Jurnal Kejuruteraan 35(4) 2023: 913-921
https://doi.org/10.17576/jkukm-2023-35(4)-13

Characteristics of Oil Palm Fruit Ash as Binder in Asphaltic Concrete

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Received 20 October 2022, Received in revised form 25 January 2023
Accepted 25 February 2023, Available online 30 July 2023

ABSTRACT

In order to reduce energy and natural resource consumption during road construction, the sustainability concept needs to be seriously addressed. Oil Palm Fruit Ash (OPFA) is one of the by-products of palm oil production that are typically disposed of in landfills as a result of the growing number of plantations in Malaysia, particularly in Sarawak. Due to the fact that OPFA is known as biomass with pozzolanic qualities (siliceous material), this study was carried out to examine the applicability of OPFA with varying concentrations (0% - 40%) by weight as a modifier in bitumen grade 60/70. Based on the results of the laboratory testing, it was discovered that the modified bitumen provided greater resistance to rutting, temperature, and skid resistance on the bituminous mixture (AC20) compared to the control sample. The 40% OPFA modified samples had the greatest resilient modulus test value, measuring 10992 MPa at 25 °C and 2936 MPa at 40 °C, respectively. In addition, the combination containing 40% OPFA produced the lowest deformation value in the dynamic creep test, which was only 0.20mm, while producing 83.63 skid numbers in the skid resistance test. OPFA can be utilized as a binder modifier to improve the performance of bituminous mixture, which indirectly supports the sustainable development goals (SDGs) concept in road construction, as this study conclusively demonstrated.

Keywords: Sustainability; waste material; oil palm fruit ash; binder modifier; bituminous mixture

INTRODUCTION

Accountability for consumption and production is one of the significant elements of the Sustainable Development Goals (SDGs). Sustainable development aims to rationalize the use of natural resources while minimizing social and environmental concerns (Lastra-Gonz á lez et al. 2016; Cao 2016; Modarres & Hamedi 2014). The demand for roadway construction is constantly rising since it is a basic human necessity that is being affected by population growth, urbanization, and industrialization. The transportation sector is essential, but it also has a significant negative impact on the environment, especially concerning the harmful CO_2 gas emissions that contribute to global warming and may cause the depletion of natural resources, toxic pollution, climate change, and ecosystem disruption. In recent years, as the global emphasis has changed toward alternative energy and sustainability, biomass derived from agricultural byproducts has gained popularity in order to mitigate inadequate waste management while exploring ecologically acceptable low-cost resources as alternative materials (Jikol et al. 2022; Rashidi et al. 2022). Thus, asphalt mixture manufacturing also has been moving toward sustainable development.

About 95% of the roads in the world are composed of flexible pavement, which mostly consists of aggregates and bitumen (Huang et al. 2007). About 94 to 96% of the mix's weight is made up of aggregate and filler, with the remaining 4 to 6% coming from bitumen (Babalghaith et al. 2020). Due to the increasing number of landfill wastes, the majority of these natural pavement materials have exhibited a diminishing rate, making it impossible to guarantee their sustainability for future generations (Idham and Hainin 2015; Azahar et al. 2016).

Implementing the 3Rs (Reuse, Recycle, and Reduce) principle in road construction is one of the sustainable ways to reduce the number of wastes that end up in landfills. This indirectly might help to reduce construction costs as well (Bolden et al. 2013). These materials can be used to replace the natural pavement materials that come from a variety of sources, such as waste glasses (Su and Chen 2002; Shafabakhsh and Sajed, 2014; Arabani and Pedram, 2016; Androjic' and Dimter 2016; Zakaria et al. 2017), steel slag (Wu et al. 2007; Pasetto and Baldo 2011; Ameri and Behnood 2012; (Karakus 2011).

Due to the limited supply of natural resources for petroleum-based products, its price continues to rise due to the amount of non-renewable petroleum in the world. Thus, in order to decrease and eventually replace the consumption of natural bitumen, the creation of modified binders is a crucial topic that needs to be researched and taken into consideration (Rahman et al. 2017). As reported by Rusbintardjo et al. (2013), a better understanding of the properties and behaviors of binders has prompted more studies to consider the benefits of adding additives and modifiers to bitumen as well as the environmental demands in highway construction. Because of the bitumen properties that have inherent vulnerabilities and can "flow" at high temperatures, causing rutting, and become brittle at low temperatures, causing cracking, the majority of bitumen industries, governments, and researchers are concerned with replacing petroleum-based bitumen with bio-binders (Ali et al. 2016; Al-Sabaeei et al. 2020).

Based on Tan et al. al. (2009), oil palm is a common crop in Equatorial Africa and Southeast Asia. Malaysia and Indonesia are the world's leading producers of palm oil and waste generators (Yaro et al. 2021). There are about 90% of the palm oil produced worldwide was primarily produced in Malaysia and Indonesia and exported to the other countries (Alengaram et al. 2013; Johari et al. 2015; Huda et al. 2016; Hamada et al. 2018). Malaysia produces about32% of the world's palm oil supply, making it one of the major palm oil producers (Abdullah and Wahid 2010; Lam et al. 2019). Oil Palm Fruit Ash (OPFA) is a by-product of the palm oil mill, and the greyish ash is formed from the burning of waste palm oil, namely palm kernel shell, fiber, bunches, and oil palm husk in order to produce energy, as illustrated in Figure 1. About 5% of the OPFA will be left after the combustion process as a solid waste product, and these wastes are typically dumped in open areas and landfills where they could accumulate over the years (Coelho et al. 2019; Hamada et al. 2021). The use of OPFA and its potential performance as replacement materials in asphalt mixture need to be considered due to environmental concerns and rising values of disposal costs. If the massive amount of trash generated is not effectively handled and repurposed, it poses an environmental concern and disturbs the ecosystem's stability. To overcome this difficulty, it is essential to address the current problem without endangering future generations' access to sufficient resources (Al-Hdabi 2016; Lindsey 2011). Consequently, waste reduction, recycling, and reuse (RRR) is a globally prevalent technique for promoting a sustainable environment (Hasan et al. 2019; Jamshidi & White 2020; Zhang et al. 2016).

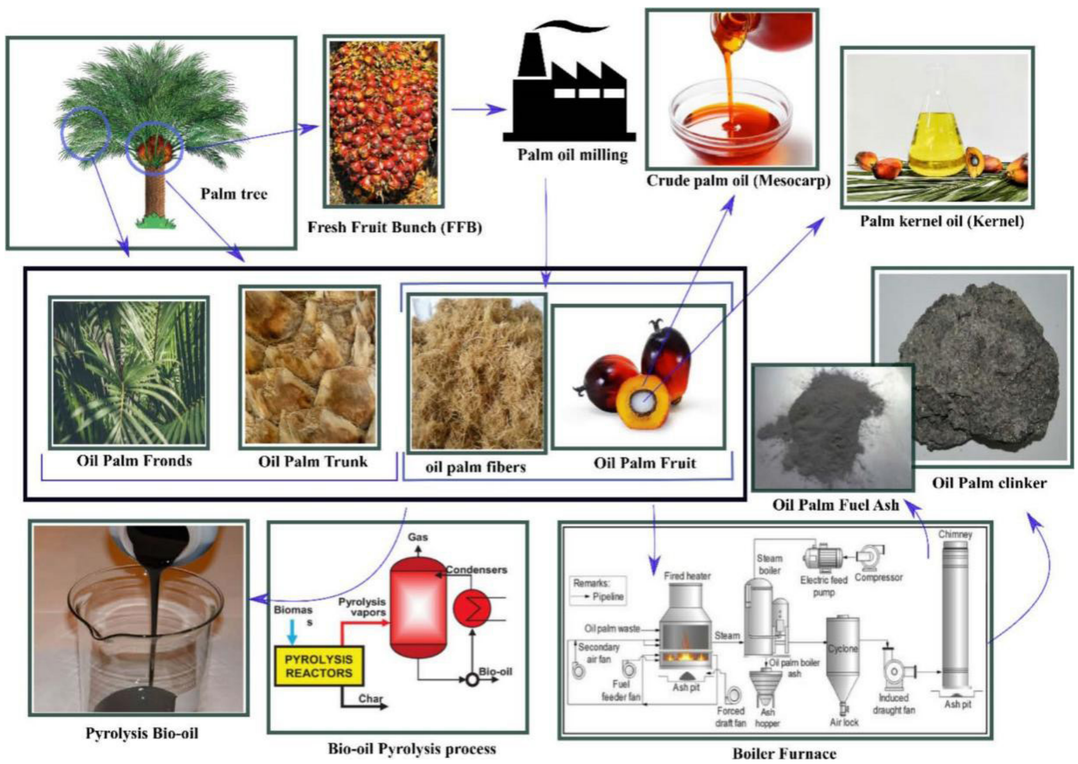

FIGURE 1. The production process of OPFA (Muthusamy and Azzimah, 2014; Mazlan et al. 2015; Iskandar et al. 2018; Rizal et al. 2020)

Therefore, in a bid to reduce the negative impact of such waste materials, these materials can be employed as an additive and especially as a replacement for cement and bitumen in building and pavement materials respectively (Babalghaith et al. 2020). The number of publications published in respected journals that include palm oil and its byproducts in concrete and asphalt mixtures has progressively increased over the years. The number of articles in the area of asphalt is depicted in Figure 2. Al-Sabaeei et al. (2022) reported that most published research has focused on concrete mixtures, while asphalt mixtures have received relatively less attention and information incorporating OPFA as a binder modifier. This indicates a research gap that requires additional investigation, especially on the different types of mixtures.

As a result, this paper examines the effectiveness and suitability of a modified binder that contains OPFA in an asphaltic mixture. This paper aims to promote the use of OPFA as a modifier to reduce the consumption of natural bitumen in road construction as the amount of oil palm waste is continually rising. Apart from that, this approach could be an alternative way to overcome environmental issues since it could indirectly increase the performance and service life of pavement (Borhan et al. 2010; Rusbintardjo et al. 2013; Zulkefli et al. 2018).

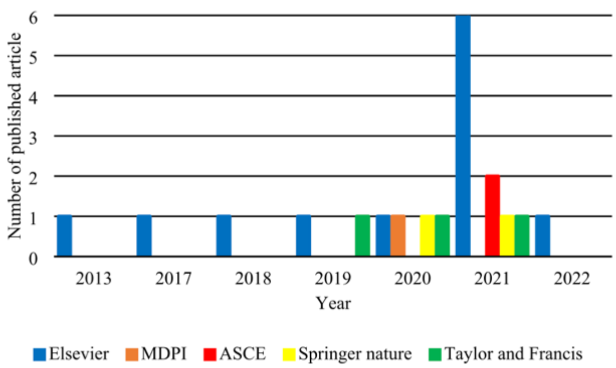

FIGURE 2. The trend in bio-asphalt pavement research that includes palm oil and its byproducts (Al-Sabaeei et al. 2022)

MATERIALS AND METHODS

Laboratory testing on aggregates, bitumen, and asphalt mixtures was carried out at University of Technology Sarawak (UTS) in accordance with the ASTM standard for the laboratory works. Lamy Industries Sdn Bhd supplied the aggregates, which had a 20-mm maximum size whereas OPFA with a size of less than 0.075 mm and bitumen grade 60/70 were obtained from Retus Palm Oil Mill Sibu and Fosxil Petroleum Sdn. Bhd respectively. respectively. The chemical and physical characteristics of OPFA are shown in Table 1. As part of a modified binder preparation, oven-dried OPFA was mixed by weight with natural bitumen in four various proportions: 10, 20, 30, and 40% at a mixing temperature of 160 C for 60 minutes and a stirring speed of 800 rpm. These mixing variables were determined through trial-and-error utilizing mixing temperatures of 145 and 160 °C, mixing times of 30 and 60 minutes, and mixing stirring speeds of 400–1000 rpm, with a 100-rpm increment (Rusbintardjo et al. 2013).

In this study, the aggregates and bitumen were tested with water absorption test, aggregate impact value (AIV) test, aggregate crushing value (ACV) test, Los Angeles abrasion value (LAAV) test, softening point test, penetration test, and specific gravity test. To ascertain the suitability of OPFA as a binder modifier in hot mix asphalt, a total number of 110 samples were used for the resilient modulus test, dynamic creep test, and skid resistance test (AC20). Figure 2 depicts the study's operational structure.

TABLE 1. Physicochemical properties of OPFA (Rusbintardjo et al. 2014)

Physical property	Value
Specific Gravity	2.22
Chemical composition	%
Aluminium Oxide (Al_2O_2)	11.40
Ferric Oxide (Fe_2O_2)	4.70
Silicon Dioxide (SiO_2)	43.60
Magnesium Oxide (MgO)	4.80
Calcium Oxide (CaO)	8.40
Potassium Oxide (k_2)	3.50
Sodium Oxide (Na_2O)	0.39
Loss on Ignition (LOI)	18.00
Sulphur Trioxide (SO_3)	2.80

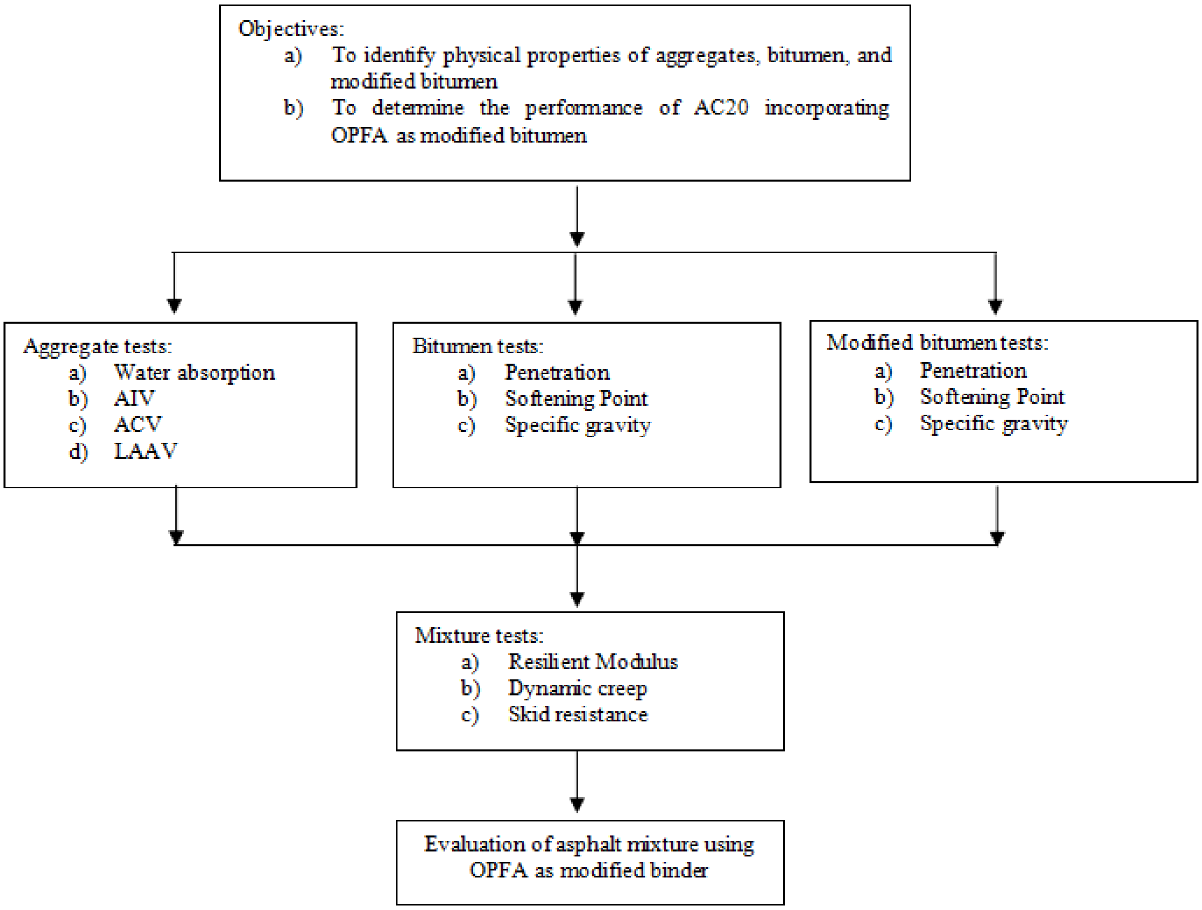

FIGURE 2. Operational Framework

RESULTS AND DISCUSSION

SIEVE ANALYSIS

Crushed limestone was used as the main material in this study and sieve analysis was conducted by following the JKR standard (JKR, 2008). The aggregate size ranging from 20 mm to 0.075 mm, including pan, was used in this investigation. The gradation limit of the aggregate used in this investigation is shown in Figure 3 and the limit is acceptable because the results were within its upper and lower limit.

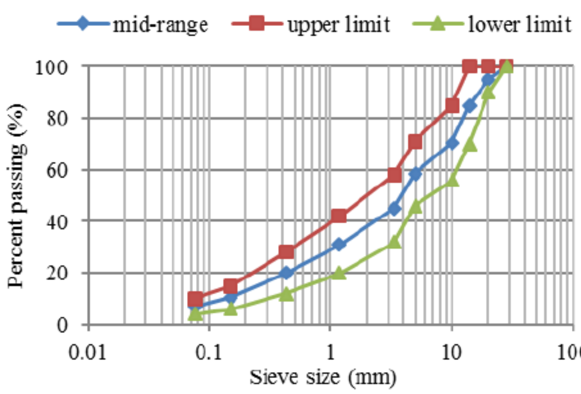

FIGURE 3. Limit of Gradation AC20

AGGREGATE TEST

Table 2 shows a summary of all the findings for the aggregate tests. To ensure the allowable water content that the aggregates may absorb, a water absorption test was performed. This test is to determine the absorption and porosity rate of the aggregate to coat with bitumen and establish a strong bond in the mix design. Thus, 1.8% was the average of the results for water absorption test. The outcome was acceptable under the JKR standard because it should have been less than 2%. (JKR, 2008). In addition, the AIV test is used to gauge an aggregate's resilience to abrupt shock or impact. It can be viewed as a test created to ascertain the aggregate's hardness under repeated impacts. According to JKR standards, the average AIV value was 13.0%, which was less than 25%. As a result, it was demonstrated that these aggregates were suitable for use in construction since they were able to withstand the disintegration caused by vehicle collisions. Higher durability and toughness in an aggregate's qualities are indicated by a lower impact value (JKR, 2008). Additionally, the ACV test is run to gauge the resistance to crushing under compressive stress that is applied gradually. As a result, the average ACV for this study was 24.5%, which was a good result because the JKR guideline for ACV test is should be less than 25%. Hence, the aggregates could withstand the crushing load under wheel loadings as they were appropriate to be used in construction (JKR 2008). The

LAAV test was used to assess the resistance of aggregate qualities to crushing, disintegration, and deterioration. Therefore, based on the JKR standard, the LAAV test value in this study was 23,0%, which was less than 25%. (JKR 2008). These aggregates were suitable to be used in this investigation because they could withstand the abrasion force brought on by moving vehicles.

TABLE 2. Test of Aggregate

Aggregate test	Average Value (%)	JKR standard Value (%)
Water Absorption	1.8	< 2
Aggregate Impact Value	13.0	< 25
Aggregate Crushing Value	24.5	< 25
Los Angeles Abrasion Value	23.0	< 25

BITUMEN TEST

The overview of the bitumen test findings from this investigation is shown in Figure 4. By measuring the distance in tenths of a millimeter that the standard needle penetrated the bitumen specimen at a known loading, temperature, and time, the penetration test measures the accuracy of the bitumen sample. In addition, this test can be used to determine the hardness or softness of bitumen by determining its consistency. The control sample's average penetration test result (0% OPFA) in this study was 62.5 mm, demonstrating that bitumen grade 60/70 was suitable to be used as the bitumen grade in the range of 60 mm to 70 mm penetration. Meanwhile, the penetration values drop as the OPFA content of bitumen rises. The control sample passed the softening point test with a temperature of 48 °C, which was within the allowed range (48-56 °C) for use. This shows that bitumen will soften and melt at a temperature of 48 degrees Celsius, and the value is rising as bitumen content in OPFA increases. The specific gravity (SG) test was used to determine the bitumen's specific gravity, which is calculated as the mass of a particular volume of bitumen divided by the mass of a corresponding volume of water. In contrast to the rising value when the natural bitumen was combined with OPFA, the average value of SG for the control sample in this study was 1.04, satisfying the standard criteria and suitable to be used as a binder in pavement mixture. These findings demonstrated that an increase in OPFA in natural bitumen may boost the mixture's hardness and ability to withstand higher temperatures.

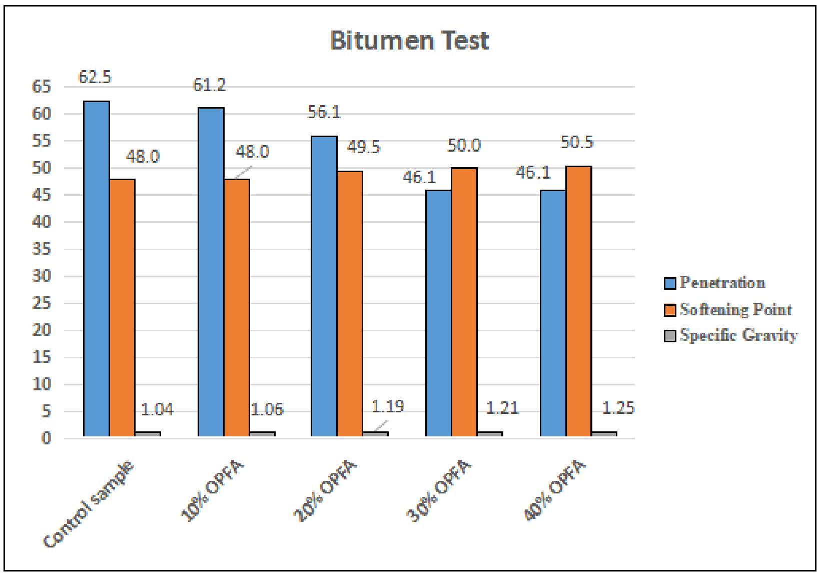

FIGURE 4. Bitumen tests

RESILIENT MODULUS TEST

As indicated by the material stiffness, the resilient modulus (Mr) is an essential parameter for pavement design. An estimation of elasticity modulus can be determined through the resilient modulus test. When the repeated loadings are applied based on dynamic stresses-strains, this test aids in measuring the basic material property. Additionally, at two different temperatures—25 and 40°C—the structural behavior of the pavement under traffic loadings can also be determined. Figure 5 presents the resilient modulus test results for the control samples and OPFA-modified binder at 25 and 40°C. It shows that OPFA raises the modulus values and the data obtained demonstrate that at 25 and 40°C, the 40% of OPFA modified binder achieved the highest value of modulus, which was 10992 MPa and 2936 MPa respectively. This is because the OPFA's properties with pozzolanic cementing element provide strong binding agents that strengthen the bonding of the mixture (Borhan et al. 2010). The addition of filler may alter the viscoelastic characteristics of the asphalt mixture and change the stiffness (Likitlersuang & Chompoorat 2016). These findings proved that increasing the amount of modified binder combined with OPFA in an asphalt mixture can increase stiffness and, as a result, the load-bearing capacity of the pavement.

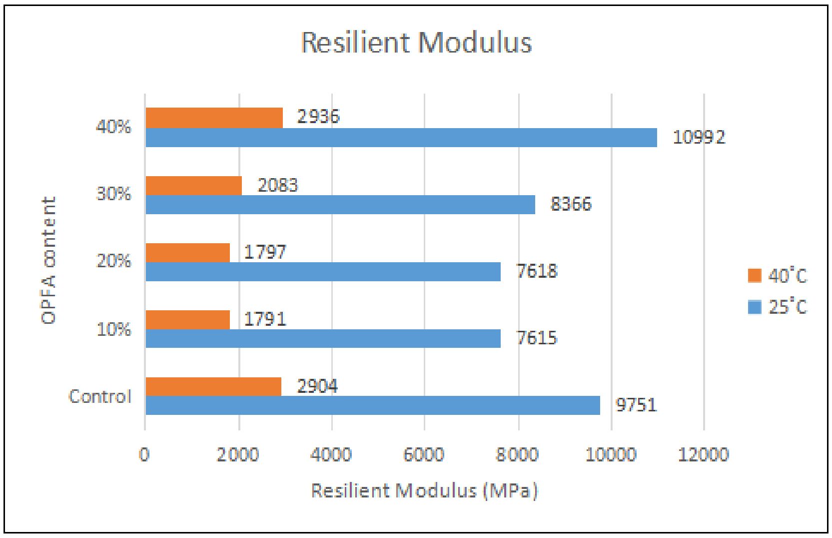

FIGURE 5. Resilient Modulus Test

DYNAMIC CREEP TEST

The main issue with the flexible pavement is rutting. It is the constant rut depth in the transverse profile of the wheel patch that begins at zero and increases over time as loading repetitions increase. Asphalt pavement subjected to repetitive axle loads can be reasonably simulated using a repeating uniform compressive stress on a cylindrical specimen from a dynamic creep test. In order to assess the rutting resistance of asphalt pavement at a temperature of 40°C, the dynamic creep test is conducted to investigate the relationship between deformation and pavement loadings. The results of the creep curves in the deformation test at 40 °C for the control sample and OPFA-modified binder are plotted as illustrated in Figure 6. In the control sample, 10% of OPFA, 20% of OPFA, 30% of OPFA and 40% of OPFA-modified binder experienced a deformation of 0.91 mm, 0.60 mm, 0.40 mm, 0.30 mm and 0.20 mm respectively. These findings indicate that when OPFA concentration has increased, the creep deformation value has decreased which increases performance deformation resistance. This is because OPFA has pozzolanic cementing capabilities that could improve and enhance the mixture's strength and resistance to permanent deformation or rutting. This study has proved that OPFA can be a modifier in any type of mixtures either in Hot Mix Asphalt (HMA), Cold Mix Asphalt (CMA), Stone Mastic Asphalt (SMA), and others (Usman et al. 2021).

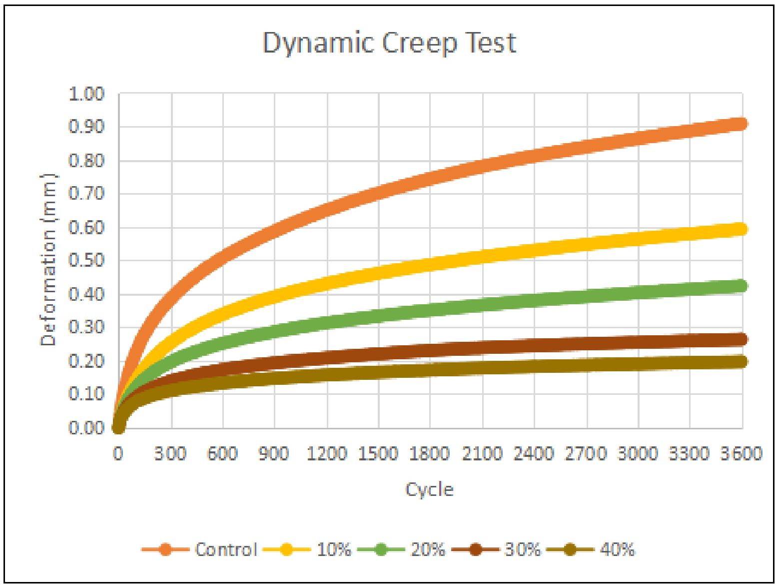

FIGURE 6. Creep Deformation Test

SKID RESISTANCE TEST

The force experienced when a tire is prevented from rotating and slides on a pavement surface is known as the skid resistance test. It is crucial because improper skid resistance can result in a skid that can cause a traffic accident. This measurement can be used to assess different kinds of construction materials and approaches used. The results of the skid resistance test for the control sample and the OPFA-modified binder samples are shown in Figure 7. The control sample, 10, 20, and 30% of OPFA-modified binder obtained gradually increasing skid resistance values, with skid resistance values of 70.73, 71.24, 74.34, and 82.09, respectively. Based on the results, 40% of OPFA-modified binder achieved the highest value of skid resistance, which was 83.63. It demonstrates that surfaces of mixture samples with greater OPFA contents have more friction compared to the control sample.

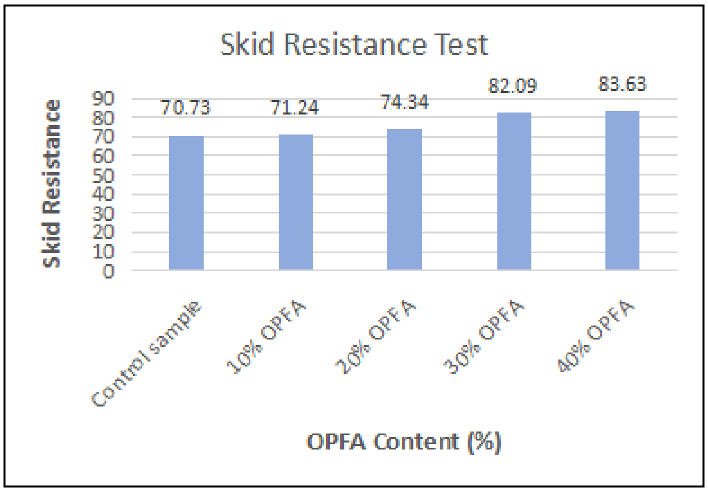

FIGURE 7. Skid Resistance Test

CONCLUSIONS

Several conclusions were drawn based on the laboratory tests findings in this study:

1. According to the findings of the bitumen tests, the addition of OPFA to the bitumen 60/70 enhanced the hardness of the binder mixture, the temperature at which it softens, and the specific gravity value in comparison to the control sample.
2. In comparison to AC20 mixed with natural bitumen 60/70, the results revealed that modified bitumen with 40% OPFA increased the performance of asphalt mix (AC20) in terms of its strength, stiffness, deformation, and skid resistance. It was discovered that it could withstand rutting and skid in hot weather.
3. Due to its pozzolanic cementing characteristics, OPFA improves the rheological behavior of the asphalt mixture and improves the binder adhesion between the particles in AC20.
4. In order to improve highway growth and address environmental issues, it is crucial to broadly introduce OPFA as a substitute binder in bituminous mixtures in Malaysia.

ACKNOWLEDGMENT

The authors appreciate the financial assistance provided by University of Technology Sarawak through the research grant (UCTS/RESEARCH/4/2018/03).

DECLARATION OF COMPETING INTEREST

None.

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