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High temperature properties of rejuvenating recovered binder with rejuvenator, waste cooking and cotton seed oils

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HIGHLIGHTS

- Rejuvenator, waste cooking and cotton seed oils were employed for rejuvenation of RAP.
- High temperature characteristics of rejuvenated asphalt binder were tested.
- The used rejuvenated additives can reduce the viscosity value and fail temperature.
- Rejuvenator, cotton seed oil or waste cooking oil result in an increase of phase angle.

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ABSTRACT

Rejuvenator, waste cooking and cotton seed oils contain a great amount of unsaturated fatty acids, similar to the light oil component of asphalt binder which usually decreased due to a long term aging procedure. Based on the rejuvenation theory and some related studies, rejuvenator, waste cooking and cotton seed oils can be used for asphalt regeneration. The objective of this study was to investigate the high temperature rheological properties of rejuvenating aged asphalt binder with rejuvenator, waste cooking and cotton seed oils. The materials used for this study included three sources of aged asphalt (recovered from reclaimed asphalt pavement), one virgin asphalt (PG 64-22), and three rejuvenating materials: rejuvenator, waste cooking and cotton seed oils with three percentages (0%, 5%, and 10% of rejuvenating asphalt). The used mass ratio of aged to virgin asphalt is 1:3 (i.e. 25% aged binder) in this study. The high temperature characteristics of these rejuvenated asphalts were tested including rutting resistance factor (phase angle and complex modulus), failure temperature and rotational viscosity. The results indicated that the rutting resistance factor and the complex modulus of rejuvenated binders decreased due to the addition of rejuvenator, cotton seed oil or waste cooking oil while their phase angles increased. In addition, the aged asphalt used a small amount of waste cooking oil or cotton seed oil can more easily achieve the demand of PG 64 binder in rutting resistance factor, phase angle, complex modulus and failure temperature of aged asphalt compared with rejuvenator. Finally, waste cooking oil or cotton seed oil can slightly reduce the viscosity value of the aged asphalt and thus decrease the mixing and compaction temperatures of the mixture.

1. Introduction

Waste cooking oil, a type of the waste greases produced during the cooking and food processing, contains large amounts of toxic substances such as alfatoxin but also is a kind of available resource for further recycling. Management of such oils and fats poses a significant challenge because of their disposal problems and possible contamination of the water and land resources. In general, the amount of the reused waste cooking oil accounts for 20–30% of the total consumption of the cooking oil [1]. The annual waste cooking oil produced in China is about 5–7.5 million tons and only 4 million tons can be collected as a recycled resource [1]. Waste cooking oil has become one of the environmental pollutants and seriously affects the food safety in China. In recent years, the waste cooking oil incidents occur frequently (using wasted cooking oil as a common oil into the food), which seriously endangers the health of human being.

Some researchers did a lot of research projects in the reuse of waste cooking oil [2–4]. One method is to produce soap, which

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results in the secondary pollution but the recycled amount of waste cooking oil is very limited. Another way is to produce biodiesel, which has some disadvantages such as high energy consumption and cost. Waste cooking oil, similar to the light oil component in asphalt, contains a lot of unsaturated fatty acids. The oil component of asphalt reduces after a long term performance. According to asphalt rejuvenating theory [4–8], a low viscosity oil content (i.e. regenerative agent) or softer virgin asphalt can be added into aged asphalt to coordinate its chemical composition and proportion to produce new asphalt binder. Therefore, waste cooking oil can be used for asphalt regeneration [9], which may be expected to increase the utilization of waste cooking oil, with better environmental, social and economic benefits, and capacious applications prospects. A US Patent has mentioned that the waste cooking oil can be used as a rejuvenator to soften asphalt [10]. Wen reported that waste cooking oil can be used to produce bioasphalt [11]. Asli and Karim [12] used physical index and rheological properties index to evaluate the effect of waste cooking oil on the indoor aged asphalt, and concluded that the waste cooking oil can be used as a regenerative agent in recycled asphalt which can yield the lower penetration value and similar to its original bitumen.

The cotton seed oil can be edible after refined, but crude cotton seed oil can damage sperm cells. The cotton seed oil can also produce soap and biodiesel, but has the same problem of waste cooking oil. The major components of the cotton seed oil is fatty acids, similar to the light oil component in asphalt, so it can be also used for asphalt regeneration.

To find a more environmentally friendly alternative asphalt is a big challenge. As used in asphalt pavement, bioasphalt should be easy to mix and lay down. In addition, it is also stiff enough to withstand traffic loading. Meanwhile, it should not crack at a relatively low temperature. Asphalt mixture lacking high temperature stability is prone to yield the permanent deformation at a high performance temperature. State Highway Research Program (SHRP) indicates that asphalt provides 40% of the rutting resistance ability of an asphalt mixture [13]. The key to improve the high temperature resistance to deformation of bituminous pavement is to accurately evaluate high temperature performances of asphalt [14–16]. Consequently, rheology has become a useful tool in characterizing the asphalt high temperature performance. SHRP protocol brought up a series of tests in a very wide range of temperatures which allow obtaining information about the suitability of a given asphalt in a further application [17].

Some research articles have proven that waste cooking oil is one of rejuvenating agents that possibly improve the aged bitumen properties to the similar level of the virgin bitumen [11,12], but no research was found to compare the effect of waste cooking oil to other rejuvenators on rheological properties. Moreover, it is a known fact that effect of the regenerative agents on various asphalts is also different. The objective of this paper is to conduct a laboratory investigation on the high temperature properties of the recovered asphalt binder rejuvenating with rejuvenator, waste cooking and cotton seed oil. Dynamic shear rheometer (DSR) test and rotational viscosity test were conducted at different temperatures on the rejuvenating asphalt to determine the rutting resistance factor, phase angle, complex modulus, failure temperature and rotational viscosity.

2. Experimental process and materials

Three sources of aged asphalts (referred to as *A*, *B*, and *C*) recovered from RAP materials were used to blend with one type of virgin asphalt (PG 64-22) and three percentages (0%, 5%, and 10%) of rejuvenator, cotton seed oil, and waste cooking oil (referred to as *R*, *O*, and *W*). The mass ratio of recovered aged asphalt to virgin asphalt is 1:3. Table 1 shows that $G^*/\sin\delta$ and failure temperature values of recovered and virgin asphalt binders. It can be observed that the recovered binder *B* has the highest failure temperature while other two aged binders have a similar failure temperature. All rheological tests were performed in accordance with AASHTO and ASTM Superpave specifications in this study.

Table 1
$G^*/\sin\delta$ and failure temperature values of recovered and virgin asphalt binders.

Testing temperature		*A*	*B*	*C*	PG 64-22
$G^*/\sin\delta$ (kPa)	64 °C		123.31		1.51
	70 °C		55.06		0.88
	76 °C	5.94	24.74	9.64	
	82 °C	2.85	11.30	4.58	
	88 °C	1.45	5.26	2.29	
	Failed temp. (°C)	90.8	101.0	91.7	65.8

The recovered binder, rejuvenator, and virgin binder (PG 64-22) were blended at 145 °C and a speed of 200 rpm for 15 min based on their contents. Then samples were immediately used for viscosity and DSR tests. Viscosity was measured using a spindle spinning at a 20 rev/min rate according to AASHTO T316 [18] after 30 min of thermal stabilization at four different temperatures (e.g. 120, 135,150 and 160 °C). A number 10 spindle and a specimen weight of 8.5 g were used for this test. Two replicates were tested for all samples.

The high temperature rheological properties of each binder were measured using a DSR at different grade-specific testing temperatures according to AASHTO T315 [19]. In this research, a one millimeter gap and 25 mm diameter plate for all binders were used to obtain DSR values at high temperatures. Each binder was measured in terms of phase angle (δ) and complex shear modulus (G^*) values starting from its PG temperature until failed in accordance with Superpave specifications.

The grade determination feature of the DSR was used to determine the failure temperature for each sample. This procedure tests the sample at a starting temperature (i.e., 64 °C for PG 64-22) and increases the temperature to the next PG grade if the $G^*/\sin\delta$ value is greater than the value required by AASHTO M320 [20] (1.000 kPa for original binder).

3. Results and discussion

3.1. Rutting resistance factor ($G^*/\sin\delta$)

$G^*/\sin\delta$ reflects the irrecoverable deformation of asphalt during the loading process. Asphalt, with a higher $G^*/\sin\delta$ value but a smaller flow deformation at high temperature, has a higher rutting resistance.

Fig. 1 shows that the influence of the amount of *R*, *O* or *W* on the rutting resistance factor of different binders. It was observed that the rutting resistance factors of the rejuvenated binders strongly depend on the *R*, *O* or *W* contents and the test temperatures. Generally, their rutting resistance factors decrease as test temperatures and *R*, *O* or *W* concentrations increase. The rejuvenated asphalts containing *W* or *O* show lower $G^*/\sin\delta$ values than those with the same content of *R* at the same test temperatures. Thus, under the same condition, the asphalt containing *R* has a better

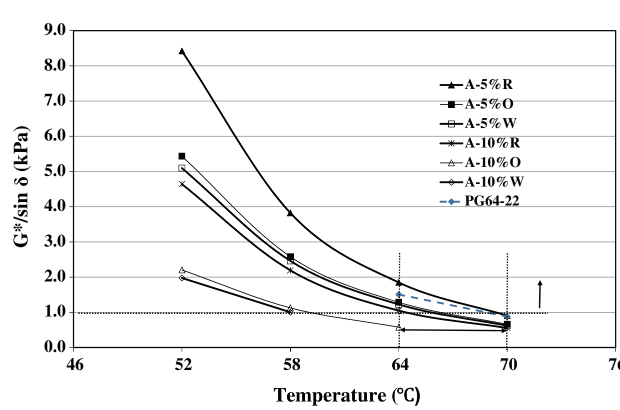

Fig. 1a. $G^*/\sin\delta$ values vs. temperature for rejuvenating asphalt *A* with different contents of *R*, *O* or *W*.