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Evaluation of Permanent Deformation of Palm Oil Mill Sludge Modified Asphalt Binder

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Abstract: The palm oil industry is one of the most contributing sectors towards Malaysia's economy in recent decades. As the industry is expanding widely upon years, the production of palm oil waste has an alarming outcome towards the sustainability of the environment. Thus, to alleviate waste management difficulties, the use of a waste modifier in asphalt modification is being investigated extensively. Palm oil mill sludge (POMS) is a common byproduct of the palm oil industry. The application of POMS in asphalt binder modification was proposed in this study to improve the performance of the asphalt pavement against permanent deformations. POMS were mixed with a base binder with a penetration grade of 60/70, at various percentages (1%, 2%, 3%, 4%, and 5%) together with aggregates as governed by Marshall Mix Design. To assess the permanent deformation characteristic of POMS modified asphalt mixture, cyclic loading of 300kPa and testing temperature of 40°C were used in a Dynamic Creep Test. The permanent deformation characteristics of the POMS modified asphalt mixture were then evaluated using three different analyses including the creep strain slope (CSS), dynamic creep modulus (DCM), and permanent deformations. Based on the analyses, it was found that the addition of POMS inside the asphalt binder improved the permanent deformation characteristics of the pavement. However, the result of all samples surpasses the modified asphalt mixture requirement set by Jabatan Kerja Raya (JKR) in terms of its CSS value. All samples, however, met the DCM standard. By comparing the result from the three different analyses, 3% of POMS were found to have the best effect in terms of resistance towards permanent deformation under 40°C. Thus, it may be inferred that the percentage of POMS as a modifier in an asphalt binder modification should be restricted to have the optimum result to reduce distresses.

Keywords: Palm Oil Mill Sludge (POMS), Asphalt Binder, Dynamic Creep Test

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1. Introduction

From 2010 to the first quarter of 2021, Malaysia's population has increased by about 14.5 percent [1]. The economy is also growing in tandem with the growing population. Malaysians' mobility also increases as the country's economy grows, particularly in land transportation. As a result, the pavement structures' well-being, especially in terms of their physical properties and performance, may remain safe for users to use every day. Pavement damage or distress, notably permanent deformations or rutting, can affect the user's comfort and safety. Thus, a good construction method and high-quality pavement materials are required to secure the pavement layers against permanent deformation, particularly the asphalt binder, which acts as a glue to hold the pavement layers together due to its viscoelastic properties at certain temperatures [2]. To enhance the workability of the asphalt binder against rutting, a modification of the base binder is highly anticipated and a previous study that was done by [3], a modification of asphalt binders are popular and a common material that was used as a modifier is styrene-butadienestyrene (SBS), ground tire rubber (GTR) and polyphosphoric acid (PPA). Also, [4] stated that the utilization of agricultural waste, mainly palm oil waste is deeply studied to be used in pavement engineering.

Elaeis Guineensis, or palm oil, was originally introduced to Malaysia as an aesthetic plant, but due to the plant's many applications and advantages, palm oil tree farming is rapidly spreading across the country. According to a study by [5], the oil palm sector has become the fourth largest contributor to Malaysia's economy in terms of Gross National Income (GNI), with a total cultivation cover area of 5.87 million hectares in 2020, particularly in Sabah and Sarawak in western Malaysia [6]. With a large number of cultivation areas in recent decades, agroindustry has emerged as one of the businesses critical to the nation's economic success. However, due to the rising demand for oil palm in Malaysia, the production of oil palm-based waste, particularly palm oil mill sludge (POMS), has skyrocketed, leading to the development of highly contaminated wastewater [7].

Considering Malaysia is the world's second-largest producer of palm oil after Indonesia, a lot of palm oil mill waste is generated [8]. Instead of being disposed of and negatively impacting the environment, the waste, namely palm oil mill sludge, was repurposed as a modifier in an existing asphalt binder mixture for wearing course. POMS can be used as a modifier since its fundamental qualities and chemical makeup are comparable to that of a petroleum-based binder [9]. The inclusion of POMS in asphalt binder is thought to enhance the binder's softening point, which will improve the pavement structure's resistance to irreversible deformation and deterioration [10].

POMS have a viscous and slurry texture as they are made up of 4-5 percent solid, 95 percent water, 0.5 – 1.0 percent residual oil, are acidic (pH 4-5), brown in color, and contain a high amount of organic content (50 000 mg/l COD and 25 000 mg/l BOD, respectively) as well as an infinite concentration of organic nitrogen, making them highly unsafe to the environment [7]. During the palm oil milling process, nearly half of the water is converted to POMS [11]. POMS will be treated biologically to make them ecologically pleasant, but the treatment is complicated since POMS encompasses a wide range of pollutants, which necessitates a long hydraulic retention time (HRT) during the treatment process to thoroughly remove the pollutant [12]. As it was complex and costly to treat, the notion of converting POMS from a waste to a profitable product is eagerly anticipated, in line with awareness of the need to create a less polluted environment.

A modification of the existing asphalt binder can be made by adding POMS as a modifier to enhance the function of the binder mixture, to reduce POMS production while also improving the characteristics and behavior of the asphalt binder. POMS is commonly thought of as a waste, but it can also be utilized as a raw and fresh material in the form of fertilizer and asphalt binder modifier [13]. Petroleum distillation is the most common source of existing binder in Malaysia [14]. However, petroleum and POMS have nearly identical chemical compositions, thus using POMS as a modifier in an existing asphaltic binder should improve the function of preventing permanent deformation of pavement structures [15].

The purpose of this study is to assess the permanent deformation of the pavement structure when the AC14 wearing course asphalt binder was blended with a modifier, palm oil mill sludge (POMS). Previous research has shown that a modifier in an asphalt binder mixture can improve the asphalt binder's deformation resistance while also lowering construction and maintenance costs as well as slowing the aging process of the pavement [10]. Thus, the use of POMS as a modifier to a traditional asphalt binder is predicted to enhance the pavement structures against permanent deformation under any traffic load as the addition of POMS was expected to soften the binder to make the pavement more flexible when applied with axle load from the traffic [9].

This research was primarily focused on one laboratory testing, the dynamic creep test, which was performed to determine the permanent deformation characteristics of the POMS modified asphalt binder by applying a vertical force to the sample. Five distinct POMS modified asphalt binder samples were evaluated, with 0%, 1%, 2%, 3%, 4%, and 5% of palm oil mill sludge added to an AC14 asphalt mixture with a penetration grade of 60/70. All of these samples were evaluated at 40°C, with vertical stress of 300 kPa acting on the sample. Three analyses were done to compute the performances of the asphalt pavement against permanent deformations including creep strain slope (CSS), dynamic creep modulus (DCM), and permanent deformation itself.

2. Materials and Methods

The materials used in this study, as well as the experimental testing and procedures, were all described in this section. The American Society for Testing and Materials (ASTM), American Association of State Highway and Transportation Officials (AASHTO), British Standard (BS), and Malaysian Standard from Jabatan Kerja Raya (JKR) were used to develop the standards and specifications used in this study.

2.1 Materials

This study is mainly focused on three materials such as:

- PEN 60/70 base binder
- Aggregates
- Palm Oil Mill Sludge (POMS)

2.2 Methods

400g of PEN 60/70 asphalt binder were heated until became liquid and in the pourable form before being mixed with 0%, 1%, 2%, 3%, 4%, and 5% by weight of the POMS at 160°C ± 5°C using the Silverson-L4RT high shear mixture at 800 rpm and 30 minutes of blending durations [16]. The AC 14 gradation was utilized in this mixture fabrication, following the Marshall Mix Design guidelines as outlined in [17]. The aggregate was warmed to 105° to 110°C inside the oven before the fabrication began [18]. The aggregate and asphalt binder then were mixed at a temperature that provided 0.17 ± 0.02 Pa.s of viscosity and 0.28 ± 0.03 Pa.s of viscosity for compacting temperature [19]. The mixture was then compacted with 75 blows per face using a standard Marshall hammer. The effectiveness of the POMS modified binder against permanent deformations was next evaluated using a dynamic creep test [20], on the unmodified and modified asphalt mixture samples.

2.3 Testing

The dynamic creep test was conducted by cyclic loading of 300kPa and testing temperature of 40°C to determine the permanent deformation characteristic of the POMS modified asphalt mixture. Three analyses were conducted to evaluate the permanent deformation properties of the POMS modified asphalt mixture. Creep strain slope (CSS) and dynamic creep modulus (DCM) analysis were done to evaluate the relationship of whether these two analyses affect the permanent deformations' value of the modified asphalt mixtures under the selected temperature.

3. Results and Discussion

The rutting resistance qualities of the asphalt mixture were determined by a dynamic creep test. This experiment provided information on the cumulative permanent strain, dynamic modulus, creep strain slope, and permanent deformation. The greatest value of cumulative micro-strain for 40°C temperature is 0% of POMS at 8441.300 kPa, while the lowest value is 6508.290 kPa for 5% POMS modified binder. Accumulated strain for the rest of POMS modified binder lays in between 0% and 5% with 7464.891 kPa, 7164.896 kPa, 6758.179 kPa at 6575.453 kPa for 1% POMS, 2% POMS, 3% POMS and 4% POMS, respectively. Figure 1 depicts the results of a dynamic creep test performed at 40°C with a 300 kPa cyclic load. As a study done by [10], a higher value of accumulated micro-strain obtained from the testing showed a lower rutting resistance. Thus, the result in Figure 1 showed that 0% of POMS that was added as a modifier in the asphalt binder resulted in a higher possibility of permanent deformations occurring on the pavement structures while 5% of POMS showed the vice versa.

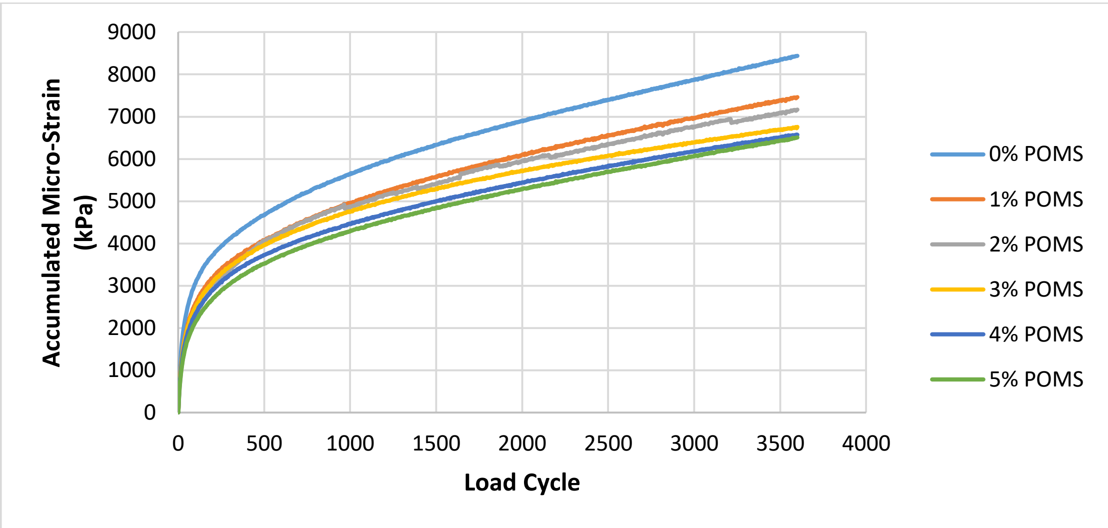

Figure 1: Cumulative permanent strain at 40°C

3.1.1 Creep Strain Slope (CSS)

In a typical repeated load creep test, the slope of the second phase is referred to as the creep strain slope (CSS) [21]. It is made with a regression line that excludes the first stage and properly represents the rate of deformation impacted by load cycling [20]. CSS is a type of analysis that involves calculating the slope of a graph of cumulative micro-strain against the load cycle particularly lays in stage two of the dynamic creep curve. The micro-strains in 2000 and 3600 cycles were chosen since they are found in stage two of the dynamic creep curve [17]. The CSS calculation must be done at the second phase of the cumulative axial strain versus load cycle graph, and the standard adhered by [17] specifically stated that CSS must be done at cycles 2000 and 3600. The equation for creep strain slope analysis is shown in Eq. 1. Table 1 shows the result for creep strain values at 40°C. The standard requirement for CSS as adhered to [17] must be less than 0.25. However, from the result, each percentage of POMS showed a result surpassing the minimum requirements for CSS. By means, if the result were greater than 0.25, the rutting resistance towards permanent deformations was low. A limited number of samples during laboratory testing led to an unclear pattern of the result thus the actual result may be affected.

$$CSS = \frac{log\ \varepsilon_{3600} - log\ \varepsilon_{2000}}{log_{3600} - log_{2000}}\ Eq.1$$

Table 1: Creep strain slope (CSS) value at 40°C

Sample	Strain at 2000 Load Cycle (kPa)	Strain at 3600 Load Cycle (kPa)	CSS	Requirement [17]	Remarks
0% POMS	6905.094	8441.300	0.343	< 0.25	Exceeding standard
1% POMS	6103.135	7464.891	0.342	< 0.25	Exceeding standard
2% POMS	5953.135	7164.896	0.315	< 0.25	Exceeding standard
3% POMS	5707.825	6758.179	0.287	< 0.25	Exceeding standard
4% POMS	5445.781	6575.453	0.321	< 0.25	Exceeding standard
5% POMS	5282.691	6508.290	0.355	< 0.25	Exceeding standard

3.1.2 Dynamic Creep Modulus (DCM)

To quantify mixture resistance to rutting, the dynamic creep modulus (DCM) was calculated by dividing the applied stress by the cumulative axial strain of the samples throughout the second stage of the dynamic creep curve [22]. The higher the dynamic creep modulus, the more resistant the asphalt mixes are to permanent deformation, which causes pavement rutting [10]. Table 2 showed the obtained results for 40°C of dynamic creep modulus. The value of the dynamic creep modulus of an unmodified asphalt mixture (0% POMS) is lower than the value of a modified binder from 1% to 5%. From Table 2, the addition of POMS as a modifier in the asphalt binder exhibits the dynamic creep modulus value above 200 MPa. As a result, at this temperature, these modified samples are more resistant to rutting compared to the unmodified samples.

Table 2: Dynamic creep modulus (DCM) value for 40°C

Sample	Strain at 2000 Load Cycle (kPa)	Strain at 3600 Load Cycle (kPa)	Accumulated Strain		DCM	Requirement [17]	Remarks
			Ɛ 2000	Ɛ 3600			
0% POMS	6905.094	8441.300	0.007	0.008	195.286	> 75 MPa	Fulfill
1% POMS	6103.135	7464.891	0.006	0.007	220.304	> 75 MPa	Fulfill
2% POMS	5953.135	7164.896	0.006	0.007	247.574	> 75 MPa	Fulfill
3% POMS	5707.825	6758.179	0.006	0.007	285.618	> 75 MPa	Fulfill
4% POMS	5445.781	6575.453	0.005	0.007	265.564	> 75 MPa	Fulfill
5% POMS	5282.691	6508.290	0.005	0.007	244.778	> 75 MPa	Fulfill

3.1.3 Permanent Deformations

The deformation on the sample as detected by linear variable displacement transducer (LVDT) during the dynamic creep test was shown in permanent deformation analysis. The sample deformation was recorded for each cycle, and the overall deformation of each sample was calculated using a simple formula of final deformation minus the initially recorded deformations [20]. The permanent deformation happens when the road surface is subjected to the axle load from a vehicle. The permanent deformation of the road pavement directly displays how the rutting is generated [23].

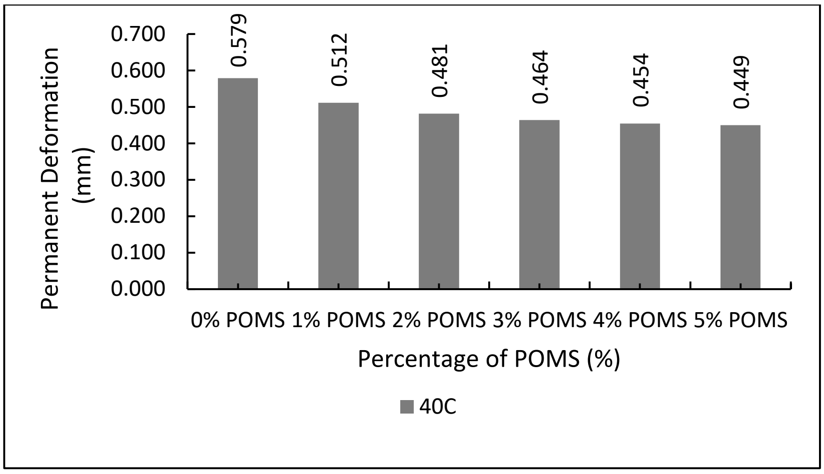

Figure 2: Permanent Deformations

When palm oil mill sludge (POMS) is added as a modifier at a temperature of 40°C, the permanent deformation value decreases as can be referred in Figure 2. According to Figure 2, the maximum deformation value was 0.579 mm for 0% of POMS modified binder, followed by 0.512 mm, 0.481 mm, 0.464 mm, 0.454 mm, and 0.449 mm for 1%, 2%, 3%, 4%, and 5%, respectively. It illustrates that adding POMS to the pavement structure resulted in less deformation of the pavement structure when it was subjected to heavy traffic loading. These obtained results supports the study done by [10] in which the addition of POMS as a modifier helps to soften the binder and make the pavement surface became more flexible when applied with a continuous loading by the axle.

4. Conclusion

In conclusion, by comparing the result from three different analyses done in the dynamic creep test, it can be proven that the addition of palm oil mill sludge (POMS) as a modifier in asphalt mixture helps to boost the performance of the pavement against permanent deformation when the load is applied. However, from the findings, the optimum percentage of POMS was needed to guarantee the performance of the pavement structure to make sure that the pavement is flexible enough to avoid rutting and at the same time, it is not brittle when applied with axle load. According to the findings, 3% of POMS modified binders were founded to have the most favorable influence on permanent deformation at the temperature of 40°C. However, since the result for all samples exceeded the requirement from CSS from [17], thus several modifications should be done in future studies. Modifications of the study may include the additional number of samples tested during the test to obtain the pattern for the results.

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