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Evaluation the effects of nanoclay on permanent deformation behavior of stone mastic asphalt mixtures

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HIGHLIGHTS

- SMA asphalt mixture is mixed with the SBS and nanoclay.
- The modified bitumen samples have better rheological properties.
- SBS and nanoclay have positive effects on mechanical properties of SMA asphalt mixture.

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ABSTRACT

In stone mastic asphalt (SMA) mixtures the binder phase has an important role in the integrity of the mixture and should withstand the applied shear forces. Due to platy structure of nanoclay particles and having a large length over width ratio, they have considerable effects in enhancing properties of bitumens. In this paper the effects of nanoclay on high temperature properties of two distinct categories of SMA mixtures namely those with fibers and polymers have been investigated. A 60/70 pen grade neat bitumen, limestone aggregates, cellulose fibers and Styrene Butadiene Styrene (SBS) polymer alongside different dosages of montmorillonite nanoclay particles in the range of 1–4 percent by the weight of bitumen were used. Performance characteristics of different asphalt materials were evaluated in terms of the storage stability of modified asphalt binders as well as Marshall stability and flow, creep properties and rutting resistance of SMA mixtures having different amounts of nanoclay particles. Results revealed that the nanoclay polymer asphalt binders have higher storage stability as well as better performance characteristics. SMA mixtures with polymer modified asphalt binder have better permanent deformation characteristics (higher rutting resistance). Moreover, the SMA mixture containing 3% of nanoclay has the highest rutting resistance.

1. Introduction

With increasing the traffic volume and axle loads, pavements are subjected to more stresses and strains which can lead to premature distresses [1]. Fatigue and rutting are the most important load-induced distresses in flexible pavements [2]. A lot of researches have been conducted to produce more durable pavements. These were based on some modifications in asphalt mixture's constituents including both the aggregate skeleton and the asphalt binder. Among the suggested solutions, the stone mastic asphalt (SMA) mixtures are those with modified aggregate skeleton which have high resistance against the permanent deformation or rutting [3,4].

In stone mastic asphalt (SMA) mixtures, gap-graded aggregate gradations are used to provide a higher binder content and inter-aggregate contact. The stability and strength of SMA mixtures are mainly due to the coarse aggregates. SMA mixtures have higher amounts of coarse aggregate and asphalt binder compared to hot mix asphalt (HMA) mixtures. The first application of SMA mixtures dates back to 1960s in Germany. Since then, its usage was spread in other European countries and the United States [2,5].

The high amount of asphalt binder and gap-graded structure in SMA mixtures, are the main factors to cause bleeding. To overcome this shortcoming, fibers and polymer modified asphalt binders are used. Fibers are used to meet two requirements. The first one is to prevent bleeding and providing the integrity of the mixture. Increasing the mixture's stiffness and resistance against failure is the second objective to utilize fibers in SMA mixtures. Mineral

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and organic fibers are considerably used in gap graded and SMA mixtures [6–8].

Polymer modified asphalt binders can be used as a replacement of fibers in SMA mixtures. They contribute to better performance characteristics and durability of flexible pavements. Different kinds of polymers including Polyvinyl chloride (PVC), Ethyl Vinyl Acetate (EVA), Styrene Butadiene Rubber (SBR) and Styrene Butadiene Styrene (SBS) have been used in SMA mixtures. The SBS polymers can affect all the performance characteristics of the asphalt binder. Based on the previous study the optimum content of the SBS is the 5% by the weight of the asphalt binder. At this dosage, all performance characteristics of the asphalt binder and the associated asphalt mixture can be improved [6,9–11].

Nanomaterials are another type of additives which have shown promising results in enhancing the physical properties of asphalt materials [12]. Among different types of nano particles, nanoclay particles have considerable effects on increasing the performance characteristics of both asphalt binders and mixtures [13–17]. They have also been used as additives in polymer modified asphalt materials [13,17]. One of the most important properties of nanoclay particles is their high length over thickness ratio. The sheet structure of nanoclays increases the strength and modulus of polymers [18].

Permanent deformation or rutting is one of the most important parameters in designing the flexible pavements. By increasing the traffic load and tire pressure, most portion of permanent deformation occurs in the surface layer. Determination of permanent deformation parameters of the pavement materials is the critical factor in estimating the rut depth of the pavement. The repeated load creep or dynamic creep test is one of the widespread testing protocols in assessing the permanent deformation characteristics of asphalt mixtures. In this test, the specimen is subjected to a cyclic uniaxial or triaxial compression and the accumulated strains in terms of loading cycles are measured. The rut depth due to the surface layer is a function of the asphalt mixture's stiffness. The Hamburg Wheel Track (HWT) test is another kind of testing protocol which measures the rut depth of an asphalt mixture under a repeated wheel load [19,20]. Chelovian and Shafabakhsh investigated the effects of nano-AL_2O_3 on the dynamic performance of SMA mixtures. In their research, the nano-AL_2O_3 particles were added at 0.3, 0.6, 0.9 and 1.2 percent to the base binder, while the cellulose fibers were use at the dosage of 0.3% to prevent draindown phenomena in the mixture. The dynamic performance was investigated by means of dynamic creep test, wheel track test and the indirect tensile fatigue test [21]. Results indicated the potential effects of different amounts of nano-AL_2O_3 on performance characteristics of SMA mixtures with varying degrees. Considering the economic issues, they suggested the SMA mixture containing 0.6% of nano-AL_2O_3 as the optimum alternative to use in pavements [21]. In another study, nanoclay particles were used as filler in hot mix asphalt (HMA) mixtures in different dosages of 2, 3.5 and 5 percent by the weight of the total mix [22]. The performance characteristics was investigated through moisture susceptibility, indirect tensile strength, repeated creep and modified Lottman tests which the mixture containing 2 percent of nanoclay had the best performance.

The main objective of the current research is to investigate the permanent deformation characteristics of SMA mixtures modified nanoclay particles.

In order to investigate the basic properties of the modified asphalt binders, the penetration, ductility and softening points of all the modified asphalt binders were measured. Furthermore, to study the workability of the modified binders at high temperatures as well as the potential of non-uniformities during thermal storage, the rotational viscosity and storage stability tests were performed. SMA mixtures containing SBS and fibers are modified with different dosages of nanoclay particles. The permanent deformation properties and the rut depth of the asphalt mixtures are measured by means of dynamic creep and Hamburg Wheel Track tests, respectively.

2. Materials and testing

As mentioned previously, this research aims to investigate the trends in viscoelastic properties of two types of SMA mixtures while their nanoclay content changes. The first type of SMA mixture consists of a neat asphalt binder. The second one has a polymer modified asphalt binder. In order to keep the integrity of the mixtures, all of them contained organic fibers.

2.1. Materials

The aggregate gradation was in accordance with the NCHRP 425 and is shown in Table 1 [3]. Aggregate properties are presented in Table 2. The aggregates and fillers are of crushed limestone due to the critical role of aggregate in the resistance of asphalt mixtures against permanent deformation.

The asphalt binder used is a 60/70 penetration grade from Tehran Oil Refinery and its properties are shown in Table 3. The polymer used in this research was a Styrene-Butadiene-Styrene (SBS). This kind of polymer contributes to considerable

Table 1
Aggregate gradation.

Sieve size (mm)	Passing percent
19	100
9.5	95
4.75	45
2.36	25
1.18	18
0.6	16
0.3	14
0.15	12
0.075	10

Table 2
Aggregate properties.

Properties	
Bulk specific gravity, g/cm^3 (ASTM C127)	2.59
Absorption fine aggregate/% (ASTM C127)	2.4
Absorption coarse aggregate/% (ASTM C127)	2.2
Los Angeles abrasion loss/% (AASHTO T96)	22.3
Two fractured faces/% (ASTM D5821)	93
Plasticity index, Fine Aggregate (AASHTO T96)	Non
Liquid limit, Fine Aggregate% (AASHTO T8)	13

Table 3
Bitumen properties.

Property	Base binder
Penetration (100 g, 5 s, 25 °C), 0.1 mm	64
Ductility (25 °C, 5 cm/min), cm	110
Softening point (°C)	53
Penetration index	-0.3
Flash point (°C)	260
Kinematics viscosity at 135 °C, C. St	357
Absolute viscosity at 60 °C, poise	255

Table 4
SBS properties.

Property	Specification
Molecular structure	Linear
Tensile strength (MPa)	31.8
Elongation at break (%)	880
Specific gravity	0.94
Shore hardness (A)	71
Melt index	<1