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Infrared spectra and rheological properties of asphalt cement containing waste engine oil residues

Xiaoyang Jia, Baoshan Huang *, Benjamin F. Bowers, Sheng Zhao

Department of Civil and Environmental Engineering, The University of Tennessee, Knoxville, TN 37996, USA

HIGHLIGHTS

- Both asphalt binder and waste engine oil consist of similar function groups.
- Waste oil compromised rutting resistance and elastic recovery of asphalt binder.
- Waste oil had positive effects on low temperature properties of asphalt binder.
- The threshold of concentration was recommended based on test results.

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ABSTRACT

This paper presents a study in which the engineering properties of asphalt binder containing waste engine oil residues were evaluated through laboratory performance testing. The infrared spectra and rheological properties of asphalt binder were evaluated with Fourier transform infrared (FT-IR) spectroscopy and dynamic shear rheometer (DSR). Asphalt binder specimens containing different concentrations of waste engine oil were fabricated with two types of binder, PG64-22 and PG76-22, and were blended with two types of laboratory aged binders to simulate the inclusion of reclaimed asphalt pavements (RAP). The results from this laboratory study indicated that the inclusion of waste engine oil up to 5% significantly altered the infrared spectra and rheological properties of asphalt binder, which may lead to the improvement of low temperature performance, but would also compromise many other performance indices, such as rut resistance at high temperature, certain aspects of fatigue resistance and elastic recovery of the binder.

1. Introduction

The United States generates billions of gallons of waste motor oil annually. The waste engine oil may cause irrecoverable damages to the environment if not disposed properly. For example, it only takes a few liters of oil to contaminate a sizeable body of water [1]. The U.S. Department of Energy (DOE) estimates that the majority of the waste engine oil is burned as fuel [2]. For instance, asphalt mixing plants are among the common consumers for burning used oil [3].

As for asphalt contractors, the value of used oil would be much higher if it could be blended into asphalt mixture as partial replacement of asphalt binder rather than just as fuel. Since both motor oil and asphalt binder are products of petroleum refining, some contractors have been investigating into blending waste engine oil as a potential binder replacement or rejuvenator when incorporating reclaimed asphalt pavements (RAP). Due to their chemical similarity, the results from Fourier Transform Infrared Spectroscopy (FT-IR) test indicate that both used engine oil residues and asphalt binder consist of aromatic hydrocarbons and saturated hydrocarbons [4]. These components are in the continuous phase surrounding the asphaltene molecules and attribute to the liquidity in asphalt materials [5]. Therefore, engine oil residues do have the attributes to soften the asphalt binder [6,7]. This is especially important when a mix design utilizes the aged asphalt binder from reclaimed asphalt pavement (RAP). The incorporation of engine oil residues may recover the flexibility of RAP binder in a way similar to the inclusion of an asphalt rejuvenating agent. Due to the above reasons, waste engine oil may be included into asphalt paving mixtures with or without the knowledge of the paving customers or agencies.

However, systematic studies on the influence of waste engine oil to the performance of asphalt paving mixtures are not well

* Corresponding author. Tel.: +1 865 974 2608; fax: +1 865 974 2669.
E-mail address: bhuang@utk.edu (B. Huang).

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reported. Hesp and Shurvell indicated that the performance of the asphalt binder will be sacrificed by the addition of engine oil residues. Based on a distress survey in Ontario, Canada, engine oil residues were discovered in some core samples from poorly performing asphalt pavement at typical modification levels ranging from 5% to 20% by X-ray fluorescence analysis. The researchers attributed the thermal cracking in asphalt pavement to the physical hardening and losses in strain tolerance caused by the presence of waste engine oil residues [8]. The excessive softening of the asphalt binder by engine oil may also increase the rutting potential in asphalt mixture [9,10].

2. Objective and scope

The objective of the present laboratory study was to investigate the influence of waste automobile engine oil on the properties of asphalt binder at different inclusion contents. FT-IR and dynamic shear rheometer (DSR) were considered to characterize the infrared spectra and rheological properties of asphalt binder containing waste engine oil residues. Two types of asphalt binders, a PG64-22 base binder and a PG76-22 SBS polymer modifier binder commonly used in southeast US were considered as control asphalt binders. Two aging procedures, Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel (PAV) were considered.

3. Laboratory experiments

3.1. Materials

The waste engine oil utilized in the study was collected from a local auto repair shop. As a common practice, automobile repair shops collect waste motor oil residues from different vehicle sand dispose of them collectively. Due to the contaminants arisen from wear of engine component and from heating and oxidation of lubricating oil during engine operation [22], the chemical composite of waste engine oil may be different from each other. From the previous studies, some metals such as lead, zinc, calcium, and magnesium are found in the used engine oil [4,22]. Furthermore, compared to fresh oil, waste engine oil may contain higher percentages of polycyclic aromatic hydrocarbons (PAHs) and additives compared to fresh oil [23]. It is important to note that waste motor oil from different vehicles may vary significantly in terms of molecular structure and viscosity. However a collective blend of waste motor oil from auto workshops showed similar properties based on FTIR and rheological analyses, which may be due to the similar statistical distributions of different automobiles used in US.

Two types of asphalt binders commonly used by the paving industry in Southeast US, a PG64-22 based asphalt and a PG76-22 SBS polymer modified asphalt binder, were employed in this study. In addition to virgin asphalt binder (un-aged), laboratory aged binder (through RTFO and PAV) residues were blended at different proportions to simulate the situation when reclaimed asphalt pavement (RAP) to be used in an asphalt mixing plant.

3.2. Sample preparation

The waste engine oil residues were mixed into asphalt binders by weight proportions of 2.5%, 5%, 7.5% and 10% as listed in Table 1. In the table, RAP-A and RAP-B represents the asphalt binders with a blend of virgin to aged binder ration of 90:10 and 70:30, respectively. The blending of virgin to aged asphalt binders simulates a condition in asphalt mixing plants when reclaimed asphalt pavements (RAP) being used, typically at weight concentrations between 10% and 30%.

Table 1
Proportions of component for specimens tested.

Component (%)	PG64-22	PG76-22	RAP-A	RAP-B
PG64-22	100	0	90	70
PG76-22	0	100	0	0
Aged binder	0	0	10	30
Oil				
concentration0, 2.5, 5, 7.5, 100, 2.5, 5, 7.5, 100, 2.5, 5, 7.5, 100, 2.5, 5, 7.5, 10				

3.3. Infrared (IR) spectra analysis

The Fourier transform infrared analysis has been proven to be an effective tool for the analysis of macromolecule materials such as polymer sand asphalt [11,12]. Based on the principle that the rotation or oscillation of molecules at specific frequencies will affect the absorbance of infrared spectra, the functional groups of the medium can be identified. In the study, the infrared spectra analysis was conducted using a Nicolet6700 FT-IR spectrometer. Through the measurement of IR absorbance, the change in composition of asphalt binder due to the incorporation of engine oil residues can be detected. The FT-IR specimens were prepared by mixing asphalt binder with a common asphalt solvent, toluene. The asphalt film was fabricated by drop-casting the solution onto KBr salt plates. The solvent was then evaporated and the finished specimens were placed into infrared spectrometer for testing.

During the process of oxidation, changes may happen to the chemical bonds and molecular structure of the asphalt binder, resulting in a variation on peak values of absorbance or transmittance on infrared spectrum. This characterization of the binder can be employed to quantify the degree of aging of the asphalt binder [13–15].

The process of asphalt hardening can be explained by the formation in asphalt of polar oxygen-containing functional groups [16]. Therefore, by the identification of changes in these functional groups, the oxidation of asphalt can be quantified [17]. It has been demonstrated that the increase in the intensity of the bands around 1695 cm^{-1}, which correspond to carbonyl (C=O) groups, with aging correlates with an increase in the content of the most polar components that constitute those of higher molecular size [14]. In an infrared spectrum, the changes in C=O can be quantified by the absorbance or transmittance at band peaks. However, the variation of asphalt film thickness between samples will have effects on the results of absorbance or transmittance [15]. Therefore, the ratio of intensity of the 1695 cm^{-1} region to that of 1455 cm^{-1}, which is attributed to saturated C—C vibrations, is calculated to quantify the relative degree of oxidation of the samples [17]. The calculation is illustrated in Fig. 1 and accordance with the following equation:

$$Ratio_{1695/1455} = \frac{A_1}{A_2} \tag{1}$$

where A_1 is the Area of carbonyl C=O centered around 1695 cm^{-1} and A_2 is the Area of saturated C—C centered around 1455 cm^{-1}.

3.4. DSR rutting index $G^*/\sin\delta$

The Superpave performance grading system adopts the index $G^*/\sin\delta$ to characterize the performance of asphalt binder in high temperature. The asphalt binder is more desirable with a higher value of $G^*/\sin\delta$. It indicates that higher $G^*/\sin\delta$ is accompanied by a higher complex shear modulus, G^* and/or a lower phase angle, δ. DSR test is conducted on an unaged binder and RTFO-aged residues in accordance with the Superpave binder specification. In this study, the DSR test was conducted to evaluate the asphalt