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Comparison of Wilhelmy plate and Sessile drop methods to rank moisture damage susceptibility of asphalt – Aggregates combinations

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HIGHLIGHTS

- The CA measurement by SD method showed high variability compared to the WP method.
- The SFE of asphalt measured by the SD method had higher values than that of WP.
- SD method found to be less sensitive to capture acidic component of SFE of asphalt.
- CR value of 0.25 by SD method would be approximately equal to 0.5 by WP method.

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ABSTRACT

The present study compares two techniques namely Wilhelmy plate (WP) and Sessile drop (SD) methods to rank moisture damage susceptibility of twelve different asphalt-aggregate combinations. Three asphalt binders: unmodified (VG30), polymer modified (PMB40), and crumb rubber modified (CRMB60) binders, and four aggregates (basalt, limestone, granite, and sandstone) were selected in this study. The contact angle of selected asphalt binders was measured using both WP and SD techniques. Thereafter, surface free energy (SFE) components of asphalt binders, bonding energy and compatibility ratio (CR) of selected asphalt-aggregate combinations were estimated. The results showed that the SD method showed a high variability in measurement of contact angle of asphalt binders compared to the WP method. The SD method found to be less sensitive to capture acid component of SFE of asphalt binders. Both the methods showed that PMB40-basalt, VG30-basalt, PMB40-limestone combination can have least susceptible to moisture damage. However, in majority of the cases (9 out of 12 asphalt-aggregates combinations, excluding PMB40-basalt, VG30-basalt, PMB40-limestone), both the methods resulted in different moisture damage ranking of asphalt-aggregates combinations. Currently set a minimum threshold value of CR as 0.5 based on the WP method for screening moisture damage susceptibility of asphalt-aggregate combination may not be applicable to the SD method. The present study develops a correlation between the CR of asphalt-aggregate combination estimated from the WP and SD methods.

1. Introduction

The moisture damage causes premature failure of asphaltic pavements. Many laboratory test methods namely, retained indirect tensile strength ratio, Hamburg wheel tracking, water immersion have been developed to evaluate moisture susceptibility of asphalt mixes. Though these tests are simple and easy to conduct, they exhibited a poor correlation with field performance [1,2]. Further, none of these tests describe a mechanism behind bonding and debonding of aggregates-asphalt system [1,2]. Recently, researchers reported that surface free energy (SFE) of asphalt binder and aggregates can be a promising parameter in identifying a moisture resistant mix [3–8]. The SFE of aggregate and asphalt binder is used to estimate dry and wet adhesion energy and compatibility ratio (CR) to evaluate moisture susceptibility of asphalt mixes. The SFE of asphalt binder is estimated based on measurement of contact angle. The two methods namely, Wilhelmy plate (WP) and Sessile drop (SD) are being successfully used by many researchers to measure contact angle of asphalt binders [1,4,6,9,10]. Both the WP and SD methods have different principle of measuring contact angle of asphalt binders. For example, WP method measured dynamic contact angle derived by principle of force difference, whereas the SD method measures static contact angle based on an image of a drop.

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The SD method is quick and simple to conduct compared to the WP method. The WP method is being used by many researchers to study effects of antistripping agent, warm mix additives on SFE of asphalt binder and to determine compatibility ratio (CR) of different types of asphalt-aggregate combinations [3–7,11]. A good correlation between the CR estimated from the WP method and laboratory tests has been reported by Bhasin and Little [4]. Similarly, Wei et al. [12], Wasiuddin et al. [7], Lambert et al. [13], Koc and Bulut [10] used the SD method to quantify effects of different type of additives on moisture susceptibility of asphalt mixes. These studies reported that the SFE concept can be used to select the appropriate treatment to minimize moisture damage in asphalt mixes.

A study by Little and Bhasin [1] suggested a minimum threshold value of CR as 0.5 to screen moisture resistant mix. A mix with a CR below 0.5 indicates high moisture damage potential and vice versa. However, this threshold value of CR was established based on SFE components of asphalt binder measured using the WP method. Therefore, it is important to understand if the set threshold value (CR = 0.5 based on the WP method) would work if the SFE components of asphalt binders are measured using the SD method. The present study shows that both methods can rank moisture sensitivity of an asphalt-aggregate combination in a different order. Though both the techniques are promising, limited studies [16,17] have been conducted to compare these methods for different types of asphalt binders and aggregates. Therefore, the present study was undertaken to compare the WP and SD methods to measure contact angle, SFE, dry and wet adhesion energy and CR of different asphalt-aggregate combinations. In addition, the present study first time evaluates performance of crumb rubber modified binder with varieties of aggregates. Three different types of binders (virgin, polymer modified, and crumb rubber modified) and four different aggregates (basalt, limestone, granite, and sandstone) were studied in the present study. A total of 12 aggregates-asphalt binder combinations (3 binders × 4 aggregates) were evaluated in this study. The contact angles of asphalt binders were measured using the WP and SD methods, and thereafter their SFE components were estimated. The SFE of different types of selected aggregates were adopted from literature [4]. Further, moisture susceptibility rank of different asphalt-aggregate combination was established based on the WP and SD methods. The study presents how both methods can differ in measurement of contact angle, SFE components and energy parameters. It is expected that the present study will be helpful in selection of an appropriate method for measurement of contact angle of asphalt binders and compatibility check of asphalt-aggregate combination to minimized moisture damage of pavements.

1.1. Objectives

The objectives of this research were to:

- Compare contact angle and SFE components of polymer modified, crumb rubber modified and unmodified asphalt binders measured using the WP and SD methods.
- Compare bonding compatibility of modified and unmodified asphalt binders with four different aggregates (basalt, limestone, granite and sandstone) using dry adhesion energy, wet adhesion energy and CR estimated from the WP and SD methods.
- Determine moisture susceptibility rank of different combinations of asphalt binders and aggregate based on CR value estimated from the WP and SD methods.

2. Background on surface free energy (SFE)

The SFE of a material is work required to create a unit area of new surface in vacuum [1]. According to the acid-base theory [14], SFE of any material is divided into three components namely: Non-polar or Lifshitz-van der Waals component (γ^{LW}), Lewis acid component (γ^{+}), and Lewis base component (γ^{-}). These components are used to estimate total SFE (γ) of a material as per Eqs. (1) and (2) [1]. Further, bonding energy of a material in presence and absence of water and CR are estimated based on SFE components.

$$\gamma = \gamma^{LW} + \gamma^{AB} \tag{1}$$

$$\text{where, } \gamma^{AB} = 2\sqrt{\gamma^{+}\gamma^{-}} \tag{2}$$

2.1. Bonding energy between aggregate and asphalt binder

2.1.1. Cohesion energy (W_{BB})

The bonding within asphalt binder is known as a cohesive bond. The cohesion energy (W_{BB}) is calculated using Eq. (3) [1].

$$W_{BB} = 2\gamma_B \tag{3}$$

where, γ_B = total SFE of asphalt binder.

2.1.2. Dry adhesion energy (W_{AB})

The dry adhesion energy (W_{AB}) is work required to detach coating of asphalt binder from aggregate surface in a dry state (Eq. (4)) [1].

$$W_{AB} = 2\sqrt{\gamma_A^{LW}\gamma_B^{LW}} + 2\sqrt{\gamma_A^{+}\gamma_B^{-}} + 2\sqrt{\gamma_A^{-}\gamma_B^{+}} \tag{4}$$

where, γ_A^{LW} and γ_B^{LW} = Lifshitz-van der Waals component of aggregate and asphalt binder, respectively, γ_A^{+} and γ_B^{+} Lewis acid component of aggregate and asphalt binder, respectively, and, γ_A^{-} and γ_B^{-} Lewis base component of aggregate and asphalt binder, respectively.

2.1.3. Wet adhesion energy (w_{ABW}^{wet})

The presence of water makes coating of asphalt binder to separate from aggregate. The wet adhesion energy (W_{ABW}^{wet}) of asphalt-aggregate combination can be estimated using Eq. (5) [1].

$$W_{ABW}^{wet} = \gamma_{AW} + \gamma_{BW} - \gamma_{AB} \tag{5}$$

where, γ_{AW}, γ_{BW}, and γ_{AB} are interfacial energy between aggregate-water, asphalt binder-water and aggregate-asphalt binder, respectively.

2.1.4. Compatibility ratio (CR)

Little and Bhasin [1] and Hossein et al. [9] suggested to estimate a compatibility ratio of aggregate-asphalt binder combination based on dry and wet adhesion energy. The CR is defined as ratio of wettability ($W_{AB} - W_{BB}$) to the wet adhesion energy (W_{ABW}^{wet}) as shown in Eq. (6) [1]. Little and Bhasin [1] reported that asphalt mix with CR below of 0.5 considered to have a poor moisture damage resistance.

$$CR = \left| \frac{(W_{AB} - W_{BB})}{W_{ABW}^{wet}} \right| \tag{6}$$