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Effect of layered double hydroxides on ultraviolet aging properties of different bitumens

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HIGHLIGHTS

- Layered double hydroxides (LDHs) were used to modify different bitumens.
- The properties of LDHs modified bitumen are closely related to the binders' nature.
- LDHs better improve the anti-aging properties of bitumen which is more sensitive to UV aging.

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ABSTRACT

The objective of this paper was to investigate the effect of layered double hydroxides (LDHs) on physical and rheological properties of different bitumens (SK-90, TY-90 and GF-70) before and after ultraviolet (UV) aging. The results show that the physical properties of different bitumens are slightly influenced by LDHs. And the effect of LDHs on rheological properties of investigated bitumens largely depend on the bitumen nature, and LDHs show the least influence on rheological properties of SK-90 with highest phase angle and lowest complex modulus among the three bitumens. Due to the UV aging, LDHs modified bitumen shows the lower softening point increment, viscosity aging index and complex modulus aging index in comparison with the unmodified bitumens, indicating their good UV aging resistance. Compared with SK-90 and GF-70, LDHs show a better improvement in UV aging resistance of TY-90 which is more sensitive to UV aging.

1. Introduction

Bitumen is one of the most important binders in the field of pavement construction [1,2]. However, as all organic substances, aging has greatly limited the application of bitumen. Bitumen aging, caused by the ultraviolet (UV) radiation, heat and oxygen during the service life of the pavements gives rise to the hardening of bitumen, as a consequence, leading to great damage to its road performance [1,3]. In the areas of strong UV radiation, the problem is more serious [4–6]. In order to improve the aging resistance of bitumen, many researches have been carried out. Adding modifiers such as montmorillonite [7,8], UV absorbers [9], antioxidants [10,11] and carbon black [12] is one of the most effective ways to improve aging resistance properties of bitumen.

In recent years, layered double hydroxides (LDHs) have drawn widespread attention due to their various applications as adsorbents, catalyst supports and anti-aging additives, etc [13–16]. LDHs are a kind of cationic and anionic layered materials formed by interlayer anions and laminates with a positive charge [13,17]. Their inorganic layers can physically shield UV rays and metal cation in the layer and interlayer anion can chemically absorb UV rays [14,19], therefore the aging of materials caused by UV radiation can be reduced by adding LDHs [18–21]. Cho et al. [21] found that nanoscale NiAl-NO_3-LDHs improved the mechanical properties of LDPE to some extent. Also with regard to the studies on bitumen modification, researches [18–20] showed that LDHs made contribution to enhance the UV aging resistance of bitumen.

However, bitumen is generally extracted from crude oil with various constitutions and complex structures, and the properties of the bitumen depend on the crude oil source and the actual operating procedure [22–24]. Xiao et al. [25] found that the bitumen source rather than carbon nanoparticles played a key role in determining the rheological properties of bitumen. Therefore, the effect of one certain modifier on properties of different bitumens is very complex. Furthermore, most published studies that reported on

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LDHs modified bitumen were limited to one certain bitumen, few researchers paid attention to the effect of LDHs on properties of different bitumens.

In this paper, LDHs were added into three different bitumens and the effect of LDHs on physical and rheological properties of different bitumens was investigated by conventional physical properties test and dynamic shear rheometer test before and after UV aging.

2. Experimental

2.1. Materials

Three base bitumens (SK-90, TY-90 and GF-70) produced from three different manufactures were used in this study. TY-90 and GF-70 were obtained from Tianyuan Petrochemcal Co., Ltd., Xinjiang, northwest of China and Gaofu Petroleum Co., Ltd., Foshan, southern China, respectively. SK-90 was manufactured by SK Crop., Korea. The physical properties of three bitumens are given in Table 1. LDHs (MgAl-CO_3^{2-}-LDHs) were provided by Ruifa Chemical Co., Ltd., Jiangyin, China.

2.2. Preparation of LDHs modified bitumen

The LDHs modified bitumen was prepared in the laboratory using a high shear mixer at about 150 °C. When the bitumen became a fluid, LDHs was added into the bitumen with a shearing speed of 4000 rpm for 60 min. The same process was also applied to base bitumen for using as the control specimen.

2.3. Aging procedures

The thin-film oven test (TFOT) was performed before UV aging to simulate the thermal-oxidative aging of bitumen during mixing and laydown process. TFOT was executed in accordance with ASTM D1754. After TFOT, bitumen was placed in a UV radiation oven for 3, 6, and 9 days. The aging temperature was 60 °C, and the UV lamp was 500 W with a main wavelength of 365 nm, and the average intensity irradiation on the bitumen surface was about 1200 μW/cm^2. The thickness of bitumen film was about 3 mm.

2.4. Physical properties tests

The physical properties of base and LDHs (1 wt%, 3 wt%, 5 wt%, 7 wt%) modified bitumens were tested before and after UV aging. The penetration (25 °C), softening point, ductility (10 °C) and viscosity (135 °C) were measured according to the standard ASTM D5, ASTM D36, ASTM D113 and ASTM D4402, respectively.

2.5. Dynamic shear rheometer test

The dynamic rheological properties of the base and 5 wt% LDHs modified bitumens were measured by a dynamic shear rheometer (DSR, MCR101, Anton Paar Company, Austria). In this paper, DSR tests were performed under strain-controlled mode at a frequency of 10 rad/s. And the temperature range from 30 °C to 80 °C with increment rate of 2 °C/min. The parallel plate diameter and gap of each sample was 25 mm and 1 mm, respectively.

3. Results and discussion

3.1. Physical properties

Physical properties of base and LDHs modified bitumens are shown in Fig. 1. As can be seen, the penetration (Fig. 1a) and ductility(Fig. 1c) of three bitumens are decreased gradually with increasing LDHs content, while softening point (Fig. 1b) and viscosity (Fig. 1d) of investigated bitumens are increased. However, in terms of the influence degree of LDHs, the effects of LDHs on physical properties of different bitumens are quite similar. For example, the increase in softening point and viscosity of three bitumens is relatively consist with increasing LDHs content, and the increment in softening point and viscosity of investigated bitumens is almost the same. With regard to penetration and ductility, differences in the decrement of penetration and ductility of three binders are not significant, except a smaller decrease in penetration of bitumen GF-70 and a minor reduction in ductility of TY-90.

3.2. Dynamic rheological properties

Effect of LDHs on complex modulus for different bitumens before aging is displayed in Fig. 2. As depicted in Fig. 2, the G^* values of all investigated bitumens are increased by the introduction of LDHs especially at the temperature domain of 30–60 °C, which suggests that LDHs can improve the deformation resistance of bitumens. However, unlike the physical properties, the influence of LDHs on rheological properties of three bitumens is different. With the introduction of LDHs, the increment in G^* values of investigated bitumens is TY-90 > GF-70 > SK-90, though the G^* values increment of SK-90 is a little higher in the temperature range from 30 °C to 35 °C. The results indicate that the influence degree of LDHs on G^* values of different bitumens is related to their sources. In addition, comparing the G^* values of base bitumens, the influence degree of LDHs on G^* values of bitumens is correlated to their own rheological properties. Seen from Fig. 2, SK-90 shows the lowest G^* values. And as discussed above, the influence degree of LDHs on G^* values of SK-90 is also the lowest. Therefore, a conclusion can be obtained that the effects of LDHs on rheological properties of SK-90 with lower G^* values are less significant.

Fig. 3 showed the effect of LDHs on phase angle of different bitumens before aging. As can be seen, the addition of LDHs decreases the δ values to different extents for three binders. For example, with the addition of LDHs, there is only minor decrease in δ values of SK-90, but significantly decrease for TY-90 and GF-70, which manifests that the effect of LDHs on δ values of different bitumens is also related to the binders sources. Furthermore, comparing the δ values of different bitumens, it should be noted that the influence degree of LDHs on rheological properties of bitumen with higher δ values is less significant. As depicted in Fig. 3, though TY-90 shows the lowest δ values and SK-90 shows the highest, the influence degree of LDHs on δ values of TY-90 is higher than that of SK-90. And comparing the δ values of bitumen at different temperature, it also indicates that the greater the δ values of bitumen, the smaller differences in δ values between base and modified bitumens. Therefore, the effect of LDHs on rheological properties of SK-90 with higher δ values is slighter.

3.3. Aging properties

3.3.1. Softening point increment

Softening point increment (SPI), calculated from formula (1), is an important aging index to evaluate the aging properties of bitumens. And the differences in SPI between base and modified bitumens (ΔSPI) can be calculated by formula (2).

$$SPI = S_{aged} - S_{unaged} \tag{1}$$

$$\Delta SPI = SPI_{base} - SPI_{LDHs} \tag{2}$$

Table 1
Physical properties of the base bitumens.

	Penetration, 25 °C, 0.1 mm	Softening point, °C	Ductility, 10 °C, cm	Viscosity, 135 °C, Pa·s
TY-90	93	53.6	15.6	0.57
SK-90	89	45.2	20.3	0.43
GF-70	73	47.2	17.8	0.54