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Performance of nano kaolin clay modified bitumen under aging through the viscosity

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Abstract. Increasing traffic volumes and rising cost of bitumen making it necessary to improve the performance of binder through bitumen modification. Nano particle have emerged as the potential solution to greatly enhance the properties of binder. This study explores the potential application of nano kaolin clay (NKC) as a modifier to improve the performance of bitumen incorporating different percentages of NKC. The performance of NKC modified bitumen was assessed using a viscosity and ageing test. The average size of NKC used was 57.7 nm. Then, 0% (control), 3%, 5%, 7% and 9% NKC by weight of bitumen PEN 60/70 was added. Generally, the results reveal that bitumen binder including nano kaolin clay is more effective in improvement the viscosity properties of asphalt before and after aged.

1. Introduction

Asphalt binder which also known as bitumen is a crucial material used in pavement. The basic purpose of bitumen is to “bind” the aggregate particles together. Bitumen is a black or dark in colour of complex mixture which comprises of hydrocarbon in solid and liquid particle, known as asphaltenes and maltenes. Asphaltenes functional for binder viscosity is categorized as a polar compound which possesses a high molecular weight that ranged from 5% to 25% of bitumen component. Meanwhile, maltenes provides stability to the asphaltenes compound [1]. Generally, there are five basic characteristic of bitumen which are bitumen has good adhesion bonding, elastic, plastic, viscoelastic and ages. Bitumen has excellent adhesive qualities. However, in presence of water the adhesion does create some problems due to the weak of dispersion force. The elastic property of bitumen can be observed when bitumen is stretches or elongates, it has the ability to return to the original state. On the other hand, when temperatures are raised, as well as when a load is applied to bitumen, the bitumen will flow, but will not return to its original state when load is removed. This condition is referred to a plastic behavior of bitumen. There are various material states of bitumen where bitumen may be rigid and friable at low temperature, liquid and fluid at high temperature and semi-rigid at medium temperature. Therefore, bitumen can be classified as a viscoelastic material. The bitumen viscoelastic property can be interchangeable depending on the temperatures and time of load factors. In addition, bitumen ageing is one of the main causes of degradation of asphalt pavement. The most important ageing mechanisms are oxidation, volatilization and exudative hardening [2]. In bitumen ageing, two mechanisms are involved which are chemical changes in binder and physical hardening where can cause the bitumen to harden. Kaolin clay (KC) is clay that is composed of kaolin stone [3]. It is mainly formed after kaolin stone is completely weathered and rain washed [4]. KC is found in white or near-white powder, is odourless, fine in particle size, soft and has a non-abrasive texture [5]. KC also has good plasticity and cohesiveness, excellent electrical insulation and good acid soluble cationic [6]. Most importantly, KC is relatively low in cost compared to other modifiers, especially polymer. Due to this fact, the utilisation of KC in asphalt binder seems to have positive improvement in properties and performance of the binder. However, a limited study was reported on the application of KC in the asphalt binder especially under ageing condition. Ouyang [7] found that KC at micro-scale improved the storage stability issue in polymer modified asphalt. This finding was supported by Fang et al. [8] reported that KC influences the properties of modified asphalt binder in terms of aging resistance, rheological and thermal storage properties. However, in term of nano size, viscosity and ageing test, there are no improvement was observed. Therefore, this study was investigating the performance of nano kaolin clay (NKC) in asphalt binder and subjected to viscosity test at different ageing conditions.

2. Materials and Methods

2.1. Nano kaolin clay

Kaolin clay (KC) was used as a modifier in binder. To produce the NKC, a ball mill apparatus was used as grinding machine [9]. At the laboratory, approximately 500g of KC powder was sieved and passing through 0.075 mm sieve size. The KC was placed in the grinding to be crushed efficiently. Normally, the KC powder was ground into different durations to obtain the NKC. In order to obtained the smallest size of particle, only the KC powder that passing through 0.075 mm sieve size underwent a Transmission Electron Microscopy (TEM) to measure the nano size of KC powder. The average nano sizes used in this investigation was 32nm as illustrated in Figure 1.

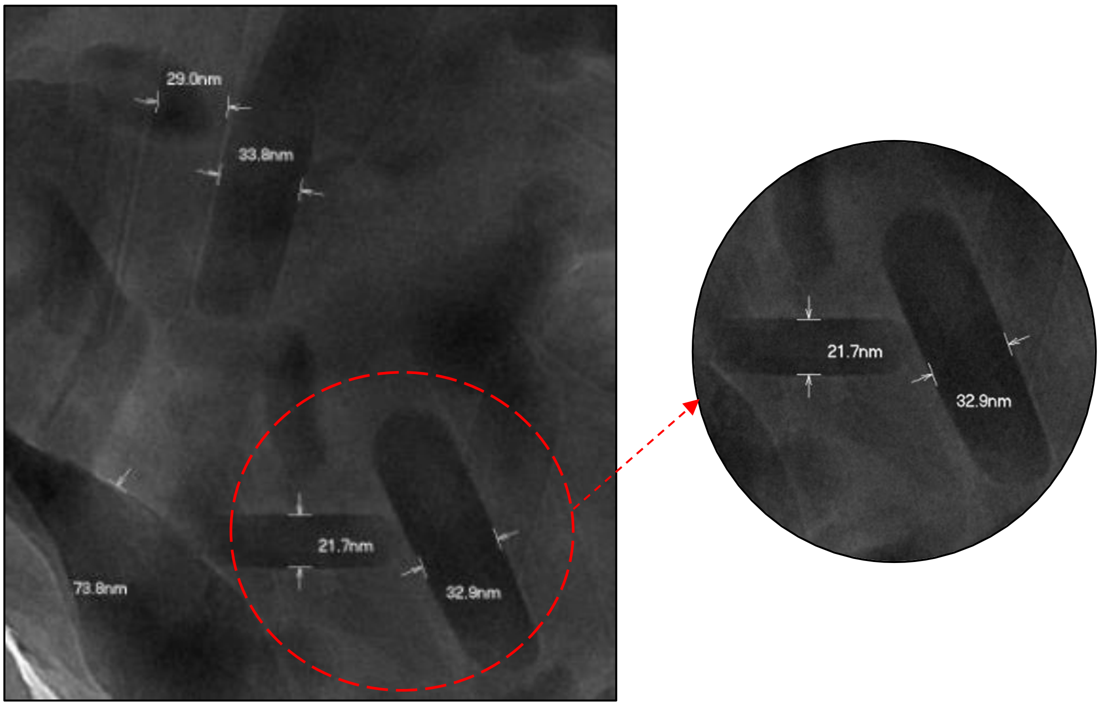

Figure 1. TEM images of NKC powder after 20 hours of grinding

2.2. Bitumen modification

The binder used in this study was PEN grade bitumen 60/70 as recommended in the new JKR Standard Specification for Road Works [10] based on tropical climate. The bitumen exhibited the following physical properties i.e. penetration (69 dmm at 25°C) and softening point (52°C). The blending of NKC in the bitumen was performed at the content of 0%, 3%, 5%, 7% and 9% by weight of the bitumen. The blending process of bitumen and NKC was conducted by using a high shear mixer with the speeds of 1500 rpm (60 min) at 160°C. This speed was used to ensure that the NKC was well dispersed in the bitumen.

2.3. Viscosity test
The viscosity of the asphalt binder is used in order to determine its flow characteristics and provide some assurance that it can be pumped and handled at the hot mixing facility and also in order to determine the mixing and compacting temperature of asphalt mixtures [11]. The viscosity test was conducted at a temperature of 135 °C and 165 °C because it approximates the mixing and compaction temperature used in the construction of asphalt pavements.

2.4. Rolling Thin Film Oven (RTFO) Test
The Rolling Thin Film Oven (RTFO) test is performed to simulate the effect of the short-term ageing of asphalt binder in accordance to ASTM D2872 [12]. A total of 8 cylinder glass containers (35 g base asphalt binder per container) were rotated horizontally in the oven with the temperature of 163 °C and airflow at 4000 mL/min for 85 minutes. During the aging test, the initial and final mass of the asphalt binder in a cylinder glass was weighed and recorded, as the mass loss should be less than 1% after the short term aging was performed. The residue of the asphalt binder was used in order to determine the physical and rheological properties of the aged asphalt binder.

3. Results and discussion

3.1. Viscosity at unaged condition
The viscosity decreasing trend was observed as temperature increased from 135 °C and 165 °C as show in Figure 2. For example, at 135 °C temperature, a higher viscosity was observed for NKC replacement by increasing the value at 3% for 0.8 Pa.s, 5% for 0.7 Pa.s, 7% for 0.8 Pa.s and 9% for 0.8 Pa.s, accordingly. This indicated that the modified binder with NKC exhibited higher viscosity as compared to control binder. At 165 °C, a similar viscosity trend of at 135 °C was recorded, wherein a higher result achieved by 9% NKC content for 0.4 Pa.s as compared to control binder. Meanwhile, the other percentages of 3%, 5% and 7% of NKC content displayed a consistent result at 0.3 Pa.s. It can be noticed that, the addition of NKC content at a temperature of 135 °C and 165 °C increases the viscosity value by an average of 110%. The obtained viscosity result conforms to the result study by Abdullah *et al.* [13]. According to their study, the increase in viscosity value was due to the formation of the nanoclay exfoliated structure that causes the particle agglomeration. This phenomenal might have prevented the movement of the asphalt binder’s molecule chains. In addition, the increase in the viscosity value is a good resistance property against rutting and permanent deformation at high temperature. Therefore, it can be said that even at maximum pavement service temperatures, the NKC makes the binder stiffer. It can also be noted that, as the temperature increases, in general, the viscosity value increases for all the five NKC contents.

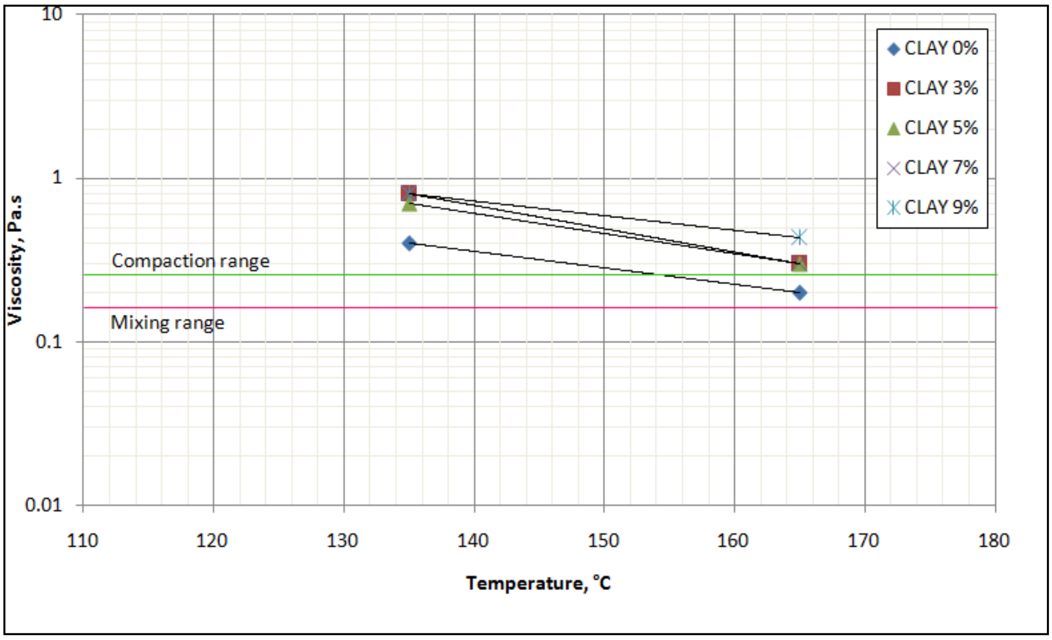

Figure 2. Relationship between kinematic viscosity and NKC content for un-aged binder

3.2. Viscosity at aged condition

For aged condition, the similar trend was observed at 135 °C where the addition of the NKC content increases the viscosity value of aged binder as illustrated in Figure 3. This was attributed to the high internal friction due to the binder hardening during aging and thus increased the binder stiffness and brittleness. Due to the high stiffness in aged binder, it resulted in high viscosity performance. With reference to the results, viscosity was decreased as the sample was subjected to a higher temperature at 165 °C. The viscosity values of all binders are almost similar which at 135 °C the viscosity for modified binders presented a consistent result at 0.8 Pa.s. Meanwhile, at 165 °C the viscosity value for modified binders displayed a consistent result at 0.2 Pa.s. From this result, it is obviously that at aged condition, the NKC does not significantly affect the viscosity of the binder.

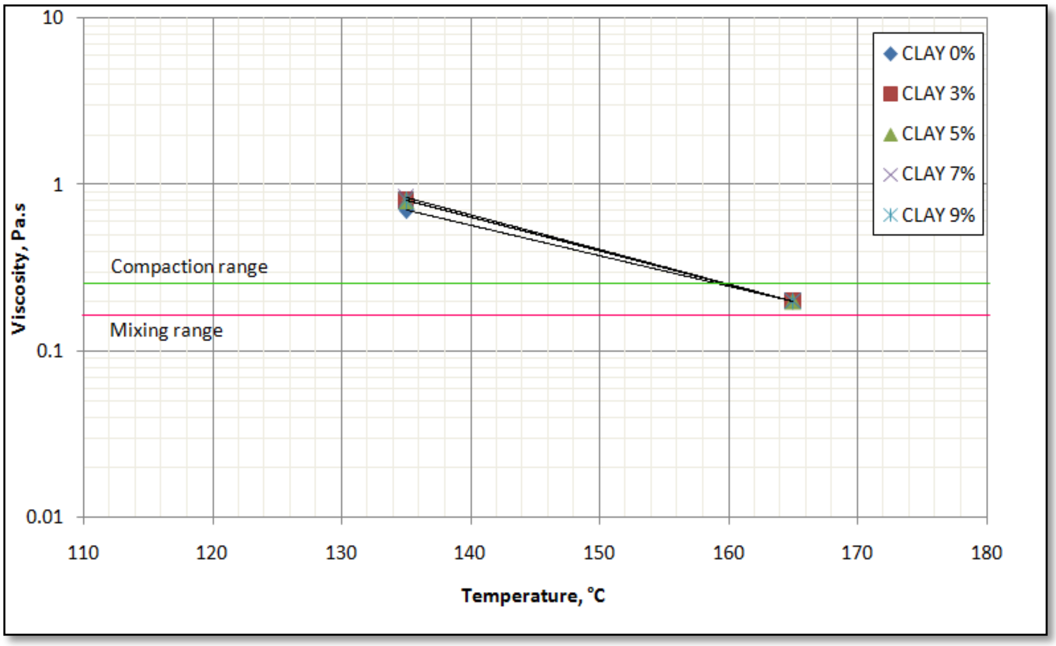

Figure 3. Relationship between kinematic viscosity and NKC content for aged binder

3.3. Mixing and compaction
Table 1 summarised the mixing and compaction of the asphalt binder incorporating different percentages of NKC content. Mixing and compaction temperature was determined as the viscosity line intercept with the value of 0.17 Pa.s for the mixing temperature line and 0.28 Pa.s for the compaction temperature line, as illustrated in Figure 1 and 2 for un-aged and aged binder respectively. The result indicates that the modified binder incorporating NKC has higher mixing and compaction temperature compared to the control binder. Therefore, the use of NKC could increase the production temperatures of asphalt mixture. Jamshidi *et al.* [14] stated that this is inconsistent with sustainable practices due to higher energy consumptions and greenhouse gas emission. Furthermore, high temperature for the mixing and compaction of mixture due to high viscosity will increase the heating costs of construction [15].

Table 1: Mixing and compaction temperatures of NKC porous asphalt mixture

Construction Temperature (°C)	**Asphalt Binder Designation**				
	NKC0	NKC3	NKC5	NKC7	NKC9
Mixing	170	180	180	180	190
Compaction	155	168	170	170	180

4. Conclusions
In this study, laboratory tests were conducted on NKC modified binders in order to evaluate the potential impact of different NKC contents on the viscosity characteristics before and after aged. In general, the proper amount of NKC can significantly improve its viscosity value. At unaged condition, the results demonstrated that even at maximum pavement service temperatures, the NKC makes the binder stiffer. However, at aged condition, the NKC show less significant affects the viscosity of the binder. In addition, NKC could increase the production temperatures of bitumen mixture.

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