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Use of Nano SiO_2 and Nano TiO_2 to improve the mechanical behaviour of stone mastic asphalt mixtures

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HIGHLIGHTS

- Addition of Nano materials can improve the mechanical behaviour of SMA mixtures.
- Results suggest the using of Nano materials to increase fatigue life of SMA mixtures.
- Using 1.2% Nano SiO_2 and 0.9% Nano TiO_2 obtained the highest number of cycles for SMA mixtures.
- The best content of nanoparticles to reduce the rutting in SMA mixtures is 0.9% Nano TiO_2 or 1.2% Nano SiO_2.
- Stiffness modulus of samples containing 0.9% Nano TiO_2 and 1.2% Nano SiO_2 is higher than other nano contents.
- Results show that the addition of 1.2% Nano TiO_2 in mixtures resulted in an increase in TSR of 7%.

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ABSTRACT

The service life of asphalt mixtures decreases due to heavy traffic and environmental conditions. Thus, pavement researchers are constantly trying to improve the HMA conditions, such as reducing the incidence rate of damages in the roads and delay the incidence time as much as possible. Stone mastic asphalt (SMA) is a type of hot mix asphalt which contains more coarse aggregate particles. The primary objective of this research is evaluation the effects of adding Nano SiO_2 and TiO_2 as modifier additives on mechanical behaviour of SMA mixtures. Nano SiO_2 and TiO_2 are studied as an additive in this research and, the effect of these Nano materials on mechanical behaviour of SMA is investigated by wheel track, indirect tensile fatigue, and indirect tensile stiffness modulus tests. Bitumen 60–70 is modified with different contents of Nano SiO_2 and Nano TiO_2 (0, 0.3, 0.6, 0.9 and 1.2%, respectively, by weight of the bitumen). The Results of this research show that adding the different percentages of Nano materials is capable to improve the mechanical behaviour of stone mastic asphalt, significantly.

1. Introduction

The asphalt concrete is one of the materials that used widely for pavement of roads and airports. The researchers and engineers constantly try improving the performance of asphalt concrete. The pavement of roads as the surfaces that are exposed to the frequent loadings of heavy axes should have enough strength against the fatigue, cracking, creep and skid resistance [1].

Hot mix asphalt (HMA) is used as a surface layer to distribute the stress caused by the loading and protect the unprotected bottom layers against water effect. HMA should be resistant against the weather effects and stand up against the permanent deformation and cracks caused by loading and environmental factors [2].

SMA is a kind of HMA consisted of two parts of large size aggregate and bitumen-filled mortar (bitumen mix, filler and stabilizing additives). SMA mixtures should have coarse aggregate structure with stone on stone contact [3]. Fig. 1 shows this contact in a SMA mixture.

SMA is mainly used as binder course on roads with heavy traffic loads. Due to the use of high-grade and 100% crushed materials, the aggregates larger than 4.75 mm be consumed in this hot mix asphalt more than continuous-graded. SMA mixtures with stone on stone contact structure which increases the strength and resistance of mixture against rutting and permanent deformations and due to the high consumption of bitumen, SMA mixture has reliability and higher durability [3].

Bitumen used in the SMA should be as the classified pure bitumen according to penetration degree, or functional or modified bitumen. The optimum bitumen content in SMA is at least 6%, that

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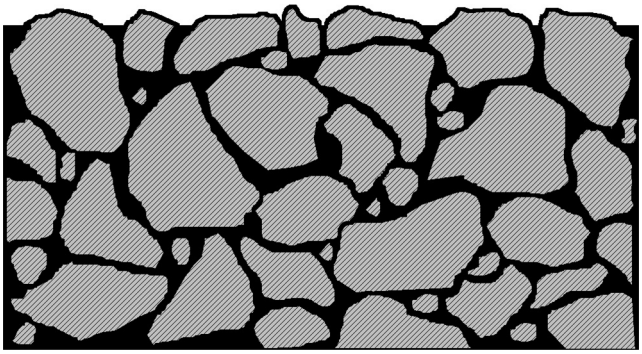

Fig. 1. Coarse aggregate stone-on-stone contact in a SMA mixture.

it is more than the amount of bitumen in continuous graded hot mix asphalts. The gap gradation and large amount of filler is the reason of the high consumption of bitumen in the mixtures. The stabilizing additives can be used in the SMA mixtures in order to prevent the separation or drain-down. Any additives that cause improvement by improving the properties of bitumen in one or more of the following cases can be used [3]:

I. Aggregate separation or bitumen drain-down
II. The permanent deformation
III. Fatigue & Low Temperature Cracking
IV. Economic issues, particularly the reduction of required thickness to design

The using of modifiers such as polymers and fibers in bitumen and asphalt samples is a common method to improve the behaviour of asphalt mixtures, while the researchers used the nano materials to improve the behaviour of bitumen and asphalt mixtures in recent years. According to previous researches, Wet or dry processes are two separate methods for adding the nano modifiers to the bitumen and mixture. In wet method, the modifiers and bitumen are mixed with together at specified temperature, and after this, the aggregate particles will be added to this mix. Although, in the dry method, the modifiers are added directly to the mix. In earlier studies it was investigated that Nano materials had positive effects on asphaltic mixtures and provide better cohesion and adhesion between aggregate and bitumen [4,5].

2. Literature review

Ghasemi et al. (2011) evaluated the potential benefits of Nano SiO_2 powder and SBS for the Stone mastic asphalt mixtures used in pavements. Five asphalt binder formulations were prepared by using various percentages of SBS and Nano SiO_2 powder. Then, Marshall Samples were prepared by the modified and unmodified asphalt binder. The results of this investigation indicated that the asphalt mixtures modified by 5% SBS plus 1% Nano SiO_2 powder could give the best results in the tests [6].

Shafabakhsh et al. (2014) investigated the effect of adding Nano TiO_2 on mechanical performance of asphalt mixtures. Permanent deformation, fatigue and stiffness modulus of mixtures modified with Nano TiO_2 was evaluated in this research. The results of this test show that the various percentages of Nano TiO_2 could improve the mechanical behaviour of asphalt mixtures [7].

Fang et al. (2013) reported the influence of Nano TiO_2 particles on the high temperature properties of TiO_2-modified asphalt. It was found that the rutting factor and the elasticity of the modified asphalt were increased, thus the resistance to permanent deformation was enhanced and the service life of modified asphalt pavement was prolonged [4].

Tanzadeh et al. (2012) evaluated the effect of Nano TiO_2 on rutting performance of asphalt mixtures. The purpose of this study was laboratory research on the effect of Nano TiO_2 in improving Asphalt binder property and rutting resistance in Asphalt pavement under dynamic loading. For this purpose, the wheel-tracking test was carried out on ordinary and Nano TiO_2 modified hot mix asphalt samples. This study indicated that using Nano TiO_2 in asphalt binder samples caused to an improvement in rutting resistance in comparison with the ordinary mixtures [5].

Sadeghpoor et al., (2015) evaluated the effect of Nano Silica on bitumen behaviour. In this study, different contents of Nano-silica, 2 wt%, 4 wt% and 6 wt%, have been added to bitumen to modify the physical, mechanical and rheological properties of warm mix asphalt (WMA). The rheological investigations showed that the complex modulus of base bitumen increases by increasing the percentage of Nano-silica from 2 to 6 wt%. From rheological analysis, 6 wt% Nano-silica has been selected as the optimum content. Results of investigations on the asphalt mixtures demonstrated the fact that by increasing Nano-silica content, the quality of the warm mix asphalt has been improved [8].

Chelovian and Shafabakhsh (2017) evaluated the effects of Nano Al_2O_3 on dynamic performance of stone mastic asphalt mixtures. Nano Al_2O_3 was studied as an additive in this research and also, in order to improve the hot mix asphalt strength against the damages, the type of stone mastic asphalt was examined. The effect of Nano Al_2O_3 additive on dynamic performance of stone mastic asphalt was investigated through dynamic creep test, wheel track test and indirect tensile fatigue test. Results showed that addition of different percentages of Nano Al_2O_3 was capable to improve the dynamic performance of stone mastic asphalt, significantly [9].

Ghaffarpour et al. (2010) carried out comparative rheological tests on asphalt binder and mechanical tests on asphalt mixtures containing unmodified and Nano clay modified binder. Results showed that nanoclay could improve properties of asphalt mixtures such as stability, resilient modulus, and indirect tensile strength [10].

2.1. Goal of study

The objective of this research is to investigate the effect of Nano SiO_2 and Nano TiO_2 as additive on the mechanical properties of SMA mixtures. For this purpose, SMA samples are made according to ASTM D 1559. After preparation, indirect tensile stiffness modulus (ITSM), indirect tensile fatigue (ITFT), Indirect tensile test (ITS) and wheel track tests are carried out on SMA mixtures constructed with control bitumen and bitumen modified with various contents of Nano SiO_2 and Nano TiO_2.

3. Materials and methods

3.1. Materials

In this study, the Stone materials gradation is the average gradation proposed by Iran Highway Asphalt Paving Code, No. 234 [11] for SMA mixtures with the biggest aggregate size of 19 mm. The limits for this gradation are presented in Table 1. $CaCO_3$ powder is used as filler and it is passed from the sieve No. 200. The used bitumen is 60–70 penetration prepared from Tehran Pasargad Oil Processing Complex and its basic specifications are mentioned in Table 2. The specifications of nanoparticles (Nano SiO_2 and Nano TiO_2) are shown in Table 3. Also Figs. 2 & 3 show Nano SiO_2 & Nano TiO_2 used in this research.

In order to achieve the goals of this research, it is required that the homogeneous mixtures consisted of bitumen and Nano SiO_2 and Nano TiO_2. Achieving more favorable results is largely dependent on the mixture of bitumen and nanoparticles. In this research, different percentages of nanoparticles (0.3, 0.6, 0.9 and 1.2% by weight of bitumen), were added to the bitumen and mixing process was carried out by high shear mixer according to Fig. 4. In this study, to incorporate the Nanoparticles into bitumen, the wet method was used, so that first Nano dispersed in the solver. The solver should have the solving ability in bitumen at low and mod-