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Improving the short-term aging resistance of asphalt by addition of crumb rubber radiated by microwave and impregnated in epoxidized soybean oil

JiMing Yin [a,b,*], ShengYue Wang [a,*], FanRen Lv [b]

[a] School of Transportation, Southeast University, Nanjing 210096, China
[b] Department of Civil Engineering, Yangzhou Polytechnic College, Yangzhou 225009, China

HIGHLIGHTS

- ESO was used to improve the short-term aging resistance of crumb rubber asphalt.
- The performance of CRIMIESO modified asphalt was investigated.
- Mechanism of aging resistance of CRIMIESO modified asphalt was discussed.

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ABSTRACT

The study was initiated to investigate the anti-aging performance of asphalt modified by crumb rubber impregnated in epoxidized soybean oil (ESO). For this laboratory study, the crumb rubber was radiated by microwave and then impregnated in ESO. The asphalt modified by crumb rubber impregnated in ESO was aged using a rolling thin film oven method (RTFO). The properties of this asphalt were evaluated from the perspective of penetration, softening point, ductility, mass loss and viscosity test. Also, the anti-aging mechanism of asphalt modified by crumb rubber impregnated in ESO was discussed. The results showed that the asphalt modified by crumb rubber impregnated in ESO had an edge over the microwave radiated crumb rubber modified asphalt in terms of high temperature stability, low temperature ductility and anti-aging performance. The reasons are: (1) the polarity oil contained in the ESO can infiltrate into the asphalt and supply oil to the aging asphalt due to oxidation; (2) the compound, which had three-dimensional network structure, was generated when the opening-ring reaction between epoxy bond in ESO and unsaturated bond in asphalt took place. As a result, the compatibility of crumb rubber and asphalt was improved; the structure of cumber rubber modified asphalt was stabilized.

1. Introduction

The addition of crumb rubber modifier (CRM) to asphalt/bitumen has been shown and proven by many research projects and field applications to be an effective method of increasing the performance grade (PG) of the asphalt, improving the high temperature properties, decreasing susceptibility to permanent deformation as well as providing resistance against reflective cracking [1–5]. It also provides an environmental option for the disposal of the scrap tires [6]. In addition, using crumb rubber as modifier instead of expensive polymer modifier (SBS, SBR, etc.) can also reduce the cost of road asphalt. Recently, CRM used in asphalt has attracted a close attention of many countries [7].

However, like other modified asphalts, the aging of crumb rubber modified asphalt (CRMA) is thought to be a potential factor responsible for asphalt pavement thermal and fatigue cracking failures. This is due to volatilization and oxidation in short and long-term performance of mixtures [8,9]. It is agreed that two types of aging takes place during asphalt life: (1) the short-term aging during the construction phase of asphalt concrete and (2) the long-term aging induced by the environmental factors and traffic loads in the field [10].

In an effort to resolve this problem, researchers have been working on searching for the anti-aging or modifying agents to modify asphalt or crumb rubber. The use of furfural (C5H4O2) as an activation agent has been suggested as a method to improve the rheological properties of asphalt binders due to its compatibility with crumb rubber [11]. The effect of three warm mixture asphalt (WMA) additives on the high temperature rheological properties of both unaged and rolling thin film oven (RTFO) aged crumb rubber modified (CRM) binders was investigated [12]. The antioxidant potential of grape pomace from Cabernet Sauvignon was used to control the asphalt age hardening. To evaluate the

* Corresponding author. Tel.: +86 13813148702.
E-mail address: yinjiming1124@163.com (J. Yin).

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performance of the antioxidant, samples were aged according to SUPERPAVE standards (RTFOT and PAV) and physical, chemical, and rheological properties were analyzed. The results strongly suggest that grape pomace is a suitable alternative as antioxidant for asphalt binder to reduce age hardening [13]. Effects of organo-montmorillonite (OMMT) on thermo-oxidative and ultraviolet (UV) aging properties of asphalt were investigated, and the results suggested that the effect of thermo-oxidative aging on dynamic rheological behaviors of the modified asphalt is restrained due to introduction of OMMT [14]. Warm mix additives, asphaltene dispersants, and other chemical modifiers were regularly added to asphalt to improve workability during construction, to increase the useful temperature interval in service, or to impart other benefits such as enhanced resistance to chemical aging or moisture damage [15]. Zinc dialkyl dithio phosphate (ZDDP), carbon black, octabenzone (UV531) and bumetrizole (UV326) were used to improve the aging resistance of asphalt [16,17]. The possibility of using waste cooking oil (WCO) to rejuvenate the bituminous binder was investigated, and the statistical analyses confirm that there was no significant difference between the original bitumen and rejuvenated bitumen [18,19].

Asphalt acted as cementitious material must satisfy some conditions such as high initial viscosity, easily controlled gelation times, small curing shrinkages, and good adhesion and permeabilities to the powder particle. Epoxy systems can satisfy these requirements [20–24]. In this sense, functionalized vegetable oils (FVO) such as epoxidized soybean oil (ESO) are considered to be attractive additives to improve the anti-aging performance of CRMA.

The objective of this research was to improve the anti-aging performance of CRMA by the following two methods: (1) crumb rubber irradiated by microwave and (2) then impregnated with ESO. Based on this, the anti-aging mechanisms were discussed then.

2. Material and experimental scheme

2.1. Material

2.1.1. Asphalt and crumb rubber

80-mesh fine tread crumb rubber was used to modify 70/100 penetration grade asphalt obtained from ZhongHai refinery. The crumb rubber was generated by scraping old tires of trucks and buses. The properties of ZhongHai asphalt are given in Table 1.

2.1.2. ESO

The chemical pure grade ESO was purchased from HongWei additives company (ShanDong, China) and used directly without further purification. The properties of ESO are listed in Table 2. From Table 2, we can see that ESO is a non-toxic, light yellow viscous oily liquid. ESO is not soluble in water but soluble in hydrocarbon, ketone, esters, higher alcohols. ESO has low volatility. There are a lot of epoxide groups in ESO. These epoxide groups are more reactive than double bond, thus providing a more energetically favorable site for reaction and making the oil a good hydrochloric acid scavenger and plasticizer.

Table 1
The properties of ZhongHai asphalt.

Parameter measured		Value
Penetration (25 °C, 5 s, 100 g)/0.1 mm		67
Softening point (ring and ball)/°C		48.0
Ductility (15 °C, 50 mm/min)/mm		>1000
Flash point (Cleveland open cup)/°C		⩾230
Wax content (distillation)/%		⩽3
Solubility (solvent:trichloroethylene)/%		⩾99
RTFOT (163 °C, 5 h)	Mass loss/%	0.06
	Penetration ratio/%	66%
	Ductility (25 °C, 50 mm/min)/mm	⩾500

Table 2
The properties of ESO.

Index	Value
Appearance	Light yellow oily liquid
Density	0.994 g/cm^3
Molecular weight	1000
Melting point	0 °C, 273 K, 32 °F
Oxirane oxygen	>6.6%
Flash point	227 °C (441 °F)
Weight loss after heating	⩽0.2%
Solubility in water	Insoluble

2.2. Experimental scheme

2.2.1. Crumb rubber irradiated by microwave and impregnated with ESO

The specific surface area of the CRM particles plays an important role in the CRM binder behavior [25,26]. Therefore, any modification to the surface area properties could have an effect on the rheological properties of the CRM binder. The purpose of this modification is to generate a more reactive rubber surface [11].

In this study, the CRM particles were irradiated in the ultrasound microwave oven under the power of 600 W for 2.5 min [27], after being dried and dehydrated in the thermostatic oven at 60 °C. The weight of CRM particles were controlled at 60 g each time in order to ensure the CRM particles to be radiated fully and uniformly. Crumb rubber, irradiated by microwave, was designated as CRIM.

After irradiation, the CRM particles were impregnated with ESO for 24 h in the glassware (Fig. 1), and then placed in the filter screen to drain off the redundant ESO. Crumb rubber, irradiated by microwave and then impregnated with ESO, was designated as CRIMIESO.

2.2.2. Modified asphalt preparation

The wet dress process was used to produce crumb rubber modified asphalt. The 60 g of crumb rubber prepared previously represents 15% of the weight of asphalt. The CRM was gradually added to the 175 °C preheated asphalt and a mechanical and thermal energy was applied through a high-speed shearing and dispersing emulsifying machine at 7000 rpm and a heated plated controlling the asphalt binder mix temperature. This setup was continued for 60 min, were after it the asphalt rubber mix was removed from the plate and allowed to cool for further testing. The preparation processes of the three crumb rubber modified asphalt were presented in the Fig. 2.

2.2.3. Experimental scheme

The RTFOT for the three modified asphalt binders was conducted at 163 °C for 85 min to simulate the short-term aging of an asphalt binder (JTJ 052-2000) [28]. The process is presented as follows: the bottle filled with sample is laid inside the bottle fixture. Then the rotating switch is started to move the anular frame in speed of 15 r/min after the oven gate turned off. At the same time hot air flow is jetted into the sample bottle with velocity of 4000 ml/min lasting for 85 min. Attention should be paid that the oven temperature is designed to rise to 163 °C in 10 min, ensuring the heating time over 75 min.

The penetration, softening point, 5 °C ductility, mass loss and viscosity were used to evaluate the anti-aging performance of the three modified asphalt. The experimental scheme was illustrated in the Fig. 3.

2.3. Evaluation method of anti-aging performance

The ratio or difference value of a certain index between original asphalt and its residual having experienced RTFOT is recommended to evaluate asphalt potential of aging resistance [6]. The corresponding expression is

$$K = \frac{X_2}{X_1} \text{ or } K = X_2 - X_1 \tag{1.1}$$

where X_1 and X_2 are index values of original asphalt and its residual, respectively.

The mass loss after RTFOT can be expressed as

$$L_T = \frac{m_2 - m_1}{m_1 - m_0} \times 100 \tag{1.2}$$

where L_T is the percent mass loss; m_0 is the mass of sample dish; m_1 is the total mass of dish and sample before RTFOT; m_1 is the total mass of dish and sample after RTFOT, with unit of gram for the last three indexes.