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Fundamental and rheological properties of oil palm fruit ash modified bitumen

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HIGHLIGHTS

- We investigate the suitability of using oil palm fruit ash as a bitumen modifier.
- Several fundamental and rheological tests had been conducted in this study.
- The OPFA-modified bitumen can be categorised as a binder with penetration grade of 60/70 or as PG 70-16.

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ABSTRACT

This study was conducted to investigate the suitability of using oil palm fruit ash (OPFA) as a bitumen modifier. The OPFA was used to fulfil all bitumen modification requirements, as well as to take advantage of a waste by-product of the palm oil mill industry which could help to reduce environmental pollution. Twenty-four OPFA-modified bitumens (OPFA-MBs) were produced by the laboratory mixing of normal bitumen (80/100) from two sources with Fine and Coarse OPFAs of six different contents. This process was conducted at a mixing temperature of 160 °C, a mixing time of 60 min and a mixing stirring speed of 800 rpm. The consistency and rheological characteristics of the OPFA-MBs were analysed by means of conventional as well as dynamic mechanical analysis using dynamic shear rheometer (DSR), bending beam rheometer (BBR) and direct tension test (DTT). The results of the investigation indicate that binder compounded with OPFA becomes less susceptible to temperature, improve resistance to rutting at 70 °C, fatigue cracking at 20 °C, and thermal cracking at −17 °C of the surface pavement temperature compared to the unmodified bitumen. The OPFA-MB can be categorised as a binder with penetration grade of 60/70 or as PG 70–16 in the performance based system. Finally, it can be deduced that it is feasible to use OPFA as a modifier of bitumen.

1. Introduction

For several decades it was accepted that the empirical method of blending different types of base (unmodified or neat) bitumen was the only way to improve binding characteristics [1]. However, in recent years, increased traffic levels, larger and heavier trucks, new axle designs and increased tyre pressures have added to the already severe load and environmental demands on the highway system, resulting in the need to enhance the performance of the existing bituminous material [2,3]. Most base bitumen does not meet these requirements in regions with extreme climatic conditions [4,5]. Furthermore, a better understanding of the behaviour and characteristics of binders, in conjunction with the greater development of technology, has encouraged and enabled researchers to examine the benefits of introducing additives and modifiers into bitumen.

The modifiers currently available fall into various categories, such as naturally occurring materials, industrial by-products and waste materials, as well as carefully engineered products. Some of the more common categories include reclaimed rubber products, fillers, fibres, catalysts, polymers (natural and synthetic) and extenders, to name a few [6]. Among them, a blend of bitumen and polymer is the most popular to improve the fundamental characteristics of bitumen, as its characteristics are related to the performance of asphalt mixtures. Polymer-modified bitumens, commonly abbreviated as PMBs, have been used for many years with asphalt mixtures and their usage is forecast to continuously increase in the immediate future, particularly in Europe, the United States of America, Canada and Australia [7]. For example, in the United Kingdom, the first polymer used, in the middle of the 1800s, was natural polymer latex rubber [8].

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In general, PMBs feature improved resistance to rutting, abrasion, cracking, fatigue, stripping, bleeding and ageing at high temperatures, and improved flexibility at low temperatures [9]. In addition, the structural thickness of asphalt mixture pavement can also be reduced [10,11]. PMBs with similar polymer content and prepared with identical penetration grade bitumens but from different crude sources have different chemical composition and performance characteristics. In addition to altering the chemical composition of the PMB, polymers also affect the microstructure of the binder. Fluorescence microscopy is one of the most useful techniques to look at the morphology (structure) of PMBs. Under ultraviolet light, a two-phase image can be produced, with the polymer-rich phase appearing light and the dark region representing the bitumen-rich (or asphaltene-rich) phase. Using this method it is possible to determine the quantity of modifier in the PMB and estimate the linear viscoelastic rheological characteristics of the binder [12]. Despite real achievements in formulation, characterisation and use of PMBs, many challenges and opportunities remain.

Work done by various researchers has found that the use of PMB is not able to simultaneously fulfil all bitumen modification requirements such as enhance resistance to rutting, thermal and fatigue cracking, moisture damage and ageing [13–15]. Therefore, this study was conducted to investigate the suitability of using oil palm fruit ash (OPFA) as a bitumen modifier. The aim of using of OPFA is to find an alternative bitumen modifier instead of polymer and other modifiers, to be able to fulfil all bitumen modification requirements, as well as to take advantage of a waste by-product of the palm oil mill industry which could help reduce environmental pollution. Several tests such as consistency tests (penetration and softening point tests), dynamic shear rheometer (DSR), bending beam rheometer (BBR) and direct tension test (DTT) were conducted, both on unmodified and OPFA-modified bitumens (OPFA-MBs). The consistency test was done to initially determine whether OPFA can be used to improve the characteristic of the base binder. Rheology testing was conducted by means of DSR to investigate the ability to resist rutting and fatigue cracking at intermediate to high temperatures. Both the BBR and DDT tests were conducted to investigate the ability of the OPFA-MB to enhance resistance to thermal cracking at low temperatures.

2. Experimental design

2.1. Bitumen

Two sources of bitumen with penetration grade 80/100 denoted as bitumen B-1 and bitumen B-2 were modified with OPFA. The properties of bitumen used in this study are presented in Table 1.

2.2. Oil palm fruit ash (OPFA)

OPFA is a by-product of palm oil mill, or the ash from burning the mesocarp of fruitlets. This by-product has been disposed of as waste, thus polluting the environment and affecting the health of the surrounding community. Physically, OPFA is greyish in colour and becomes dark with increasing proportions of unburned carbon, as shown in Fig. 1. The physical properties and chemical composition of OPFA are given in Table 2 [16]. Originally from the palm oil mill, OPFA consists of rough grains. The form of the grain is elongated-flat with a maximum grain length of 6 mm. Two grain sizes were used in this research. One was very fine which had a uniform grain size of 75 μm resulting from grinding the original OPFA and sieving using sieve size 75 μm, and the other one resulted from sieve analysis using a maximum sieve size of 300 mm and minimum size 75 μm. OPFA with a uniform grain size of 75 μm is denoted as Fine-OPFA (F-OPFA), and OPFA with maximum grain size of 300 μm denoted as Coarse-OPFA (C-OPFA).

Fig. 1. Oil palm fruit ash; up-left-inside: cross section of fruitlet.

Table 2
Physical properties and chemical composition of OPFA.

Physical properties	
Fineness – Sp. surface area (m^2/kg)	518
Soundness – Le Chatelier method (mm)	1
Specific gravity	2.22
Chemical composition	**%**
Silicon Dioxide (SiO_2)	43.6
Aluminium Oxide (Al_2O_2)	11.4
Ferric Oxide (Fe_2O_3)	4.7
Calcium Oxide (CaO)	8.4
Magnesium Oxide (MgO)	4.8
Sodium Oxide (Na_2O)	0.39
Potasium Oxide (K_2)	3.5
Sulphur Trioxide (SO_3)	2.8
Loss on Ignition (LOI)	18

3. Methodology

OPFA was mixed into the bitumen using a propeller mixer at 160 °C mixing temperature, 60 min mixing time, and 800 rpm mixing stirring speed. These mixing variables were found from the trial-and-error mix using mixing temperatures at 145 and 160 °C, mixing time 30 and 60 min, and mixing stirring speed 400–1000 rpm, with an increment of 100 rpm. The amount of bitumen to mix with OPFA was 1500 g which was sufficient to perform all of the tests needed, as well as to conduct RTFO and PAV ageing. Twenty-four types of OPFA-MBs resulted from the mix of six percentages of OPFA content (2.5–15%), bitumen B-1 and bitumen

Table 1
Bitumen properties.

Base bitumen	Penetration test at 25 °C (dmm)	Viscosity test		Softening point test (aver. of 4 reading, °C)	Specific gravity	PI	PVN
		60 °C (Pa s)	135 °C (Pa s)				
B1	83	33.1	0.3	46	1.03	−2.25	0.87
B2	87	35.5	0.4	44	1.06	−2.50	−0.43