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Evaluating effectiveness of polymerized pellets mix additives on improving asphalt mix properties

Hamidreza Sahebzamani, Mohammad Zia Alavi *, Orang Farzaneh

School of Civil Engineering, University of Tehran, 16th Azar St., Enghelab Sq., Tehran 1417466191, Iran

HIGHLIGHTS

- Polymerize pellets are made of a high amount of SBS polymer and asphalt binder.
- Polymerized pellets can be added directly to the asphalt mix during production.
- Mixes with SBS modified binder and polymerized pellets showed relatively similar properties.
- Laboratory results should be validated based on the field performance of the mixes.

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ABSTRACT

Polymer-modified asphalt binders have been used for years to produce asphalt mixes with improved resistance to rutting, fatigue cracking, and thermal cracking. Special equipment and technique, which may not be always available, are required to produce polymer-modified binders with desired engineering properties. Recently, a new approach is introduced to facilitate the use of polymers in asphalt mixtures. Polymerized pellets mix additive, which contains a high amount of Styrene Butadiene Styrene [SBS] and asphalt binder, can be directly incorporated into the mix during production in asphalt plant without the need for any special equipment. Logistically, this new form of mix additive simplifies and expands the use of polymers even for small paving projects. However, due to the novelty of this technology, more research is required to assess its efficacy. In this paper stiffness, rutting, fatigue, and thermal cracking resistance properties of asphalt mix modified with polymerized pellets are compared to the mixes containing unmodified and polymer-modified binders. The effects of long-term oxidative aging on stiffness and strength of mixes were also evaluated. Results of this study showed that the polymerized pellets had similar effects as the SBS polymer-modified binder in improving stiffness, rutting resistance, fatigue cracking resistance, and low temperature cracking resistance of asphalt mixes.

1. Introduction

The benefits of using polymers to improve engineering properties of asphalt binder and consequently mixes have been well recognized. The main motivations for using polymers are to increase the resistance of asphalt to permanent deformation (or rutting), fatigue, and thermal cracking. With the dramatic increase in volume and weight of truckloads, pavement surfaced with conventional mixes could not perform well and reaches to failure before the end of expected design life. Therefore, polymer-modified asphalt (PMA) mixes can be used to resolve this issue. Research conducted by Asphalt Institute [1] showed that polymer-modified asphalt (PMA) mixes reduce cracking for about 50% and rutting for about 60% compared to conventional mixes. PMA mixes result in approximately 25% increase in service life (i.e., 2 to 10 years longer); thus, reduces frequencies of maintenance and rehabilitation and their associated costs.

Properties of polymer-modified binders depend on the polymer characteristics and content, nature of base asphalt binder, and the blending process [2]. Currently, the most commonly used polymer for asphalt binder modification is Styrene Butadiene Styrene (SBS), followed by other polymers such as Styrene Butadiene Rubber (SBR), Ethylene Vinyl Acetate (EVA), and polyethylene [3]. SBS polymers, as elastomers, increase the elasticity of asphalt binder, which makes them probably the most appropriate polymers for asphalt binder modification [4]. When SBS is blended with asphalt binder, the elastomeric phase of SBS absorbs light fractions (e.g. aromatic oils) from the binder and swells up to nine times

* Corresponding author.
E-mail addresses: hsahebzamani@ut.ac.ir (H. Sahebzamani), zia.alavi@ut.ac.ir (M.Z. Alavi), ofarzane@ut.ac.ir (O. Farzaneh).

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its original volume forming a three-dimensional network in asphalt binder. SBS can modify the performance of asphalt binder at high and low temperatures due to the widely separated glass transition temperatures (Tg) of the constituent phases. At temperatures between glass transition temperatures of the polybutadiene and polystyrene, SBS shows two-phase morphology including glassy polystyrene domains that are connected together by the rubber polybutadiene segments; thus, SBS exhibits cross-linked elastomer network behavior [5]. According to the findings of a recent study by Liang et al. [6], a moderate amount of styrene (about 30%) in SBS would be optimal to meet the desired compatibility and viscoelastic requirements of modified asphalt binders. Dong et al. [7] also reported similar findings with respect to the optimal ratio of styrene in SBS.

2. Background

Evaluation of properties of SBS modified asphalt binder and mixes has been the focus of many studies. Modaress [8] evaluated the influence of SBS polymer on fatigue and toughness properties of asphalt mixes. At 20 and 50 °C, higher Indirect Tensile Strength (ITS) values were observed for mixes with SBS modified binders compared to conventional mixes, but the trend was reversed at −10 °C. SBS modified mixes overall had higher toughness than conventional mixes. With respect to fatigue performance, SBS modified mixes showed higher fatigue lives than the conventional ones, especially at 20 °C and at higher strain levels (i.e., >250 micro-strain). Kim et al. [9] evaluated the strength and fatigue properties of SBS modified mastic asphalt mixes used for bridge deck pavements. Results revealed that the SBS modified mix had lower ITS values than the conventional mix at both -10 °C and 20 °C. The fatigue life was considerably 100 times greater for SBS modified mix, measured at 20 °C and at higher strain levels (i.e., 800–1200 micro-strain). Hao et al. [10] also found that modification of a soft binder (i.e., 120–140 penetration grade) with 5% SBS was successful to meet the requirements for a location in China with the minimum ambient temperature of −42 °C. Khodaii and Mehrara [11] evaluated the rutting performance of mixes made with modified binders containing different amounts of SBS using dynamic creep test performed at 40 and 50 °C. It was found that 5% SBS was more effective than 4% and 6% in improving rutting resistance properties. Yilmaz and Celoglu [12] compared the effectiveness of binder modification with SBS and different natural asphalts. Considering the efficiency by using additives, SBS was found to be the most appropriate one.

The rutting performance of SBS modified mixes was evaluated by Heavy Vehicle Simulator (HVS) testing [13]. The results showed that sections made with SBS modified mix distinguishably outperformed the ones made with the conventional mix. The mechanism of rutting in sections with the SBS modified mix was only densification (i.e., no showing). A study conducted by the National Center for Asphalt Technology [14] revealed that the test section paved with the highly polymer-modified mix (i.e., asphalt binder contained 7.5% SBS) outperformed the conventional section in terms of rutting and fatigue cracking after 20 million equivalent single axle-loads of trafficking and six years of environmental actions, despite being 32 mm (1.25 in.) thinner. The ride quality of highly polymer-modified mix section did not decay over time. The results of the test performed at the University of Nottingham [15] revealed that using modified binder containing 5% and 7% SBS improved rutting performance of asphalt mix. However, 5% of SBS was recommended considering the cost of production.

The aging potential of SBS modified binders is very critical considering the expected longer life for polymer-modified mixes. Gao [16] studied the effect of short and long-term aging on properties of SBS modified binders and concluded that SBS polymer fully degraded after long-term aging. Xu et al. [17] found that thermal oxidation in SBS occurs mainly in butadiene block through a self-catalyzed reaction. Wang et al. [18] observed that the polymerized network of SBS binder degraded to medium molecular size structure during short-term aging. After long-term aging, the SBS modified binder was completely degraded and its temperature susceptibility was close to the base binder due to the loss of modification effects. Zhang et al. [19] also found that the degradation of SBS polymer was more severe under UV radiation aging than just thermal oxidation.

Polymer-modified asphalt binders are produced through the mixing of asphalt binder and polymer at elevated temperatures for a length of time and usually using a high shear mixer. Usage of polymer-modified binders in developing countries is still a new technology. The industry has not yet encouraged the use of polymer-modified binder due to the limited resources and logistic difficulties such as the need for modification of asphalt plants, requirement for additional hot binder tanks and pumping facilities, and the known storage stability problems of polymer-modified binders. It is not very efficient to use polymer-modified binders to produce asphalt mixes in small quantities, especially when using the batch plant.

Polymerized pellets, with a high concentration of polymer, were recently developed and introduced to pavement industry to facilitate the use of polymers in asphalt mixtures. These polymerized pellets can be directly added to the pugmill during asphalt mix production without the need for increasing the mixing temperature. With proper mixing operation, uniformity of the mix and sufficient distribution of polymer within the mix can be achieved. Using polymerized pellets will also eliminate excessive aging of the base asphalt binder occurring during production of polymer-modified binder at high temperatures. To date, only commercial information is available on such mix additives. Therefore, research is needed to clearly understand their effectiveness and limitations.

3. Objective

The objective of this study was to evaluate performance-related properties of modified asphalt mixtures produced using SBS polymerized pellets in comparison with mixtures produced with unmodified and SBS modified binders. Stiffness, rutting resistance, fatigue potential, cracking at low temperatures, and aging susceptibility of mixtures were evaluated.

4. Experimental plan

4.1. Materials

Crushed Dolomite aggregates used in asphalt mixtures were obtained from Asbcheran quarry located near Tehran, Iran. The nominal maximum aggregate size was 19.00 mm. The gradation of aggregate structure and its consensus properties are provided in Tables 1 and 2.

Table 1
The Gradation of Aggregate Structure for Asphalt Mixes Evaluated.

Sieve	Passing (%)	Acceptable tolerance (%)*
¾ inch	100	100
½ inch	95	90–100
No. 4	58	44–74
No. 8	35	28–58
No. 50	10	5–21
No. 200	5	2–10

* According to Iran Highway Asphalt Paving Code No. 234.