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Evaluation of cracking properties of SBS-modified binders containing organic montmorillonite

Shengjie Liu [a,*], Sheng Bo Zhou [b], Yinshan Xu [c]

[a] College of Civil and Transportation Engineering, Hohai University, No.1 Xikang Road, Nanjing, Jiangsu 210098, China
[b] Guangxi Transportation Research Institute, Nanning, Guangxi 530007, China
[c] Zhejiang Scientific Research Institute of Transport, Hangzhou, Zhejiang 310006, China

HIGHLIGHTS

- Cracking properties of SBS-modified binders containing OMMT are analyzed.
- FTIR and XRD are used to reveal the structure type of OMMT/SBS modified asphalt.
- The compound modification of OMMT and SBS improve the intermediate and low-temperature cracking resistance.
- The effect of OMMT on the intermediate cracking resistance is not significant.

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ABSTRACT

In recent years, organic montmorillonite (OMMT) has become a popular additive for the Styrene–Butadiene–Styrene (SBS) modified binder to improve its storage stability. Though many studies have examined the effect of OMMT additive on asphalt performance, little research has focused on the cracking properties of SBS/OMMT-modified binders. In this study, SBS/OMMT-modified binders for asphalt were first produced using five SBS contents of 1%, 2%, 3%, 4%, and 5% and then blended with 3% OMMT additives. First, FTIR and XRD tests were performed to verify the structure of the asphalt/SBS/OMMT. Then, the intermediate-temperature fatigue cracking property was determined by the $G^{*}\sin\delta$ of pressure aging vessel (PAV) specimen through a dynamic shear rheometer (DSR) test, while the low-temperature cracking performance was characterized by the creep stiffness and m-value for the unaged, short-term aged, and long-term aged specimens through bending beam rheometer (BBR) tests. The results show that the OMMT/SBS modified asphalt has formed an intercalated structure and a nanocomposite. The compound modification of OMMT and SBS generally exhibited more intermediate-temperature cracking resistance than that of the single SBS-modified bitumen, but the influence of SBS and OMMT is statistically insignificant. Both SBS and OMMT play key roles in determining the m-value, and higher SBS contents lead to a lower stiffness under three aging conditions at low temperatures.

1. Introduction

Asphalt binder has been widely used in pavement construction to coat the aggregate and supply adhesive properties [1]. However, conventional asphalt could not satisfy the requirement of pavement as expected because of the extreme temperature and continuously increasing heavy traffic loads, which will weaken the durability of the asphalt pavement [2]. Therefore, many additives are used to improve the properties of the asphalt [3]. Polymers especially have been widely used for the modification of bitumen in the recent decades [4,5]. It is a common practice to use polymers to modify the asphalt.

Among these polymer additives, Styrene–Butadiene–Styrene (SBS) presents an excellent ability to ensure the pavement durability and sustainability [5,6]. The constituents of SBS are polystyrene (hard block) and polybutadiene (soft block), with a modulus that is very flat over a wide temperature range [7].Therefore, the SBS modified asphalt has a better resistance to temperature sensitivity. Furthermore, the Styrene component and Butadiene component in the SBS provide the strength and elasticity properties, which improve the mechanical property of the asphalt. However, due to the poor compatibility and immiscibility between SBS and bitumen, when they are exposed to the specific conditions (ultraviolet

* Corresponding author.
E-mail address: lsjwork@hhu.edu.cn (S. Liu).

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light, oxygen, moisture and heat), SBS is prone to separate from bitumen [8–12]. This will affect the performance of the pavement and deterioration.

To solve this problem, extra agents such as clays, functional groups, and crosslinking agents have been adopted to modify the asphalt [3]. Among these agents, organic montmorillonite (OMMT), a type of layered silicate clay, is believed to have advantages in enhancing the storage stability of asphalt [6,13–16]. When OMMT is added to polymer-modified bitumen (PMB), the layered silicate intercalates in the polymer chains on the nanometric scale, which will promote the intensive interaction between the OMMT and bitumen [17,18]. The mechanical and thermal properties of asphalt are improved by the surface/interface effects and small size effect, as the surface area is enormous [17,19]. Furthermore, montmorillonite could change layered silicate from hydrophilic into hydrophobic, which would ensure a better compatibility with other organic materials [20].

Numerous researchers have conducted extensive work to research and evaluate the effects of montmorillonite on asphalt performance. The results showed that the montmorillonite has positive effects on the performance of asphalt [13,16,21–26]. Specifically, for the SBS-modified asphalt, Jasso et al. (2012) studied the properties of asphalt containing montmorillonite clay and linear SBS and found that the montmorillonite clay had a positive influence on the rheological properties of the SBS-modified asphalt [27]. Zhang et al. [25] confirmed that the OMMT had a good aging resistance for the SBS-modified asphalt [25]. Tang et al. [28] found that the montmorillonite could prevent the thermo-oxidative aging of SBS-modified asphalt [28]. Yu et al. [6] and Pamplona et al. [1,29] all concluded that the storage stability and high-temperature performance had been improved by the presence of montmorillonite [6,29]. Muniandy et al. [30] explored the effect of organic nanoclay on the properties of the asphalt binder and found the organic nanoclay modified asphalts had higher rutting resistance and lower dissipated energy [30]. Zapién-Castillo et al. [24] indicated that the montmorillonite had enhanced the thermal storage stabilities, rheological behavior and morphology [24]. Dehouche et al. [31] also found that the nanocomposite asphalt had a higher complex viscosity and complex modulus compared to neat bitumen [31]. The results from the above studies indicate that the use of the appropriate amount of montmorillonite can result in an increase in the high failure temperature, storage stability and anti-aging ability.

However, although many research studies have conducted laboratory experiments to explore the effects of montmorillonite on the performance of the SBS-modified asphalt, limited studies have focused on the cracking properties of asphalt containing SBS and OMMT additives. In this research, the aim is to evaluate the intermediate-temperature fatigue and low-temperature cracking properties of SBS-modified binders containing organic montmorillonite. FTIR and XRD tests were first launched to verify the structure of asphalt/SBS/OMMT. The G∗sinδ of PAV asphalt, the stiffness and m-values of the original asphalt, the short-term aged (RFTO), and long-term aged (RFTO + PAV) asphalt were measured to study the cracking performance of SBS-modified binders with OMMT additive.

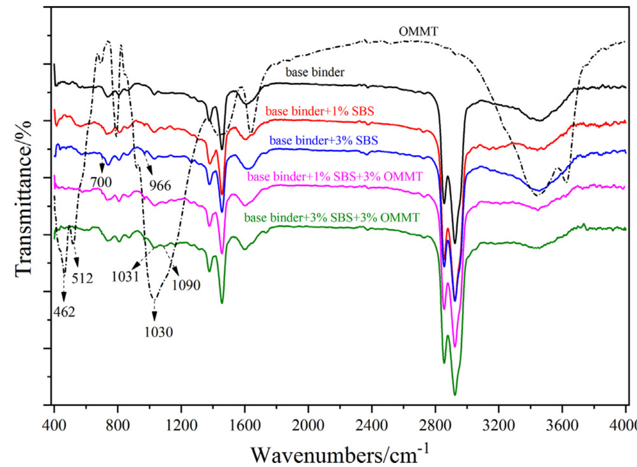

Fig. 1. FTIR results for OMMT and asphalt samples.

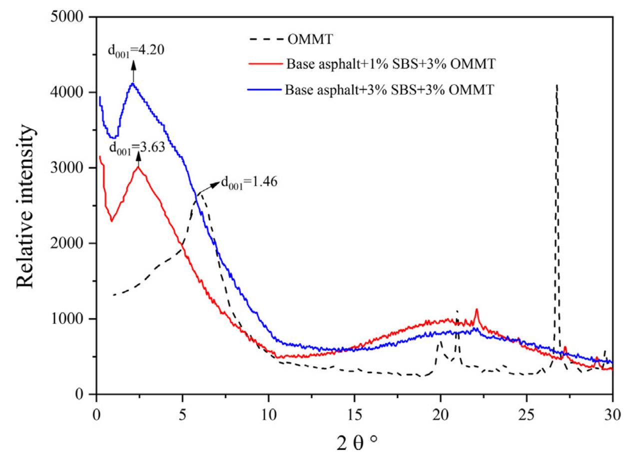

Fig. 2. XRD results from the OMMT and asphalt samples.

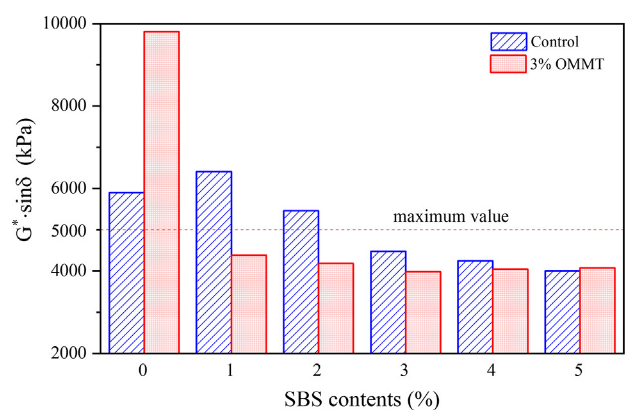

Fig. 3. G^{*}sinδ value at 25 °C (PAV residual).

Table 1
OMMT content in the existing studies and practices.

OMMT content	Asphalt type	Other additives	Literature
3.33 wt%	90# base asphalt	Ethylene vinyl acetate (EVA)	Xin Yan [14]
0–3 wt%	AH-90	Styrene-butadiene-Styrene (SBS)	Junyan Yi [32]
0–2 wt%	36–1 asphalt	Waste polyethylene (WPE)	Changqing Fang [16]
0–3.25 wt%	85/100 bitumen	Styrene-butadiene-Styrene (SBS)	Galooyak [12]
3 wt% (Optimal dosage)	Ssangyong-70	None	Jianzhong Pei [33]
<7 wt% (Optimal dosage)	AH-70	None	Xiaojiao Zhang [26]