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Effect of polystyrene grafted graphene nanoplatelets on the physical and chemical properties of asphalt binder

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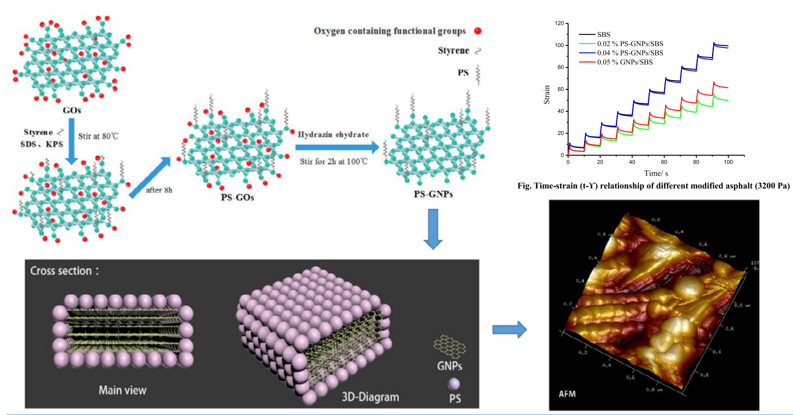
HIGHLIGHTS

- PS-GNPs were effectively used as modifiers to SBS for modified asphalt preparation.
- Spring-like PS-GNPs prepared by in-situ polymerization possessed higher toughness.
- PS-GNPs/SBS modified asphalt showed good performance in wide range of temperature.
- Anti-rutting performance of PS-GNPs/SBS modified asphalt was greatly enhanced.

GRAPHICAL ABSTRACT



Effect of Polystyrene Grafted Graphene Nanoplatelets on the physical and chemical properties of asphalt binder

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ABSTRACT

Polystyrene (PS) grafted graphene nanoplatelets (GNPs) composite (PS-GNPs) was prepared by in-situ polymerization and applied as modifier to Styrene-butadiene-styrene (SBS) for modified asphalt preparation. Specific amount of PS-GNPs incorporation improved ductility, softening point and penetration while DSR, MSCR, BBR and LAS tests showed enhancement in viscoelastic, high temperature rutting resistance performance, anti-fatigue and low temperature performance of the parent asphalt. FT-IR, XRD, SEM and AFM techniques confirmed the successful grafting of PS onto GNPs surface, which increased the interplanar spacing of GNPs with a spring-like macromolecular structure. It was deduced that PS grafted onto GNPs surface dissolved the SBS network in modified asphalt, thus greatly improving its dispersions. This study could be of great help for highway and construction industries.

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1. Introduction

In recent years, graphene nanoplatelets (GNPs) have been rapidly developed and widely studied [1–3]. It has large shape ratio (diameter/thickness) and specific surface area (SSA), and their scalable pore dimension and surface properties can be chemically controlled to desired demands and applications [4]. These GNPs modifications provide a wider range of applications by modified materials. In particular, its prospects for road materials are more interesting and has been the center of research for many groups [5–7].

The studies of Peyvandi et al. [8] have shown that the incorporation of surface modified GNPs into concrete can improve the acid resistance and reduce water absorption by concrete, which is attributed to the smaller spacing between molecules and high specific surface area of GNPs. Yan et al. [9] found that the addition of 3% GNPs increases the mixture strength of Styrene-Butadiene-Styrene (SBS) modified asphalt to about 80–150%. Furthermore, the effects produced by GNPs in modified asphalt are quite different compared to classical additives, hence making the former of great scientific interest. According to the US Department of Transportation [10], GNPs can effectively improve the penetration, softening point, ductility and high temperature performance of SBS modified asphalt, and can reduce its porosity, which can improve durability of the road material. Although the reported GNPs/SBS composites have improved the strength and high temperature properties of asphalt, the toughness of GNPs/SBS modified asphalt has decreased at low temperature, which is not conducive to the application of composite materials. For example, Gao et al. [11] found that GNPs addition can improve the rutting performance at intermediate temperature, while lower temperature compaction exerts detrimental effects. Le et al. [12] reported that GNPs as a modifier with SBS can effectively enhance high temperature performance of asphalt, but faced serious compatibility problems. These reports show that modifying asphalt by GNPs is attractive and worth digging but concomitantly a challenging job due to serious compatibility issues between the modifier and asphalt molecules and low temperature performance. In this regard, incorporation of PS-GNPs composite and SBS as a modifier (PS-GNPs/SBS) could offer a new way of modifying asphalt with minimized issues of compatability and low temperature performance. Up to our knowledge, no reports on the application of PS-GNPs as a modifier to SBS modified asphalt can be found in literature so far.

Thus, in this paper, we, for the first time report the preparation of modified asphalt by SBS and a novel in-situ polymerization prepared composite of PS-GNPs [13–17]. Mechanical analysis of the modified asphalt [18], dynamic shear rheometer (DSR) and multi-stress creep recovery (MSCR) tests, and asphaltene segregation test showed that incorporation of PS-GNPs significantly improved high temperature rutting resistance, low temperature cracking resistance, viscoelastic properties, anti-fatigue property, low temperature performance and storage stability of SBS modified asphalt. The mechanism of PS-GNPs in SBS modified asphalt was explained from chemical analysis by Fourier transform Infra-red (FTIR) spectroscopy, Scanning electron microscopy (SEM) [19,20], X-ray diffraction (XRD) and Atomic force microscopy (AFM) [21–23]. The data regarding mechanical properties and performance of PS-GNPs incorporated SBS modified asphalt reported herein, are superior to some earlier reports [24,25]. Furthermore, current approach is easy in operation and cost effective with high performance of the resulting modified asphalt compared to some previous reports [24,26].

2. Preparation of GNPs/SBS composite modified asphalt

2.1. Materials and methods

2.1.1. Materials

All the reagents used in this study were of analytical reagent grade and used without further purification. Original asphalt (AH-70, ESSO) and Linear SBS modifier (YH791 type) were supplied by Shandong heavy traffic bridge Engineering Co., Ltd. China. Sublimation sulfur (CP) was provided by Sinopharm Group Chemical Reagent Co., Ltd. Multilayer graphene nanoplatelets (SSA: <50 m^2/g, thickness <20 nm and purity: 90%) was supplied by Suzhou Carbon Fung Electronic Technology Co., Ltd. China. Multilayer Oxidized graphene nanoplatelets (film diameter: 10–50 µm, thickness: <20 nm, SSA: 100–300 m^2/g) was purchased from Suzhou carbon abundance Electronic Technology Co., Ltd. China. Styrene was supplied by Chengdu Kelon Chemical Reagent Factory, China. Sodium dodecyl sulfate (SDS) and 80% Hydrated hydrazine were obtained from CP, Guangdong Chemical Reagent Engineering Technology Research and Development Center, China. Potassium persulfate (KPS) was supplied by Chengdu Kelon Chemical Reagent Factory, China.

Table 1
Specifications and test conditions of SBS-YH791.

Type	Test conditions	Test Data
Melt flow rate	ASTM D1238	0.15–5.0 g/min
300% Tensile stress	–	≥2.0 MPa
Elongation at break	–	≥700%
Shore hardness	–	≥68 A
Tensile Strength	ASTM D638	≥15.0 MPa
Permanent deformation	ASTM D790	≤40%
Volatile	–	≤0.70%
Ash content	–	≤0.20%

Table 2
Specifications and test conditions for ESSO-AH-70#.

Test Type		ESSO-AH-70#		Experimental method
		Measured value	Prescribed value	
Penetration 30 °C (0.1 mm)		115	–	T0604
Penetration 25 °C (0.1 mm)		69.7	60 ~ 80	T0604
Penetration 15 °C (0.1 mm)		28.9	–	T0604
Penetration index (PI)		−0.4	−1.0 to 1.0	T0604
Ductility (5 cm/min) 10 °C (cm)		80.6	≥25	T0605
Ductility (5 cm/min) 15 °C (cm)		>150	≥100	T0605
Softening Point (°C)		48	≥46	T0606
60 °C dynamic viscosity (Pa·s)		110	–	T0620
Density (15 °C)/g/cm^3		1.032	–	T0603
Wax content		2.02	≤2.2	T0615
Rotating film heating test (163 °C, 85 min)	Loss of quality (%)	−0.215	−0.8 to 0.8	T0609
	Penetration ratio (%)	67.96	≥61	T0609, T0604
	Ductility (5 cm/min)-10 °C (cm)	8.57	≥6	T0609, T0605