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Mechanical and moisture susceptibility properties of HMA containing ferrite for their use in magnetic asphalt

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HIGHLIGHTS

- The results proved the highly effective role of active fillers in HMA mix.
- Considering the small size and softness of ferrites, they can be used as fillers in asphalt mixes.
- Using ferrite as asphalt filler can lead to increase in resistant properties of asphalt mix and also increase in moisture durability.

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ABSTRACT

Fillers have some properties which can have a great impact on the characteristics of asphalt concrete. Several physical and chemical transactions take place among fillers and binders, which affect asphalt mix performance. Ferrites are iron magnetic oxides with other metals such as barium, strontium, manganese, nickel, and zinc which can be grouped into two soft and hard groups. Considering the small size and softness of ferrites, they can be used as fillers in asphalt mixes. In this paper, mechanical properties and moisture susceptibility of the asphalt mix containing ferrite are studied in comparison with limestone and cement filler in different combinations. The necessary samples to conduct the experiments of the Marshal resistance, indirect tensile strength (ITS) and resilient modulus (Mr) were prepared as in filler segment of the specimen, ferrite with different percentages of 0%, 35%, 70%, and 100% of the total of fillers are placed in such manner that the remaining percent in each sample was replaced once with cement filler and once with limestone filler. And thus, the seven mixtures were obtained by three filler types. According to the results, adding ferrite increased the Marshal resistance and the sample with 100% ferrite filler increased the mix resistance by 11% and 35%, respectively, compared with the samples with cement and limestone by 100%. The largest amount of ITS was for the sample with 100% ferrite filler, which compared with the sample with limestone, increased the amount of ITS by about 39% in the unconditional state and by 62% in the conditional state, indicating its higher bonding with bitumen. This sample in combination with cement also showed higher resistance than limestone. These results proved the highly effective role of active fillers in HMA mix. The impact of ferrite on asphalt mix maintenance can be found at higher ferrite percentages. This impact was observable in the chart of toughness rate of the unconditional to conditional states in a way that increased with the increase in ferrite and its amount was 7% higher in the sample with 100% ferrite filler than the samples with 100% cement and limestone filler.

1. Introduction

Fillers which are usually added to the asphalt mix has the particle size range of 0–100 μm. Fillers have properties which can greatly influence asphalt concrete characteristics. Several physical and chemical interactions take place between fillers and binders, which affect asphalt mix performance [1,2]. As a result of volumetric assessment of the mechanical properties of asphalt mixes, it has been shown that different fillers have different positive effects on the mixes. Different varieties of fillers have different effects on the mix. In fact, filler properties determine the interactions with other constituents of the asphalt mix as well as the portion in the mix performance [3]. Review of the literature on asphalt concrete has shown that different varieties of fillers have been applied for improving the asphalt mix properties. Their physical and geometrical properties also have considerable impacts on the interactions between filler and bitumen. The images of scanning electronic microscope (SEM) has demonstrated significant differences between size, shape, and surface textures of the fillers which

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are made of particles and tend to aggregate and adhere to each other and usually are of high solidification power. Specific surface, fractional voids, and bitumen number affect each other and differences are related to the shape, surface texture, and distribution size (SEM images) of the particles. f/b_{max} value (filler to bitumen ratio), which is obtained from absorbing capacity, has a very good relationship with the fractional voids (linear relationship) and bitumen number (power relationship), the parameters and variables which should be considered filler characteristics and should be added and applied to filler content as the threshold values. SEM images present rather qualitative evaluation of particles' geometrical characteristics, while specific surface, fractional voids, and bitumen number are common and simple experimental processes which provide useful information for predicting filler solidification power [4].

Cement is one of the fillers, the effect of which on hot asphalt mix's mechanical properties has been studied. The experimental results have shown that Marshal and mechanical properties of concrete asphalt improve using cement powder; however, flow, voids ratio, and voids in mineral aggregates decrease. Indirect tensile strength and easy compressive strength increase with the increase in the percentage of the cement [5]. Asphalt rutting factor increases with fixing the amount of filler and cement [6].

Cement is one type of the fillers and studies so far have investigated the effect of using cement as a filler on the mechanical properties of hot mix asphalt; these properties include Marshal strength, indirect tensile strength, resilient modulus, permanent deformation characteristics, moisture susceptibility, and fatigue resistance. The results have shown that using waste-recycling limestone as mineral fillers improves permanent deformation characteristics, fatigue resistance and stiffness, and fatigue endurance of asphalt in a wide range of temperature. It is also indicated that the mixes with recycled waste limestone show higher resistance to stripping compared with asphalt concrete [7].

Fly ash can be also used as filler in asphalt mix and provide significant savings in the amount of bitumen in asphalt mixes. Fatigue life of fly ash samples is longer than that of usual samples which can be mainly explained due to filling the effects of fractional voids and stiffness of fly ash fillers which function as a useful additive in asphalt mixes [8].

The effect of using asphaltite as filler in asphalt mix has been evaluated. In Marshal resistance test, no fixed order for the changes of Marshal resistance values of unconditioned mixes against increase in asphaltite content has been shown; in fact, no effect of using asphaltite as filler on unconditioned Marshal resistance has been observed via this method, while the resistance of conditioned mixes increases with the increase in asphaltite content. Therefore, the results of Marshal resistance value show that asphaltite can well resist water effects. The results of the stiffness modulus test at different temperatures show the systematic increase of ITS values with the increase in asphaltite and its high resistance against high loading at higher temperatures [9].

It seems that it is possible to use recycled brick powders as filler in asphalt mixes, because when the mechanical performance of asphalt mixes containing recycled brick powders as filler is evaluated, the mix with recycled brick filler has higher ITS than limestone filler at 40 °C, which indicates that this mix is more resistant to crevice corrosion. Recycled brick filler can also improve susceptibility to water and fatigue life of asphalt mixes [10].

Ferrites are iron magnetic oxides with other metals such as barium, strontium, manganese, nickel, and zinc [11]. The structure of spinel ferrite, $MeFe_2O_4$, in which Me is a metal, can be considered a cubic close pack of oxygen atoms with Me^{2+} and Fe^{3+}, in which the metal cations with the distribution of other ions provides a magnetic system [12]. Magnetic materials are categorized into hard and soft groups based on their ability to be magnetized and demagnetized, not their ability to withstand penetration or abrasion. Soft materials can be easily magnetized and demagnetized; thus, they are used for electromagnets. However, hard materials are used in permanent magnets. Soft ferrites are the materials whose magnetic properties are originated from the interaction between their metal ions which occupy places regarding oxygen ions in their own spinel crystal structure. Soft ferrites are semiconductor; this means that their ability in guiding electron flow is something between conducting and insulating. Soft ferrites have wider advantages such as inherent high resistivity and high permeability than electromagnetic materials in a wide range of temperature. These characteristics are some factors of superiority for soft ferrites over other magnetic materials [13]. Regarding the small size and characteristics of soft ferrites, it seems that they can be used in asphalt mixes as filler. Recently, the effect of ferrite powder in asphalt mixes has been studied by replacing ferrite with 0.5% limestone filler. The results of studies have shown that the mix formed by limestone and ferrite filler presents a good cover of materials on the mix without affecting the main rheological properties. Replacing 0.5% of limestone filler weight with ferrite could reduce the volume of the filler, since specific weight of ferrite particles is almost twice as the specific weight of limestone filler. Granulometry of the mix with the added ferrite is of more continuity than that of the conventional mixes. Adding 0.5 percent of ferrite to the mix improves the resistance to permanent deformation which is considered a tool for improving the rutting performance of the wearing courses. Moreover, adding ferrite powder causes the ferromagnetic performance of the mix. In the resulted material, when an external field is applied, it is possible for all dipole moments to orient in one direction. When the mix is exposed to the external field of 50 mT for 1 min, the magnetization of the mixture reaches 100 micro-Tesla, which makes the mix have reversible magnetization with a particular orientation that is specifically directed as a function of the intensity and direction of the applied external field. This feature can make its various usages such as wireless sensing pavements, pavement-vehicle interaction, or transferring inductive energy the topics for further research [14].

In this paper, mechanical properties and moisture susceptibility of the mix with ferrite were studied in comparison with those of limestone and cement filler at different percentages to observe the impact of increase in the used ferrite percentages on mechanical properties and moisture susceptibility of asphalt mix and then compare them with those of limestone and cement.

2. Materials

Limy materials and different combinations of ferrite, limestone, cement, and bitumen filler with the absorption degree of 60/70 penetration grade bitumen were used in this study to prepare the asphalt samples.

2.1. Aggregate

The gradation of the aggregates was selected based on the granulometry curve 4 of Iran Road Asphalt Pavement Regulations (Code No. 234 [15]) as shown in Table 1. According to this grading, the materials with the size of 0–19 mm were used and the amount of filler for all the studied samples was fixed to 5%.

Table 1
The aggregate gradation used to prepare HMA mixes.

Sieve size (mm)	Specification (%)	Designed gradation (%)	Remained percentage (%)
19	100	100	0
12.5	90–100	95	5
4.75	44–74	59	36
2.36	28–58	43	16
0.3	5–21	13	30
0.075	2–10	7	6
<0.075	–	–	5