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Investigating effects of using nanomaterial on moisture susceptibility of hot-mix asphalt using mechanical and thermodynamic methods

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HIGHLIGHTS

- Adding SBS nano-composite increased the adhesion and cohesion of the asphalt mixture.
- Adding SBS nano-composite significantly increased resistance to moisture damage.
- Use of SBS nano-composite increased the base component of SFE of the bitumen.

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ABSTRACT

One of the main reasons of premature damage to the asphalt layers of flexible pavements is the damage caused by moisture which is also called moisture damage or stripping. Stripping is defined as the loss of resistance and strength induced by moisture. Various methods have been used to decrease this type of damage using anti-stripping materials as the most common method. Problems associated with the practical application of anti-stripping materials coating aggregates and adverse effect of using bitumen-modifying additives have motivated us to investigate the effect of using styrene-butadienestyrene nano-composite as a new anti-stripping additive in hot-mix asphalt. In this study, besides applying modified Lottman test as a conventional test for moisture susceptibility, surface free energy methods were also utilized to determine the mechanism by which the considered nanomaterial affected cohesion and adhesion properties of asphalt mix components. Materials used in this study included two types of aggregates with different hydrophilic degrees (limestone and granite aggregates), bitumen with 60–70% penetration grade (PG 64-22), and SBS nano-composite with two different percentages. Results of the modified Lottman test showed that use of nano-composite improved the resistance of the asphalt mix manufactured by two types of aggregates used in this study. Also, the results of measuring surface free energy components of bitumen indicated that use of nano-composite increased the force required for producing the aggregate's stripping in the bitumen, which further improved the strength of the asphalt mix against moisture damage.

1. Introduction

Moisture susceptibility in asphalt mixtures commonly referred to as the potential for the occurrence of anti-stripping phenomenon, is one of the major damage occurring in flexible pavements. However, it must be pointed out that the effect of the presence of moisture in asphalt mix is not considered the most important factor for pavement stimulation, because two major causes of pavement stimulation and destruction are the application of traffic loads and temperature variations; however, moisture entrance into the asphalt mix can significantly increase the asphalt mix vulnerability against all the above-mentioned factors [1]. Two important questions related to this type of damage include: (1) methods that can decrease degree of moisture damage, and (2) methods and conditions that can accurately predict the potential for moisture damage [2].

Moisture damage potential for particular asphalt mixture depends on bitumen, aggregate properties, asphalt mix properties, weather, traffic, executive methods, and pavement design considerations. From the executive point of view, selecting aggregates

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and bitumen for a specific project is mainly based on the availability and financial issues and the option of changing the materials arises generally when other methods cannot produce the desired asphalt mix. Executive methods and asphalt mix properties can be altered to some extent; but, weather and traffic conditions are constant in a specific project. Therefore, it seems that the most logical approach to decrease the moisture damage in asphalt mixtures is the use of anti-stripping materials appropriate to the type of aggregates, bitumen, environmental conditions, and traffic [3]. A modifier is selected based on different conditions and experiences to improve the performance of the mixture against moisture damage [4]. There are two main methods for improving aggregate-bitumen adhesion and consequently decreasing the moisture damage in asphalt mixtures based on using anti-stripping additives. The first method is based on using liquid anti-stripping additives added to the bitumen in order to improve cohesion and adhesion properties of bitumen and bitumen-aggregates, respectively. In fact, the liquid anti-stripping materials are the chemical activators which alter the bitumen structure in order to increase the adhesion of bitumen-aggregates and provide better coating on the aggregates by the bitumen. Most of the liquid anti-stripping materials are from the family of amins and amidoamines [5]. The second method is based on the application of aggregates' surface coating by the appropriate materials which alter the surface properties of the aggregates, especially acidic aggregates and also decrease hydrophilic level of this type of aggregates so that the intensity of stripping would decrease when water enters the bitumen-aggregate system. Among the most widely used material in this regard is the hydrated limestone or polymer [5–7]. Although use of the above-mentioned materials decreases the moisture damage in asphalt mixtures, their applications are accompanied by a series of executive or technical problems [8–13].

Performance of hot-mix asphalt against moisture is a complicated topic which has been the focus of different studies during the last 6 decades. During this period, technicians and researchers in road and transportation laboratories and organizations have proposed different experiments in an attempt to achieve a reliable experiment which could be also in agreement with the results of field performance. The facts that the adhesion between bitumen and aggregates decreases in the presence of water and cohesive of bitumen disappears due to moisture have long been identified by asphalt mix workers. Generally, tests which have been used so far can be classified into two general categories: qualitative and quantitative [14,15].

Most of the tests used for determining moisture susceptibility provide advantages including quantification moisture damage in asphalt mixtures by materials' cumulative properties (bitumen and aggregates), mixture design parameters, and environmental conditions. Nonetheless, despite the above-mentioned advantages and commonality of these tests by road organizations, these methods suffer from a series of weaknesses such as weak correlation with field results, long testing time, lack of measurement of material properties related to stripping phenomenon, and inability to explain the reasons for good or weak performance of an asphalt mix against moisture [16]. Due to the mentioned weaknesses, many pavement research bodies have decided to identify new methods that use fundamental properties of the materials applied in the asphalt mix for detecting the mixture's moisture susceptibility [17]. The most important considered method is the surface free energy method, which has been established based on fundamental properties of materials that affect the asphalt mixture resistance against loss of adhesion and cohesion. The most important parameters used in the surface free energy method include cohesion of bitumen and adhesion of bitumen-aggregates under dry and wet conditions, in which these two parameters have the most important role in the occurrence and level of stripping phenomenon in real conditions [18].

Surface free energy is defined as the amount of energy required for creating a new surface unit (crack with surface unit) under vacuum conditions. The sum of these energies which are required for the occurrence of a rupture is called adhesion work, which must dominate the internal adhesion forces of the two materials in contact with each other [19]. Adhesion work and surface energies play a significant role in understanding adhesion and adhesion theories. Even a small change in these values would cause significant changes in the calculated adhesion [20]. Considering the results reported by the previous studies [21–24], it seems that use of surface free energy can be useful in detecting the moisture susceptibility potential and providing appropriate strategies to decrease this type of damage.

1.1. Literature review

Although studies on the moisture damage of asphalt mixtures have begun since 70 years ago, studies focusing on the use of thermodynamic methods for investigating moisture damage in asphalt mixtures are limited and quite novel.

Chang [21] conducted a comprehensive study on the concept of surface free energy as well as its measurement and application in pavement industry. He proposed two models for moisture damage based on the principle mechanism of moisture rupture. Results of the two proposed models showed correlation with the conducted field experimental results for moisture damage. In a study by Hefer [23], optimizations methods were followed for measuring surface free energy components of bitumen and aggregates along with factors effective for bitumen-aggregates adhesion. The results led to the introduction of a methodology for the use of surface free energy method to decrease the moisture damage. Howson et al. [22] created a database for surface free energy measurements, which could be useful as a diagnostic tool for finding reasons of weak resistance of different asphalt mixtures against moisture damage. Another application of this database was that an appropriate solution could be provided based on the components of surface free energy of adhesion and cohesion for different aggregate-bitumen mixtures, such as adding an appropriate anti-stripping material to strengthen the mixture against moisture damage. In a study, Arabani and Hamedi [6] studied the role of polymer coating of the aggregate surface on decreasing the moisture damage in asphalt mixtures using surface free energy method and dynamic modulus. They measured the surface free energy components of bitumen and aggregates in order to determine the surface free energy of cohesion for bitumen and adhesion for bitumen-aggregates. They showed in this study that results of surface free energy method had acceptable correlation with the experimental results of laboratory loading. Use of polyethylene coating on the aggregate surface increased the basic component and decreased the acid component of the surface free energy, which resulted in adhesion improvement between granite aggregates and bitumen with acidic properties. In another study by Arabani et al. [25], they studied the effect of using liquid additives on the moisture susceptibility of warm mix asphalt using thermodynamic methods. Results of this study demonstrated that using liquid anti-stripping additives increased the adhesion between the granite aggregates and bitumen. In the mentioned study, beside the surface free energy tests, dynamic modulus test was also used to determine the moisture susceptibility and the results demonstrated the positive effect of applying the liquid anti-stripping additives. Also, results of dynamic modulus tests could verify the validity of the results of surface free energy method. In 2012, Moghadas Nejad et al. [5] investigated the role of using hydrated limestone in determining the moisture susceptibility of asphalt

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