

MECHANICAL PERFORMANCE OF ASPHALT MIXTURE CONTAINING CUP LUMP RUBBER

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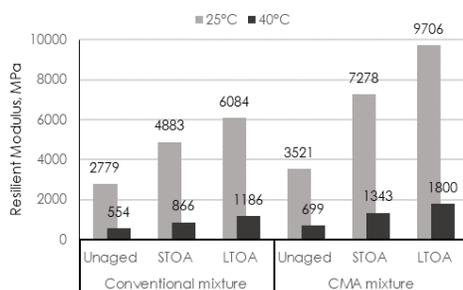
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Graphical abstract



Abstract

The use of cup lump rubber as an additive in asphalt binder has recently become the main interest of the paving industry. The innovation helps to increase the natural rubber consumption and stabilize the rubber price. This study evaluates the mechanical performance of cup lump rubber modified asphalt (CMA) mixture in terms of resilient modulus, dynamic creep and indirect tensile strength under aging conditions. The CMA mixture was prepared using dense-graded Marshall-designed mix and the observed behavior was compared with that of conventional mixture. From the results, both mixtures passed the volumetric properties as accordance to Malaysian Public Work Department (PWD) specification. A comparable result was obtained for stability and indirect tensile strength. The addition of 5% cup lump rubber provides better resistance against permanent deformation through the enhanced properties of resilient modulus and dynamic creep by 27% and 126% respectively under unaged condition. Furthermore, lower permanent strain was also observed for CMA compared to conventional mixture.

Keywords: Cup lump rubber, CMA mixture, resilient modulus, permanent deformation, tensile strength, aging

Abstrak

Penggunaan getah beku sebagai bahan tambahan di dalam pengikat asfalt telah menjadi tumpuan utama di dalam industri turapan kebelakangan ini. Inovasi ini membantu meningkatkan penggunaan getah asli dan menstabilkan harga getah. Kajian ini menilai prestasi mekanikal campuran asfalt yang diubah suai getah beku (CMA) dari segi modulus kebingkasan, rayapan dinamik dan kekuatan tegangan tidak langsung di bawah keadaan penuaan. Campuran CMA disediakan dengan menggunakan campuran direka bentuk Marshall bergred tumpat dan perilaku yang diperhati dibandingkan dengan campuran asfalt konvensional. Hasilnya, kedua-dua campuran melepasi ciri-ciri volumetrik selaras dengan spesifikasi Jabatan Kerja Raya Malaysia (PWD). Penambahan 5% getah beku meningkatkan ketahanan terhadap perubahan kekal turapan melalui peningkatan modulus kebingkasan dan rayapan dinamik masing-masing sebanyak 27% dan 126% dalam keadaan tanpa penuaan. Tambahan lagi, pengurangan perubahan kekal juga dapat diperhatikan pada campuran CMA berbanding campuran konvensional.

Kata kunci: Getah beku, campuran CMA, modulus kebingkasan, perubahan kekal, kekuatan tegangan, penuaan

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1.0 INTRODUCTION

Natural rubber can be efficiently used as an additive in asphalt modification. It is stated that the elastomeric properties of natural rubber potentially impart high stability, excellent tear strength and fatigue resistance which could enhance the durability of road pavement [1-3]. Laboratory assessment and some full-scale road trials were established using the rubberized mixture to improve the performance of road surfacing since the early 1950s. Unfortunately, none of these trials was monitored closely and as such not much information is available for references. Nevertheless, there were indications that the rubber improves adhesion and resistance against stripping problems [4].

Recently, some field trial projects were carried out by Malaysian Public Works Department (PWD) involving cup lump rubber as modifier in asphalt mixture at Jalan Gemas-Rompin, Tampin, Negeri Sembilan [4] and along Jalan Kuala Lumpur-Kuantan, Malaysia [5]. From the results, a little improvement on the strength of the compacted rubberized mixture was found when subjected to loading. Even so, the flow value of the rubberized mixture was lower than conventional mixture, indicated that the flexibility of natural rubber asphalt mixture was enhanced. This field trial results seem opposite to the study undertaken by Krishnapriya [6] based on Marshall mix design results, where the stability of the rubberized mixture increases by about 47% compared to the control mixture. Nevertheless, increment on the flow value and the voids filled with asphalt (VFA) was in line with the field trials evaluation data. For the most part, asphalt mixture incorporating natural rubber improves the conventional mixture by stiffening the mixture with low air voids content [5]. Shaffie *et al.* [7] and Tuntiworawit *et al.* [8] on the other hand, performed Superpave mix design in determining the design binder content of natural rubber modified asphalt mixture. The design binder content when incorporating natural rubber as modifier in asphalt mixture was found ranging from 5.1% to 5.2%, which is lower than conventional mixture. Although the binder amount reduced, the adhesion among the aggregates improved and the rate of stripping reduced.

In terms of pavement performance, polymer modified mixtures reveal more resistance to the rutting deformation at high temperature compared to the conventional mixture [1, 9-11]. Rutting is a progressive accumulation of permanent deformation of each layer of the pavement structure under repetitive loading. This type of distress usually accumulates small pavement deformations that appear as longitudinal depressions in the wheel path of roadways [12-13]. According to Shaffie, Hanif, Arshad and Hashim [14], who studied the rutting resistance of rubberized mixture incorporating cup lump rubber as modifier found that the rut depth of the modified mixture decreases compared to the conventional mixture. The low rut depth resulted from

the wheel tracking test indicated that natural rubber elastic properties resist repetitive load at high temperature. Furthermore, Tuntiworawit *et al.* [8] found that resilient modulus of rubberized asphalt mixtures increases with the increase in natural rubber content. However, deformation was mostly recoverable compared to conventional mixture. In terms of fatigue, polymer that has been cross-linked creates a three-dimensional network in modified asphalt, impart greater strength and exceptional elasticity, thus increase its capability to resist higher strain. However, for polymer that exhibits crystalline behavior i.e. natural rubber, the rubberized mixture can take high number of load repetitions without damage at lower strain. At higher strain, the formation of cracks will occur due to crystallize nature of rubber that impart rigid properties and cannot be stretched, but the performance of rubberized mixture incorporating natural rubber was improved compared to the conventional mixture [15]. According to Krishnapriya [6], the increase in resilient modulus at the same time enhanced the fatigue life of the rubberized asphalt mixture. However, the increase in air void percentage and initial strain of the rubberized mixture can shorten the pavement service life than the expected duration.

In addition, Shaffie *et al.* [7], Krishnapriya [6] and Tuntiworawit *et al.* [8] proved that rubberized mixture has better tensile strength compared to conventional mixture. This indicates that the mixture has tendency to tolerate high strain prior to failure under static loading at intermediate temperature. In fact, conditioned samples (immersed in water for 24 hours at 60°C) of natural rubberized asphalt mixture share similar trend with the unconditioned samples, which exhibit higher tensile strength compared to the conditioned conventional mixture. Other than that, proper mix design process was also highlighted to minimize cracking factor [16]. On the other hand, exposure to oven aging (short or long term) increased the resilient moduli of asphalt mixture by the increase in viscosity of the asphalt due to loss of volatility and consequent stiffening in the mixture. However, this might cause the mixture to become excessively hard and brittle and susceptible to disintegration and cracking failures [17]. The study under aging conditions on the asphalt mixture performance incorporating polymer as additive is always recommended in order to determine the responses in terms of stiffness, cracking and permanent deformation. The effort of using cup lump as road construction materials is currently undertaken by the Malaysian Public Works Department (PWD) [18]. However, the implementation of such works still at early phase, where extended period of time is needed to examine the behavior of the field trial CMA. Therefore, this study provides information that can be used as reference by the industries in using CMA as paving material. Also, the laboratory evaluation conducted in this study has made it possible to predict CMA performance under various aging conditions.

2.0 METHODOLOGY

2.1 Materials

In this study, Marshall mix design was conducted to determine the optimum binder content (OBC) for dense-graded AC10. Conventional asphalt binder of 60/70 PEN and 5% CMA binder were used for the asphalt mixture preparation. The binders were tested for physical properties and the results are compared with the Malaysian Public Works Department (PWD) and MS 124 (Standard and Industrial Research Institute of Malaysia, 1996) specification [18-19]. Table 1 shows the physical properties of the conventional and CMA binder. From the table it can be seen that the cup lump rubber harden the asphalt binder with lower penetration, LOH and less ductile compared with the conventional asphalt. As a result, it increases the asphalt's viscosity and softening point which in other words could possibly improve the resistance against permanent deformation.

Table 1 Properties of 60/70 PEN and 5% CMA binder [17-18]

Properties	Requirement	60/70 PEN	CMA
Penetration at 25°C (dmm)	60 - 70	65	47
Softening point (°C)	49 - 52	42	48
Viscosity at 135°C (Pa s)	3.0 (Max)	0.5	1.0
Ductility at 25°C (cm)	100 (Min)	136	96
Loss on heating, LOH (%)	0.2 (Max)	0.32	0.18

The aforementioned asphalt binder design modification came into prominence as a result of laboratory experiments conducted by Azahar *et al.* [20]. In addition, the viscosity results of conventional and CMA binder were used to plot a graph as in Figure 1. From the graph, the conventional mixture was mixed at 168°C and compacted at 155°C while CMA mixture was mixed at 179°C and compacted at 168°C. As expected, higher temperature is needed for the preparation of CMA due to high viscosity of the binder compared to conventional asphalt.

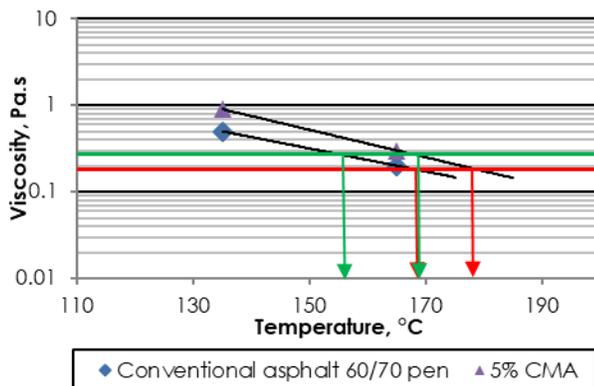


Figure 1 Plot of viscosity versus temperature

2.2 Sample Preparation

Initially, the CMA binder was prepared in accordance to the design conducted by Azahar *et al.* [20]. The Marshall mix design procedure was conducted to prepare the AC10 mixture for conventional and rubberized mixtures with the binder content range from 5% to 7%. The OBC of dense-graded asphalt mixture was estimated corresponding to Marshall parameters i.e. bulk specific gravity, VFB, VTM, stability, flow and stiffness. The design binder content of conventional asphalt and CMA mixtures were found to fulfil the specification at 5.5% and 5.6%, respectively.

2.3 Resilient Modulus Test

A resilient modulus test was carried out to measure the stiffness modulus of asphalt mixtures using the repeated load indirect tensile test, according to ASTM D4123. Through this method, the effect of temperature and load on resilient modulus was examined. This test was conducted for both conventional and CMA mixtures where the samples were tested at the temperatures of 25°C and 40°C with loading frequency of 1 Hz, a load duration of 0.1s and 0.9s rest period as recommended in PWD [18]. The test was conducted by applying compressive load with a haversine waveform. The load was vertically applied to the vertical diametric plane of a cylindrical sample of asphalt mixture. The samples were placed in a temperature-controlled cabinet at the specified test temperature and conditioned for at least 3 hours prior to testing by using the Universal Testing Machine (UTM-5).

2.4 Dynamic Creep Test

Dynamic creep test is also known as unconfined repeated load axial test. The test was performed using the Universal Testing Machine (UTM-5) with specific dynamic creep fixture. This test is conducted to analyze the densification of pavement at an early stage of rutting, characterize the pavement under repeated load and susceptibility of mixture to permanent deformation. As specified in ASTM D3497, repeated pulsed uniaxial stress was applied to the sample at 40°C. Prior to the test, samples were conditioned at the desired temperature for 3 hours. Sample was preloaded for 30 seconds at 150 kPa as conditioning stress to ensure that the plate is loaded flat on the sample. The axial cyclic loading was then set at 300 kPa and applied until 3,600 cycles or accumulated axial strain attained 5%, whichever occurred first.

2.5 Indirect Tensile Strength test

Indirect Tensile Strength (ITS) test was performed to evaluate cracking potential of the asphalt mixture. The samples were conditioned at 25°C for 2 hours. A single compressive load was applied at 50 mm/min

on a cylindrical sample, which acted parallel to the vertical diametric plane. The test was conducted in accordance to ASTM D6931.

2.6 Aging Test

The aging procedure was conducted according to AASHTO R30-02. For short-term oven aging (STOA), the loose mix samples were cured in a forced-draft oven at $135 \pm 2^\circ\text{C}$ for 4 hours prior to the test. To maintain uniform conditioning, the mixtures were stirred thoroughly every 60 ± 5 minutes. The short-term aging ends with the removal of mixtures from the oven after the set period and the samples were compacted. On the other hand, the long-term oven aging (LTOA) condition was performed on the compacted samples of STOA. The compacted samples were arranged in a forced draft oven and maintained at a temperature of 85°C for 120 hours (5 days). The LTOA samples were then removed from the oven and prepared for further testing.

3.0 RESULTS AND DISCUSSION

3.1 Marshall Properties

3.1.1 Volumetric Properties

The volumetric properties (VTM, VFA and VMA) of the conventional and CMA mixtures are shown in Figure 2. From the result of, it can be seen that the VFA of rubberized binder is higher than the conventional mixture, where the percentage slightly increases from 72% to 77.6%. This indicates an increase in effective binder film thickness due to the higher viscosity of the CMA compared to conventional asphalt mixture. The result of VFA was supported by the VMA value, where it decreases from 17.6% to 16.6% for conventional and CMA mixture, respectively. On the other hand, the VTM for the CMA mixture is comparable with that of conventional mixture. Overall, all the values are found to comply with the PWD specification.

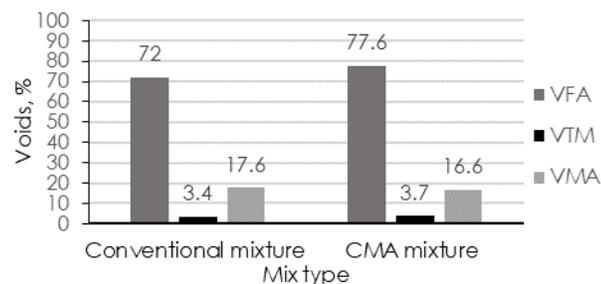


Figure 2 Volumetric properties of conventional and CMA mixture

3.1.2 Stability, Stiffness and Flow

Figure 3 shows the results of Marshall stability, stiffness and flow of the conventional and CMA mixtures. Generally, all the values comply the PWD specification [18]. Based on the figure, it can be seen that Marshall stability of the CMA mixture is comparable to the conventional mixture. However, the flow value decreases from 3.96 mm to 3.36 mm with the cup lump rubber addition, thus contributes to the greater stiffness of the CMA mixture. Therefore, it can be concluded that the rubber has a potential to improve the bonding between the binder and aggregate in asphalt mixture through strong adhesion, hence provides better resistance against damage specifically cracking potential.

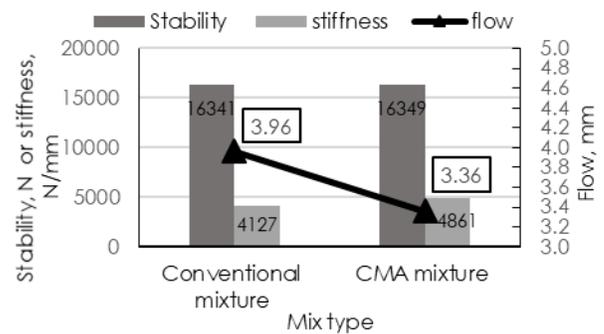


Figure 3 Stability, stiffness and flow of conventional and CMA mixture

3.2 Resilient Modulus

The result of resilient modulus for the conventional and CMA mixtures are given in Figure 4. At 25°C , the rubberized mixture attained highest resilient modulus value with an average of 3521 MPa under normal condition and the modulus increases to 7278 MPa and 9706 MPa for short and long term aging conditions which are better than the conventional mixture. This shows that the modulus of elasticity of the asphalt mixture increases with the addition of cup lump rubber, thus the mixture is able to control fatigue cracks caused by tensile stress at the bottom layer of asphalt mixture and permanent deformation throughout the pavement. This finding was significant with the nature behavior of rubber, which impart high elasticity and resiliency. The resilient modulus of the samples decreases by approximately 80% for both mixtures when the temperature increases from 25°C to 40°C at all conditions. As the temperature increases, the recoverable strain increases as well, hence resulting in lower resilient modulus. The effect of aging increases the resilient modulus for both mixtures. Aging causes oxidation and hardened the asphalt, thus increase the resilient modulus as the result. The aging of binder containing cup lump rubber obviously alters the viscoelastic and plastic characteristics of the modified mixture. It was stated

by Hamzah and Teoh [17], that as the asphalt binder and the mixture becomes stiffer, the stresses on the underlying layers of pavement were reduced. The age hardening may cause embrittlement and increases the cracking potential of the mixtures, especially at low temperature.

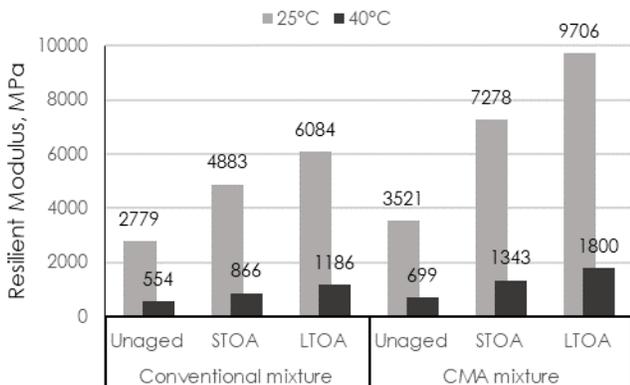


Figure 4 Resilient modulus results

3.3 Dynamic Creep

Figure 5 shows the cumulative permanent strain curves for the different mixtures under various aging conditions. According to the result, CMA mixture shows lower ultimate strain compared to the conventional mixture. The addition of rubber in asphalt binder gives significant impact on the asphalt mixture by reducing its strain value which implies the increase of the elastic response. The same result was obtained for both aging conditions where the rubber seems to provide better resistance against permanent deformation. On the other hand, the aging condition has hardened the sample and thus produces a lower strain under the loading than the unaged sample.

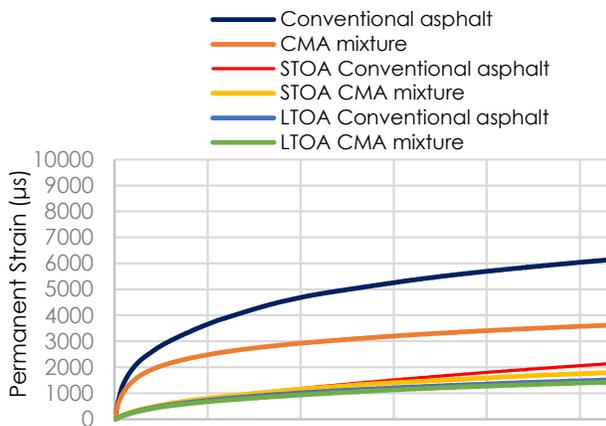


Figure 5 Cumulative strain of conventional and CMA mixture at all condition

In conjunction with the cumulative permanent strain, the results of creep stiffness modulus and creep strain slope (CSS) were also provided as in Figure 6. It can be seen that CMA mixture produces better creep modulus compared to conventional mixture particularly for unaged and short term aged samples. The result was supported by the increase in resistance to permanent deformation as reflected by the permanent strain. However, under long term aging condition, CMA mixture recorded slightly lower modulus although it experiences lower cumulative permanent strain compared to unaged CMA mixture. This is possible due to the susceptibility of natural rubber against potential of oxidative degradation as a result of chain scission in rubber molecule [22]. It can also be seen that the higher the CSS, the lower the mixture resistance against permanent deformation. The asphalt mixture incorporating cup lump rubber exhibits lower CSS than the conventional mixture based on the reduction in CSS by 13%, 29 % and 6% for unaged, short term and long term aging, respectively.

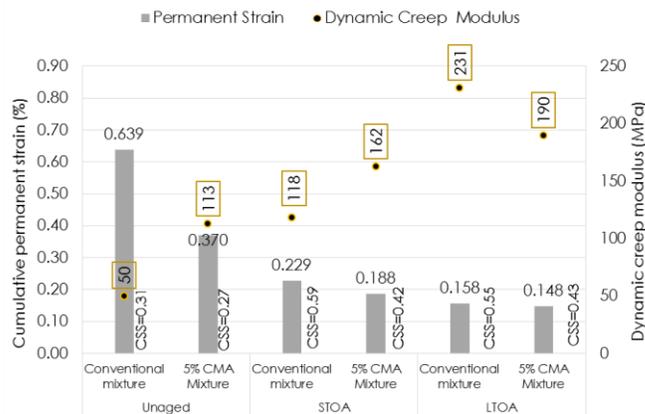


Figure 6 Permanent strain, creep stiffness modulus and CSS of asphalt mixtures

3.4 Indirect Tensile Strength (ITS)

The ITS result is given in Figure 7 for the dry samples conditioned at 25°C. The plotted value represents the average readings on the samples tested. The results indicate that the tensile strength at failure under loading of the conventional mixture is comparable with the CMA mixture. This finding was contradicted by the results obtained by Shaffie et al. [7], Tuntiworawit et al. [8] and Krishnapriya [6] which reported that the strength of modified mixture with natural rubber was higher than dense-graded conventional mixture. On the other hand, the effect of aging on the conventional and CMA mixtures can be interpreted by the increase of tensile strength of both mixtures. The conditioning process has stiffened the asphalt mix and produces higher tensile strength compared to unaged mixture. The tensile strength of CMA mixtures increased by 57% from unaged to STOA compared to the aged conventional mixture,

which is 48%. For LTOA samples, the CMA mixture shows slightly higher tensile strength compared to the aged conventional mixture. Nevertheless, the tensile strength of both mixtures under short term aging is comparable with that of long term aging at intermediate temperature.

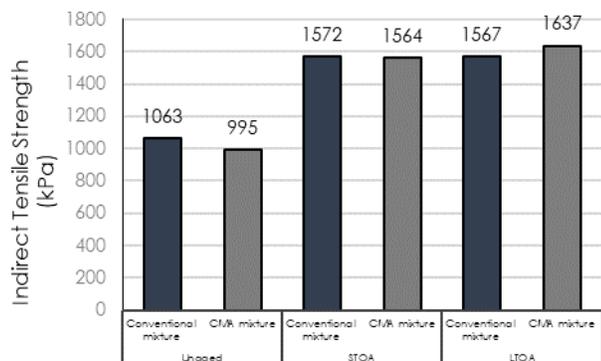


Figure 7 ITS of asphalt mixture

4.0 CONCLUSION

In this study, the results of volumetric properties obtained by both dense-graded mixtures comply with the PWD specification. Based on the result, good correlation was observed between the resilient modulus and dynamic creep of the rubberized asphalt mixture in that both agreed that the rubber addition increases the mixtures' resistance against permanent deformation. The tensile strength of the rubberized mixture conditioned at intermediate temperature was found comparable to the conventional asphalt respected to the aging conditions. Additionally, aging conditions for the rubberized mixtures was noted to stiffen the mix from those of the unaged mixture. This also could contribute to the increase in modulus, making them less susceptible to experience permanent deformation based on lower strain value compared to the aged conventional mixture.

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