Construction and Building Materials 169 (2018) 276–282

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effects of ethylene vinyl acetate and nanoclay additions on high-temperature performance of asphalt binders

Elfadil A.A. Siddig [a,b], Cheng Pei Feng [a,*], Li Yi Ming [a]

[a] Civil Engineering Department, Northeast Forestry University (NEFU), P.O. Box 150040, Harbin, PR China
[b] Civil Engineering Department, Faculty of Engineering Sciences, University of Nyala, P.O. Box 155, Nyala, Sudan

HIGHLIGHTS

- Nanoclay (NC), EVA copolymer, and polymer-modified nanoclay (PMN) were used.
- The physical and rheological properties of modified asphalt binders improved.
- Adding EVA and NC reduced the temperature sensitivity of the asphalt binder.
- PMN-modified asphalt is potentially more resistant to rutting at high temperature.
- Addition more than 5 wt% NC does not provide significant improvement.

ARTICLE INFO

Article history:
Received 20 October 2017
Received in revised form 27 February 2018
Accepted 1 March 2018

Keywords:
Modified asphalt
Ethylene vinyl acetate
Nanoclay
Rheological behavior
Aging index
Rutting parameter

ABSTRACT

This study investigates the effects of adding ethylene vinyl acetate (EVA) copolymer and nanoclay (NC) on the high-temperature performance of asphalt binders. Three different types of modified binders were prepared using melt blending, NC-, EVA-, and polymer-modified nanoclay at concentrations of 1, 3, 5, and 7 wt%. Their physical and rheological properties were evaluated by conventional tests (penetration and softening point), viscosity measurements, and a dynamic shear rheometer. The results show that EVA and NC significantly improve the binder properties. Specifically, the rutting parameter increased after binder modification indicating its superior performance at high temperatures.

1. Introduction

Asphalt is widely used as a binder in pavement construction worldwide due to its good viscoelastic properties and superior service performance. However, asphalt is sensitive to temperature, and changes in climatic conditions substantially reduce the quality of asphalt pavement causing various defects, such as rutting at high temperature and cracking at low temperature. Additionally, asphalt pavements experience heavy traffic loads, which substantially reduce their quality [1]. Hence, proper modification of asphalt must be performed to develop high-quality safe, reliable, and environment-friendly pavement materials [2].

The ideal properties of asphalt binders are purely theoretical and cannot be fully implemented in practice. Therefore, various modifiers must be used to enhance their rheological characteristics. Although different types of materials were previously utilized for asphalt modification, the best results were obtained for polymers [3,4]. The high elasticity of polymer modifiers enhances the durability of asphalt binders and increases the range of their service temperatures [5]. In addition, polymers can be added to asphalt materials to improve their toughness and viscosity. Thus, polymer-modified asphalts (PMAs) have been widely used for several decades, and the range of their industrial applications is expected to increase in future, especially in the developed world [6].

Among various polymer modifiers, plastomeric ethylene-vinyl acetate (EVA) copolymers and thermoplastic block copolymers have attracted large attention in the field of asphalt pavements [7]. The addition of EVA significantly improves the stiffness of asphalt pavements and, therefore, reduces their degree of permanent deformation caused by the heavy traffic loads at high temperatures. However, despite the extensive research studies conducted

* Corresponding author.
E-mail addresses: elfadil@nefu.edu.cn (E.A.A. Siddig), chengpeifeng@126.com (C.P. Feng).

https://doi.org/10.1016/j.conbuildmat.2018.03.012
0950-0618/

in the field of plastomers, their effects on the high-temperature performance of PMAs were not investigated in sufficient detail due to the complex nature of the interactions between the asphalt and the polymer [8].

Recently, nanomaterials have received considerable attention as additives for infrastructural materials. While several researchers reported the use of nano-additives in Portland cement materials, very few studies have been published on the application of nanomaterials in asphalt pavements, including nanoclays (NCs), monohydrated lime, nanosilica, nanosized plastic powders (polymerized powders), nanotubes, and nanofibers [9,10]. Among these materials, NCs are considered the most popular since they can increase the aging resistance and softening point of asphalt binders by improving their rheological properties and stiffness and reducing their phase angle [3,6]. In general, NC modifiers are of two types: nanomodified nanoclays (NMNs) and polymer-modified nanoclays (PMNs). NMNs are the most frequently used layered silicates with a 2:1 superimposed clay structure, which consists of one octahedral alumina sheet inserted between two tetrahedral silica layers, as described by Ray and Okamoto [11]. The thickness of NMN layers varies from 1 nm to 100 nm, and they are commonly used to improve the mechanical and thermal properties of the modified matrix [2]. NMNs can be obtained via melt processing, in situ polymerization, and solution blending [12].

To improve the high-temperature properties of asphalt binders, we compare PMNs obtained from NC and EVA with unmodified asphalt and NC- and EVA-copolymer-modified asphalt binders because the some limitations have been reported for the polymer, including a high cost, low compatibility with bitumen, and poor stability during storage [13]. The PMN was prepared at a 60:40 mass ratio (EVA:NC) and was used to modify asphalt in percentages ranging from 1 wt% to 7 wt% with respect to the weight of the asphalt. Thus, the use of PMNs offers a double advantage: (i) improving the polymer and asphalt properties and (ii) compatibilizing the polymer and asphalt [7,13]. Furthermore, PMNs have been used to improve asphalt binder performance while reducing the cost of the polymer by replacing 40% of the EVA content with NC and consuming less time and temperature during the production.

The aim of this study was to investigate the effects of the NC and EVA additions on the high-temperature properties of an asphalt binder by performing conventional penetration, softening point, and viscosity tests as well as rheological (dynamic shear rheometry, DSR) studies. Further, the aging behaviors of the virgin and modified asphalts were examined using a rolling thin film oven (RTFO).

2. Materials and methods

2.1. Materials

The unmodified asphalt binder used in this study was AH-70# (hereafter, AH for simplicity), and its various physical and rheological properties including penetration depth, softening point, viscosity, and specific gravity are listed in Table 1. EVA copolymer with a vinyl acetate content of 28 wt% was used as the polymer modifier, and its physical and mechanical properties are listed in Table 2. The utilized NC modifier was derived from montmorillonite clay, and its properties are described in Table 3.

Table 1
Conventional properties of the AH-70# asphalt binder.

Test	Standard	Result
Penetration depth (100 g, 5 s, 25 °C), 0.1 mm	ASTM D5	75.5
Ductility (25 °C, 5 cm/min), cm	ASTM D113	150+
Softening point (°C)	ASTM D36	48.7
Viscosity at 135 °C (Pa s)	ASTM D4402	1.12
Specific gravity at 25 °C (g/cm^3)	ASTM D70	1.03
RTFO testing. Mass change after 85 min at 163 °C (%)	ASTM D2872	0.08
Flash point (°C)	ASTM D92	320
Retained penetration after RTFO testing (%)	ASTM D5	63.5
Softening point (°C) after RTFO testing	ASTM D36	51.4

Table 2
Physical and mechanical properties of EVA.

Property	Value
Density (g/cm^3)	0.9335
Tensile strength (MPa)	29
Melting Point (°C)	290
Flexural modulus (MPa)	3100
Elongation at break (%)	800
Water Absorption (%)	0.07

Table 3
Physical and chemical properties of the NC modifier.

Property	Value
Base	Montmorillonite
Concentration of modifier (%)	48
Moisture content (%)	1
pH	7.1
Free space between particles (Å)	60
Specific surface (m^2/g)	80
Density (g/cm^3)	5–7
Particle size (nm)	9

2.2. Sample preparation

In this study, all modified asphalt samples were prepared using a mechanical mixer and a high-shear mixer. About 500 g of virgin asphalt was heated to 165 °C to reach a viscosity level of about 0.175 Pa s [14]. After that, various mass concentrations of EVA and NC (1%, 3%, 5%, and 7%) were added gradually to the base binder while mixing at a speed of 500 rpm for 15 min using the mechanical mixer. Subsequently, the obtained samples were transferred to the high-speed mixer and blended at a speed of 4500 rpm, constant temperatures of 180 ± 5 °C (for EVA) and 145 ± 5 °C (for the NC), and durations of 90 and 45 min, respectively [2,13,15]. The resulting mixtures were degassed for 5 min to remove the air molecules entrapped during mixing.

The PMN was prepared using melt blending for its efficiency and simplicity. The conventional twin-screw extruder and high-shear mixer stirred at a rate of 60 rpm for a time of 15 min at 185 °C. Next, the product was cooled for nearly 3 h, and finally, the desired amount of PMN was added to the asphalt to prepare the modified asphalt binder at a shearing rate of 4500 rpm for 60 min at 150 ± 5 °C.

2.3. Testing procedure

The conventional penetration depth, softening point, rotational viscosity, and DSR measurements were performed in accordance with the ASTM specifications to evaluate changes in the physical and rheological properties of the NC-, EVA-, and PMN-modified asphalt specimens and compare them with the corresponding parameters of the unmodified asphalt binder. At least three samples were measured for each type of specimen, and the average of three values was considered the result.

Penetration testing was used to evaluate the consistency of the binder by measuring the vertical depth of the asphalt specimen