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Evaluation of rutting, fatigue and moisture damage performance of nanoclay modified asphalt binder

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HIGHLIGHTS

- Nanoclay (CL-30B) addition to binder showed improved rutting resistivity potential.
- SFE approach showed improved moisture resistivity of binder with CL-30B addition.
- LAS study showed improvement in fatigue life of binder with CL-30B modification.

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ABSTRACT

Recent impetus on utilization of different types of nanomaterials for modification of asphalt binders has motivated the authors to undertake the present study. The present study evaluated the rutting, fatigue and moisture damage performance of nanoclay (CL-30B) modified asphalt binder based on newly adopted test methods. Based on Superpave rutting parameter, it was observed that rutting resistivity of a binder increases with an increase in CL-30B content. Moisture resistivity of CL-30B modified asphalt binder with different types of aggregates system was studied using Surface Free Energy (SFE) approach. The SFE components of nanoclay modified binder were measured using Wilhelmy plate method. Four different types of aggregates (Basalt, Limestone, Sandstone and Granite) were chosen for the study. Overall increase in total SFE of the binder was observed with addition of CL-30B. Increase in work of cohesion and decrease in work of debonding was observed with an increase in CL-30B for all type of considered aggregate. Based on Energy ratio (ER), asphalt binder with basaltic aggregate was found to have better moisture damage resistivity among different types of aggregate selected in this study. The fatigue performance of CL-30B modified binder was evaluated using Linear Amplitude Sweep (LAS) test which is based on Visco Elastic Continuum Damage (VECD) theory. The analyses of the data showed that addition of CL-30B enhances fatigue life of a binder. The study showed potential of CL-30B to enhance various rheological performance of a binder for better and long lasting pavements.

1. Introduction

There has been increasing interest in highway community on improving quality of asphalt binders to enhance design life of flexible pavements. Though polymer modified binders have been immensely popular, the high cost and thermal instability of these binders encouraged researchers to explore new materials to improve performance of binders. Recent impetus on utilization of different types of nanomaterials namely, nanoclay, nanosilica, nanozinc oxide, and nanolime for modification of asphalt binders has motivated the authors to undertake the present study [1–4]. Hossain et al. [5] reported that cost of nanoclay modified asphalt binder can be approximately 22–33% lower than that of polymer modified asphalt binder. The studies conducted by numerous researchers showed that organo modified montmorillonite nanoclay can be a potential solution to minimize rutting failure [6–8]. The Superpave rutting parameter provides a valuable information on rutting resistant of a binder; however, limited work has been reported on nanoclay modified asphalt binders.

Similarly, effect of nanoclay on fatigue performance of asphalt binders is evaluated by some researchers using different approaches. For instance, fatigue life of asphalt binder containing nanoclay was evaluated by Liu et al. [7] and Wu et al. [9] using stress controlled mode and improvement in fatigue life was

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reported. Similarly, Yu et al. [10] reported improvement in fatigue life of asphalt binder with addition of nanoclay evaluated using Superpave fatigue parameter. Contrary to this, Jahromi et al. [11] and Ghile [12] observed reduction in fatigue life of binders with addition nanoclay evaluated using Superpave fatigue parameter. Ghaffarpour et al. [13] showed dependency of fatigue life of nanoclay modified asphalt mixture on temperature. In this study, improvement in fatigue life of nanoclay modified mixture was observed at 25 °C, while reduced fatigue life was reported at 5 °C compared to control mix. Hintz et al. [14] reported that determination of fatigue life of asphalt binder using under stress controlled test is time consuming and usually unrepeatable. Similarly, Superpave fatigue parameter is estimated by conducting test under linear visco-elastic range of asphalt binder and hence it lacks to capture the damage beyond this range. Also, it doesn't account for different traffic loading experienced in the actual situation [14–15]. Recently linear amplitude sweep (LAS) test is developed based on viscoelastic continuum damage (VECD) approach for better characterization of fatigue life of asphalt binders. The LAS has been reported as a promising test to evaluate the fatigue behaviour of asphalt binders under high stress and strain conditions beyond their viscoelastic range [14–16]. So far, as per the authors' understanding, limited studies have been found to utilize the LAS test to evaluate fatigue life of asphalt binder with addition of nanoclay [17]. Hence, the present study provides a valuable addition to the current repository of information available to the scientific community.

Recently, Golestani et al. [18] reported improvement in moisture damage resistivity of polymer modified binders with addition of nanoclay using Tensile Strength Ratio (TSR) test. Though TSR test is being widely popular, outcome from this test showed a poor correlation with field performance of pavements and failed to address specific failure mechanism related to moisture damage of asphalt mixes [19]. An important fundamental material property which can help to address moisture resistivity of asphalt mixes is the surface free energy (SFE) of aggregate and asphalt binder. The SFE approach has been reported as a vital tool to evaluate the moisture damage potential of conventional and polymer modified asphalt binders by various researchers [20–23]. Recently, Hamedi et al. [3] used the SFE approach to study the moisture resistivity of nanozinc oxide modified asphalt binder. Improvement in the total SFE was observed with addition of nanozinc oxide. Similarly, Hossain et al. [5] evaluated moisture damage potential of a PG64-22 binder modified with Cloisite-15A and Cloisite-11B using the SFE approach. Increase in the total SFE was observed with addition of nanoclay. However, decrease in compatibility between aggregate and asphalt binder was observed with addition of nanoclay indicating a poorer moisture resistive damage potential of nanoclay modified asphalt binder. Overall, the review of literature showed mixed trend of moisture damage resistivity of nanoclay modified binders. Also, it has not been extensively evaluated using the SFE approach.

Considering limited work reported on characterization of nanomaterials modified binders, the present study focuses on evaluation of rutting, fatigue and moisture damage potential of nanoclay modified asphalt binder using some recently developed advanced test methods and approaches. It is expected that present study would help in developing better understanding on characterization of nanoclay modified asphalt binders.

2. Objectives

The specific objectives of the present research study are to:

a. Evaluate rutting behaviour of nanoclay modified asphalt binders using Superpave rutting factor.
b. Evaluate effects of nanoclay on moisture susceptibility of asphalt binder and aggregate system using SFE approach.
c. Assess fatigue performance of asphalt binders with and without nanoclay using LAS test.

3. Theoretical background

3.1. Review on SFE

The SFE is defined as the magnitude of energy required to increase the unit surface area under vacuum condition [24]. The Acid-Base theory proposed by Van Oss et al. [24] divided total energy (λ_T) into three components as (a) Van der Walls/apolar (λ_{lw}), (b) Lewis/monopolar acid (λ_+) and (c) Lewis/monopolar base (λ_-) as expressed in Eq. (1).

$$\lambda_T = \lambda_{lw} + 2\sqrt{\lambda_+\lambda_-} \tag{1}$$

Using acid-base theory, work of adhesion (ΔW_{dry}) between two materials can be expressed in terms of their respective SFE components as given in Eq. (2).

$$\Delta W_{dry} = 2\left(\sqrt{\lambda^A_{lw}\lambda^B_{lw}} + \sqrt{\lambda^A_+\lambda^B_-} + \sqrt{\lambda^A_-\lambda^B_+}\right) \tag{2}$$

where, A and B represent aggregate and asphalt binder used respectively.

A higher value of work of adhesion indicates that higher energy will be required to create unit area of new surface in dry condition. Likewise, in wet condition, water tries to displace asphalt from aggregate surface, and creates two new interfaces (i.e., water - aggregate and asphalt-water), resulting in release of energy. Based upon the concept of interfacial energy, external work required for displacing binder from aggregate-binder interface is "$-\lambda^{AB}$". Similarly, work done for formation of two new surfaces is "$\lambda^{WA} + \lambda^{WB}$". The total work done to displace the asphalt binder from aggregate surface is known as work of debonding (ΔW_{wet}) as shown in Eq. (3). A lesser value of ΔW_{wet} is desirable to have moisture resistant mix [22].

$$\begin{aligned}\Delta W_{wet} &= \lambda^{WA} + \lambda^{WB} - \lambda^{AB}\\ &= 2\lambda^W_{lw} + 4\sqrt{\lambda^W_+\lambda^W_-} - 2\sqrt{\lambda^B_{lw}\lambda^W_{lw}} - 2\sqrt{\lambda^W_+\lambda^B_-} - 2\sqrt{\lambda^B_+\lambda^W_-}\\ &\quad - 2\sqrt{\lambda^A_{lw}\lambda^W_{lw}} - 2\sqrt{\lambda^W_+\lambda^A_-} - 2\sqrt{\lambda^A_+\lambda^W_-} + 2\sqrt{\lambda^B_{lw}\lambda^A_{lw}} + 2\\ &\quad \times \sqrt{\lambda^B_+\lambda^A_-} + 2\sqrt{\lambda^A_-\lambda^A_+}\end{aligned} \tag{3}$$

where, Superscript W, A and B represent water, aggregate and asphalt binder respectively.

Considering work of adhesion and work of debonding, Little et al. [19] defined a single term known as "Energy Ratio (ER)" which quantifies moisture damage potential of asphalt mixes as shown in Eq. (4)

$$ER = \left|\frac{\Delta W_{dry} - W^{BB}}{\Delta W_{wet}}\right| \tag{4}$$

where, W^{BB} represents work of cohesion of asphalt binder. Asphaltic mixture with higher ER value will have better moisture resistant potential and vice versa. Based on ER value, Bhasin et al. [21] recommended the following moisture resistant categories of asphalt mixes (a) good:[A], when $ER > 1.5$; (b) fair:[B], when $0.75 < ER < 1.5$; (c) poor:[C], when $0.5 < ER < 0.75$; and (d) very poor:[D], when $ER < 0.5$.