Construction and Building Materials 66 (2014) 361–367

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Rheological behavior of bitumen mixed with Trinidad lake asphalt

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## HIGHLIGHTS

- Critical content of TLA in the modified blend by weight is determined as the interaction of mineral particles occurred.
- It is recommended that the percentages of TLA added as a modifier in an asphalt blend be in the range of 20–33% on a weight basis of TLMA.
- For TLMA, SSV (steady state viscosity) has the lowest values, followed by Carreau ZSV (zero shear viscosity) and Cross ZSV.

## ARTICLE INFO

*Article history:*
Received 6 December 2013
Received in revised form 20 April 2014
Accepted 16 May 2014

*Keywords:*
Trinidad lake asphalt
Zero shear viscosity
Low shear viscosity
Steady state viscosity

## ABSTRACT

Trinidad lake asphalt (TLA) has been utilized as a modifier to blend with conventional petroleum bitumen for road and bridge applications where highly stable surfacings are required. The aim of this work was to evaluate the effect of TLA on rheological properties of Trinidad lake modified asphalt (TLMA). The critical content of TLA in the modified blend by weight was determined as the interaction of mineral particles occurred. Test results showed that TLA stiffened asphalts, but the degree of stiffening varied significantly with the TLA concentration levels. An increase in complex modulus ($G^*$) and elastic response ($\delta$) resulting from the introduction of TLA to asphalt binders had the potential benefit of improving resistance to rutting. In addition, zero shear viscosities (ZSVs) obtained from the Cross model were equal to the low shear viscosities (LSVs) at a frequency of 0.05 Hz, while the ZSVs from the Carreau model were close to the LSVs at 0.1 Hz. Steady state viscosities (SSVs), having the lowest values, approximately equaled the LSVs at 0.5 Hz. The concentration of TLA was recommended to be in the range of 20–33% by the weight of naturally modified asphalt according to the SSV stiffening effect.

## 1. Introduction

Naturally occurring Trinidad lake asphalt (TLA) has been utilized as a modifier to mix with traditional bitumen forming Trinidad lake modified asphalt (TLMA) purported to enhance the engineering properties of asphalt concrete. The TLA modifier generally performed similar to other polymer additives in that they can increase asphalt pavement strength. Marshall stability, elastic modulus and tensile stress were found to increase with the use of the natural material according to laboratory studies [1]. Highway agencies have incorporated TLA into hot-mix asphalt mixtures to help resist fatigue cracking and permanent deformation on the pavement surface [1–3]. The TLA was also used in mastic asphalt mixtures where it replaced up to 20% of the paving grade binder for pavements on steel bridge decks [4]. However, the current utilization of the natural asphalt additive is generally limited to enhance mix durability in thin thickness overlays and steel bridge surfacings based on empirical properties [5,25]. To have wide use of the blend of asphalt cement modified by TLA for great performance, it is required to understand the fundamental properties of the conventional asphalt mixed with TLA. The TLMA needs to be engineered by choosing the right combination to ensure that the TLA used is compatible with the conventional asphalt cement. The composition of TLA typically includes mineral matter, organic matter and binder to form a colloidal system which provides the benefit of stiffening effect on asphalt cement. The fine particles have been naturally pre-mixed with binder for thousands of years, thereby forming the natural material with consistence properties. The refined TLA normally has a low penetration value and a high softening point [6,7,26]. In addition, TLA is generally mixed with

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http://dx.doi.org/10.1016/j.conbuildmat.2014.05.068
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crude petroleum asphalt cement in certain blending ratios since it is too hard to be used alone in asphalt concrete.

Traditionally, the material properties as well as typical blend ratios of TLMA are specified in terms of empirical properties. Typical blend ratios of the TLA to asphalt cement are not well understood, therefore, highway engineers in different regions adopt their own practices. In the United Kingdom, TLA and pen grade 160/220 asphalt were used to produce hot rolled asphalt for surface course in a 50:50 blend, resulting in a new blend having a penetration value of 50 [6]. PG76-28 binder modified with 25% TLA by weight was utilized for asphalt overlay pavements in Colorado in order to tackle the problem of decreasing availability of quality aggregates [2]. A 25:75 blend of TLA and penetration grade 20/40 asphalt cement was employed in the production of Gussasphalt mixture for the surfacing deck of a steel bridge in Taiwan [8]. SBS polymer modified asphalt with 20% TLA forming composite modified asphalt was used in China as waterproof materials for bridge deck pavements [4]. However, the reinforcement mechanisms associated with the presence of the particles of mineral matters in TLMA is not well understood. In fact, the absence of in-depth research has contributed to a general proliferation of specifications. Few studies have focused on the fundamental properties of TLMA. There are serious shortcomings in describing the rheological behavior of the modified asphalt through the empirical relationships using routine test data such as penetration, softening point and ductility. It is essential to characterize the rheological behavior to provide the rational basis for development of test methods together with determination of optimal combination that improves pavement performance.

Due to presence of particles of mineral matter in the TLA, shear viscosities of TLMA were much higher than those of conventional bitumens. Concerns have been raised over the role of viscosity at an extremely low shear or a steady state condition as performance indicators of deformation resistance [9–12]. A change in an asphalt binder is due to viscous flow as a function of temperature and loading time. The use of the dynamic shear rheometer (DSR) enables operations to be performed on asphalt binders at low shear conditions. Oscillation testing with frequency sweeps was used to measure dynamic viscosities. With these viscosity values varying with loading frequency at a specific temperature, attempts have been made about the interpretation of the results of fundamentally rheological testing. To estimate viscosity at zero shear condition, mathematical models were utilized to acquire zero shear viscosity (ZSV) or low shear viscosity (LSV) [13–16]. In addition, in order to obtain viscosity at a steady state, creep recovery testing was used to calculate steady state viscosity (SSV) [17–21]. However, relationships between the viscosities of ZSV, LSV and SSV for asphalt binders have not been developed. The understanding of shear viscosity properties provided the key by which the modified asphalt containing TLA could be properly selected for the optimal combination. The objectives of this study are as follow:

- To analyze the traditional properties of TLMA.
- To evaluate the fundamental properties of TLMA.
- To determine the critical content of TLA.

## 2. Test program

### 2.1. Materials and material preparations

A combination of pen 60/70 asphalt cement and TLA was selected to assess the effect of TLA on traditional and fundamental properties of the TLMA. The physical properties of pen 60/70 asphalt and TLA are listed in Table 1. The ratio of TLA to pen 60/70 asphalt was selected at a TLA increment of 20% up to 50% by weight of the blend. There were four different types of TLMA labeled as follows: PT20 (i.e., 20%), PT25 (i.e., 25%), PT33 (i.e., 33%) and PT50 (i.e., 50%). The above percentage represents a 20:80 (i.e., 1:4), 25:75 (i.e., 1:3), 33:67 (i.e., 1:2) and 50:50 (i.e., 1:1) blend, respectively.

**Table 1**
Properties of base asphalt and TLA.

| Tests | Pen 60/70 | TLA |
|---|---|---|
| Pen@25 °C, $d_{mm}$ | 65 | 1 |
| Softening point, °C | 48.7 | 99 |
| Ductility@25 °C, cm | 120 | N.A. |
| Solubility (TCE), % | 99.7 | 54 |
| Flash point (C.O.C), °C | >240 | >240 |
| Specific gravity@25 °C | 1.03 | 1.37 |
| Ash, % | N.A. | 36 |

An experimental protocol was developed to obtain homogeneous TLMA. The mixer, a model of Chemist MH-4000D manufactured in Taiwan, was used to apply a constant mixing speed to ensure no voids are created in the mixture. TLA was heated in an oven at 200 °C for 2 h, and pen 60/70 asphalt cement was preheated at 160 °C in an oven for 1 h, to make them liquid and ready to blend. TLA was added slowly while the mechanically stirring was continued at 3000 rpm. The blending time was restricted to a maximum of 30 min. The blending process was carefully monitored so that the TLA was homogeneously dispersed in the base asphalt. Prior to testing, the sample was stirred with a spatula to homogenize the blend. Multiple replicates were tested to ensure the homogeneity of the asphalt blends.

### 2.2. Traditional testing

Conventional tests of penetration, softening point and ductility were carried out to study the empirical properties of pen 60/70 asphalt, TLA and TLMA. The penetration test in accordance with ASTM D5 is a common test performed to characterize the hardness and specify different grades of asphalt binders. In the penetration test, an asphalt specimen was penetrated by a needle under a load of 100 g for a loading time of 5 s at test temperature of 25 °C. The penetration is measured in decimillimeter. In addition to performing penetration test, a conventional blending formula was used to predict the penetration values of the blend of the TLA and pen 60/70 asphalt at different TLA concentration levels.

Blending is an effective method of improving the quality of petroleum asphalts. By mixing an asphalt binder with TLA in different ratios, it is possible to obtain a large number of commercial grades of asphalt. The quality indices of the compounded asphalts are considered to be a function of both the properties and ratio of the components and the process that take place when they are mixed. The equation used to predict the penetration value of an asphalt blend is defined as follows [6,7,22]:

$$\log \mathrm{Pen}_{\mathrm{TLMA}} = A \log \mathrm{Pen}_{\mathrm{TLA}} + B \log \mathrm{Pen}_{60/70} \tag{1}$$

where $\mathrm{Pen}_{\mathrm{TLMA}}$ is the predicted penetration value (0.1 mm) of the new blend of the modified asphalt, $\mathrm{Pen}_{\mathrm{TLA}}$ and $\mathrm{Pen}_{60/70}$ are the measured penetration values (0.1 mm) of TLA and pen 60/70 asphalt, and $A$ and $B$ are the percentages of TLA and pen 60/70 asphalt, respectively.

The ring-and-ball softening point test in accordance with ASTM D36 was utilized to decide the temperature at which a phase change in the TLMA occurs. By measuring the temperature at the beginning of the fluidity range, the softening points of the asphalt binders were determined. In addition, a conventional blending formula was employed to predict the softening point values of the modified asphalt at different TLA concentrations. The following equation can be used to predict the softening point of an asphalt blend [6,7,22]:

$$\mathrm{SP}_{\mathrm{TLMA}} = a\mathrm{SP}_{\mathrm{TLA}} + b\mathrm{SP}_{60/70} \tag{2}$$

where $\mathrm{SP}_{\mathrm{TLMA}}$ is the predicted softening point value (°C) of the new blend of the modified asphalt, $\mathrm{SP}_{\mathrm{TLA}}$ and $\mathrm{SP}_{60/70}$ are the measured softening point values (°C) of TLA and pen 60/70 asphalt, and $a$ and $b$ are the percentages of TLA and pen 60/70 asphalt, respectively.

The ductility test in accordance with ASTM D113 was undertaken to characterize the elongated properties of the TLMA. In the ductility test, a specimen was pulled apart at a speed of 50.2 mm per minute at 25 °C. The ductility value of the modified asphalt was measured by the distance to which it elongated before breaking.

In addition, aging of the modified asphalt was performed using the thin-film oven test (TFOT) and rolling thin-film oven test (RTFOT) according to ASTM D1754 and D2872, respectively. Standardized conditions, i.e., 163 °C and 75 min for RTFOT, and 163 °C and 5 h for TFOT, were used. The aged materials were evaluated by measuring their penetration and ductility properties.

### 2.3. Frequency sweep testing

Dynamic oscillatory testing was performed under strain-controlled loading conditions by applying a sinusoidal angular displacement of constant amplitude using a dynamic shear rheometer (DSR). All tests were carried out in the linear viscoelastic range. The complex modulus ($G^*$), phase angle ($\delta$) and complex viscosity ($\eta^*$) of the