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Evaluating the effect of amorphous carbon powder on moisture susceptibility and mechanical resistance of asphalt mixtures

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HIGHLIGHTS

- Amorphous Carbon Modified samples are more resistant to moisture sensitivity.
- Amorphous Carbon Modified samples are more resistant to permanent deformation.
- Hydrophobicity of modified binders and mixtures were measured by sessile drop technique.
- Resistance to moisture sensitivity of samples produced using Amorphous Carbon as filler material are more pronounced.
- Resistance to permanent deformation samples produced using Amorphous Carbon as bitumen modifier are more pronounced.

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ABSTRACT

The detrimental effect of water in asphalt mixtures is regarded as one of the major distresses in flexible pavements since it is generally accompanied by mechanical related distresses. This detrimental effect is a complex phenomenon and involves thermodynamic, chemical, physical and mechanical processes. Several methods are used to reduce the moisture sensitivity of mixtures, one of which is to add hydrophobic material in asphalt mixtures as an additive. In this study, amorphous carbon powder, a by-product of paraffin production factory, is used as a replacement of filler (25, 50, 75, and 100%) and as a modifier of bitumen (5, 10, and 15%) to improve the hydrophobicity of mixtures. The sessile drop test was used along with several conventional methods to investigate the hydrophobicity and moisture sensitivity of mixtures. Mechanical stability of mixtures modified by the amorphous carbon powder was also studied using dynamic creep and wheel tracking tests. The results showed that not only did the hydrophobic powder improve the moisture sensitivity, but it also increased the rutting resistance of mixtures. The enhancement of moisture susceptibility was more pronounced when carbon powder was incorporated as filler compared to that of using as binder modifier. However, dynamic creep and wheel tracking test results showed bitumen modified mixtures are more resistant to mechanical deformation. The results of this research provide more insight on the application of waste carbon powder to produce environmental friendly asphalt mixture.

1. Introduction

The term “stripping” is regarded as the detachment of asphalt binder from aggregates due to presence of water or moisture [1]. Stripping is considered to be one of the important distresses of asphalt pavements because it is accompanied by other distresses such as rutting, potholes, alligator cracking, etc. Generally, the presence of moisture exacerbates the extent and severity of the existing distresses [2]. The phenomenon occurs due to the greater affinity of aggregates to water than asphalt binder. However, several other factors such as traffic loading, freeze-thaw cycles and pore pressure can contribute in moisture damage. The bonding between aggregates and bitumen is mainly caused by polar

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component of bitumen. Generally, polar asphaltenes and resins have greatest affinity to bond with aggregates compared to aromatic hydrocarbons.

There are two main mechanisms for moisture damage namely loss of adhesion and loss of cohesion. Adhesion loss is the loss of bonding between aggregates and asphalt binder that can be manifested by bare aggregates. However, the cohesion loss is generally regarded to loss of binder properties due to presence of moisture [3]. The factors affecting moisture sensitivity of asphalt concrete can be categorized into: (a) physical and chemical properties of asphalt binder and aggregates; (b) characteristics of asphalt concrete such as the percentages of asphalt binder and volumetric properties; (c) external factors such as climate condition and traffic loading [3].

The methods to evaluate moisture sensitivity date back to the 1920s [4]. Since then, researchers have been developing several tests to assess moisture resistance of asphalt concrete that can be categorized into 5 categories [5]:

- Tests on loose mixtures
- Destructive mechanical tests on asphalt concrete
- Nondestructive mechanical tests on asphalt concrete
- Energy based methods
- Non-destructive non-mechanical tests

One of the common *destructive mechanical* tests for evaluating moisture resistance of asphalt concrete is modified Lottman test (AASHTO T283) which is claimed to be one of the most accurate tests for predicting the moisture resistance of asphalt concrete. However, this test is time consuming and various saturation levels can affect the results. The boiling test which is conducted on *loose samples* is one of the simple and common methods; however, subjective judgment may introduce bias into the results.

Although, the aforementioned tests are considered to be useful indicators, neither of these tests indicates the failure mechanism [6]. In the other word, their drawbacks include the empirical nature of the procedures and the dependence of the results on the moisture conditioning methodology.

A *non-destructive non-mechanical* test is the Fourier transform infrared spectrometry (FTIR) test. This test is used for determining chemical functional groups within a medium. Carboxylic acids were found to have greatest adsorption on the aggregate surfaces. However, it is easily displaced from most aggregates by water. 2-Quinolone types and sulfoxides have similar behavior [7].

One of the materials surface properties in Micro/Nano scale applications that can affect its macro scale properties is hydrophobicity. Generally, the tendency of one substance to react or dissolve in water is called hydrophilicity. Two main mechanism are associated with hydrophobic surfaces:

1- Low surface energy surfaces that have low energy are hydrophobic that can be obtained by changing the morphology of surfaces [8].
2- Surface roughness it is nearly impossible to have a mega hydrophobic surface just based on chemical properties of surface, without having any surface roughness in the Nano/Micro dimension. Thus, surface roughness is an important factor in hydrophobic surfaces [7,9]. When a surface contains Nano-roughness texture, the interface of air-water for a drop increases which results in reduced capillarity force. Some plants such as lotus are a good example of hydrophobic surfaces due to Nano textures.

The hydrophobicity of a solid can be characterized by the contact angle between the solid and the liquid which is shown in Fig. 1. The greater the contact angle, the more hydrophobic the material. Surfaces with contact angles above 150° are called super-hydrophobic [8].

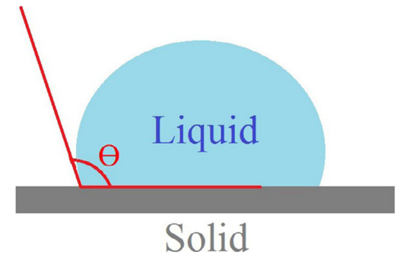

Fig. 1. Contact angle.

On the basis of hydrophobicity/hydrophilicity of surfaces, this study aims to relate the hydrophobicity of asphalt mixtures to their moisture sensitivity. It is hypothesized that hydrophobicity is related to moisture sensitivity of mixtures. In the other words, the lower the hydrophobicity of the material, the greater the affinity to moisture and, thus, the higher the moisture sensitivity.

In order to reduce the moisture susceptibility of mixtures, several mineral additives such as hydrated lime, fly ash, cement kiln dust can be used which incorporate various mechanisms for increasing the resistance of mixtures to stripping. Hydrated lime mechanisms for increasing moisture susceptibility may be attributed to the following reasons: (1) reaction with aggregate surface and formation of aggregate products; (2) producing calcium rich bonding sites for acid polar components of bitumen through ion exchange/pozzolanic reactions; (3) reacting with carboxylic acids and 2-quinolones to reduce water sensitivity [10]. One of the mechanical methods for increasing the adhesion bond is to increase the surface roughness [11]. Also, incorporation of hydrophobic fillers can result in a more durable mixture [12]. Fly ash which is an industrial by-product of coal-fired electric power generating plants is a hydrophobic substance and contains lime. Some researches showed that it can increase the resistance of asphalt mixtures to moisture [13,14]. Studies show that mixtures containing slag with higher amounts of calcium composition (CaO) compared to aggregates are more resistant to moisture due to hydrophobic nature of calcium composition [15]. In this research, the effect of amorphous carbon powder (a hydrophobic powder) on moisture sensitivity of asphalt mixtures is studied by the use of all 5 tests categories for evaluation of moisture susceptibility. Moreover, due to the fact that the usage of amorphous carbon in asphalt concrete is not well established, the mechanical resistance of the modified asphalt concrete is investigated by dynamic creep and wheel tracking test.

2. Materials

2.1. Base materials

In this study, the aggregates were crushed limestone aggregates. The gradation with nominal maximum aggregate size of 12 mm were selected based on ASTM D3515 [16]. Aggregate gradation and aggregate properties are presented in Fig. 2 and Table 1, respectively. Standard PG 64-22 bitumen was kindly provided by Pasargad Oil Company.

Chemical properties of the aggregates were analyzed using X Ray Fluorescence (XRF) and are presented in Table 2.

2.2. Additive

The additive used in this study was a byproduct of solid and liquid paraffin production factory. Due to acidic nature of this substance, its deposition has enormous environmental hazards. However, burning this substance results in an amorphous carbon that is a solid black powder. In this study, the amorphous carbon was used as an additive in asphalt mixtures. The amorphous carbon had particle size of 10–70 μm. The specific gravity of the carbon powder is 0.92 (g/cm^3). It has three fold