Fuel 202 (2017) 529–540

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Evaluation of optimized bio-asphalt containing high content waste cooking oil residues

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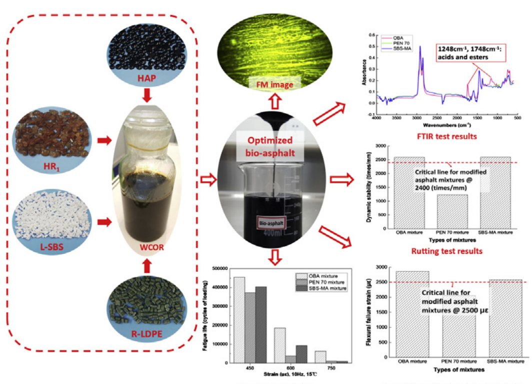
HIGHLIGHTS

- A new bio-asphalt containing high content WCOR (33.3% by weight) was obtained.
- Bio-asphalt with high WCOR content shows excellent mechanical and chemical performance.
- Bio-asphalt with high WCOR content has a promising application in the road industry.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 12 April 2017
Accepted 14 April 2017
Available online 24 April 2017

Keywords:
Waste cooking oil residues
Rheological properties
Optimized bio-asphalt
Chemical composition
Mixture performance

ABSTRACT

Waste cooking oil residues (WCORs)-based bio-asphalt is a potential substitute for petroleum asphalt. However, asphalt binders with a high WCOR content indicates a low rheological property, leading to a limited WCOR mixed content (usually no more than 10 wt% of asphalt binder). This study aims to prepare an eco-friendly bio-asphalt with a high WCOR content. Based on the formula uniform design method, the optimum blending proportion of the bio-asphalt was determined as 33.3% WCOR, 31.8% hard asphalt particles (HAP), 30.3% hydrocarbon resin (HR_1), 4.6% recycled low density polyethylene (R-LDPE), and external 4% linear SBS polymer (L-SBS). Rheological test results indicated that the optimized bio-asphalt (OBA) presented similar high-temperature performance to SBS modified asphalt (SBS-MA), and much better low-temperature performance than both of SBS-MA and PEN 70 base asphalt (PEN 70). Fourier transform infrared spectroscopy (FTIR) test proved that OBA had some special chemical composition such as the acids and esters originated from the addition of WCOR. On the basis of mixture performance tests, it confirmed that OBA mixture possessed similar rutting resistance and moisture susceptibility to SBS-MA mixture, and showed more satisfying low-temperature capability than both of SBS-MA mixture and PEN 70 mixture. Additionally, OBA mixture showed prominent fatigue performance since it had the highest fatigue life and stable fatigue sensitivity at different strain levels. All above evaluations imply the feasibility of using high content of WCOR in road construction applications since OBA containing 33.3% WCOR shows excellent binder and mixture performance.

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http://dx.doi.org/10.1016/j.fuel.2017.04.069
0016-2361/

1. Introduction

Bio-oils are generally applied in asphalt binder industry as asphalt modifiers (<10% asphalt replacement), asphalt extenders (25–75% asphalt replacement), and direct alternative binders (100% asphalt replacement) [1]. Most of previous studies examined the feasibility of utilizing bio-oils as asphalt modifiers [2–5]. It was found that bio-asphalt from different sources may have different effects on the petroleum asphalt.

The bio-oils sources can fall into three categories [6–10]: (1) agricultural or forest production wastes that include but are not limited to crop residues (like maize straw), wood wastes (like sawdust and bark), and urban organic wastes (like microalgae and coffee grounds), (2) animal wastes that include but are not limited to swine manure, bovine feces, (3) waste oil wastes that include but are not limited to cooking oil/residues, waste auto engine oil/residues, cottonseed and soybean oil residues. Actually, properties of the bio-asphalt vary with the sources and contents of bio-oil [11–13]. To produce bio-asphalt binder based on agricultural or forest production wastes, additional content of bio-oil is generally within 5%–10% of the control asphalt [14,15]. Recent studies indicated that asphalt binder containing wood waste bio-oil has a higher viscosity and superior low temperature performance but shows a weak high temperature property [2,15], and asphalt mixtures made from wood wastes have been proved to provide better crack resistance and anti-fatigue properties [16]. For bio-oil based on animal wastes, its content is generally less than 10% of the control asphalt [11,17–21]. It is commonly believed that animal waste bio-oils can increase the low temperature crack resistance of the asphalt mixture, but reduces the viscosity and high temperature stability of the asphalt [18,19]. Fini et al. investigated the performance of asphalt binder modified by swine manure based bio-oils [19]. In his study, to improve the high temperature performance of bio-oil modified asphalt binder, 1.5% poly phosphoric acid (PPA) should be added.

The bio-oils generated from wood wastes or animal feces go through a very complicated processing process at a high cost [22,23]. By contrast, the soft waste oils (such as waste auto engine oil/residues, waste vegetable oils and waste cooking oil/residues) can become the ready substrate with lower feedstock and production expenses. It was reported that the United States generated billions of gallons of waste motor oil annually [24]. Another report from the United States Environmental Protection Agency pointed out that hotels and restaurants in the United States generated 3 billion gallons of waste cooking oil (WCO) per year [25]. About 10% waste cooking oil residues (WCORs) are left after the WCO is refined into biodiesel through alkaline catalysis procedure [4,26]. Reusing of soft waste oils as paving substitute materials not only reduces the burden of the government in disposing the waste, saving natural resources and reducing energy consumption, but also in some cases maintains and improves pavement performance [4,5,24]. Jia et al. concluded that the inclusion of waste engine oil residues into asphalt binder led to the improvement of low-temperature performance, but would also compromise many other performance indices, such as rut resistance at high temperature, fatigue resistance and elastic recovery of the binder [24]. They also evaluated the influence of waste engine oil on the performance of hot-mix asphalt (HMA) containing reclaimed asphalt pavement (RAP) and presented that the inclusion of waste engine oil offset the increase of stiffness caused by aged binder in RAP, but reduced rut resistance and fatigue resistance of the mixtures [27]. However, a study investigated by Ji et al. showed that the waste vegetable oils as rejuvenators was beneficial for both fatigue and low-temperature cracking resistance [28]. In respect to the WCO/WCOR, due to their chemical similarity, the addition of WCO or WCOR also has a positive effect on the low-temperature performance of control asphalt since it does attribute to the liquidity in asphalt materials [29]. Sun et al. proposed that the waste cooking oil-based bio-asphalt can improve the stress relaxation property of control asphalt [4]. Additionally, Gong et al. concluded

Table 1
Applications of WCOR/WCO to develop bio-asphalt.

Authors	Sources	Additional content (by weight of control asphalt)	Effect of WCO/WCOR on properties of bio-asphalt
Mahrez et al., 2009 [31]	WCO	2%–6%	Improving the viscoelastic properties of the aged bitumen
Chen et al., 2014 [32]	WCO	5%–10%	Reducing the rutting resistance factor and viscosity of the rejuvenated asphalt binder, decreasing failure temperature of the regenerative asphalt
Maharaj et al., 2015 [33]	WCO	2%–10%	Resulting in the softening of Trinidad asphaltic material, and a gradual decrease in elasticity
Azahar et al., 2016 [34]	Treated WCO	3%–5%	Increasing the rutting resistance and reducing temperature susceptibility of control asphalt, and improving failure temperature of the control asphalt
Azahar et al., 2016 [35]	WCO	Less than 10%	Restoring the properties of aged binder (as a rejuvenating agent)
Sun et al., 2016 [4]	WCOR	2%–8%	Decreasing the deformation resistance but improving the low-temperature cracking capability of control asphalt
Gong et al., 2016 [5]	WCOR	0.5%–3%	Enhancing the workability, the rheological properties and the low-temperature cracking resistance of aged asphalt
Wen et al., 2013 [30]	WCOR	More than 10%	Reducing the PG grade of base binder and increasing the susceptibility of the binder to rutting

Table 2
Trial and error test results.

Binders' codes	Material combinations	Mass ratio	Penetration (25 °C, 100 g, 5 s), 0.1 mm	Softening point (°C)	Ductility (15 °C, 5 cm/min), cm
Binder 1	WCOR:HR_1	1:1	WCOR's viscosity and adhesion increase obviously, but it is still too soft to be tested		
Binder 2	WCOR:CR	1:1	CR was segregated from WCOR		
Binder 3	WCOR:HAP	1:1	WCOR's viscosity was improved little, and cannot be tested		
Binder 4	WCOR:HAP:HR_1	1:1:1	63.0	50	12
Binder 5	WCOR:HAP:HR_2	1:1:1	90.0	42	30
Binder 6	WCOR:HAP:HR_1, L-SBS/R-LDPE	1:1:1, 5%	50.7	59	30

Note: HR_1 and HR_2 had different softening points of 140 °C and 120 °C respectively.