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Effects of graphite on rheological and conventional properties of bituminous binders

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Abstract

In this study, the effects of graphite used for developing the rheological and conventional properties of bitumen were investigated using various bituminous binder tests. Penetration, softening point, rotational viscosity (RV), dynamic shear rheometer (DSR) and bending beam rheometer (BBR) tests were applied to bituminous binders modified with four different proportions of graphite by bitumen weight. The penetration values declined while softening point values increased with rising graphite content. While graphite induced 8 °C increases in mixing-compacting temperature by increasing the viscosity values, it also increased the rutting parameter. According to the BBR test, the deformation and stiffness values changed significantly with increasing graphite content, but the m-values did not change significantly. These results showed that graphite generally used for improving the thermal properties can improve to high temperature performance of mixtures.

Keywords: Graphite; Bitumen; Conventional properties; Rheological properties

1. Introduction

Due to viscoelastic behavior of asphalt binder, mechanical features of asphalt pavement vary significantly because of daily and seasonal temperature changes. Asphalt pavement surface temperatures can reach 70 °C in summer due to its high absorption coefficient to solar radiation [1]. This eventually degrades the durability of asphalt concrete. High temperatures will induce permanent deformations of asphalt concrete with the impact of traffic [2]. The high pavement temperature is usually induced by its high solar radiation absorption and can easily generate rutting problem [3–5]. Field results showed that thermal-induced strain is 1.4–2.0 times greater in cold seasons than in warm seasons following the same pavement temperature variations [6]. Viscoelasticity, modulus and shear strength of bitumen significantly influence the asphalt temperature [7]. Especially in a high-temperature zone, a small temperature increase will lead to a sharp decline in performance [8]. High temperatures can also accelerate thermal oxidation, which will result in degradation of the pavement performance. There are two main ways to prevent deterioration that occurred in the pavement due to high temperature. One of these is the use of polymers to improve the resistance of pavements to adverse effects of high temperature [9–11]. The other method is the use of thermal conductive materials to prevent excessive temperature increases in the pavement.

Du and Wang showed that using graphite in asphalt mixture successfully transmits the temperature to the bottom layers. The temperature decreased 6.5 °C at 4 cm

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depth from the surface, and this induced a 43.5% decrease in rutting using graphite as an additive [12]. It has been determined that it is necessary to add graphite alongside conductive fibers in order to achieve a reasonable heat transfer. There is an optimum value of conductive additive depending on the filler/bitumen ratio [13]. Liu et al. [14] determined that using 40% graphite with 0.3% carbon fiber induces 78% increase in dynamic modulus of the bituminous mixtures. The differences in the softening point values decrease after storage modulus test with the use of graphite instead of mineral filler. The complex modulus increases and aging properties improve with increasing graphite content [15,16]. Graphite can transform more free asphalt to structural asphalt depending on its high specific surface area. The softening point of bitumen increases from 45 °C to 70 °C when graphite is used in the bitumen modification. The rutting parameter increases from 1.555 kPa to 3.745 kPa at 40 °C by 9% graphite [17]. Theoretically and experimentally, the materials containing graphite improves the thermal, electrical and mechanical properties more than the materials with other mineral powders.

Although there are some studies about the properties of bituminous mixtures containing graphite, there are limited studies about the effect of graphite on rheological binder properties. In this study, the effects of different amounts of graphite on the properties of bitumen were investigated on a large scale.

2. Materials and methods

Asphalt binder (B 50/70) was utilized as pure bitumen for preparation of modified binders. The graphite particle size is lower than 150 μm, and the carbon content is 84.5%. SEM images of graphite are shown in Fig. 1. Graphite was added into pure bitumen in 4 different ratios as 7%, 10%, 13% and 16% by weight of bitumen. They are represented as 0% (G0), 7% (G7), 10% (G10), 13% (G13) and 16% (G16) respectively. Asphalt binder (500 g ± 5 g) was first heated to 165 ± 5 °C in a container. Then, graphite was added gingerly within 10 min, while the shear speed was kept at 1000 rpm. In sum, 5 different binders were evaluated. The effects of graphite on the binder's penetration, softening point, rotational viscosity (RV), dynamic shear rheometer (DSR) rutting parameter and bending beam rheometer (BBR) tests were examined.

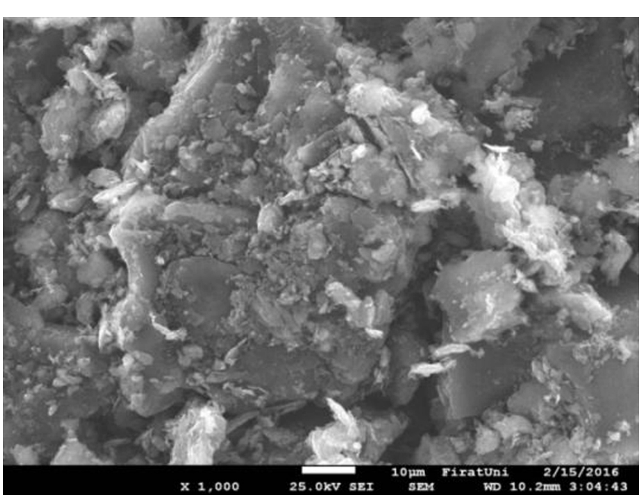

Fig. 1. SEM image of graphite.

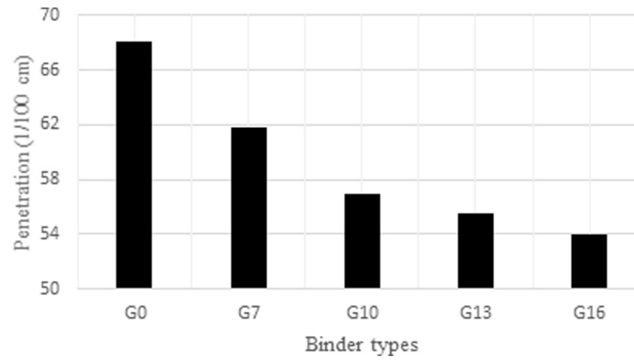

Fig. 2. The relation between additive content and penetration.

3. Results and discussion

3.1. Penetration test

This test was created according to ASTM D5. In this test, a needle of specified dimensions is allowed to sink into the bitumen under a constant load (100 g) at 25 °C for 5 s. The distance of the needle sink (0.1 mm) is considered the penetration. The test is the basis upon which the penetration category of the asphalt binder is classified into standard penetration ranges. It is essential that the test methods are followed precisely because even a slight variation can cause large differences in the result.

The penetration test data obtained from pure and modified binders are shown in Fig. 2. The results given here are the average of 6 measurements performed for a test sample. The increase in graphite content caused a steady decrease in penetration value. The G7, G10, G13 and G16 binders have lower penetration values than values of pure binder by 9.2%, 16.3%, 18.5% and 20.7%, respectively.

3.2. Softening point test

The softening point value of the asphalt binders is defined with ring and ball according to ASTM D36. Mixtures prepared with high softening point bituminous binders could nicely resist deformation at high temperatures. The softening point of pure asphalt binder and 7%, 10%, 13%, and 16% graphite-modified bituminous binders were tested to evaluate the individual effects of the additives on softening characteristics. The results are shown in Fig. 3.