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Laboratory evaluation on the characteristics and pollutant emissions of nanoclay and chemical warm mix asphalt modified binders

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HIGHLIGHTS

- The addition of WMA could delay and weaken the oxidative reaction of the binders.
- NCMB shows better resistance to rutting at high temperatures.
- The modified binders exhibit significantly higher surface free energy values.
- The WMA mixtures reduced up to 50% of the pollutants emitted during mixing process.

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ABSTRACT

This study was conducted to investigate the performance characteristics of nanoclay- and chemical warm-mix asphalt (WMA) additive-modified asphalt binders in terms of their chemical, morphology, rheological and surface energy properties in comparison to conventional asphalt binder. Both the nanoclay modified asphalt binder (NCMB B) and the chemical WMA additive modified asphalt binder (CWAA) were artificially aged under short-term and long-term aging conditions prior to evaluation. The chemical and morphological properties were measured with Fourier Transform Infrared (FTIR) spectroscopy and Field-Emission Scanning Electron Microscopy (FE-SEM) respectively. Rheological evaluations were conducted to determine binder's behavior under short-term aging in terms of frequency sweep, temperature sweep, and creep recovery tests by utilizing the dynamic shear rheometer (DSR) machine. Emission test was also conducted on the unmodified and modified WMA mixtures to estimate the gaseous pollutants emitted during their manufacture. FTIR spectroscopy results showed that the addition of WMA modifiers into asphalt binder could delay and weaken the oxidation reaction of the binder which in turn improved the aging process. However, the physical structure did not seem to show any changes after undergoing long term aging. The use of NCMB B 4% (by weight of asphalt binder) seemed to produce better resistance towards rutting when compared to CWAA 1%, 2% and 3% for unaged, and short- and long-term aging test conditions. The modified binders exhibit significantly higher surface energy and hence produced good adhesion between aggregates, which imply increased resistance toward moisture-induced damage. This study also revealed that the manufacture of WMA mixtures reduced up to 50% of the pollutants emitted during mixing in laboratory.

1. Introduction

In recent years, the demand for the use of warm-mix asphalt (WMA) in the construction of pavements have been steadily increasing throughout the world with the aim of reducing energy consumption and emissions throughout the manufacturing process without compromising in-service performance. In principle, WMA technology could reduce asphalt binder viscosity, which allows the asphalt binder to achieve optimal viscosity for coating with the aggregate. This ensures that the mixing and compaction processes could be done at lower temperatures without adversely affecting its performance when compared to conventional hot-mix asphalt (HMA) [1–5]. Blankendaal et al. [6] reported that, by using the life

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cycle assessment (LCA) model, the use of WMA mixture decrease negative environmental impact by 33%.

The modification of asphalt binders with organic WMA additives changed the viscosity of the modified binders and result in a better workability of the mixtures at lower temperature. A previous study done by Al-Rawashdeh [7] showed that these technologies function as compaction aids as well as in reducing the requirement for the compaction process. Another benefit is that it allows construction to be carried out during cold weather. The cooling period for asphalt mixture was dramatically reduced since the temperature is closer to ambient temperature. This condition allows the paving and compacting works to be extended for a longer time. Additionally, it allows for the mixtures to be transported over longer distances between asphalt plants and pavement construction sites [8]. The decrease in temperature difference contribute towards reducing the time required for road construction and thus allows it to be opened to traffic earlier; it also provides a better condition in the construction of certain pavements, such as airport, tunnel, rehabilitation area, and heavy traffic city road [9–11]. WMA technology could also extend construction season and reduce the aging process of asphalt binders in terms of oxidation and volatilization [4].

It is a well-known fact that asphalt mixing is one of the most energy-intensive processes in comparison to other industrial activities. Energy consumption during the mixing process is approximately 60% of the total energy required for the construction and maintenance of a given road over a typical service life of 30 years. The manufacture of WMA produce a temperature that is 10–40 °C lower than in the manufacture of conventional HMA. The advantage of this technique is not only in terms of energy saving but also in terms of emission reduction. There is virtually no asphalt emission when WMAs are manufactured at temperatures below 80 °C [12]. However, at about 150 °C, the emission recorded was only approximately 1 mg h^{-1} while significant emission was recorded at 180 °C. This shows that the temperature reduction in the manufacture of WMA mixtures result in a dramatic drop in fumes and pollutants such as carbon dioxide, CO_2 (between 15% and 40%), sulphur dioxide, SO_2 (between 18% and 35%), nitrogen oxide, NO_X (between 18% and 70%), carbon monoxide, CO (between 10% and 30%), and dust (between 25% and 55%) [12]. Moreover, this reduction in emission is also beneficial to workers who might suffer the negative effects of the emission due to long-term exposure to the fumes during asphalt paving process; the condition is even worse for paving projects done in a closed area such as during construction of tunnels [13]. Additionally, electric consumption in the mixing of the materials and in moving the materials throughout the plant is reduced due to the lower manufacturing temperature of WMA mixture [14,15].

The hot asphalt fumes generated during the asphalt mixing processes contain polycyclic aromatic hydrocarbon (PAH) compounds. PAH contains hazardous compounds such as carcinogen, mutagen, and teratogen. Currently, HMA is the most widely used asphalt mixing process which produces PAH emissions especially during the compulsory warming and drying of the aggregate. Goh [9] found that WMA reduces the emission of PAH between 30% and 50%. Hence, the use of WMA processes could effectively reduce the emission of these fumes which in turn reduce exposure to paving crews, contractors, local authorities, and the public [1,12].

Despite these potential benefits, the lower mixing temperature in the manufacture of WMA mixtures might increase the potential for moisture damage. Previous researches conducted by the National Centre for Asphalt Technology (NCAT) revealed that the lower mixing and compaction temperatures in the manufacture of WMA mixtures resulted in incomplete drying of the aggregate [16–18]. The water trapped in the coated aggregate could cause moisture damage through moisture intrusion in flexible pavement which then leads to, among other, severe distressed-like stripping, localized bleeding, potholes, and shoving and structural failure. Moreover, rutting or permanent deformation is also likely to occur with some WMA products, although it could also increase durability [1,19,20].

One common method to deal with these problems is by adding anti-stripping mineral additives or liquid anti-stripping agents [21]. The use of nanoclay effectively reduces moisture susceptibility, while other characteristics of WMA mixtures could contribute to better pavement construction and environmentally friendly maintenance in the future. Additionally, the effects of WMA additives on base asphalt binders have yet to be fully determined, especially with regard to rutting and aging conditions [22]. Even though researches have been conducted in the past, none of them studied the effects of nanoclay as an anti-stripping agent or other benefits of WMA. Nanoclay particle has great potentials due to its finer particles and amine characteristic, which could produce better stripping resistance in WMA mixtures. However, there is currently insufficient reports and/or guideline regarding the optimum percentage of nanoclay to be used in WMA mixtures and their potential benefits.

This study was conducted to evaluate the chemical, morphological, and rheological properties of two types of modified binders, namely nanoclay-modified asphalt binder (NCMB B) and chemical WMA additive modified asphalt binder (CWAA). The unmodified and modified (NCMB B and CWAA) asphalt binders were artificially aged under short- and long-term aging conditions prior to testings. The performance characteristic of NCMB B was then compared with those of CWAA, a product that is currently widely available in the market. Finally, emission test was also conducted in the laboratory on unmodified and modified WMA mixtures with NCMB B and CWAA to estimate the gaseous pollutants produced during the manufacture of WMA mixtures. Details of the tests conducted and the results obtained from these tests are discussed in the following sections.

2. Experimental design

2.1. Material and sample preparation

The base 80/100 penetration grade asphalt used in this study was obtained from Kemaman Bitumen Company, Malaysia. The physical and rheological properties of the base asphalt binder are shown in Table 1. Two types of modifiers, namely nanoclay and chemical WMA additive at various percentages were used to modify the base binder. Chemical WMA additive is an established additive that is currently being used by the asphalt industry as a modifier in the manufacture of WMA mixtures. The physical and chemical properties of unmodified and modified asphalt binders have been discussed previously in [23] and will not be discussed here for the sake of brevity.

During sample modification, 400 g 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%, and 3% (by weight of asphalt binder) for 10 min. On the other hand, 4% nanoclay (by weight of asphalt binder) was gradually added (5 g/30 s) into the melted asphalt binder under a high shear mixer at 5500 rpm for 30 min. The different modified asphalt binders were named nanoclay modified asphalt binder (NCMBB) and chemical WMA modified asphalt binder (CWAA), e.g. CWAA 2% corresponds to an asphalt binder modified with 2% chemical WMA additive (by weight of asphalt binder).