Construction and Building Materials 170 (2018) 217–224

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Integrated utilization of recycled crumb rubber and polyethylene for enhancing the performance of modified bitumen

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HIGHLIGHTS

- Integrated modification by using CR and PE improved the bitumen properties at both high and low temperatures.
- Integrated modified bitumen obtained comparable rheological properties with the SBS modified bitumen.
- The integrated modified bitumen has much more economic benefit than SBS modified bitumen.

ARTICLE INFO

Article history:
Received 5 September 2017
Received in revised form 29 October 2017
Accepted 9 March 2018

Keywords:
Modified bitumen
Crumb rubber
Polyethylene
Permanent deformation
Thermal cracking

ABSTRACT

With the development of urbanization, a huge amount of wasted vehicle tyre and wasted green house plastic film are generated everyday and they have a potential risk for human health and environment. In this article, an integrated modification method was developed by proportionally using recycled crumb rubber (CR) from vehicle tyre and polyethylene (PE) from wasted green house plastic film in the bitumen in order to modify its functioning in pavements. Experimental tests such as Softening point, Penetration, Dynamic Shear Rheometer (DSR), Multiple Stress Creep Recovery (MSCR) and Bending-Beam Rheometer (BBR) were carried out in comparison with the bitumen properties. Analysis on physical and rheological performance of modified bitumen binders indicated the addition of CR decreased the bitumen creep stiffness at low temperature which in turn reduced the brittleness and cracking risk. Meanwhile, the addition of PE increased the bitumen stiffness at high temperature. According to the morphology analysis, two continuous twisted phases were formed in the modified bitumen, which indicated enhanced rheological property and high-temperature performance. The addition of CR and PE cooperatively improved the bitumen properties at both high and low temperatures. Consequently, the utilization of these two waste materials not only improved the pavement performance with the modified bitumen, but also minimized their disposal at landfills.

1. Introduction

Since 2016, total expressway length in China is over 130 thousand km. In the field of pavements, the asphalt mixture is the dominant material for surface paving course. Asphalt mixture is produced at high temperatures by mixing predetermined ratio of aggregates (coarse and fine), bitumen and filler, after paving and compaction process to form a flexible pavement [1]. The physical and rheological properties of bituminous binders play an important role in the performance of asphalt mixtures [2,3]. Sybilski et al. reported that bitumen properties have approximately a 40% contribution to the rutting resistance of asphalt pavement [4]. In high-temperature regions, rutting (permanent deformation) is a major distress of asphalt pavements, where mixtures placed in the wheel paths compact to form a groove or rut due to a heavy vehicle. It is important to improve the bitumen properties so as to accommodate increasing traffic loading and environmental attack.

Traditionally, the incorporation of polymer based materials in bitumen by mechanical mixing or chemical reaction can significantly improve the properties of the conventional bitumen [5,6]. There are numerous polymer agents applied for bitumen modification which can generally be classified into two categories: thermoplastic elastomers and plastomers [7]. Thermoplastic elastomers are a type of copolymers exhibiting both thermoplastic and elastomeric properties which can resist permanent deformation under loading and elastically recovering once unloading [8]. There are several thermoplastic elastomers, such as styrene-butadiene

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https://doi.org/10.1016/j.conbuildmat.2018.03.080
0950-0618/

styrene (SBS), styrene-isoprene-styrene (SIS) and styrene-ethylene/butylene-styrene (SEBS), were successfully used for bitumen modification [9,10]. Although these agents are capable of increase the bitumen complex modulus and viscosity to some extent, but the price is extremely higher than the conventional bitumen. Plastomers combined qualities of elastomers and plasticsus ually result in improved permanent deformation at elevated temperatures. The commonly used plastomers for bitumen modification include polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate (EVA) and ethylene-butyl acrylate (EBA) [11,12]. However, use of these plastomer agents cannot improve the elastic recovery of bitumen which in turn failed to improve the low-temperature properties of asphalt mixtures [8].

Nowadays, in modern cities, a huge amount of wasted vehicle tyre and wasted green house plastic film are generated everyday. Commonly, these wastes management is to dispose at landfills, which certainly have a potential risk for human health and environment due to hazardous components in these wastes. It has been estimated that over 10 billion tires are discarded worldwide every year and the inadequate disposal of tyre pose a potential to fire risk, rodents, soil pollution and water pollution which eventually threat to human health and environment [13,14]. Besides, the improper disposal of wasted plastic film pollutes the soils through atmospheric precipitation, water irrigation, and fertilizer application, which threats to human health through contamination of the food chain [15,16]. Therefore, their recycling and reuse is becoming great significance and has been focused by many researchers [17,18].

In this article, the use of recycled crumb rubber (CR) and Recycled PE to modify the performance of bitumen has been researched. Previous researchers recognized that the CR is able to improve the resistance of bitumen to permanent deformation, fatigue cracking and crack reflection at both high and low in-service temperatures [19–21]. Additionally, researchers found that the PE can bring a high rigidity to the bitumen and improve its deformation resistant under traffic load at high in-service temperatures [22,23]. Since these two materials have high decomposition temperature, high resistance to ultraviolet radiation and are mostly not biodegradable, they can remain for years causing environmental pollution [24]. From an environmental and economic standpoint, the application of these recycled materials cannot only improve the performance of road pavement, but also solve a waste disposal problem [21]. Besides, the price of these two additives is significantly lower than the commonly used commercial modifying agents.

The main aim of this paper was to develop an integrated bitumen modification method by using these cheap recycled waste and their unique characteristics in order to overcome some drawbacks of commonly used modified bitumen. One type of additive was first added to bitumen with different dosages to characterize the influence of a single component on the bitumen property. Then, these two recycled waste additives were mixed with bitumen and finally determined the best formula for integrate modification. Fluorescence Microscopy (FM) technique was carried out to characterize the morphology of the integrated modified bitumen and evaluate the homogeneity and phase structure. Experimental tests such as Softening Point, Penetration, Dynamic Shear Rheometer (DSR), Multiple Stress Creep Recovery (MSCR) and Bending-Beam Rheometer (BBR) were applied to analyze the mechanical performance of bitumen at both low and high temperatures.

2. Materials and sample preparation

2.1. Materials

One type of 70# base bitumen was selected to prepare modified bitumen. This is widely used for expressway construction in China. Commercial SBS modified bitumen (with the SBS dosage of 5%) which was produced using the same 70# base bitumen was selected as a reference to compare the properties with the modified bitumen by using selected recycled agents. These two bitumen were all supplied by Huarui Road Material Company. The physical properties of these two bitumen are listed in Table 1.

The CR derived from reclaimed vehicle tyre was selected as one additive for bitumen modification. The tyre was first shredded and chipped using large machinery to obtain rubber shreds [13]. Furthermore, large rubber shreds were experienced ambient grinding process to reduce the particle size in the range of 0.4–0.8 mm, as showed in Fig. 1a. Another additive, reclaimed PE was produced from wasted plastic greenhouse film. The wasted plastic film experienced cleaning, drying, extrusion and pelleting process to obtain the reclaimed PE with the particle size of 2.0–3.0 mm, as showed in Fig. 1b. The CR and PE used in this research were supplied from Shandong Qilufa transportation technology co. Ltd.

2.2. Sample preparation of modified bitumen

Before preparing the modified bitumen, the contribution of a single additive to bitumen property should be evaluated. Therefore, the modified bitumen with single additive was first prepared. The bitumen was heated to 160 °C until it has melted. Then, the additive was added to the bitumen with different dosage (11% and 15% for CR, or 6% and 7% for PE) and followed by swelling process at 160 °C for 1 h [25]. During swelling process, the polymer agents can adequately contact with the hot bitumen to make the agents expand and soft. Furthermore, the hot bitumen with additive experienced high-speed shear process at the speed of 5000 r/min for 1 h to obtain essentially homogeneous modified bitumen. The same procedure was applicable to prepare integrated modified bitumen by adding both CR and PE agents with different dosages. Well mixed modified binders were stored at room temperature and ready for further evaluation.

Herein, three groups of bitumen including ten samples were investigated in the next section as listed in Table 2.

3. Methodology

3.1. Morphology evaluation

A Fluorescence Microscopy (FM) test was performed to evaluate the morphology of binders before and after modification. By attempting this test, factors such as the dispersion state of polymer additives as well as the nature of continuous and discontinuous phases in the modified bitumen can be characterized [26,27]. During testing, polymer components in the modified bitumen can be illuminated by fluorescent light so that the polymer rich phase appears light while the bitumen rich phase appears dark or black [26]. It has been reported that the FM test is the most advantageous method to study the morphology of polymer modified bitumen due to its ability to observe the homogeneity and the structure in the raw state [26,28].

By preparing specimens for FM test, the liquid bitumen was first dropped in the center of a clean glass slide and followed by covering a piece of glass slide on the top. Then, covered samples were placed in an oven at 135 °C for 5 min with the view of obtaining a smooth and flat surface. After cooling down to room temperature, these samples were examined under a microscope with the images were taken with a digital camera.

3.2. Conventional bitumen tests

The ring and ball test was performed based on the ASTM D36 standard to evaluate the softening point of bitumen before and after modification. According to ASTM D5, the penetration test

Table 1
Physical properties of bitumen.

Property	Sample	
	Base bitumen	SBS modified bitumen
Softening point (°C)	46.2	61.3
Penetration (25 °C, 0.1 mm)	68.2	53.9
Ductility (15 °C, cm)	>100	>100