Effects of Nano-kaolin Clay on the Rutting Resistance of Asphalt Binder

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Abstract. Nowadays, nanotechnology has been widely study because it's proven to improve the properties of asphalt. There a lot of nano-materials in industrial area and one of them are Nano clay. Therefore, this study was performed to investigate the rutting resistance of asphalt incorporating Nano-kaolin. The asphalt was evaluated in fresh and aged condition. In this study, asphalt binders with five different percentages of Nano-kaolin (0%, 3%, 5%, 7%, and 9%) contain was prepared. The results indicated that the addition of Nano-kaolin was helpful in enhance the rutting resistance of the binders. In addition, based on the testing results, the ideal asphalt was achieved at 5% of Nano-kaolin content.

INTRODUCTION

Year by year, with increasing of traffic volumes, larger and heavier trucks with new axle design, and higher tire pressures may lead to several road failures. One of the most critical problems is rutting or permanent deformation at high temperatures. Therefore, asphalt modification is introduced to enhance the rheological properties of asphalt binders and at the same time can pro-long the service life of the pavement.

In the last decade, nanotechnology has emerged as the potential solution to greatly enhance the performance and durability of construction materials. Nanomaterials are defined as materials with at least one dimension that falls in the length scale of 1-100 nm [1]. One of the nanomaterials that have gained more interests among researchers is the modification of control asphalt with nanoclay. The application of nanoclay as asphalt modifier is growing rapidly due to its unique characteristics that significantly improve the performance of asphalt binder.

Numerous researches are reported on the utilization of nanoclay in asphalt binder. For example, Yao et al. [2] found that utilization of non-modified nanoclay and polymer modified nanoclay have higher stiffness and lower deflection compared to control asphalt, which indicated a better resistance to rutting. You et al. [3] conducted research on larger amounts of nanoclays as modifiers to evaluate the mechanical properties of the asphalt binders. It was found that nanoclay used in this study increased the complex shear modulus, G* and viscosity of the modified asphalt binders. The effects of two types of nanoclay (Cloisite® and Nanofil®) on the rheological properties of polymer modified asphalt were studied by Jahromi and Khodaii [4]. The asphalt blends of the studied showed that nanoclay increased the stiffness and improved the rutting resistance. However, fatigue performance decreased at low temperatures.

Based on the literature reviews, researchers suggested that the application of nanoclay modifications help in improve some characteristics of the asphalt binders, but more research is required before it can be applied on a large scale. In this paper, nano-kaolin clay is used as a modifier. The effects of different percentages of nano-kaolin content were investigated to observe the rutting resistance index. Asphalt binders were evaluated in two conditions which are unaged and short term aged to simulate the service life of pavement. The results of these tests show the addition of nano-kaolin can enhance the rutting resistance at high service temperature

METHODOLOGY

Materials and Preparation of Samples

In order to achieve objective of the study, five different percentages of nano kaolin clay (0%, 3%, 5%, 7%, and 9%) were prepared. Asphalt with 60/70 PEN grade was used as a control asphalt. Nano kaolin clay (NKC) with average diameter 40– 50 nm was used as modifier. To produce modified asphalt incorporating nano-kaolin, high shear mixer with 2800 rpm rate for 1 hour at temperature of 160 °C was used to disperse the intercalated nano-kaolin. Table 1 tabulated the basic properties kaolin clay.

TABLE 1. Basic properties of kaolin clay [5-7]

Properties	Values
Surface area m^2/g	6-20
Specific gravity	2.58-2.65
pH, 10% dispersion	3.5-8.0
Optimum moisture content (%)	24-25
Hardness (Mohs' scale)	1.5-2.0

Dynamic Rheological Properties

Rheological properties of asphalt binders were determined using a Dynamic Shear Rheometer (DSR) according to ASTM7175 [8]. The DSR tests were conducted at temperatures ranging 46 to 76 °C and at a loading frequency of 1.59 Hz (10 rad/s). A frequency of 1.59 Hz is used to simulate the shearing action corresponding to a traffic speed of about 90 km/h, which is a standard speed limit for federal highways. This test was performed to characterize the viscous and elastic behavior of asphalt medium to high temperature as represented by the complex shear modulus (G^*) and phase angle (δ). The both values of G^* and δ were used to evaluate performance of rutting resistance. High service temperature for a binder is determined as the temperature at which the $G^*/\sin(\delta)$ is greater than 1 kPa for unaged and greater than 2.2 kPa for the rolling thin film oven (RTFO).

RESULTS AND DISCUSSION

Rutting Resistance

Figure 1 shows the rutting resistance for unaged and short term aged sample respectively. The rutting factor values of modified asphalt are higher than the control asphalt binder. The similar trend was observed for short term aged condition. However, for unaged condition highest rutting factor occurs at 5% and 9% nano-kaolin content while for short term aged condition highest rutting factor shows at 3% nano-kaolin content. This indicates that the modification on the rutting resistance of the unaged binder remains and only slightly changes with the modifier production parameters after manufacture and construction of porous asphalt pavements (short term aging). In addition, nano-kaolin modified asphalt binders showed significant increase in the rutting index. This improvement can be attributed to the stiffening effect caused by the addition of the modifiers and found to be consistent with the viscosity analyses at high service temperatures [9]. According to BS EN 14770 [10] specifications, these modified binders reduce the rutting susceptibility, and also have the improvement on permanent deformation resistance at high temperature compared to the control asphalt.

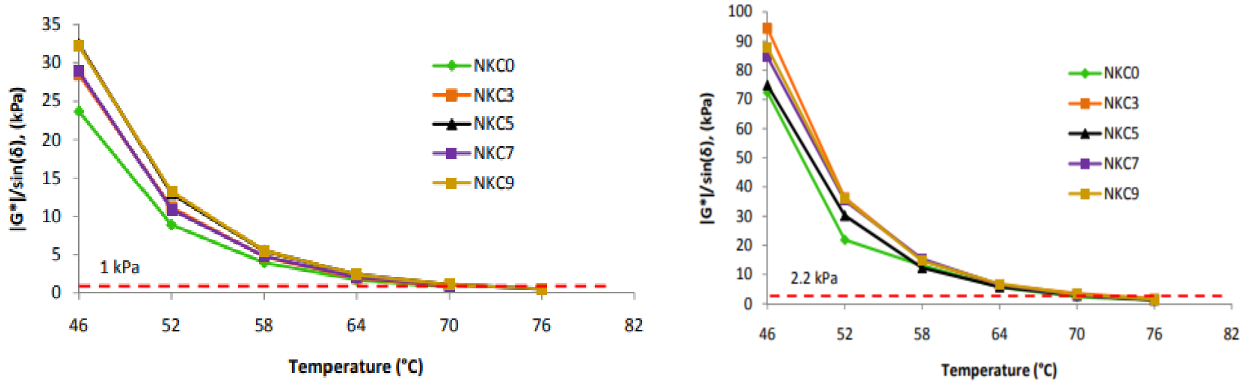

FIGURE 1. Rutting resistance for unaged (left) and short term aging (right)

Phase Angle

Phase angle (δ) is defined as the time lag between strain and stress under traffic loading and is highly dependent on the temperature and frequency of loading. Figure 2 shows the relationship between temperature for unaged and short-term aged condition respectively. Based on figure, it shows that 5% of nano-kaolin content had a lowest δ values compare to control asphalt and other percentages. This result shows that asphalt with 5% nano-kaolin possess a better performance specifically at high temperatures and at the same time approaching the behavior of the ideal asphalt. Furthermore, small δ can also indicates that the binder have a lower perdurable deformation in hot weather condition. In addition, all binder incorporating nano-kaolin decreases the slope of diagram as well compared to the control asphalt. On the other hand, 3% nano-kaolin content shows the lowest δ values compare to other percentages in aged condition. During aging process binders become stiff compare to unaged asphalt which lead to slightly decrease the viscous-elastic behavior. However, all δ values of modified asphalt demonstrate lower values compared to control asphalt. As a result, it can be concluded that the addition of the nano-kaolin plays an important role in affecting the viscous-elastic behavior of binder. In comparison, the nano-kaolin modified asphalt was less sensitive to temperature changes. In other words, the modified asphalt binders demonstrate a higher ability to maintain elastic/viscous capability than the control asphalt does.

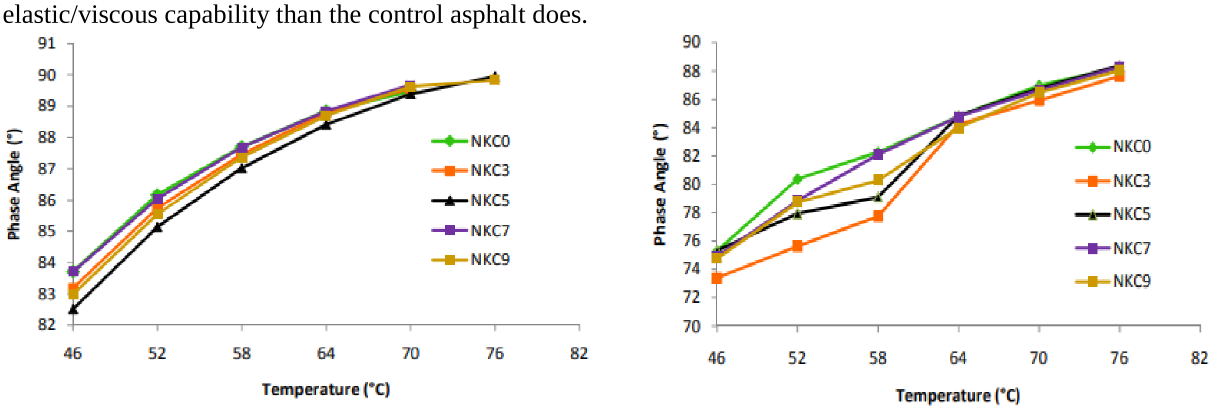

FIGURE 2. Changes of phase angle vs. temperature for unaged (left) and short term aging (right)

Failure Temperature

Failure temperature of asphalt binders was determined based on the data of rutting resistance test for unaged and short term aged condition. Figure 3 shows the high failure temperature at 70 °C of control and modified asphalt binders in both unaged and short term aged conditions respectively. The trends of failure temperature for modified asphalt binders containing 5% and 9% of nano kaolin content were almost similar for both percentages. This indicates that the rutting performance of asphalt binder was influenced by the amount of nano kaolin, which is consistent with the results reported by Nazzal et al. [11] and El-Shafie et al. [12]. Short term aged control sample present the similar trends as unaged sample. However, highest complex shear modulus occurs at 3% nano kaolin content. High complex shear modulus of these modified asphalt binders reveal that the asphalt binder can reflect more energy when loading is applied, and also indicate that the modified asphalt binders have more resistance ability to rutting temperatures.

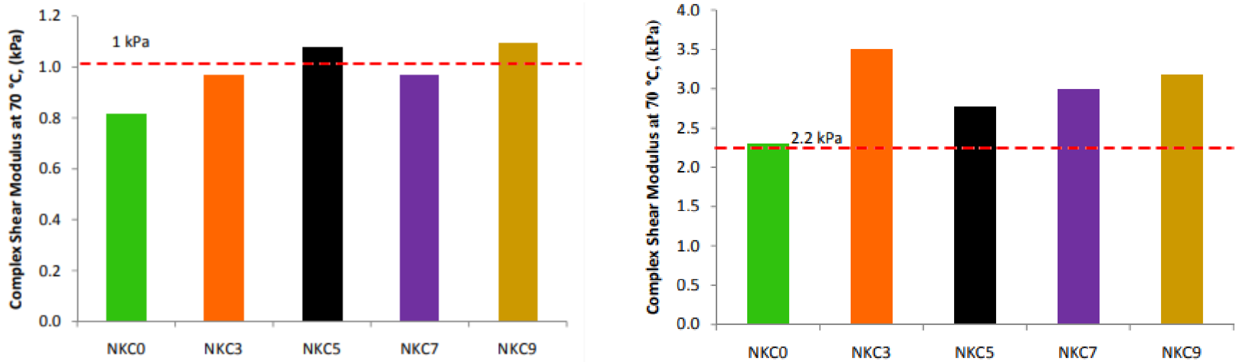

FIGURE 3. Failure temperature at 70°C for unaged (left) and short term aging (right)

CONCLUSIONS

From the following results and discussion, it can be concluded that the rutting resistance of asphalt binder with addition of nano kaolin clay produced a stiffer binder, which help to enhance the rheological properties of asphalt. On the other hand, decreasing on percentage of nano kaolin clay content in $G^*/\sin(\delta)$ due to aging process when asphalt become more stiffer compare to unaged condition which may lead to slightly decrease the viscous-elastic behavior. Finally, it can be said that 5% of nano kaolin clay content is considered the optimum percentage of asphalt modifier.

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