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Evaluating mechanical properties of stone mastic asphalt modified with Nano Fe_2O_3

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HIGHLIGHTS

- The increased amount of fatigue life of samples modified with optimum percentage (0.9% nano) compared to the control samples is between 15 and 35%.
- Using the bitumen modified with 0.9% Nano Fe_2O_3 in producing stone mastic asphalt mixtures can decrease the hot mix asphalt thickness.
- Results show that the increased rutting depth in all the modes is increasing with the usual rate.
- The amount of rut depth of asphalt samples containing 0.9% Nano Fe_2O_3 is about 25–40% lower than control samples.

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ABSTRACT

The pavement of roads during their lifetime suffered from different damages such as cracks and rutting. Due to the growing trend of amount of traffic loads, the engineers attempt to improve the functional characteristics and properties of hot mix asphalt using the additives. These modifiers are used because the bitumen cannot have proper performance in all the environmental and loading conditions. Nano-materials are one of the newest technologies quickly developing in various sciences. Numerous benefits of the technology make the pavement researchers use it to improve the hot mix asphalt. This research aimed to evaluate the effect of adding different percentages of Nano Fe_2O_3 on the mechanical properties of stone mastic asphalt. The results show that Nano Fe_2O_3 can improve the mechanical properties of stone mastic asphalt to an acceptable level so that the stiffness modulus of the mixtures have improved due to using nano-material and the mixtures strength is also enhanced against the fatigue. Additionally, with addition of Nano Fe_2O_3, the strength of hot mix asphalt against rutting is also improved to an acceptable level.

1. Introduction

The roads are as the economic arteries of any country with particular significance. Hence, the transportation infrastructures and consequently, the pavement of roads are always regarded as the wealth of any country. Accordingly, protecting the wealth is a priority for policy-making in the countries. However, about 95% of roads pavement in the world is the flexible pavement, but these pavements due to the fact that they are partly formed by the bitumen and considering its specific features, cannot have appropriate performance in all the loading and thermal conditions. According to what has been said, the civil engineers always attempted to modify the properties of the material.

Today, with optimal use of usual and accessible properties, the specific materials are provided with completely different effects with human imagination. A group of these materials, presented today as nano-materials knowledge due to the specific characteristics of nano-scale materials create the special properties used to produce and modify the different materials.

Since that most of the asphalts produced in different areas in order to improve the performance, are combined and modified with polymer and non-polymer materials, therefore, different modifiers in research and administrative centers of the world are investigated. Also, nowadays the scientific studies are concentrated at the border of nanotechnology knowledge to use the technology to produce and create materials to give appropriate answer to the questions that conventional materials cannot answer. Recently, some studies have been conducted on using different types of nano-particles as the modifying factor of bitumen and hot mix asphalt. However, no comprehensive studies have been

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performed in particular on the impact of bitumen modified with nano-materials on the mechanical properties of Stone mastic asphalt (SMA) mixtures. As a result, Nano Fe_2O_3, as a material that is growing to be utilized due to its features in different industries, in this study as the bitumen modifier. Afterwards, the impact of modified bitumen on the mechanical properties of stone mastic asphalt will be studied.

2. Stone mastic asphalt

Stone mastic asphalt is gap-graded hot mix asphalt consisted of two parts of coarse aggregate and bitumen-filled mortar (bitumen mix, filler and stabilizing additives including cellulosic or mineral fibers). This hot mix asphalt should have coarse aggregate structure with stone on stone contact [1].

Stone mastic asphalt is mainly used as binder course in the tropical areas and the crowded roads with heavy axial load. Stone mastic asphalt due to the use of high-grade and 100% broken stone materials, relatively high consumption of the aggregates larger than 4.75 mm compared to the continuous-graded, with stone on stone contact structure which increases the strength and strength of hot mix asphalt against rutting and permanent deformations and because of the relatively high consumption of bitumen, has higher reliability and durability. In using SMA as an asphalt layer, the following advantages can be mentioned [2].

- High durability
- Low permeability
- Low traffic noise pollution
- High strength against reflective cracks
- High strength against rutting

This type of hot mix asphalt (SMA) was first designed in the mid-1960s in Germany to deal with corrosion and damage caused by the ribbed wheels. Then, the mixture was recognized in many countries as stone mastic asphalt (SMA) which was not only resistant against the ribbed wheels but also has good strength against rutting [3].

3. Application of nanotechnology in pavement engineering

Many studies have been conducted on using nano-material in different sciences, but about using these materials in pavement industry, only the use of few nano-materials to improve the asphalt concrete properties can be mentioned. In 2009, Khodail et al. in a study on the effect of nano-clay on properties of bitumen concluded that by increasing the clay percent, the rheological properties of bitumen are improved. [4]. Zhanping et al. after using nano-clay in hot mix asphalt concluded that using these materials will increase the dynamic modulus of hot mix asphalts [5]. In 2012, Khattak et al. evaluated the effect of carbon nano-fibers on the rheology of bitumen and concluded that using it would improve the bitumen characteristics [6]. In another study in 2011, Amirkhanian et al. examined the effect of carbon nano-tubes on the rheological characteristics caused by short-term aging of bitumen and concluded that the addition of this material will improve the short-term aging characteristics of bitumen [7]. Studies conducted in the Netherlands showed that modifying the bitumen with nano-clay has improved some of the properties of bitumen and hot mix asphalt. But the researchers noted that before the materials to be used on the massive scale, more research is required. The most important reason to request more investigations was that while nano-clay has increased the strength against rutting, has not resolved the fatigue problem [8].

In China, similar research was conducted on bitumen modified with nano-calcium carbonate. The results showed that nano-calcium carbonate has increased the strength against rutting. Also, it was cleared that nano-calcium carbonate mixture and bitumen has formed the uniform and stable system that has improved the bitumen thermal sensitivity at high temperatures [9]. In 2007, Yu studied the effect of nano-montmorillonite on the properties of bitumen modified with Styrene-Butadiene-Styrene (SBS) polymer. The results of viscosity test on the bitumen mixtures modified with nano-montmorillonite showed that its addition has increased the viscosity of the bitumen modified with SBS. Additionally, the bitumen modified with nano-montmorillonite/SBS has higher mix modules and lower phase angle. They knew the reason as stiffness and elasticity of bitumen with addition of nano-montmorillonite. Also, the results showed that bitumen modified with nano-montmorillonite, has higher strength against the rutting compared to the pure bitumen or the bitumen modified with styrene butadiene styrene [10].

Liao et al. described a new use of nano-materials that modification with titanium oxide is a treatment against UV degradation and erosion of bituminous mixtures. Their analysis showed that titanium oxide on the nano-scale can positively affect the aging of bitumen and using it in small quantity leads to lower rates of aging. [11]. In 2013, Arbani et al. have evaluated the effect of Nano ZnO on the engineering properties of bitumen. In this study, the properties such as viscosity, permeability and softening point and elasticity of bitumen affected by Nano ZnO have been evaluated. The results of the group's studies showed that Nano ZnO can lead to improve the parameters of permeability, softening point and elasticity of bitumen [12].

According to all the above-mentioned study cases, it is clear that hot mix asphalt (including continuous and stone mastic) has many disadvantages that need to be improved, on the other hand, the nano-technology has many advantages that can be used as a proper additive to improve the properties of bitumen and hot mix asphalt. As a result, this study aimed to assess the effect of Nano Fe_2O_3 on the mechanical properties of stone mastic asphalt.

4. Consuming materials and mix design

4.1. Consuming materials

Stone materials formed 90–95% weight and 75–85% volume of asphalt concrete mixtures. The stronger structure of stone materials leads to asphalt concrete mixtures with high strength against the deformation caused by cyclic loading. Stone materials grading has an impact on the important properties of an asphalt concrete mixture including stiffness, durability, performance, fatigue strength, friction strength, and moisture damage strength. Stone materials used in this study are provided from the Makadam Corporation in Tehran to produce stone mastic asphalt samples. The selected grading of stone materials according to the suggestion of Publication 234 is the average SMA grading with maximum 20 mm stone materials shown in Fig. 1.

Tests of particle density, bulk density and water absorption percentage of stone materials mixture remained on the sieve 8 were conducted, according to AASHTO-T85, and the materials passed through sieve 8 and remained on sieve 200, according to AASHTO-T84. Also, the specific weight of materials passed through sieve 200 was determined according to AASHTO-T100. The results with particle density of stone materials mixture shown in Table 1.

Bitumen in the asphalt concrete mixture acts as an adhesive factor that binds the stone materials as a continuous volume. The consuming bitumen used in this research, is pure bitumen with 60–70 permeability of Pasargad Oil Refinery which characteristics