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International Journal of Pavement Research and Technology 10 (2017) 148–157

www.elsevier.com/locate/IJPRT

Characteristics of asphalt binder and mixture containing nanosilica

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Received 20 June 2016; received in revised form 23 September 2016; accepted 30 November 2016
Available online 19 December 2016

Abstract

The aim of this study is to address the feasibility of using nanosilica (NS) in bituminous pavements from the perspective of asphalt binder and corresponding mixture characteristics. In this paper, the characteristics of asphalt binder containing 0%, 2%, 4% and 6% of NS have been investigated in terms of the penetration, softening point, viscosity, and changes in chemical bonds using the Fourier Transform Infrared (FTIR) Spectroscopy. An additional laboratory study was conducted to characterize the performance properties of the corresponding asphalt mixtures based on the resilient modulus, indirect tensile strength, fracture energy, moisture susceptibility, and fatigue life. Overall, the addition of NS material has a positive influence on different properties of the asphalt binder and mixture and can be used to construct durable pavements, thereby reduce the life-cycle costs of the pavement.

Keywords: Nanosilica; Binder properties; Mixture; ITS; Fatigue

1. Background and introduction

When the asphaltic materials do not satisfy the requirements for constructing a well-performing bituminous structure, modification usually is adopted as one of the best and most attractive strategies for meeting the desired properties of used materials. Better engineering of complex materials such as asphalt at the nano level will result in a range of newly introduced smart characteristics. Researchers have tried to utilize different types of additives to alter the performance of the bituminous materials in a good way [1,2]. Feynman concept [3] and the revolutionary achievements in different sciences have motivated the possibility of engineering materials at an extremely small level (molecules and atoms) [4–6]. Since the last decade or so, nanotechnology has been intense to help to enhance the performance and construct durable pavements. Nanotechnology is the engineering of structures at the nanoscale to produce materials with characteristics comparable to same materials at the regular size [6,7]. Basically, it is new tactics of making things understandable and controlled over fundamental building scales (i.e. atoms, molecules, and nanostructures) of all physical things [8]. By reducing the material dimensions from regular to nano size, obvious changes in the optical absorption, chemical reactivity, electronic conductivity and even mechanical properties occur [9]. In other words, by moving from micro to nano size, more atoms are located on a particle's surface as the surface area is increased substantially, which results in a significant change in surface energies and surface morphologies of the whole material and alter the physicochemical properties of the material [6,10].

Several nanomaterials have the possibility to be utilized to modify asphalt, as for examples, nano-sized hydrated lime, nano-sized plastic powders or polymerized powders,

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Peer review under responsibility of Chinese Society of Pavement Engineering.

http://dx.doi.org/10.1016/j.ijprt.2016.11.009
1996-6814/

nanoclay, nanosilica, nanotubes and nanofibres [11]. The nanomaterial is composed of functional structures of the material with at least one characteristic dimension measured in nanometers (nm) [12]. A dimension that falls on the length scale of 1–100 nm range is stipulated to be used as the nanomaterial to provide a fundamental understanding of the phenomena [13–15]. In general, the application of nanotechnology has many benefits to bituminous materials [16], such as enhance the storage stability of polymer-modified asphalt, decrease the aging, decrease the moisture susceptibility, improve low-temperature properties, improve the pavement durability, and decrease maintenance costs. The nanosilica (NS) material has been extensively used as an inorganic additive to improve the properties of bituminous materials [17–20]. Over the last decade, the NS has gained a great attention by pavement researchers for preparing asphaltic materials with desirable properties because of its excellent stability, low cost, high surface area, chemical purity, strong adsorption, and good dispersing ability [21–23]. NS material has been used before to reinforce cementitious mixtures [24] and to reinforce the elastomers such as solute [25]; the advantage of such material comes from the low cost of manufacturing and the performance benefits [26]. As the silica material is highly reactant with the asphalt binder than conventional fillers, and the dispersal ability of NS particles into asphalt binder, one can prepare polymeric nano composite with desirable performance [27,28]. In a study by Yao et al. [29], the asphalt binder was modified with the NS at contents 4% and 6%, by the weight. It has been observed that the performance of aging, rutting, and fatigue cracking of NS-modified binders has been improved. When the modified binder was added to the reference (control) mixture, a considerable improvement was observed in terms of resistant to rutting (permanent deformation), flow number, and dynamic modulus.

The objective of this study is to provide practitioners some characteristics of NS-modified binder and mixture from which the feasibility of using NS in bituminous pavements can be attained. Different properties of prepared asphalt binders were examined based on the penetration test, softening point test, viscosity test, and Fourier Transform Infrared (FTIR) Spectroscopy method. In addition, the mechanical performance of the compacted asphalt mixtures were investigated by evaluating the resilient modulus, tensile strength, fracture energy, moisture susceptibility, and fatigue life.

2. Experimental program and methodology

2.1. Materials and preparation of asphalt binders

An asphalt binder of 60/70 penetration grade obtained from Suez refinery, Egypt, was used in the present investigation. The properties of the supplied base binder are listed in Table 1. The NS material in white color powder (Fig. 1a), a synthetic amorphous silica, is nanostructured polymorphs of silicon dioxide, SiO_2, has been used to modify the asphalt binder. A transmission electron microscope (model: TECNAI G2 spirit TWIN) has been used to scan the nanostructured particles of the NS material as shown in Fig. 1b. The properties and characteristics of the used material are mentioned in Table 2.

Table 1
Physical properties of asphalt binder 60/70.

Property	Results	Standard followed
Penetration at 25 °C 100 g, 5 s, 0.1 mm	65	ASTM D5
Softening Point (ring and ball), °C	51	ASTM D 36
Kinematic viscosity at 135 °C, C.st.	360	ASTM D 2170
Absolute viscosity at 60 °C, Pa.s	210	ASTM D 2171
Retained penetration (%)	50	ASTM D5
Mass loss (%)	0.12	ASTM D1754
Ductility at 25 °C, 5 cm/min, cm	+100	ASTM D113
Flash point, °C (Cleveland Open Cup)	250	ASTM D92
Specific gravity	1.018	ASTM D70
Solubility in trichloroethylene, %	99.9	ASTM D 2042

To prepare the modified binder, 500 g of the base asphalt binder was heated to 160 °C and blended with the NS material using a shear mixer at a rate of 2000 rpm for 1 h. The NS material was blended with the base binder at different concentrations (2, 4 and 6 wt.%), and various qualification test methods have been carried out on the prepared samples to determine the effect of NS on the properties of asphalt binders. It is worth mentioning that the base binder has been mixed with no additive under the same mixing conditions to avoid any varied degree of aging between the unaged prepared binders during the mixing process.

2.2. Testing of asphalt binders

Physical tests including penetration test at 25 °C [30], softening point test [31] and viscosity test [32] using Brookfield viscometer (model DV-II) were carried out on virgin asphalt binders. Although the penetration test is an old method, it is still used by many around the world for measuring the hardness of asphalt binders at standard test conditions. The flow and consistency of an asphalt binder are known from the softening point test. The Brookfield rotational viscometer is commonly used nowadays to characterize the viscosity of asphalt binders. Using the penetration and softening point (SP) results, the Penetration Index (PI) and hence the temperature susceptibility of asphalt binders can be established using the nomograph of PI (SP/pen) [33]. Further, a spectroscopic testing analysis as it serves as a fingerprint of the compound was carried out on virgin asphalt binders using an infrared spectroscopy, FTIR, to assess the effectiveness of adding the NS on the asphalt binder (bitumen) from the chemical functional groups point of view. The infrared spectra were recorded using a Thermo-Nicolet 6700 FTIR spectrometer by 32 scans in wavenumbers ranging from 4000 to 400 cm^{-1} and 4 cm^{-1} resolution. The FTIR method is