)		44.5	68	T0606-2011
Education, softening point difference (°C)		–	2	T0661-2011
Elasticity resume at 25 °C (%)		–	79	T0662-2000

2.4. Characterization methods

2.4.1. FTIR

A Thermo Nicolet Model Nexus FTIR–Raman spectrophotometer was used to record FTIR spectra of rubber asphalt. A sample was prepared by casting an asphalt film onto a KBr thin plate from 5 wt% solution in carbon disulfide, then the solvent was dried for the FTIR analysis.

2.4.2. Conventional physical properties test

The conventional physical properties tests including penetration, ductility, softening points and some other property indexes. They were conducted according to Chinese standard test methods of bitumen and bituminous mixtures for highway engineering JTG E20-2011.

2.4.3. DSR

A MCR101 Dynamic Shear Rheometer (DSR) produced by Anton Paar Company was adopted to measure the rheological property of CRMA and LDHs/CRMA. DSR temperature sweep test was performed under the strain-controlled mode at a constant frequency of 10 rad/s. The tests were performed within the linear viscoelastic range of the tested asphalts. When the test temperature is higher than 30 °C, 25 mm diameter plates with 1 mm gap were used. When the test temperature is lower than 30 °C, 8 mm diameter plates with 2 mm gap were used. Furthermore, creep testing and relaxation testing were also used to evaluate the aging resistance of CRMA and LDHs/CRMA.

3. Results and discussion

3.1. FTIR characterization analysis

FTIR was applied to study the effect of LDHs on the aging resistance of the CRMA. The aging of asphalt includes thermal oxygen and light oxygen aging. The occurrence of carbonyl groups is the result of the oxidation aging of base asphalt. According to the precious research, the carbonyl (C=O) index can be used as an indicator to evaluate the aging extent of asphalt [23,24]. It was computed as the following formula [25]:

$$I_{\mathrm{C=O}} = \frac{\text{Area of the carbonyle band centered around 1700 cm}^{-1}}{\sum \text{Area of the spectral bands between 2000 and 600 cm}^{-1}}$$

The FTIR spectrums of asphalts without aging and asphalts with UV aging were shown in Fig. 1. As an indicator of the aging extent, the corresponding functional groups indices were listed in Table 2. Fig. 1 shows no obvious absorbance peak can be observed for asphalts without aging, while carbonyl clearly appeared after UV aging for 10 days. The intensity of carbonyl absorption peaks of LDHs/CRMA were lesser than that of CRMA. Table 2 shows more details about these changes discussed above. The carbonyl index of CRMA is 0.013, larger than that of LDHs/CRMA after UV aging for 10 days, which means less carbonyl groups formation after the introduction of LDHs, indicating that LDHs modified asphalts had better resistant to the formation of carbonyl and hence might getting more stable. Therefore, the LDHs can improve the aging resistance of CRMA binder.

3.2. Conventional physical properties

Figs. 2–4 showed the conventional properties test results of CRMA and LDHs/CRMA before and after aging. It is obvious that LDHs provide increased soft points and decreased penetration of CRMA before UV aging, therefore LDHs is good for deformation resistance of asphalt at high temperatures although it degrades the ductility of CRMA slightly. After subjected to UV aging, there would be a great difference in conventional properties, the softening points decreased, the penetration and ductility increased with the addition of LDHs, especially when 5 wt% of LDHs was added.

Table 3 lists the softening point increment, ductility retention rate and penetration retention rate after UV aging using original values as references. The softening point increment, ductility retention rate and penetration retention rate can be used to evalu-

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