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Performance analysis of nano modified bitumen and hot mix asphalt

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HIGHLIGHTS

- Energy saving is improved by modification.
- Optimum binder contents are decreased by modification.
- Performance of HMA mixtures modified with nano materials are improved.

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ABSTRACT

The aim of the research was to evaluate the performance of Hot Mix Asphalt (HMA) and bitumen by modifying bitumen with nano materials according to Superpave™ mix design procedure. In this research, bitumen was modified by Multi-Walled Carbon Nanotube (MWCNT) and Carbon Nanotubes Doped with 50 wt% SiO_2 Nanopowder (SiO_2dopedCNT). Nano materials were mixed with base bitumen at contents of 1, 3 and 5% by weight. Rutting and fatigue performance of bitumen was determined. HMA is prepared with nano modified bitumen at optimum binder content (OBC). Moisture susceptibility of modified hot mix asphalt was evaluated according to Modified Lottman test procedure. Nano modified bitumens were also evaluated by scanning electron microscopy whether the modification was uniform or not.

As a result, better performance was obtained by SiO_2dopedCNT modification. Performance Grade (PG) of all modified bitumen was determined as PG 64-22 except MWCNT modified bitumen at the content of 1% (which was PG 58-22). OBCs were decreased by modification. All nano modified hot mix asphalt samples were determined as high resistive to moisture compared to reference sample except samples modified with SiO_2dopedCNT at the content of 5%. Homogenous mixture was obtained according to scanning electron microscopy results. It was found that the agglomeration of nano materials is mostly lower than 4 μm in the mixtures.

1. Introduction

The performance of HMA is affected by characteristics of components and behaviour of these components in the mixture. This effect depends on the subjected environmental factors of components. 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. The service life of pavements varies according to structural design conditions, characteristics of materials, layer thickness, maintenance and accepted damage criterion.

Damages that occur during the useful life of pavement mainly are rutting, permanent deformation and fatigue cracking. Since the recovery and reconstruction of defects will be costly, therefore, the prevention of such cases would be more economical [1].

It is expected that modification of bitumen with nano-materials improve the mechanical properties of asphalt mixtures including an increase of stiffness modulus, increase of strength against stripping, increase of strength against moisture damage, prevention of cracks and increase of resistance against creep. Several nanomaterials have the possibility to be utilized to modify bitumen, as for examples, nano-sized hydrated lime, nano-sized plastic powders or polymerized powders, nanoclay, nanosilica, nanotubes and nanofibres.

Nano materials have unique properties; they have been developed rapidly as useful additives for asphalt mixture. These properties include a large fraction of surface atoms, high surface work, quantum effects, structural features, and spatial confinement.

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Benefits of nano modified bitumen include improvement of resistant to rutting, cracking, and fatigue [2,3].

Nanosilica and carbon nanotube has been extensively used as an inorganic additive to improve the properties of bituminous materials [4–7]. Shafabakhsh and Ani aim to analyze the results of laboratory tests that were performed on modified steel slag asphalt mixture (SSAM) containing TiO_2 and nano SiO_2 particles, the materials that are added to improve the rutting resistance of nano modified asphalt mixtures. Results showed that adding nano TiO_2 and nano SiO_2 boost the bitumen's rheological characteristics and improve toughness and viscosity by an average of 30% and 109%, respectively while reducing penetration grade. In addition, the asphalt's rutting resistance and fatigue life were improved [2]. Tanzadeh et al. studied the effect of nano-TiO_2 on rutting performance of asphalt pavements. The purpose of this study was research on the effect of nano-TiO_2 in improving bitumen property and rutting resistance in asphalt pavement under dynamic loading. The results of their study illustrated that using nano-TiO_2 in bitumen samples caused to an improvement in rutting depth in comparison with the ordinary mixtures [8].

Yusoff et. al. investigated the performance characteristics of polymer-modified asphalt mixture (PMA) with the addition of nano-silica particles. The addition of 4% nano-silica with PMA appeared to have the greatest potential for beneficial modification of the binder [9]. Motlagh et. al. investigated that promote technical characteristics of bitumen and asphalt mixtures using carbon nanotubes as an additive material for bitumen. As a result, mixture with minimal mechanical changes in the characteristics of asphalt mixtures was obtained that not only in terms of physical properties is not much different, but also improves the quality of its chemical properties [10]. Tan et. al. in order to improve the performance of composite modified asphalt, the central composite design-response surface methodology was used to determine the optimum content of raw materials. The rheological behaviour including accumulation of deformation, viscoelastic ratio, creep strength, creep strain rate "m" was analyzed by testing in central composite model. Response surface of the overall desirability was established. The test results indicated that the optimum raw materials ratio was asphalt: rubber powder: additive: SBS: SBR = 100:25:7:5:3 (by weight) [11].

Also, the characterization of modified bitumen is important for better understanding the dispersion of nano materials into bitumen. Guo et. al. were conducted an adsorption-separation test of asphalt binder on surface of mineral fillers to separate the structure asphalt binder and free asphalt binder [12].

In this research, modified carbon nanotubes with SiO_2 nanopowder by weight of 50% to improve the performance of carbon nanotube were chosen. MWCNT was also chosen to compare the effect of modified carbon nanotube with SiO_2 nano powder by weight of 50%. These nano materials were added to bitumen to improve the rutting and fatigue performance of bitumen and moisture susceptibility of asphalt mixtures. Nano materials were mixed with base bitumen at contents of 1, 3 and 5% by weight. Rheological properties of nano-modified bitumen were analyzed by use of bitumen tests such as Rotational Viscosity (RV), Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR). In addition, the short- and long-term ageing properties of nano-modified bitumen were analyzed, with the ageing process simulated by Rolling Thin Film Oven Test (RTFOT) and the Pressure Ageing Vessel (PAV). Furthermore, rutting and fatigue performance of bitumen was determined by $G^*/\sin\delta$ and $G^*.\sin\delta$ parameters obtained by DSR after ageing process. Nano modified asphalt mixtures were prepared and compacted by Superpave Gyratory Compactor (SGC). OBC of all nano modified mixtures were also determined and compared to the non-modified mixture. Indirect Tensile (IDT) strength and moisture susceptibility of modified hot mix asphalt was determined according to Modified Lottman test procedure (AASHTO T283). Nano modified bitumens were also evaluated by Scanning Electron Microscopy (SEM) whether the modification was uniform or not.

2. Materials

2.1. Aggregate

Limestone aggregate was used in hot mix asphalt. HMA samples were prepared for wearing course. The nominal maximum aggregate size was selected as 12.5 mm. Gradation curve was selected in accordance with Superpave™ for the dense graded HMA (Fig. 1).

2.2. Modification materials

The chemical and physical properties of MWCNT and SiO2-dopedCNT were given in Tables 1 and 2. Because SiO_2dopedCNT is obtained from modification of CNT by SiO_2 it is given only MWCNT and SiO_2 seperately. The same component is used in this study to compare the effect of modified carbon nanotube with SiO_2 nano powder by weight of 50%.

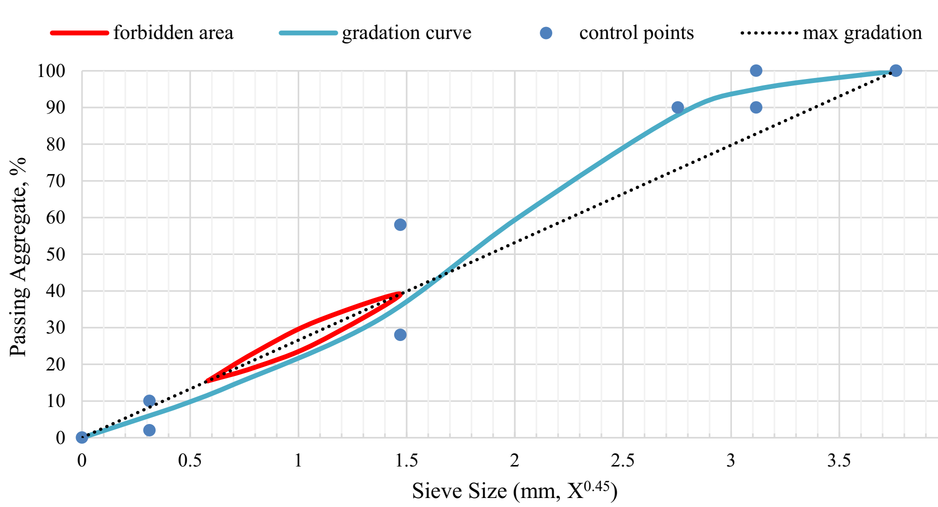

Fig. 1. Gradation curve for HMA.