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Evaluating suitability of energy efficient and anti-stripping additives for polymer and Polyphosphoric acid modified asphalt binder using surface free energy approach

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HIGHLIGHTS

- Use of WMA additives may decrease bonding potential of Control binder with aggregate.
- Chemical based WMA performed better than foam and wax based WMA with Control binder.
- Use of hydrated lime with Control binder may result in negative effect.
- Hydrated lime addition may enhance performance with foam based WMA.
- Hydrated lime addition may degrade performance with chemical and wax based WMA.
- Basalt aggregate showed better bonding with asphalt binders compared to granite.

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ABSTRACT

Polyphosphoric acid (PPA) along with reactive elastomeric terpolymer (RET) are being used to enhance rheological performance of asphalt binders. However, PPA+RET modified asphalt binders results in higher working temperature, thus difficult to use it in practice. Therefore, some energy efficient warm mix additives (WMA) are used to decrease working temperature, to saving of energy and fuel. However, suitability of varieties of energy efficient additives for PPA+RET modified asphalt binders has not been evaluated so far. Similarly, performance of PPA+RET modified asphalt binder may deteriorate with addition of anti-stripping agent such as hydrated lime (HL), because acidic effects of PPA may be neutralized with basic nature of HL. The present study contributes to understand suitability of energy efficient additives and HL on bonding and debonding potential of PPA+RET asphalt binder (called Control binder) with two types of aggregates (basalt and granite) using surface chemistry based approach. The Control binder was blended with three different energy efficient WMA additives namely, Wax based (WB), chemical based (CB), and foam based (FB) along with HL. First contact angle of Control binder with WMA additives with and without HL was measured using Wilhelmy plate. Thereafter, acidic and basic surface free energy (SFE) components of selected asphalt binders were determined using acid-base theory. The SFE components of asphalt binders and aggregates were used to evaluate adhesion bond energies in dry and wet condition. Overall, the results showed that bonding potential of Control binder with selected aggregates decreased after addition of WMA additives. In fact, addition of HL with WMA additives further degraded the bonding potential of asphalt binders, thus nullifying the effects of anti-stripping agent. Out of three WMA additives, FB showed good results with HL compared to WB and CB. Basalt aggregates (basic) showed relatively better bonding behavior with Control asphalt after addition of WMA and HL additives as compared to granite (acidic) aggregates.

1. Introduction

Recently, Polyphosphoric acid (PPA) is being used to enhance rheological performance of asphalt binders [1,2]. The PPA is a mixture of triphosphoric acid, pyrophosphoric acid, and other higher acids and highly soluble inorganic compounds [3]. The addition

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of PPA acts as a catalyst to increase reaction between epoxy and asphaltene components of asphalt binders. The PPA breaks the agglomerates of asphaltene to form a superior dispersion in maltene phase, thus enhance stiffness characteristics of asphalt binder [2,4–7]. Fee et al. [6], Moraes et al. [8] and Orange et al. [9] reported that addition of PPA increased moisture damage resistance of asphalt mixes. However, Orange et al. [9] found that performance of PPA modified asphalt binder depends upon aggregate types. They reported that addition of PPA to polymer modified asphalt binder showed better moisture damage resistance with limestone aggregate compared to granite aggregate. Though addition of PPA resulted in increased stiffness and better rut resistant asphalt binder, the following concerns have been expressed by many researchers on using PPA modified asphalt binders are (i) higher mixing and compaction temperature, (ii) compatibility with antistripping agent, (iii) bonding-debonding characteristics with different aggregates.

Recently, it has been reported that high working temperature asphalt binders can be reduced using different types of WMA additives [10–13]. However, suitability of WMA additives for PPA modified asphalt binders has not been reported in open literature. Therefore, one of the contributions of the present study is to highlight performance of PPA modified with different types of WMA additives. Some researchers have reported that inclusion of WMA additives may lead to moisture damage of asphalt mixes, and thus use of antistripping agents are recommended along with WMA mixes [10,12,14,15]. Hydrated lime (HL) is considered as one of the effective antistripping agents to improve moisture damage resistance of asphalt mixes [16]. Falkiewicz [17] reported that addition of HL to PPA modified asphaltic mixes may produce synergetic effect subjected to optimum dosage of PPA and HL. However, direct addition of HL to PPA modified asphalt binder may not produce synergetic effect due to neutralization action between PPA and HL and thus may not yield the expected benefits [1]. Further, European Lime Association [18] reviewed the compatibility of HL with different WMA additives and found to be beneficial for WMA modified asphalt mixes. However, influence of HL addition to PPA+WMA modified asphalt binders on moisture damage resistivity potential is not well understood. Therefore, another contribution of the present study is to investigate performance of PPA+WMA modified asphalt binders with addition of HL. The surface chemistry of asphalt binder and aggregates play an important role to ensure a strong bond, thus improved moisture damage resistance of asphalt mixes [19]. As per the authors understanding, no study has been conducted to evaluate bonding-debonding characteristics of PPA modified asphalt binder containing WMA and HL additives using surface free energy (SFE) approach. The SFE approach is a promising technic to evaluate interfacial bond energies of aggregate-asphalt binder system in dry and wet condition, which help to determine their compatibility [20–22]. The SFE of asphalt binder and aggregates cannot be measured directly. Usually SFE of asphalt binder is determined based on its contact angle measured using either Sessile drop or Wilhelmy plate methods [19,20]. Similarly, universal sorption device (USD) is used for determining SFE of aggregates [23,24]. A detail discussion on SFE of asphalt binder and aggregates is being presented in this paper.

The present study was undertaken to evaluate the effect of three different types of WMA additives (Wax based, chemical based and foam based) on PPA + RET modified asphalt binder. Further, the effects of HL (antistripping agent) on bonding and debonding characters of PPA+RET modified asphalt binder with and without WMA for two types of aggregates was investigated using SFE approach.

1.1. Objectives

The objectives of the present study are to:

1. Study the effects of three different WMA additives and HL on surface free energy components of PPA+RET modified asphalt binder
2. Evaluate effects of WMA additives and HL on bonding-debonding characteristics and compatibility of asphalt binder with different types of aggregates.
3. Study the correlation between SFE acid/base (A/B) ratio of asphalt binders with energy ratio of asphalt binder-aggregate system, if any

2. Background on surface free energy

The SFE of any material is the work required to create a new unit surface in vacuum [20]. The SFE of material is divided into three components namely: Lifshitz-van der Waals component (γ^{LW}) (Non-polar component), Lewis acid component (γ^{+}), and Lewis base component (γ^{-}). Acidic and basic components together called as polar component (γ^{AB}). The total SFE (γ) is the sum of polar and non-polar components (Eqs. (1) and (2)) [20].

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

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

2.1. Energy between aggregate and asphalt binder

2.1.1. Cohesion and adhesion energy

Work of cohesion (W_{BB}) or cohesion energy is work required to break the bond within asphalt binder phase (Eq. (3)). Similarly, work of adhesion (W_{AB}) or adhesion energy is the work required to break the bond between asphalt binder and aggregate in dry state (Eq. (4)) [20].

$$W_{BB} = 2\gamma_{B} \tag{3}$$

where, γ_B = Total SFE of asphalt binder

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

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; γ_A^{-} *and* γ_B^{-} = Lewis base component of aggregate and asphalt binder respectively.

2.1.2. Wet adhesion energy (W_{ABW}^{wet})

Entry of water into the asphalt-aggregate system can displace asphalt binder from aggregate, resulting in reduction of total SFE of the system. The reduction in total SFE due to presence of water can be expressed by wet adhesion energy (W_{ABW}^{wet}), as shown in Eq. (5) [20].

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

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

Interfacial energy between any two materials "x" and "y" can be determined by their respective SFE components using Eq. (6) [20] as shown below.

$$\gamma_{xy} = \gamma_x + \gamma_y - 2\sqrt{\gamma_x^{LW}\gamma_y^{LW}} - 2\sqrt{\gamma_x^{+}\gamma_y^{-}} - 2\sqrt{\gamma_x^{-}\gamma_y^{+}} \tag{6}$$