



# Rheological behavior of Japanese cedar-based biobinder as partial replacement for bituminous binder



Shih-Hsien Yang\*, Try Suciptan

Department of Civil Engineering, National Cheng Kung University, 1 University Rd, Tainan City 70101, Taiwan

## HIGHLIGHTS

- The vacuum distillation process was used to upgrade the Japanese cedar bio-oil into biobinder.
- Biobinder blends showed Newtonian behavior at all testing temperatures and shear rates.
- Addition of biobinder improves asphalt binder's high temperature rutting resistance.
- The PG binder grade bump from 64 to 70 was observed in the 50% biobinder blend.

## ARTICLE INFO

### Article history:

Received 16 April 2015

Received in revised form 7 March 2016

Accepted 20 March 2016

Available online 31 March 2016

### Keywords:

Pyrolysis

Japanese cedar chip bio-oil

Biobinder

Rheological behavior

Biobinder aging

Viscosity-temperature susceptibility

Rutting potential

MSCR

$G^*/\sin \delta$

## ABSTRACT

Currently, road and airport pavement construction uses approximately 90% asphalt, most of which is mainly derived from fossil fuels. However, with the improvement in oil refinery technology, the quality of asphalt binders is degrading gradually. Moreover, from the environment standpoint, fossil fuels are the main source of greenhouse gases, which lead to global warming. Consequently, there is an urgent need to develop a more sustainable binding material from renewable or other alternative resources to replace or modify the existing petroleum-based asphalt binder for the highway industry. The main objective of this study was to investigate the potential use of a bio-oil byproduct as a partial replacement for a bitumen-based binder. The properties of various blending combinations of a biobinder and asphalt binder were compared with those of an unmodified asphalt binder through several physical and rheological tests. The specific gravity of the biobinder was found to be higher than that of the petroleum-based binder. In general, biobinder blends have a higher viscosity than that of the unmodified binder at temperatures higher than 60 °C. Binders containing the biobinder at 25% and 50% have lower temperature susceptibility than that of the unmodified binder. Adding the biobinder at up to 25% does not significantly change the complex shear modulus of unaged binders, whereas rolling thin-film oven-aged biobinder blends show a higher complex modulus and greater viscosity than those of the unmodified binder. Moreover, the biobinder blends show higher  $G^*/\sin \delta$ , lower nonrecoverable compliance and greater recovery ability than those of conventional AC-20.

© 2016 Elsevier Ltd. All rights reserved.

## 1. Introduction

Road construction involves considerable energy and nonrenewable materials such as bitumen, aggregates, and special additives. Among these materials, bitumen is the most crucial constituent, consisting of aggregates of various sizes combined to form asphalt concrete used as a pavement surface material. Bitumen is present in most crude petroleum and in some natural deposits. At present, almost all bitumen used in road construction is derived from the

last cut in the petroleum refinery after naphtha, gasoline, kerosene, and other fractions have been extracted from crude oil. With the recent continual improvement in oil refinery technology, the quality and quantity of asphalt have degraded gradually. This has resulted in an increase in the final cost of road paving construction and perhaps shortened the service life of roadway infrastructure. Moreover, fossil fuels are considered the main source of greenhouse gases, which constitute the main cause of global warming [1]. In pavement construction, although only a fraction of asphalt is used as adhesive material (typically approximately 5%) in roadway construction, the amount of asphalt used is considerable because of the large quantity of roadway construction being

\* Corresponding author.

E-mail address: [shyang@mail.ncku.edu.tw](mailto:shyang@mail.ncku.edu.tw) (S.-H. Yang).

undertaken. Dorchie reported that the production of 1 ton of asphalt including crude oil extraction, transport, and refining 285 kg of greenhouse gas emission [2]. Therefore, there is an urgent need to develop a new binding material from a more sustainable source to completely, or at least partially, replace the currently used fossil fuel-based binder (asphalt).

Currently, numerous studies on biorenewable resources mainly focus on producing fuel and chemical feedstock from various types of biomass [3]. However, few studies have investigated the application of insoluble and high-molecular-weight components of bio-oil as adhesives and binders in the construction industry. Airey et al. demonstrated the use of sugars, triglyceride oils, and proteins as alternative sources for producing adhesives and binders. They suggested that because of the wide availability of such biorenewable sources, there are virtuous technical and economic prospects in using them for biobinder production [4]. In addition, Raouf and Williams investigated the physical and chemical properties of different vegetable and plant oils to study their applicability as biobinders in pavement construction. They concluded that biobinders can completely or partially replace asphalt binders [5]. Fini produced a bio-oil from swine manure and used it as a partial replacement for bitumen [6]. The thermochemical liquefaction process was used to convert swine manure to bio-oil, and the remaining heavy residue obtained in this process was used as an asphalt modifier. Chailleux et al. at IFSTTAR used byproducts of the microalgae industry to produce an alternative road binder through the Algoroute project, which is a part of the IFSTTAR Post Oil Pavement research program dedicated to developing alternative binders for pavement construction [7].

For the application of bio-oil in paving construction, the following three parameters relating to biobinder performance must be considered: 1) physical characteristics, 2) rheological properties (stress–strain–time relationship), and 3) aging characteristics of biobinders. The rheological properties of bio-oil and asphalt modified with bio-oil have been studied recently. Researchers at Michigan Technological University investigated the performance of fast pyrolysis of a wood bio-oil-modified binder and mixture. Their findings showed that by adding 5% and 10% bio-oil to an asphalt binder, the binder's rutting resistance at a high service temperature could be improved. Their mixture study showed that adding bio-oil significantly improved the asphalt mixture fatigue performance and had no significant effect on the rutting performance and dynamic modulus, but slightly influenced the tensile strength [8,9]. Chen et al. used waste cooking oil and cottonseed oil as rejuvenator agents to improve the properties of an aged binder. The results showed that adding the oils reduced the rutting resistance factor and complex modulus of the rejuvenated binder [10]. In addition, Fini et al. reported that the viscosity of a manure-based biobinder decreased compared with that of a pure binder at various temperatures. They stated that the reduction in the viscosity of the modified binder can improve binder wettability and mixture durability and lower the mixing and compaction temperatures [11]. Raouf and Williams used oak wood-based bio-oil as a 100% replacement for an asphalt binder and found that the viscosity of the bio-oil decreased as the temperature increased [12]. Ingram and Mohan demonstrated that at low shear rates, bio-oils were non-Newtonian but became Newtonian as the shear rate increased in the temperature range of 25–80 °C [13]. Wan Nik and Giap studied the dependence of bio-oil viscosity on shear rate and temperature. They concluded that shear thinning of bio-oil was more substantial than that of petroleum oil [14].

Although some previous studies have reported the effect of adding bio-oil on the rheological properties of the binder, they have mainly focused on the use of bio-oil as an asphalt binder modifier ( $\leq 10\%$  bio-oil blending) [8,10,11]. Moreover, only a few studies have considered the effect of aging on rheological properties

[10,12,15]. Therefore, the main objective of this study was to characterize the physical and rheological properties of both original and aged Japanese cedar chip bio-oil as an asphalt binder extender and modifier. This will facilitate understanding the fundamental engineering properties of Japanese cedar bio-oil. Ultimately, such rheological properties can be used to predict the biobinder's engineering performance in parameters such as workability and permanent deformation potential.

## 2. Materials and methodology

### 2.1. Materials

In this study, local Japanese cedar chips from the residue of the wood processing industry were employed as the biomass source to produce bio-oil as well as a biobinder. The tested bio-oil was obtained through the fast pyrolysis of Japanese cedar chips by the Green Energy and Environment Laboratories of the Industrial Technology Research Institute. This bio-oil generally contains a high proportion of water, which must be removed through an upgrading process. Thus, the thermochemical dehydration process, which indirectly heats the bio-oil through a vacuum rotary evaporator device, was undertaken. The bio-oil was heated at the minimum water evaporation temperature (at 80 °C under 0.46 atm) to minimize aging of the biobinder. The water content of the resultant biobinder was measured using the Karl Fischer MKC 520 moisture titrator. The water contents of the cedar chip bio-oil before and after the dehydration process were 42.2% and 1.3%, respectively. The Japanese cedar-based biobinder thus obtained was then blended with an AC-20 binder obtained from the Chinese Petroleum Corporation of Taiwan at different percentages. Two potential implementations of the biobinder were tested: its use as an asphalt binder modifier (2% and 8% blending) and as an asphalt extender (25% and 50% blending).

### 2.2. Experimental methods

To simulate binder aging during the pavement construction process, a rolling thin-film oven (RTFO) was employed to simulate the short-term aging of both the neat binder and biobinder in accordance with the short-term aging procedure AASHTO T240 [16]. The tested neat and biobinder residues, which were defined as RTFOT binders, were then prepared for the following measurement of rheological properties, which provided a comparison with original unaged biobinders.

First, the specification gravity and separation potential of the biobinder were measured on the basis of the ASTM D7173 method for the biobinder blended with the AC-20 neat binder in various proportions [17]. Next, the rheological properties of the neat and biobinders at high and intermediate temperatures were evaluated using a rotational viscometer (RV) and a dynamic shear rheometer (DSR). The viscosity of the biobinder was measured at 60, 100, and 135 °C by using the Brookfield RV DV-III at various spindle rotational speeds according to ASTM D4402 to evaluate the viscosity susceptibility of the shear rate and temperature of the biobinder [18]. The DSR test was performed using the parallel plate testing system, which consists of 25- or 8-mm-diameter plates with 1.00 mm or 2.00 mm testing gaps, respectively. The oscillation test was performed using angular frequencies between 0.1 Hz and 10 Hz at 6 °C temperature intervals between 10 °C and 82 °C to measure the biobinder's complex shear modulus ( $G^*$ ) and phase angle ( $\delta$ ) according to AASHTO T315, and the results were used to calculate the rutting potential parameter  $G^*/\sin\delta$  according to AASHTO M320 [19,20]. In addition, the permanent deformation potential of the biobinder was studied using multiple stress creep and recovery (MSCR) testing according to ASTM D7405 [21]. In the MSCR test, the specimen was subjected to 1 s of creep loading, followed by 9 s of unloading to enable the specimen to recover. Two stress levels of 0.1 kPa and 3.2 kPa were applied for 10 creep-recovery cycles individually. The results were used to calculate the following rutting performance parameters: average recovery percentage, R, and nonrecoverable compliance,  $J_{nr}$ .

## 3. Results and discussion

### 3.1. Physical testing of biobinder

#### 3.1.1. Separation test

Fig. 1 shows the results of separation testing of the biobinder. Values of  $G^*/\sin(\delta)$  at 64 °C were used as indicators to evaluate the separation potential of different blends of the biobinder with AC-20. A one-way ANOVA test with a 95% confidence level was performed to compare the  $G^*/\sin\delta$  values between the top and bottom portions of the biobinder. The results showed no significant difference in the  $G^*/\sin\delta$  values for 2%, 8%, and 25% blending

Download English Version:

<https://daneshyari.com/en/article/255967>

Download Persian Version:

<https://daneshyari.com/article/255967>

[Daneshyari.com](https://daneshyari.com)