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Use of waste cooking oil, tire rubber powder and palm oil fuel ash in partial replacement of bitumen

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HIGHLIGHTS

- Modification of bitumen with waste cooking oil, tire rubber powder and palm oil fuel ash.
- Laboratory investigation of modified bitumen.
- Replacement of bitumen has been done up to 15%.
- Improved binder compositions have been proposed for flexible pavement construction.

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ABSTRACT

Bitumen is a heavy hydrocarbon sourced from petroleum refineries as by-product which is widely used as binder for flexible pavement. Bitumen is non-hazardous at room temperature but when heated to 165–200 °C to coat all the aggregates it generates hazardous fume which is severely detrimental to health. Consequences such as environmental degradation, depleting petroleum reserves and price spiking, led researchers to explore alternative sources of obtaining binder for flexible pavement. This research focused on the effect of adding waste cooking oil, tire rubber powder and palm oil fuel ash to reduce the percentage of bitumen in the mixture where palm oil fuel ash was applied as additive. These three modifiers are sourced from waste materials, easily available in the market and cheap in price. This method of recycling these waste materials solves the issue of littering and can ensure a cleaner environment. Laboratory investigations based on AASHTO and ASTM standard were performed to check physical and rheological properties of modified binders. Results were compared with neat bitumen as control sample to assess the feasibility of new mixture to be used in industrial scale. Outcome from this research shows that up to 15% replacement of bitumen is possible and this could produce equal or better performance in terms of stability, flow and rutting resistance. This work contributes directly to the field of transportation and highway in development of alternative binder for flexible pavement by introducing improved modified binder compositions using waste materials.

1. Introduction

The world is now proceeding to achieve the Millennium Development Goal (MDG) where one of the most important issues is sustainability. Main objective of this goal is to utilize all the natural resources in such a way that can support the necessity of current generation without hampering the need of the future generation [1]. A global issue of the current era is that in face of increasing demands, the presence of natural resources is limited. Bio-based source of energy is renewable, efficient, cost effective and environment friendly which could be a great economical asset to any country [2]. They are originated from organic plant matter and residues e.g. agricultural and forestry by products, crops, municipal waste etc. [2–4].

Transportation and highway is the engineering sector which includes planning, designing, construction, operation and maintenance of all kind of roads, tunnels and bridges to ensure safety and comfort for the transportation of people and goods [2,5]. In case of flexible pavement, bitumen is used as traditional binder on the other hand Portland cement is used in rigid pavement as binder.

Depletion of natural resource is one of the most burning issues of this century. Limitation of the world petroleum reserve makes

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the petroleum based products expensive and the price is changing every day. As bitumen is a by-product of petroleum, the price of bitumen depends directly to the price of petroleum. This is the reason the price of bitumen is fluctuating time to time. Because of the rapid price change and the constrains in sustainability issue in natural resources, development of a modified Binder is a dire need so that the demand of fossil fuel based bitumen will decrease.

Bitumen is needed to heat up at higher temperature at the time of field application which creates bitumen fume, consists of heavy metals, saturates and aromatics which are inhaled by pavement workers and mixed with environmental elements. This bitumen fume causes severe health hazard to the workers and cause fatal diseases even lead to cancer [6,7]. The spillage of bitumen mixes with air, water and soil and pollutes the environment. Development of a modified binder can reduce the percentage of bitumen used and provide a safety for the workers and save the environment from pollution [8].

Waste cooking oil, tire rubber powder and palm oil fuel ash are waste materials widely available in Malaysia. The generation of waste cooking oil in Malaysia have been recorded 40,000 tones/year [9]. The amount of waste tire rubber was estimated approximately 57,391 tones/year [10]. As this large amount of waste products reduces the landfill area, recycling these wastes to pavement materials can be an efficient method of waste management.

The goal of this research is to develop a sustainable binder which can be used as an alternative binder for flexible pavement. This aim can be achieved by mixing waste or bio-based materials with conventional bitumen and reduce the proportion of bitumen in the binder mixture. When percentage of alternative binder increases in the mixture, the percentage of fossil fuel based bitumen will be reduced. This will reduce carbon emission and pollution by bitumen and at the same time risk of breathing bitumen fume will be decreased. A method of recycling waste materials in construction materials for pavement will be introduced. To achieve this goal, the objectives of this research work were set as follows;

i. Identification and modification of suitable materials to mix with the bitumen and design binder mixture.
ii. Investigation of physical and rheological properties of the modified binder and comparison of the results with the properties of neat bitumen binder.

2. Methodology and evaluation

2.1. Selection of materials

To develop a modified alternative binder, material selection is the most vital part. Materials were selected as per the availability, cost efficiency. Samples were prepared from the mixture of following materials.

i. Bitumen 60/70 (Penetration grade)
ii. Waste cooking oil
iii. Tire rubber powder
iv. Palm oil fuel ash

Bitumen 60/70 is recommended by Jabatan Kerja Raya (JKR) in 2013, Malaysia for the construction of flexible pavement [8,11]. Bitumen 60/70 which was used to prepare the samples was provided by Shell Singapore. Bitumen was stored at room temperature in air sealed condition.

Waste cooking oil (WCO) was collected from local restaurants. It was filtered to remove all dirt and other suspended materials. Reflux process was conducted to make all unsaturated content saturated. anti-bump agent was used to minimize loss of WCO during the process. Reflux was done at 170 °C temperature for 5 h. As the standard of reflux varies with materials and objective these parameters were found by trial and error method until when the sample oil does not burst out of the flux and colour turns slightly dark.

Tire rubber powder was used in this research sourced from waste tire rubber. Particle size < 75 μm was maintained by sieve analysis. According to the previous study it has been found that tire rubber powder can form a uniform mixture with bitumen [12,13].

Palm oil fuel ash (POFA) was collected from laboratory stock sourced from palm oil mill. Particle size for POFA used in this research was <2 mm to 75 μm maintained by sieve analysis [14,15]. In this research POFA was used as additive.

2.2. Preparation of sample

Blending of sample was performed by "Silverstone high shear mixer". Mixing procedure has been determined by literature review and trial and error method. Table 1 gives an overview on mixing methods used by previous researchers during mixing waste oil with bitumen.

In this research mixing method was determined based on trial and error method by setting different temperature and mixing duration to ensure uniform mixture based on visual inspection. Samples were prepared by setting the shear mixture at 900 rpm at 120 °C for 120 min. Fig. 1 exhibits the blending process and the samples used for further analysis.

Mixing ratios were selected by trial and error method. Initial samples were prepared based on the assumption and laboratory experiment results helped to pick the mixing ratios for further trials. After four trials, acceptable mixing ratios were found where the newly modified binders exhibit almost similar physical properties like fresh bitumen 80/100. Details of all the trial mixing ratios are provided in the Tables 2–5 for Trials 1, 2, 3 and 4 respectively where total weight of each sample was 600 gm.

2.3. Laboratory evaluation

To determine the properties of modified binder samples and compare properties and behaviour with control sample bitumen 60/70, laboratory tests were divided into 3 categories as listed below. Fig. 2 presents the detailed diagram for laboratory evaluation.

1. Physical test
2. Rheological test
3. Elemental analysis

2.3.1. Physical test

Physical properties were determined by penetration and softening point tests [23,24]. To prepare the short term aged sample RTFO (rolling thin film oven) and for long term aged sample PAV (pressure aging vessel, ASTM D6521) had been conducted. Physical test results helped the research by finding out the acceptable mixing ratios [25,26]. To prepare PAV residues, RTFO residues were used.

2.3.2. Rheological test

Rheology is the state of flow of a matter. Rheological properties of bitumen determine the elasticity and the viscosity of the binder. To investigate the rheological properties of the sample to determine fatigue and rutting criteria, in this research viscosity test and the dynamic shear rheometer test was performed.

Viscosity of the samples was determined by Brookfield rotational viscometer. The reading of viscosity was measured in two point temperatures, 135 °C and 165 °C [27].

Dynamic Shear Rheometer (DSR) was used to determine viscoelastic behaviour of bitumen [28]. The complex shear modulus