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Laboratory Assessment of Hybrid Fiber and Nano-silica on Reinforced Porous Asphalt Mixtures

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HIGHLIGHTS

- Adding glass and PP fibers reduce the asphalt binder drain down.
- The increase of lime powder results in reducing the Nano-silica influence on the asphalt binder drain down reduction.
- The least amount of rutting occurs in the specimens containing 0.2 percent glass fiber.
- The tensile strength of asphalt mixtures increases by adding fiber.
- An increase in the Nano-silica content leads to reduce rutting in the mixture.

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ABSTRACT

Porous Friction Course (PFC) is a hot mix asphalt with coarse-grained and the gap graded aggregate. In porous asphalt, high volume percentage of empty space has a number of advantages, including the creation of proper drainage on the road. On the other hand, the empty space decreases the resistance of the mixtures against rutting compared to mixtures with the dense aggregation. In this study, with the modification of asphalt binder by 4.5 percent of styrene butadiene styrene (SBS) and the amount of 2 and 4 percent of Nano silica and also by adding 0.5 and 1 percent of lime powder and as well as hybrid synthetic fiber to 0.4 and 0.5 percent by weight of asphalt mixtures as filler types, to improve the performance properties of modified porous asphalt mixtures, leading to a reduction in weight loss of asphalt binder and also increase the tensile strength and resistance to rutting. A combination of 0.1 and 0.2 percent of glass fibers with a 0.3 percent of polypropylene fibers, is defined as a type of hybrid fiber. In addition, the least amount of rutting failure occurs in the reinforced porous asphalt, using a combination of 0.2 percent glass fiber and 0.3 percent polypropylene. Also the most appropriate consuming asphalt binder in order to reduce drain down is also equal to 4.5 percent, that for the amount of 4 percent Nano silica in it. Moreover, by adding lime powder content used on the specimens from 0.5 percent to 1 percent, the tensile strength value could be increased about 16.5 percent for reinforced porous asphalt containing 4.5 percent asphalt binder.

1. Introduction

The Porous or permeable friction courses (PFC) are hot mix asphalt (HMA) mixtures characterized by a high total air voids (AV) content and placed on the surface of an asphalt pavement structure in a thin layer. The porous asphalt is something different with the other asphalt mixtures as well as hot-rolled asphalt. The major part of this type of asphalt is formed by breaking relatively coarse aggregates. In a type of categorization, porous asphalts could be divided into Porous Friction Courses (PFC) and Open Graded Friction Coarse (OGFC) mixtures. Although, in many cases both of them have approximately same performances, PFC mixtures have coarser grain size and have almost no middle grain and fine grains, while, OGFC asphalt mixtures have not any fine aggregates. Moreover, the volumetric percentage of air void in the PFC asphalt mixture ranges from 18 to 22 percent, while it is equal to 10–15 percent for OGFC asphalts. The most important benefit increases safety during wet weather. It is typically used as a sacrificial wearing course over dense graded mixtures or

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Portland cement concrete pavements in areas that experience high traffic volumes and moderate to heavy rainfall.

According to the study by Hernandez-Saenz et al. (2016) and Braga (2010), PFC asphalts are placed as thin layers in conventional pavements with the objective of obtaining frictional, safety in wet conditions and environmental benefits. An effective contrast against the development of excessive water veils is the use of porous asphalt. PFC is a layer of porous asphalt of approximately 50 mm thickness which is often applied on top of existing pavement [1,2].

Putman and Kline (2012) found that Porous asphalt can provide numerous advantages on roadways. The increased air void content of OGFCs leads to interconnected permeable voids, which create permeability in the pavement, and allow air and water to flow towards the road sides. The advantages of this type of asphalt include appropriate frictional resistance, good skid resistance, quick draining surface and minimize hydroplaning, reducing road noise, reducing splash and spray, and improvement of night visibility [3].

Although the PFC asphalt mixture is of significant advantages, some damages occurs sooner than conventional asphalts in this type due to its special construction. Rutting is one of main distresses of pavements and may be observed deep in the subgrade or be limited to surface. Imaninasab et al., (2016) and Tayfur et al. (2007) found that Porous asphalt is a gap-graded asphalt mixture that is not rut resistance compared to conventional dense-graded asphalt mix [4,5].

Based on the study by Morova (2013), hot mix asphalt concrete has been modified by the use of basalt fibers. It was used for asphalt binder with 4.5, 5, and 5.5 percentages and basalt fibers with 0.25, 0.5, 0.75, 1, and 2 percentages in total 18 specimens. Considering the marshall strength, air void, and slump tests, the most appropriate asphalt binder and basalt fiber percentages are found to be equal to 5 percent and 0.5 percent, respectively. The basalt fibers have a behavior similar to glass fibers [6].

Generally, the use of nanotechnology for establishing more efficiency, materials is expressed as creating a fully controlled and precise condition and applying this condition to regular arrangement of atoms and producing materials in the nanoscale.

The U.S. National Nanotechnology Initiative stipulates that nanotechnology involves research and technology development at the atomic, molecular, or macromolecular levels, the length scale of approximately 1–100 NM (NanoMeter) range, to provide a fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size. Due to the small size and high surface area, the property of nanomaterials is much different from normal size materials. Therefore, research engineers tried to apply the nanomaterials into the pavement engineering. According to the study by Yao et al. (2013) and Yang (2013) has been shown that the rutting and fatigue cracking resistance of asphalt binders and mixtures improved with the addition of nanomaterials [7,8].

In the study by Meena and Prapoorna-Biligiri (2016) the two outcomes of the Dynamic Shear Rheometer (DSR) test, namely, G^* (complex shear modulus) and δ (phase angle) have help investigate rutting characteristics of asphalt binders. The complex shear modulus and phase angle are effective in the prediction of rutting and fatigue crack of hot mix asphalt concrete, so that, the resistance against rutting requires presence of firm and elastic binder in the asphalt, thus, the elastic quota of complex shear modulus is needed to be increased [9].

Hasani-Niya et al. (2014) and Nur Izzi Md et al. (2014) have shown that the modification of asphalt specimens by adding Nano-silica leads to increase in resistance against rutting and fatigue cracks in middle temperatures, an increase in the elastic modulus, marshall strength, and fatigue life of asphalt mixtures [10,11].

Jamshidi et al. (2015), found that by adding 4 and 6 percent of Nano-silica to the asphalt binder, its viscosity decreases in a given temperature. Moreover, specimens containing Nano-silica have a less phase angle (δ) and greater complex shear modulus (G^*) [12].

Punith and Veeraragavan (2011) studied the impact by using modified polyethylene (PE) on the porous OGFC asphalts. It was used from 0.3 percent of PE fibers associated with 4.5–6 percent of asphalt binder, in that research. The use of PE fibers in porous asphalt mixtures causes in 46-percent reduction of the binder drain down in the modified mixtures as compared to unmodified ones. In addition, the modified asphalt specimens with PE fibers are of less aging, greater tensile strength, more rutting resistance, and longer life [13].

Therefore, PFC should not be used to correct severe rutting or depressions in the underlying pavement and due to the weakness of porous asphalt mixture for resistance to rutting and cracking failures, in this study, to modify its properties are discussed to improve flexibility and durability properties by adding materials such as fibers and nanomaterials. It was studied the effects of glass fibers, PP fibers, lime powder, and Nano-silica on porous asphalts. Binder drain down percentage, rutting, and the indirect tensile strength of modified specimens were taken into evaluation.

2. Material and laboratory test

2.1. Aggregates

The main skeleton of porous asphalt mixtures consists of coarse-grained aggregated with size of larger than 4.75 mm [10]. Broken aggregates must be stiff, durable, clean, cube shaped, and devoid of any clay, and schist materials and soil cover and loose grains. The grading of aggregates in such mixtures should be so that the coarse aggregates be interconnected with each other. The fine-grained content must also be to an extent that they fill the void spaces between coarse aggregates in such a way that do not affect the interconnecting condition.

The aggregates used in the present study were subjected to various tests according to ASTM standard method. It was also used for lime powder as filler in the production of specimens. Table 1 summarizes the grading properties of aggregates used in the current study. Moreover, the characteristics of the aggregates are presented in Table 2.

2.2. Asphalt binder

Asphalt binder (bitumen) obtained from the Pasargad Oil refinery, Iran, was about 60/70 penetration grade. The characteristics of the base asphalt binder are presented in Table 3.

Table 1
Gradation of the aggregates used in the study.

Sieve size (mm)	Percent passing	
	Design	Standard limit
19	100	100
12.5	96	90–100
9.5	65	60–100
4.75	18	15–40
2.36	9	4–12
0.075	3	2–5