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Engineering properties of asphalt binders containing nanoclay and chemical warm-mix asphalt additives

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HIGHLIGHTS

- We investigate nanoclays and a chemical WMA additive for possible WMA application.
- Nanoclays modified binders increased the $G^*/\sin\delta$ values and failure temperatures.
- The NCMB B4% could potentially become a new WMA binder.

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ABSTRACT

In the effort to promote the construction of green pavement the asphalt concrete industry has been making consistent effort to use warm-mix asphalt (WMA) in their construction. The objective of this study was to improve the properties of the asphalt binders through the addition of nanoclays and chemical WMA additive. An asphalt binder of 80/100 penetration grade was modified with different percentages of Nanoclay A (montmorillonite clay surface modified with 35–45 wt.% dimethyl dialkyl (C14–C18) amine), Nanoclay B (montmorillonite clay surface modified with 35–45 wt.% octadecylamine, and 0.5–5.0 wt.% aminopropyl-triethoxysilane), and chemical WMA additive (fatty polyamines polymer non-ionic component). After modification, the asphalt binders were named Nanoclay A modified asphalt binder (NCMB A), Nanoclay B modified asphalt binder (NCMB B), and chemical WMA modified asphalt binder (CWAA). The rheological characteristics of the unmodified and modified asphalt binders were evaluated using the rotational viscosity, dynamic shear rheometer, and bending beam rheometer tests. Results of the tests showed that NCMB B and CWAA significantly reduced mixing and compaction temperatures. However, only NCMB B showed a significant increase in rutting and fatigue resistance when compared with base asphalt binder. A change in chemical bond was also observed in the tested binders after long-term aging, which suggests that the addition of modifier could delay the aging process.
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1. Introduction

Asphalt binder is an element that acts as a binding agent in asphalt pavements. Most asphalt binders are manufactured from crude oil. Asphalt binders are traditionally regarded as a colloidal system made up of asphaltenes micelles covered with a stabilising phase of polar resins, which form an interface with a continuous oily maltenic medium. It also influences pavement performance under various loading and weather conditions as well as low and high on-site operating temperatures [1–4]. However, there are several pavement distresses that affect the performance of asphalt binder, namely high-temperature rutting (or permanent deformation), medium-temperature fatigue, moisture damage, and low-temperature cracking damage, all of which could decrease the quality of asphalt pavements. Therefore, base asphalt binders need to be modified to enhance their properties for better performance [5,6].

Previous studies have shown that, compared with unmodified base binder, the addition of modifier tend to enhance its physical and rheological properties, depending on the types and dose of the modifier utilized [7–11]. An ideal modifier should be able to sustain asphalt binder's resistance to multiple types of distresses. From an engineering point of view, an ideal asphalt binder should

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provide resistance to rutting at high temperature, fatigue at intermediate temperature, and thermal cracking at low temperature. Additionally, existing plants need to be modified slightly so that the modified asphalt binder could achieve the targeted viscosity and could be easily blended with aggregates at a particular temperature. The modified asphalt binder should remain homogenous during storage to ensure its stability and hence yield similar results as in laboratory experiments [7,12,13].

Over the last decade, the use of warm-mix asphalt (WMA) has gained increasing popularity among authorities and pavement industry as this technology reduce emissions and fuel consumption during the production and construction of asphalt mixes without significantly affecting the properties of the mixes. Previous studies on the production of WMA mix focused on modifying base asphalt binders through the addition WMA additives [14–17]. Currently, the modification of base asphalt binders with WMA additives could be done through three different processes, namely through the foaming process, the addition of organic additives, and the addition of chemical additives. Studies have shown that the use of WMA technology has significantly improved the performance of pavements [11,18].

Other researchers have shown that the physical and mechanical properties of base asphalt binder could also be improved through modification with nanoclay. The engineering properties of modified asphalt binders and mixes were also significantly improved, particularly in terms of their stiffness, storage stability, rutting resistance, thermal cracking resistance, and aging resistance [2,13,19–24]. However, no intensive studies have been done to evaluate the effects of nanoclay as WMA additive based on the performance of asphalt binders and mixes. Due to availability of numerous types of nanoclays in the market, each one with different properties, there is a need to identify the possibility of using nanoclay as a WMA additive in the future. This material could significantly reduce the mixing and compaction temperatures of asphalt mixes without compromising its performance. Therefore, the objective of this study is to evaluate the performance of nanoclay modified asphalt binder (NCMB) as a new WMA binder through the Superpave asphalt binder tests, surface energy test, and storage stability test. The performance characteristics of NCMB will then be compared with a chemical WMA modified asphalt binder (CWAA), an existing product that is widely available in the market.

2. Experimental design

2.1. Materials

The base asphalt binder used in this study was obtained from Kemaman Bitumen Company, Malaysia. Table 1 shows the characteristics of the base asphalt binder used in this study, which conforms with the Malaysian Standard MS 124 requirement [25] for an asphalt binder of 80/100 penetration grade and Superpave requirement [26] for a performance grade of PG 64-28. Three types of modifiers, namely Nanoclay A, Nanoclay B, and chemical WMA additive with varying percentages were used to modify the base asphalt binder. The chemical WMA additive is an established additive and is currently used by the asphalt industry as a modifier in the production of WMA mixes.

Nanoclay A and Nanoclay B modifiers were initially evaluated to identify their potential use as WMA modifiers. The physical properties of these modifiers are presented in Table 2. The chemical compositions of the modifiers used are described in greater details in Table 3. The chemical WMA additive has a totally different chemical composition compared to the nanoclays. The percentage of chemical composition for Nanoclay A and Nanoclay B are slightly different with the exception of ferric oxide.

2.2. Sample preparation

The physical and rheological properties of modified asphalt binders were determined to evaluate the effectiveness and potential of WMA additives, which would then be selected for the production of WMA mixes. In the sample modification process, 400 g of base asphalt binder was heated in an iron container until it became fluid under a medium shear mixer using the Silverson-L4RT at a speed of 2000 rpm. When the temperature reached 155 ± 5 °C, the chemical WMA additive was gradually added (10 g/20 s) at 1%, 2%, 3% and 4% (by weight of asphalt binder) for 10 min. On the other hand, Nanoclay A with 3%, 4%, and 5% (by weight of asphalt binder) was gradually added (5 g/30 s) into the melted asphalt binder under a high shear mixer of 5500 rpm for 30 min. A similar procedure was used for Nanoclay B. After the processes have been completed, the modified asphalt binders were categorized as Nanoclay A modified asphalt binder (NCMB A), Nanoclay B modified asphalt binder (NCMB B), and chemical WMAmodified asphalt binder (CWAA). The experimental flowchart is shown in Fig. 1.

Table 1
Characteristics of base asphalt binder.

Characteristics	Method	Result	Requirement
Penetration at 25 °C, 100 g 5 s, 0.1 mm	MS 541	93.7	80–100
Softening Point, °C	MS 687	48.7	45–52
Solubility in trichloroethylene, % wt.	ASTM D2042	99.53	Min. 99.00
Ductility at 25 °C, 5 cm per min, cm	ASTM D113	100+	Min. 100
Retained penetration after thin-film oven test, %	ASTM D5	52.1	Min. 47.0
Drop in penetration after heating, %	ASTM D5	15.8	Max. 20.0
Flash Point, °C	AASHTO T48	308	Min. 230
Loss on heating,% wt.	AASHTO T240	0.090	Max. 1.000
Viscosity at 135 °C, Pa s	ASTM D4402	0.48	Max. 3.00
Original $G^*/\sin\delta$ at 64 °C @ 10 rad, kPa	AASHTO TP5	1.63	Min. 1.00
RTFO Residue $G^*/\sin\delta$ at 6 °C @ 10 rad, kPa	AASHTO TP5	6.08	Min. 2.20
PAV Residue $G^*\sin\delta$ at 64 °C @ 10 rad, kPa	AASHTO TP5	2897	Max. 5000
PAV Residue Stiffness at −18 °C @ 60 s, MPa	AASHTO TP1	120	Max. 300
PAV Residue m-value at −18 °C @ 60 s, MPa	AASHTO TP1	0.344	Min. 0.300

Table 2
The physical properties of modifiers.

Properties	Chemical WMA additive [27]	Nanoclay A	Nanoclay B
Ingredients	Fatty polyamines Polymer Non-ionic component	Montmorillonite clay surface modified with 35–45 wt.% dimethyl dialkyl (C14–C18) amine	Montmorillonite clay surface modified with 35–45 wt.% Octadecylamine and 0.5–5.0 wt.% aminopropyl-triethoxysilane
Physical state	Solid	Powder	Powder
Color	Brown	Gray white	Gray white
Odour	Amine like	Amine like	Amine like
Solubility	Insoluble in cold water	Water soluble	Water soluble

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