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# The influence of nano kaolin clay as alternative binder on the penetration properties

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**Abstract.** In the last decade or so, nanomaterials have emerged as the potential solution to greatly enhance the properties of binder with the purpose of improving the performance of asphalt mixture. Due to that, this study evaluates the influence of nano kaolin clay as alternative binder on the penetration properties. The penetration test, penetration index and penetration-viscosity number were conducted in modifying the binder with the percentage of NKC are 0, 3, 5, 7 and 9%, accordingly. The test results showed that the penetration values of modified binder slightly decreased when compared to the controlled binder. On the other hand, the PI and PVN values significantly increase with the NKC content increased.

## 1. Introduction

In general, there are five basic characteristic of bitumen which are bitumen has good adhesion bonding, elastic, plastic, viscoelastic and ages [1]. Bitumen has excellent adhesive qualities [2]. 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 [3]. 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 [4-8]. 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 [9-10]. Therefore, bitumen can be classified as a viscoelastic material. There is a large number of modifiers are commercially available and widely used in bitumen modification. These modifiers were classified in 8 main classes which are polymer, hydrocarbon, mineral filler, antioxidants, anti-stripping additives, fibers, extenders and oxidant [11,12]. Non-metallic mineral resources such as clay, silica and so on are widely used as a constituent part or substitution element in the production of modified bitumen. One of the common and widely used of materials in bitumen is clay [13]. The clay received much attention as a modifier due to the expectation to strengthen and enhance the physical and rheological properties of the asphalt binder. There are four main groups of clays which are kaolinite, montmorillonite, Illite and chloride.

Based on previous studies, it has been proved that the utilisation of clay as nano size in bituminous material shows positive improvement in rheological and mechanical properties of modified asphalt binder [14-17]. Nanoclay is a layered silicate that has a layer thickness between 1 and 100 nm and widely used in the binder modification to improve mechanical and thermal properties. Nanoclay has low cost of production and abundance in nature [18]. Generally, there are two main categories of nanoclay used in asphalt binder which are non-modified nanoclay (NMN) and polymer modified nanoclay (PMN). NMN is the most frequently used with 2-to-1 layered structure clay consisting of one octahedral alumina sheet sandwiched between two-tetrahedral silica [19,20]. There are no research was reported on the utilisation of NKC in terms of the physical properties of the asphalt binder as well as penetration test, penetration index and penetration viscosity number while this study was performed.

## 2. Materials and methods

### 2.1. Bitumen
The 60/70 penetration grade bitumen was used through the study. This bitumen was meets the requirements of ASTM D6373 specifications.

### 2.2. Nano Kaolin Clay (NKC)
Kaolin clay (KC) was used as a modifier in bitumen. To produce the NKC, a ball mill apparatus was used as grinding media. In general, 500g of KC powder that passing 0.075 mm sieve size was placed in the grinding machine together with the steel balls to be crushed efficiently. The diameter of the steel ball was in range from 12 mm to 25 mm, respectively. To obtain the NKC, the KC powder was ground into different durations. After completing the grinding time, Transmission Electron Microscopy (TEM) was applying to measure the particle size of NKC.

### 2.3. Modified Bitumen with NKC
A high shear mixer was used to modify bitumen with NKC. Firstly, the bitumen was heated up to 160 °C to a fluid state and the NKC contents of 3%, 5%, 7%, and 9% was added. A 2800 rpm mixing rate for 1 hour was used to disperse the intercalated NKC powder. Then, after homogenous modified bitumen was obtained, the specimen was left to cool at room temperature prior to being further investigated.

### 2.4. Penetration test
Penetration test was performed in order to evaluate the bitumen consistency in accordance to ASTM D5-06e1 [21]. Bitumen was heated and poured into a penetration cup prior to testing. The sample was then cooled and conditioned in the water bath for 1 hour at 25°C. The bitumen sample was tested with the applied total load of 100 g for 5 s at 25°C.

### 2.5. Penetration Index (PI) and Penetration Viscosity Number (PVN)
The penetration index (PI) and penetration viscosity number (PVN) represent a quantitative measure the response of binder to temperature variation. According to Jeffry *et al.* [22], temperature susceptibility can be defined as changes or alteration of consistent parameter due to temperature. The suggested range of PI index is -1 to +1, where the lower the PI of binder, the higher the temperature susceptibility, and vice versa. Meanwhile, the suggested range for PVN index is -2.0 to +0.5 with the same principal as PI index. A binder which exhibits high susceptibility to temperature change is not desirable because at the lowest service temperature, the viscosity of the binder will increase gradually, which will result in a low temperature cracking exposure. The PI and PVN value was determined using the following equation:

$$PI = \frac{1952 - 500 \log Pen - 20SP}{50 \log Pen - SP - 120} \tag{1}$$

Where:
Pen is the penetration value at 25 °C

SP is the softening point value

$$\mathrm{PVN} \quad = \quad -1.5 \frac{4.258 - 0.7967 \log P - \log V}{0.795 - 0.1858 \log P} \qquad (2)$$

Where:

P is the penetration value at 25 °C

V is the viscosity value for 135 °C

## 3. Results and discussion

### 3.1. Penetration Value

In order to measure the consistency of the asphalt, a penetration test was conducted at 25 °C to stimulate the average yearly service temperature. According to Figure 1, the penetration values of modified binder slightly decreased by 6.9% to 13.5% compared to the controlled binder. A similar result was reported by El-Shafie *et al.* [23] and Abdullah *et al.* [24] in their studies on nanoclay modified binder. The same situation occurs for aged modified binder, where the penetration value declined correspondingly with the addition of NKC by 10.0% to 27.8% compared to the aged control binder. Lower penetration values indicate that the asphalt binder is stiff and hard, which can lead to cracking issues. Therefore, in order to ensure the long service life of pavement, the asphalt binder used should be as soft as possible without reducing stability below the minimum required to prevent displacement under traffic.
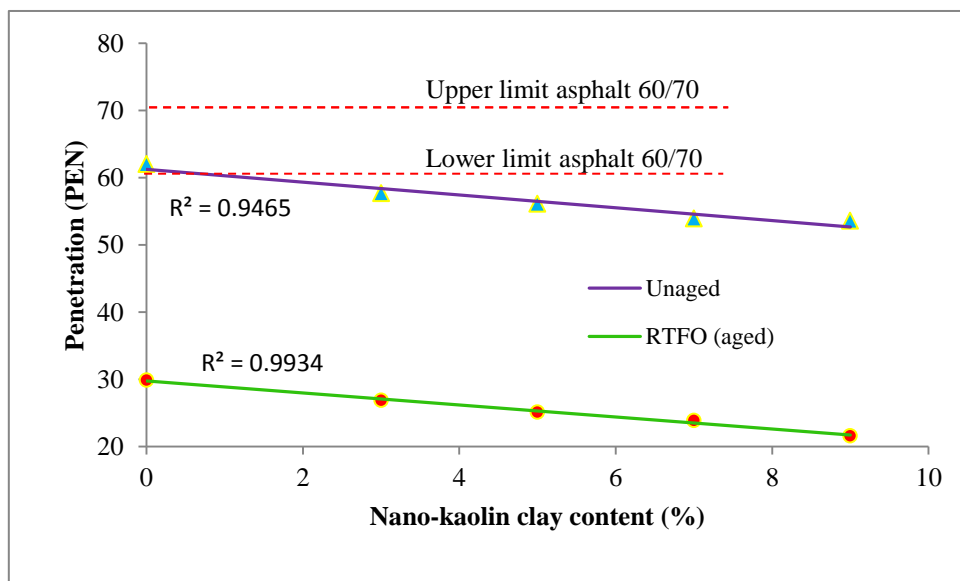


**Figure 1.** Relationship between penetration value and NKC content

### 3.2. PI and PVN

In this study, temperature susceptibility was determined on the basis of the penetration index (PI) and pen-vis number (PVN). There is no specific standard and limit to classify the condition of the PI and PVN value. However, the lower the PI values of binder, the higher its temperature susceptibility. Most of the control binder has a PI between +1 (low temperature susceptibility) and -1 (high temperature susceptibility). Asphalt binder with high temperature susceptibility usually exhibits brittleness at low temperature and is very prone to transverse cracking in cold climates. It is similar to the PVN value, the lower the PVN value of an asphalt binder, the higher its temperature susceptibility. Most of the control binder has a PVN value between +0.5 (low temperature susceptibility) to -2.0 (high temperature susceptibility). However, one notable difference between PI and PVN is that the PI change due to aging process (during mixing and subsequently in service), whereas the PVN value

remains substantially the same. Table 1 summarised the PI and PVN value of asphalt binder incorporating different percentages of NKC. The result shows that the PI and PVN values significantly increase with the increasing NKC content. The lowest PI value occurs at 7% NKC (-1.03), while the control binder shows the lowest PVN value with -0.74.  The lower PI and PVN value attributed the physical characteristics of the binder, which is soft and less viscous.  The softened binder had high sensitivity for physical alteration when exposed to the temperature due to internal bonding strength. Thus, indicated the high susceptibility to the temperature exposure. Modified binder with 5% NKC presents the highest value for both PI and PVN which are -0.81 and 0.07 respectively.  This indicates that 5% NKC is less sensitive to temperature as high temperature was required to break the strong internal bond, thereby the temperature susceptibility was reduced as evidenced by increasing PI and PVN. This also indicated that 5% NKC be more resistant to rutting as compared to other percentages.

**Table 1.** PI and PVN value of bitumen incorporating NKC at different percentage

| Asphalt Binder Designation | Penetration Index (PI) | Pen-Vis Number (PVN) |
|---|---|---|
| NKC0 | -0.95 | -0.74 |
| NKC3 | -0.87 | 0.15 |
| NKC5 | -0.81 | 0.07 |
| NKC7 | -1.03 | 0.07 |
| NKC9 | -0.92 | 0.07 |

## 4. Conclusions

The utilization of NKC as modified binder has the potential to be beneficial for the bitumen characteristic. This study has verified the positive influences of NKC over various test of bitumen. Generally, the penetration values of NKC binder modified slightly reduced from 6.9% to 13.5% when compared with the controlled binder. Furthermore, the penetration index and penetration viscosity number significantly increase with the increasing NKC level. This indicated that the NKC is less sensitive at high temperature.

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