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PHYSICAL AND RHEOLOGICAL PROPERTIES OF LATEX EMULSION MODIFIED BITUMEN

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Abstract

Natural rubber latex is one of the natural polymers that commonly used. This milky white liquid is mostly collected from the plant Hevea Brasiliensis. The latex chains in the milky white liquid combine together to form rubber lumps when contact with the bacteria in the air. Latex emulsion is produced by adding an emulsifier into the natural rubber latex to keep the polymer latex particles stable and resist polymer coagulation. The purpose of this research aimed to improve the quality of bitumen and enhance its shear and adhesion properties through the modification with latex emulsion, thereby increasing the stability of the granular structure of pavements, and enabling them to withstand higher axle load, which increasing due to the growing demands of current transportation systems. This paper presents the laboratory studies of latex emulsion modified bitumen with various amount of latex emulsion blended with bitumen. The latex emulsion concentration used in the bitumen modification was 3%, 6%, 9% and 12% by the weight of bitumen. The evaluation included parameters such as stiffness, temperature sensitivity, dynamic viscosity, complex shear modulus, and rutting resistance of the modified bitumen. Further improvement in selection of percentages of latex emulsion are required to achieve the desired bitumen properties. The surface topography of latex emulsion modified bitumen was examined by using Scanning Electron Microscopy to investigate the dispersion of latex emulsion and the homogeneity of latex emulsion. A homogenous dispersion of latex particles in bitumen was observed. The latex particles formed into strings and contributed to the enhancement of shear and adhesion properties in the modified bitumen. The results showed that an increase in the quantity of latex emulsion led to an increase in the complex shear modulus and a decrease in the phase angle. This indicates that the modification of bitumen with latex emulsion improved cohesion and adhesion properties of bitumen and enhanced its ability to resist shearing.

Keywords: Adhesion and Cohesion properties Bitumen modification, Latex emulsion, Natural rubber latex, Polymerization.

1. Introduction

The Bitumen is a cohesive and water-resistant material that is frequently employed as a binding agent for aggregates in the construction of pavement. It is primarily obtained from petroleum refineries [1]. In the past, utilizing unaltered bitumen in pavement construction was adequate to support the traffic load [2]. As a result of the present high traffic demand and heavy traffic load on the road network, a considerable proportion of the road pavement has entered a critical phase and is deteriorating prematurely, failing to meet its designated service life.

Moreover, Malaysia is categorized as a developing nation that experiences a tropical climate, where the average temperature during summer is considerably elevated, resulting in the bitumen becoming more pliable. The combination of the tropical weather and high traffic volumes contributes to a faster deterioration of road pavement, due to a deficiency of rheological and viscoelastic characteristics, resulting in pavement distress such as permanent deformation [3].

The requirement to modify bitumen arises from the increase in tire pressure, higher traffic volume, larger and heavier vehicles, and evolving environmental conditions. As a result, there is now a demand for modified bitumen with specific properties. According to Yero and Hainin's research, the behaviour of bitumen is significantly influenced by temperature and loading time. Therefore, by enhancing the properties of bitumen, modified bitumen can potentially extend the lifespan of the road and minimize pavement distress [4].

Therefore, the primary objective of this research was to improve the quality of bitumen in terms of its shear and adhesion properties by incorporating latex emulsion as a modifier. By adopting this approach, the study aimed to enhance the strength properties of asphalt pavements, improve their ability to withstand heavier axle loads, and concurrently contribute to the growth and development of Malaysia's rubber industry and the overall economy. It is crucial in enabling pavements to accommodate higher loads, which have become increasingly prevalent due to the rising demands of modern transportation systems.

Several forms of rubber modifiers have been employed to enhance the effectiveness of the primary binder. In the research, a variety of materials and tests were conducted, and it was discovered that incorporating natural rubber latex into the original binder can impact its index values and improve its properties [5].

Wang et al.'s study [6] discovered that liquid rubber-modified bitumen could improve the performance of bitumen, specifically regarding their ability to resist deformation, even after undergoing aging. In general, rubberized bitumen exhibits superior engineering performance compared to conventional bituminous mixtures, which can potentially extend the service life of flexible pavements.

Rubberized bitumen is created by blending rubber latex or powder, crumb rubber, or other rubber materials with regular bitumen. Numerous studies have been conducted on various forms of bitumen modifiers with excellent rheological properties, as ordinary bitumen has limited rheological characteristics and insufficient durability for pavement distress, both of which can impact the performance of flexible pavement. According to a study by Shafii et al. [7], flexible pavements that have been rubberized demonstrate superior resistance to permanent deformation, thermal cracking, fatigue, stripping, and temperature sensitivity [8].

Rubberized bitumen is also more viscous than unmodified binder, which can enhance its adhesive bonding to aggregate particles.

It is crucial to explore new alternatives that reduce the need on non-renewable petroleum-based asphalt. By doing so, it may be possible to create technically acceptable, environmentally friendly, widely accessible, and cost-effective pavement solutions [9]. Currently, Malaysia is ranked as the world's fifth-largest natural rubber producer. Additionally, Malaysia is the largest consumer of natural rubber latex [10]. Globally, rubber trees are estimated to sequester between 225 and 574 tonnes of carbon per hectare every year for 30 years. Natural rubber trees take in approximately 400 million kilograms of carbon dioxide from the atmosphere annually and replace it with oxygen, contributing to the rejuvenation of the earth's atmosphere and aiding in the fight against greenhouse gas emissions and global warming [11].

The application of natural rubber latex as a bitumen modifier offers benefits for both the rubber industry and the environment. Increased use of natural latex can lead to the growth of more rubber trees and the production of more oxygen, which in turn can contribute to reducing global warming. Therefore, utilizing natural rubber latex as an asphalt modifier is a sustainable approach that benefits both industries and the environment.

Natural rubber latex (NRL) is an elastomeric substance that possesses elastic and stretching qualities. These qualities can enhance the stiffness of asphalt binders and mixtures, which can help resist the influence of permanent deformation. Therefore, NRL is a desirable modifier for bitumen, which can enhance the performance of asphalt pavements [12]. Compared to other polymer-based materials obtained from crude oil, the utilization of natural rubber latex as an asphalt modifier is considered sustainable, as it has a lower embodied energy [13].

In a study conducted in year 2021, Ansari et al. suggested that the utilization of natural rubber in modifying bitumen can help reduce dependence on petroleum-based modifiers, which can help prevent permanent deformation or rutting that occurs when pavement layers accumulate strains due to repetitive traffic loadings in the wheel path of an asphalt pavement [14]. Apart from being affordable and readily available, the incorporation of natural rubber can also stimulate economic growth and extend the lifespan of roads with minimal maintenance costs.

2. Materials and Methods

2.1. Materials

2.1.1. Bitumen

The 60/70 penetration grade bitumen was used as a base bitumen in the modification with latex emulsion. Both of the materials, the base bitumen and latex emulsion, were supplied by Qastalani Sdn Bhd. The physical and rheological properties tests were conducted to characterize the properties of the base bitumen to the standard specification of Public Works Department Malaysia for road works. The physical and rheological properties test methods are presented in Table 1.

Table 1. Physical and rheological properties test methods for base bitumen.

Properties	Test methods	Results	Specification
Penetration, dmm	ASTM D5	62.5	60-70
Softening point, °C	ASTM D36	46.2	48-56
Penetration Index	ASTM D5/D36	-1.7	n/a
Flash point, °C	ASTM D92	300	Min 250
Fire point, °C	ASTM D92	305	Min 250
Temperature sweeps, °C	AASHTO T315	64	n/a
Rutting modulus, G*/sin δ, kPa Test temp. 64°C @ 10 rad/s	AASHTO T315	1.08	Min 1.0
Rotational viscosity @135°C, Pa.s	ASTM D4402	0.4	Max 3.0
Rotational viscosity @170°C, Pa.s	ASTM D4402	0.1	Max 0.8
Retained penetration, %	ASTM D2872/D5	55.5	Min 52
Mass loss, %	ASTM D2872	0.38	Max 0.2
Drop in softening point, °C	ASTM D36	4.4	Max 10

2.1.2. Emulsification of natural rubber latex

Natural rubber latex is a commonly used natural polymer that can be found in the latex vessels or cells of rubber-producing plants. The milky white liquid is primarily collected from the rubber plant, Hevea Brasiliensis [15]. Natural rubber latex is a polymer composition called cis-1,4-polyisoprene, which is a long chain aliphatic hydrocarbon polymer that is unsaturated and linear in nature [16]. The latex of the Hevea Brasiliensis tree contains approximately 30-40% of rubber latex particles by weight dispersed in water along with other non-rubber constituents.

Traditionally, ammonia-based compounds like TMTD (Tetra methyl thiuram disulphide) and Zinc oxide have been used to preserve latex, but these compounds are highly toxic and allergenic [17]. Thus, there are great interest for non-ammonia system to preserve natural latex. In the non-ammonia system of emulsion polymerization, natural rubber latex is depolymerized into a liquid form with a shorter polymer chain that can remain in liquid state at room temperature [18]. The modification process aims to improve the properties of natural rubber latex and increase the range of raw material-based product manufacturing [19].

Generally, there are four main components involved in emulsion polymerization which are the monomer(s), dispersing medium, emulsifier, and water-soluble initiator [20]. The emulsifier plays an important role in the polymerization process due to the hydrophilic and hydrophobic regions of the molecules.

As polymerization progresses within the micelle, the addition of monomers from droplets outside causes the micelle to expand, resulting in the formation of latex [21]. Emulsified rubber latex refers to a stable dispersion of polymer latex particles in water. Emulsifiers are added to prevent polymer coagulation and maintain stability of the latex particles. The emulsifier acts as a surfactant by decreasing the surface tension of the emulsion, thus stabilizing it [22].

2.1.3. Preparation of latex emulsion modified bitumen (LEMB)

The Latex Emulsion (LE) is used as a bio-modifier to improve the properties of base bitumen supplied by Qastalani Sdn. Bhd. To ensure the storage stability of the material, the LE is kept in air sealed storage container upon receive to prevent exposure to air which can lead to oxidation or undesired chemical reactions. The natural properties of rubber latex make it a material that is suitable to blend with bitumen and produce a homogenous mixture [23]. The storage stability of the latex-modified bitumen is good even under high-temperature storage. The difference between the top and bottom sections is less than 4°C after the samples were treated for 72 hours at 163°C; the samples remained relatively consistent and do not exhibit significant separation [24].

For the LEMB modification blending, different percentages of LE added to the base bitumen. The amount of LE tested in the preliminary stage were 5%, 10%, 15%, and 20% of LE by the weight of bitumen. These tests were conducted to determine the appropriate range of LE percentages for further research on LEMB. Based on the preliminary tests, it found that high percentages of LE resulted in extremely high stiffness and low workability of the modified bitumen. As a result, the percentage range for further research was narrowed down to 3%, 6%, 9%, and 12% of LE by the weight of bitumen. These percentages selected to achieve the desired bitumen properties while enabling improvements in pavement performance.

During the modification process, the base bitumen was pre-heated under temperature of 160°C until the bitumen in fluid form and viscous enough for the blending. The blending temperature of 160°C was maintained throughout the modification process by using Gilson melting pot and digital thermometer. An overhead stirrer was used in the modification; the blade propeller of the stirrer was placed perpendicularly and symmetrically at the centre of the melting pot to form a blending vortex with circulatory flow pattern during the modification to ensure uniformity of the blending. Other than the depth of blade propeller, the blending speed of blade propeller was also important in ensuring the consistency of the blending.

The mixing duration, mixing speed, and temperature are important variables that must be carefully controlled when combining the base bitumen with the latex. Both the blending temperature and duration can have a substantial impact on the properties of natural rubber modified bitumen. Therefore, it is crucial to maintain strict control over these variables to ensure the desired properties of the modified bitumen [25].

Initial blending speed was adjusted to 500rpm, latex emulsion was slowly poured into melting pot to prevent from splashing out. After that, the blending speed was increased to approximately 800rpm and stirred continuously for 30 minutes. Continuous blending for 30 minutes serves two purposes in the LEMB modification process. Firstly, it ensures the homogeneity of the blend by thoroughly mixing the latex emulsion with the base bitumen. This ensures that the latex particles are uniformly dispersed throughout the mixtures, promoting consistent modification of the bitumen.

Secondly, continuous blending helps to evaporate any trapped moisture within the bitumen mixture. When the blending process starts, the heat generated within the mixtures causes the trapped moisture to turn into steam. As the moisture evaporates, it creates bubbles within the bitumen mixture. This bubbling is an indicator that moisture is present and being evaporated. The bubbling will continue until all the moisture within the bitumen mixture has been fully evaporated. The preparation process of Latex Emulsion Modified Bitumen is shown in Fig. 1. As shown in Table 2, four combinations of LEMB were studied.

Table 2. List of latex emulsion modified bitumen tested.

Blend ID	Percentage of latex emulsion
LEMB-3%	3%
LEMB-6%	6%
LEMB-9%	9%
LEMB-12%	12%

Bitumen heated to 160°C.

Emulsified latex at room temperature (shaken well before pour).

Blending carried out for 30min at approximately 800rpm under 160 °C.

Fig. 1. Preparation process of latex emulsion modified bitumen.

2.2. Methods

Following by the modification blending of LEMB, bitumen properties tests as well as the Scanning electron microscopy (SEM) analysis were conducted on the LEMB.

2.2.1. Physical properties tests

Physical property tests were conducted on LEMB samples containing varying amounts of latex emulsion. These tests included penetration, softening point, flash and fire point, rotational viscosity, retained penetration after RTFO (rolling thin film oven) and mass loss after heating.

The short-term aging (STA) during the mixing, storage and compacting were accomplished by using RTFO method. In this method, 35 grams of unaged LEMB was poured into RTFO cylindrical glass bottles, then, the bottles were placed at carousel inside RTFO oven. The STA process was taking place by heating the samples at 163°C in the RTFO oven, carousel was rotated at 15rpm, airflow into the bottles at 4000ml/min for 85min.

Penetration Index (PI) is used to evaluate bitumen's temperature susceptibility and characterize the changes in bitumen properties over a range of temperatures. Bitumen with a lower value of PI is more temperature susceptible, and vice versa, bitumen with a higher value of PI is less temperature susceptible. The PI is determined through the formula developed by Pfeiffer and Doormaal (1936) as follows [26]:

$$\mathrm{PI} = \frac{20-500A}{1+50A} \tag{1}$$

$$\mathrm{A} = \frac{\log 800 - \log Pen\ at\ 25°C}{T_{R\&B} - 25°C} \tag{2}$$

In order to find out the appropriate temperatures of LEMB for mixing and compacting, rotational viscosity was conducted in this study to measure the viscosity of LEMB at construction temperatures. Appropriate amount of LEMB was poured into sample chamber. Sample chamber with LEMB was then placed in the thermosel and heated up the sample to desired testing temperature. Brookfield SC4-27 spindle that is fixed to the viscometer was lowered down and immerged into the hot LEMB. The test was started with spindle speed set to 20rpm after the sample temperature had stabilized. Subsequently, the temperatures of the bitumen were determined from the viscosity-temperature line, specifically within the viscosity range of 0.17±0.02 Pa.s and 0.28±0.03 Pa.s. The temperature range within this viscosity range was identified as the mixing and compacting temperature range.

2.2.2. Rheological properties tests

To determine the rheological properties of LEMB, complex shear modulus (G*) and phase angle (δ) were measured using a Dynamic Shear Rheometer (DSR) HAAKE Rheo Stress1 in accordance with AASHTO T315. The temperature sweeps test was performed to determine the complex modulus and phase angle of bitumen at various temperature for the bitumen performance classification. Testing at the temperature range of 40°C to 82°C was carried out under a fixed torque oscillation (constant stress mode) by using parallel plate of 25 mm diameter with 1 mm gap, a loading frequency at 10 rad/s (1.59 Hz) with stress level of 0.12 kPa. The rutting modulus (G*/sin δ) and bitumen performance grade of LEMB were determined through the complex shear modulus and phase angle obtained from the temperature sweeps test.

2.2.3. Scanning electron microscopy (SEM)

The Scanning Electron Microscopy (SEM) was used to observe the state of dispersion of the latex emulsion within the base bitumen. SEM was able to visualize the surface topography of the samples by scanning the surface of samples by electron beam. Signal contains sample`s information was generated when the electrons from SEM were interacted with sample atoms [27]. For non-conducting materials such as bitumen, the samples were coated with heavy metals before the electron scanning to increase the signal ratio. The LEMB samples were examined under SEM at magnification level of 200x. The images produced by SEM were observed for the homogeneity of the LEMB after gone through the modification process of heating, blending, and cooling.

3. Results and Discussion

3.1. Physical properties tests

As the latex emulsion content increased, the penetration values decreased while the softening points increased. This indicates the LEMB with higher latex emulsion content will have higher stiffness and be less temperature susceptible. As referred to Eq. 1, the PI values of the LEMBs were determined. The PI values presented in Table 4 indicates the latex emulsion modification was enabled to increase the penetration index (PI) of the bitumen; bitumen with higher PI values will be less susceptible to temperature. The outcome indicates that latex emulsion has a positive effect on enhancing the temperature susceptibility of bitumen and resulting in better resistance to low-temperature cracking and permanent deformation. Figure 2 illustrates the inverse correlation between penetration and softening point.

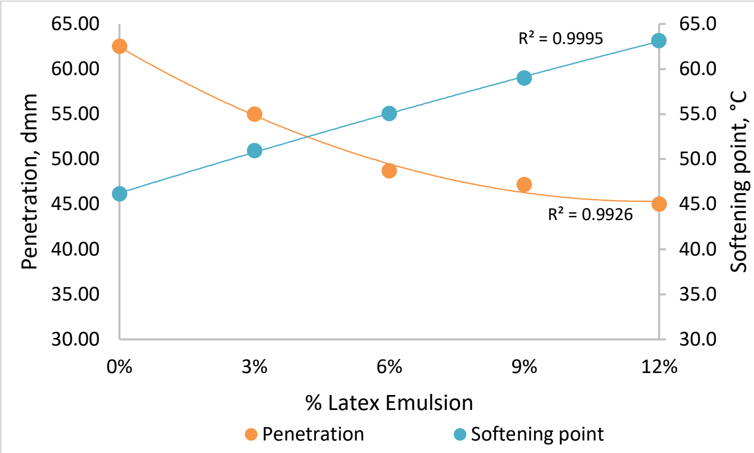

Fig. 2. Inverse relationship of penetration and softening point.

The STA of the LEMB was evaluated in terms of mass loss, retained penetration, and drop in softening point. The mass loss of LEMB was decreased and retained penetration was increased with the increase in latex emulsion content. However, drop in softening point were increased as the content of latex emulsion increase. This result indicates the LEMB with higher latex emulsion content are having higher rate of thermal oxidation.

The rotational viscosity values of bitumen increased after the latex emulsion modification. Meanwhile, the LEMB became more viscous as the amount of latex emulsion added into the base bitumen was increased. This indicates the bitumen was being stiffer as higher percentage of latex emulsion was added; higher mixing and compacting temperatures are required during the construction to ensure the workability of the bituminous mixtures. The sufficient construction temperature range for LEMB were determined through the viscosity-temperature plot; the sufficient temperature range for construction are summarizes in Table 3.

Table 3. Sufficient temperature range of LEMB for construction.

Type of Bitumen	Temperature Range, °C	
	Mixing	Compacting
60/70	139±2	134±2
LEMB-3%	160±2	155±2
LEMB-6%	176±2	172±2
LEMB-9%	227±2	221±2
LEMB-12%	279±2	272±2

Higher mixing and compacting temperatures are required for LEMB for the workability of bituminous mixtures. However, as referred to Table 4, LEMB with a higher amount of latex emulsion become more flammable at high temperature; LEMBs become more and more flammable as a greater amount of latex emulsion added into the base bitumen.

As shown in Fig. 3, the flash and fire point of the LEMB were decreased as the latex emulsion increase. The sufficient mixing temperature for LEMB-9% and LEMB-12% were higher than their flash point temperatures. This might cause the safety issue and trigger an incident while heating up the LEMB to desired construction temperatures.

The modified bitumen with latex emulsion content at 8% and above have lower flash point temperatures than the mixing temperatures. For the safety consideration, construction works at high temperature are not recommended for LEMB with latex emulsion content higher than 6%. The flash point for LEMB-6% was 230°C which is the minimum flash point requirement for modified bitumen stated in specification of Malaysian Public Works Department.

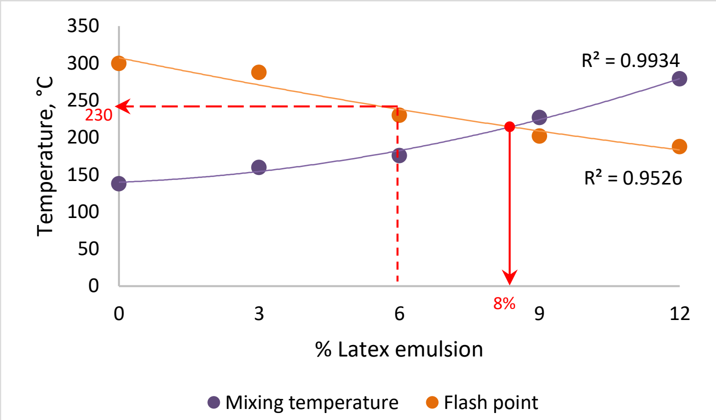

Fig. 3. Mixing temperatures and flash point temperatures for the LEMB.

Table 4. Physical properties of LEMB.

Properties	Specification	LEMB 3%	LEMB 6%	LEMB 9%	LEMB 12%
Penetration, dmm	40-60	55.0	48.7	47.2	45.0
Softening point, °C	Min 60	51.0	55.1	59.0	63.2
Penetration Index	-	-0.7	-0.1	0.7	1.4
Flash point, °C	Min 230	288	230	202	188
Fire point, °C	-	296	238	210	216
Rotational viscosity @135°C, Pa.s	Max 3.0	0.8	1.7	3.6	6.0
Rotational viscosity @170°C, Pa.s	Max 0.8	0.2	0.4	1.5	3.0
Retained penetration, %	Min 52	57.3	70.8	85.2	92.9
Mass loss, %	Max 1.0	0.28	0.19	0.10	0.09
Drop in softening point, °C	Max 10	4.4	6.4	8.5	8.6

3.2. Rheological properties test

Bitumen is a viscoelastic material that displays more viscous behaviour at higher temperatures and demonstrates elastic behaviour at lower temperatures. The viscous and elastic behaviour of LEMB were characterized in this study by using

DSR. Bitumen with larger phase angle (δ) tends to be viscous (non-recoverable) and bitumen with higher complex shear modulus (G*) tends to be elastic (recoverable) [28]. Bitumen with smaller phase angle and higher complex shear modulus will have greater resistance to deformation.

Temperature sweeps test was performed initially to find out the performance grade of the modified bitumen and the appropriate temperatures to be used in the complex shear modulus test. In the temperature sweeps test, the stress level (0.12kPa) and loading frequency (1.59Hz) were kept constant throughout the range of the testing temperature (46°C to 82°C), the test temperature with the lowest rutting factor above 1.0kPa was considered as the design temperature. Lastly, the performance grade of LEMB were evaluated and determined through G*/sin δ. The performance grade of LEMB is listed in Table 5 and the complex shear modulus under temperature sweeps for various LEMB is presented in Fig. 4.

As shown in Table 5, an increase in the quantity of latex emulsion led to an increase in the complex shear modulus and a decrease in the phase angle. This indicates the bitumen modification with latex emulsion was able to improve the cohesion properties of bitumen; the capability of modified bitumen to resist shearing is increased. Furthermore, the LEMB with higher percentage of latex emulsion have higher rutting modulus (better permanent deformation resistance) and higher stiffness. With the addition of latex emulsion, the phase angle of the bitumen decreased. This indicates that the cohesion property of bitumen has improved due to the enhancement of viscoelasticity of the bitumen.

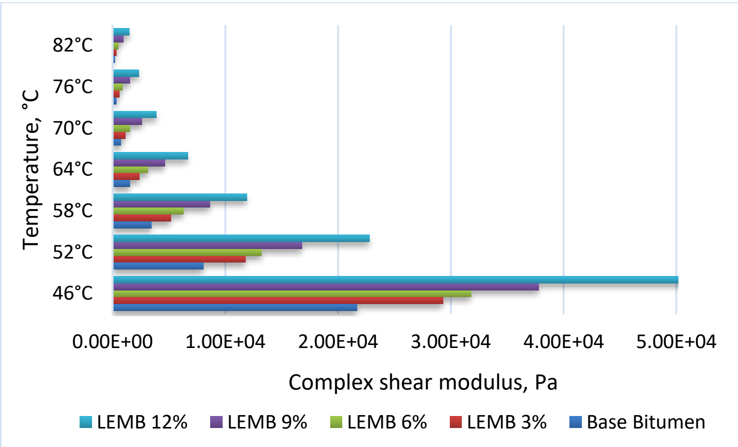

Fig. 4. Complex shear modulus under temperature sweeps for various LEMB.

Table 5. Rheological properties and performance grade of base bitumen and LEMB.

Properties	**60/70**	**LEMB 3%**	**LEMB 6%**	**LEMB 9%**	**LEMB 12%**
Performance grade	PG64	PG70	PG70	PG76	PG82
Rutting modulus, G*/sin δ, kPa Test temp. 64°C @ 10 rad/s	1.01	2.41	3.20	4.97	7.44
Phase angle, δ,°	1.55	1.45	1.37	1.20	1.10

3.3. Topography of latex emulsion modified bitumen

The topography of LEMB has been examined by using Scanning Electron Microscopy (SEM) to investigate the dispersion of latex emulsion in base bitumen and the homogeneity of the LEMB as well. In this study, the surface topography by SEM was conducted as a preliminary study to examine the homogeneity of the latex emulsion blended bitumen by observing the bitumen continuous phase and latex emulsion discontinuous phase. Fig. 5 illustrates the topography of the bitumen modified with 5% and 10% of latex emulsion.

As seen in Figs. 5(a) and 5(b), the latex emulsion discontinuous phase of the modified bitumen was in string form. With increase in the amount of latex emulsion, the latex emulsion strings in bitumen continuous phase have developed into thicker strings. Besides, Fig. 5 also indicates the homogenous dispersion of latex emulsion in modified bitumen has taken place during the bitumen modification process. The homogenous dispersion of latex particles within the base bitumen shows that the latex emulsion is a suitable material for blending with the bitumen. The presence of well-dispersed latex particles in the modified bitumen contributed to good consistency of the bitumen in terms of uniform texture and viscosity implying that the modified bitumen can be easily handled, mixed, and applied during construction processes.

(a) Bitumen with 5% latex emulsion

(b) Bitumen with 10% latex emulsion

Fig. 5. Topography of (a) Modified bitumen with 5% of latex emulsion, and (b) Modified bitumen with 10% of latex emulsion.

4. Conclusion and Recommendations

The penetration, softening point and rotational viscosity values obtained through physical properties test indicates the increase of bitumen stiffness as higher percentage of latex emulsion was added. Bitumen with PI value lower than -2 are highly temperature susceptible; base bitumen used in this study had PI value slightly higher than -2, it was considered as temperature susceptible bitumen. The modification with latex emulsion had lessen the temperature susceptible of the bitumen; LEMB have higher resistance and consistency to thermal cracking and permanent deformation.

LEMB with larger portion of latex emulsion are stiffer; higher construction temperatures were required to ensure the workability of the bituminous mixtures. For safety reasons, a bitumen safety test was performed to determine the flash point temperatures. The results indicated that LEMB with a higher proportion of latex emulsion had lower flash point values, indicating a higher level of flammability. For safety considerations, warm mix additives are recommended to be added into LEMB during the modification blending to reduce sufficient construction temperatures, to ensure the workability of the bituminous mixture throughout the paving process and most important is to improve the safety of workers.

Modifying bitumen with latex emulsion has been shown to enhance the modified bitumen's resistance to permanent deformation by increasing the complex shear modulus and decreasing the phase angle. In comparison to the base bitumen, LEMB was more elastic and less viscous at high temperatures. The improved viscoelasticity of bitumen resulting from the addition of latex emulsion leads to better shearing resistance and consistency of bitumen. The modified bitumen is less prone to cracking under high-temperature conditions and can better withstand long-term deformation or rutting caused by repeated traffic loading.

Furthermore, the integration of latex emulsion into bitumen also provides a significant boost to Malaysia's rubber industry. The utilization of latex, derived from natural rubber, promotes a cooperative relationship between the construction and rubber sectors. This collaboration contributes to the country's economic growth through increased rubber production and utilization.

This study shows the overall performance of LEMB had improved in terms of temperature susceptible, cohesion and adhesion, and rutting resistance as well. The values of drop in softening point indicate the LEMB with higher latex emulsion content were more thermal oxidized. But the rate of thermal aging of LEMB was still within the acceptable range as stated in the standard.

The surface topography of LEMB was observed and examined through Scanning Electron Microscopy (SEM) technique to determine the latex emulsion contents, latex emulsion dispersion, and the homogeneity of the modified bitumen. Under the SEM observation, latex emulsion spread homogenously within the bitumen in string form. The latex emulsion string in modified bitumen could enhance the bonding strength of the LEMB. Besides that, the appropriate amount of latex emulsion can also be determined by observing the LEMB samples under SEM.

In order to further explore the benefits of LEMB and optimize its usage or application in pavement construction, further improvement in selection of percentages of latex emulsion and mix design optimization studies on various bituminous mixes are required to help achieve the desired performance. Field trials are also important to evaluate its performance under different traffic conditions and environmental factors to provide valuable feedback.

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