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Abstract

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Keywords	asphalt mixtures; granular buton rock asphalt; stiffness modulus
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The objective of this research is to determine the potential effect on the resilient modulus of asphalt mixtures of using granular Buton rock asphalt (BRA) modifier binder. The indirect tensile stiffness modulus (ITSM) tests were performed to examine the resilient modulus of unmodified and BRA modified asphalt mixtures for dense graded aggregates of 10 mm (DG10) and 14 mm (DG14) based on standard AS-2891.13.1-1995. In this tests, three percentage of BRA natural binder, including 10%, 20% and 30% by total weight of asphalt binder, were chosen as a substitute for the base asphalt binder in the BRA modified asphalt mixtures, with the purpose was to improve the resilient modulus values. According to the test results, the resilient modulus of BRA modified asphalt mixtures was higher than for the unmodified asphalt mixtures. A higher percentage of BRA modifier binder content resulted in a higher resilient modulus. Furthermore, the unmodified and BRA modified contained only 20% BRA modifier binder of DG-10 were tested under different conditions of temperature, rise time, and pulse period. The results indicated that the BRA modified asphalt mixtures contained 20% BRA modifier binder were less sensitive to the changes in the temperature, traffic volume and loading frequency. In addition, the substitution of 20% BRA modifier binder reduced the effect of the rest period ratio and loading time on the resilient modulus of the asphalt mixtures.

Keywords: asphalt mixtures, granular buton rock asphalt, stiffness modulus

1. Introduction

Resilient modulus is a major input in the flexible pavement design methodology regarding the prediction and understanding of the behaviour of asphalt mixtures. Zoorob and Suparma [1] explain that resilient modulus is a criterion of the asphalt mixture's ability to spread the load and also to control the level of traffic. It is well known that traffic creates a tensile strain on the underside of the asphalt mixture layers which are subjected to fatigue cracking, together with compression strain in the subgrade that can lead to permanent deformation. As Pourtahmasb *et al.* [2] said, the resilient modulus test can be used to represent conditions in asphalt mixtures subjected to traffic loading and offers the ability of comparing the behaviour of asphalt mixture under various conditions and stress states.

In recent years, the mechanistic approach based on the elastic theory has been used in the philosophy of asphalt pavement design with the aim of changing the previous empirical approach. In this theory, the resilient modulus, as the elastic modulus, is required as input for the elastic properties of pavement materials [3, 4]. According to studies, obtaining the resilient modulus of asphalt mixtures using the ITSM test is a means of studying the potential elastic properties of asphalt mixtures in the form of stress-strain measurement [5-9]. Lavasani *et al.* [10] state that the material is considered to be relatively elastic when the material attains a resilient state after a certain critical number of applied loadings.

According to Shafabakhsh and Tanakizadeh [9] and Fakhri and Ghanizadeh [11], the deformation of asphalt mixtures under each load cycle is recoverable and the

material is considered to be elastic when a repeated load for a large number of times is small compared to the strength of the materials. Shafabakhsh and Tanakizadeh also state that the resilient modulus is influenced by factors such as test temperature, loading time or loading frequency, rest period and loading pulse waveforms. However, the test temperature has the greatest influence on the resilient modulus [9]. At a typical temperature and traffic speed, asphalt binder behaves in an almost elastic manner. As a consequence, the resilient modulus is a measure of an asphalt mixture's resistance to bending and hence of its load spreading ability [5]. According to Tayfur *et al.*, the asphalt binder and volumetric proportion of the mixtures influence the stiffness modulus [8].

A number of research studies on resilient modulus have been carried out to investigate the possibility of using asbuton or materials derived from asbuton as a partial material substitute/addition in asphalt mixtures. Subagio *et al.* [12] reported that the use of asbuton filler in Hot Rolled Asphalt (HRA) improved the resilient modulus and resistance to plastic deformation. The test results of Hot Rolled Asphalt (HRS) with asbuton filler conducted by Subagio *et al.* [13] revealed that the resilient modulus of HRS modified at attest temperature of 25°C were lower when compare with unmodified HRS mixtures. By comparison, at test temperature of 45°C the resilient modulus of modified HRS was greater than that of the unmodified HRS mixtures. In another experiment, the influence of granular and extracted BRA asphalt binder in asphalt mixtures was investigated by Zamhari *et al.* [14] They used ITSM test and dynamic creep test. The results indicated that using granular and extracted asphalt binder in asphalt mixtures increased the stiffness modulus and creep stiffness and decreased the rate of permanent deformation.

Despite the progress of research into the use of asbuton/asbuton materials [12-14], there are still significant gaps in the research into the resilient modulus properties of BRA modified asphalt mixtures. This is largely due to the complexities of testing magnitude in order to express the response of materials where the temperature and loading time have a significant impact on the behavior of asphalt mixtures. For example, it is still not known how rest period, traffic volume, and loading time affect the resilient modulus of BRA modified asphalt mixtures. Furthermore, more sophisticated testing devices and complex parameters are necessary to better understand the response of BRA modified asphalt mixtures. This research, however, considered the use of granular Buton Rock Asphalt (BRA) modifier binder with aim to improve the resilient modulus of asphalt mixtures.

2. Materials and methods

The determination of the resilient modulus was divided into two stages. The purpose of the first stage was to record the effect on the stiffness modulus of asphalt mixtures of using three percentages (10%, 20% and 30%) of granular BRA modifier binder in two dense aggregate gradations (10 mm and 14 mm), compared to unmodified asphalt mixtures. In this stage, the specimens were tested at under standard conditions. The purpose of the second stage was to find out the effect of temperature, rest period ratio, traffic volume and loading time on the unmodified and BRA modified asphalt mixtures. Hence, the unmodified and BRA modified asphalt mixtures specimens contained only 20% BRA modifier binder were tested under different conditions of temperature, rise time and pulse period.

2.1. Materials

Class-170 (Pen 60/80) base asphalt binder was used for unmodified asphalt mixtures. The binder was classified in accordance with the Australian Standard AS2008 [15]. Three percentages of BRA natural binder, including 10%, 20% and 30% by total weight of asphalt binder, were chosen as a substitute for the base asphalt binder in the BRA modified asphalt mixtures. The form of the BRA modifier binder (pellets) with a diameter of 7 mm to 10 mm used in this study is shown in Figure 1. Triplicate portions of granular BRA modifier binder were subjected to an extraction process [16]. The test results found that, on average, the granular BRA modifier binders consisted of about 70% mineral and 30% binder by total weight of materials. The particle size distribution of mineral is as follows: 2.36 mm (100%), 1.18 mm (97%), 0.6 mm (92%), 0.3 mm (81%), 0.15 mm (61%) and 0.075 mm (36%).

A crushed granite aggregate from a local quarry in Western Australia was used in all of the mixtures. The unmodified and BRA modified asphalt mixtures used dense graded aggregate 10 mm and 14 mm based on Specification 504 [17]. In the BRA modified asphalt mixtures, the substitution of the base asphalt binder allowed the proportion of fines passing 2.36 mm to be adjusted as shown in Table 1 with the aim of minimizing the variance in the gradation of aggregates.



Figure 1 The form of granular BRA modifier binder (pellets).

2.2. Mix design and specimen preparation

Based on specification 504 [17], dense graded asphalt mixes were assessed in accordance with the standard procedure for the Marshall method of design in order to find out the optimum binder content of unmodified asphalt mixtures. Specimens in triplicate with dimension of 101.6 ± 0.5 mm diameter and 57 - 70 mm height were compacted by applying 75 blows. The optimum binder content (OBC) was determined as 5.4% and 4.6% for DG-10 and DG-14 respectively by weight of the total mixture. The same binder contents as for unmodified asphalt mixtures were used for the BRA modified asphalt mixtures in order to maintain consistency for comparison purposes. Table 2 shows the proportion of the base asphalt binder and the BRA modifier binder in unmodified and BRA modified asphalt mixtures, as well as the proportion of granular BRA (pellets) mixed into the mixtures.

Furthermore, BRA modified asphalt mixture specimens were manufactured as presented in elsewhere [18, 19]. The specimens were cylindrical with dimension of 100 ± 2 mm in diameter and 35 mm - 70 mm in height, prepared according to standard AS 2891.13.1-1995. The compactions were done using a gyratory compactor, as set out in AS2891.2.2 -1995 [20]. In total 24 specimens were tested for the first stage and thirty specimens were tested for the second stage.

Table 1 Final crushed aggregate gradation used in this study

Sieve size (mm)	Percent passing								Limit values	
	DG-10 (BRA modifier content)				DG-14 (BRA modifier content)					
	0%	10%	20%	30%	0%	10%	20%	30%	10 mm	14 mm
19.00					100	100	100	100		100
13.20	100	100	100	100	96.5	96.5	96.5	96.5	100	93-100
9.50	97.5	97.5	97.5	97.5	84.0	84.0	84.0	84.0	95-100	79-89
6.70	83.0	83.0	83.0	83.0	68.0	68.0	68.0	68.0	78-88	63-73
4.75	68.0	68.0	68.0	68.0	54.0	54.0	54.0	54.0	63-73	49-59
2.36	44.0	44.0	44.0	44.0	37.0	37.0	37.0	37.0	40-48	33-41
1.18	28.5	28.5	28.6	28.6	27.0	27.0	27.1	27.1	25-32	22-32
0.600	21.0	21.1	21.2	21.3	19.0	19.1	19.2	19.3	18-24	15-23
0.300	14.5	14.8	15.0	15.2	14.0	14.3	14.4	14.6	12-17	10-18
0.150	10.0	10.5	11.0	11.5	8.5	9.0	9.4	9.8	8-12	6-11
0.075	4.0	4.9	5.7	6.4	3.5	4.4	5.0	5.6	3-5	2-5

Table 2 Proportion of materials used in asphalt mixtures

Materials	Percentage by total weight of mixtures (%)							
	BRA modifier content (DG10)				BRA modifier content (DG14)			
	0%	10%	20%	30%	(%)	10%	20%	30%
1. Total binder content	5.40	5.40	5.40	5.40	4.60	4.60	4.60	4.60
a. Base binder	5.40	4.90	4.30	3.80	4.60	4.10	3.70	3.20
b. BRA modified binder	0.00	0.50	1.10	1.60	0.00	0.50	0.90	1.40
2. Total aggregate content	94.60	94.60	94.60	94.60	95.40	95.40	95.40	95.40
a. Crushed rock	94.60	93.30	92.10	910	95.40	94.10	93.20	92.30
b. BRA mineral	0.00	1.30	2.50	3.60	0.00	1.30	2.20	3.10
3. Granular BRA (pellets)	0.00	1.80	3.60	5.20	0.00	1.80	3.10	4.50

2.3. Indirect tensile resilient modulus test

ITSM tests were performed to determine the resilient modulus of asphalt mixtures based on standard AS2891.13.1-1995 [21] using a universal testing machine (UTM 25) under the test conditions presented in Table 3. The load pulse was applied vertically in the vertical diameter of a cylindrical specimen through a curved loading strip. The resulting horizontal deformation was measured by attaching two linear variable differential transformers (LVDT) at the mid thickness at each end of the horizontal diameter. Initially, the test specimens were conditioned through the application of five load pulses with the specified rise time to the peak load at the specified pulse repetition period, and then the calculation of the modulus was done based on the average of a further five load pulses.

Table 3 Test conditions for the first and second stage of ITSM test

Parameters	First stage	Second stage
Test temperature, °C	25 ± 0.5	5, 15, 25, 40, 60 ± 0.5
Rise time t_u (10% to 90%), ms	40 ± 5	40, 60, 80 ± 5
Pulse repetition period (10% to 10%), ms	3000 ± 5	1000, 2000, 3000 ± 5
Recovered horizontal strain, $\mu\epsilon$	50 ± 20	50 ± 20
Air voids, %	5 ± 0.5	5 ± 0.5
Content of BRA modifier binder, %	0, 10, 20, 30	0, 20
Type of gradation	DG-10, DG-14	DG-10

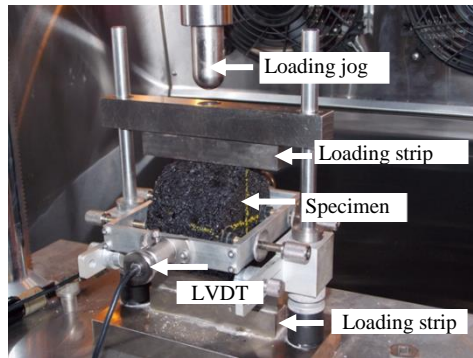


Figure 2 Set-up the ITSM test

3. Results and discussion

3.1 Effect of granular BRA modifier binder on resilient modulus of asphalt mixtures

Resilient modulus is defined as the ratio of the applied stress to the recoverable strain at particular temperature and frequency [9, 22]. The resilient modulus of the BRA modified asphalt mixtures was statistically significantly higher than that of the unmodified asphalt mixtures as illustrated in Figure 3. Comparison of the resilient modulus of unmodified and BRA modified asphalt mixtures, showed that the resilient modulus for BRA modified asphalt mixtures prepared with 10%, 20% and 30% BRA modifier binder was about 19%, 65% and 72%, respectively, higher than for the unmodified asphalt mixtures for DG-10. However, the resilient modulus value for the unmodified asphalt mixtures did not exceed the criterion (below 5000 MPa) set out by Main Road Western Australia [23]. A higher percentage of BRA modifier binder content resulted in a higher resilient modulus. Further, for DG-14, the resilient modulus of BRA modified asphalt mixtures prepared with 10%, 20%, and 30% BRA modifier binder was about 10%, 41% and 50%, respectively, higher than for the unmodified asphalt mixtures.

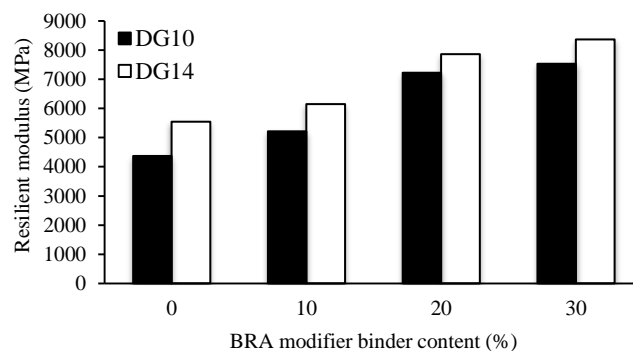


Figure 3 Resilient modulus of unmodified and BRA modified asphalt mixtures

Based on the results, substituting base asphalt binder with granular BRA modifier binder improved the resilient modulus of asphalt mixtures. BRA modifier binder helps the mixture to resist horizontal deformation. The higher the content of granular BRA modifier binder, the greater the tensile strength will be, leading to an increase in the resilient modulus of the mixtures. Asphalt mixtures with a high resilient modulus will

distribute loads over a wider area. It is expected that the BRA modified asphalt mixtures with a higher resilient modulus would have greater tensile strain and resistance to cracking.

3.2 Effect of temperature on resilient modulus of asphalt mixtures

The resilient modulus ratio was defined by dividing the resilient modulus values for BRA modified asphalt mixtures in a given loading period and pulse repetition period with the resilient modulus values for unmodified asphalt mixtures in the same loading period, pulse repetition period and temperature. Table 4 shows that the resilient modulus ratio increases as the temperature increases. At a test temperature of 5°C, the average resilient modulus ratio is 1.39, while it increases to 2.18 at a test temperature of 40°C. This indicates that the resilient modulus for BRA modified asphalt mixtures prepared with 20% BRA modifier binder increased under the same conditions of test temperature, rise time and repetition period. As an alternative means of showing the influence of BRA modifier binder on resilient modulus values, Figure 4 illustrates the relationship between the resilient modulus of unmodified and BRA modified (20%) asphalt mixtures. The points are above the equality line, representing an increase by about 1.4 times in the resilient modulus due to the substitution of BRA modifier binder.

Table 4 Resilient modulus ratio

Rise time (ms)	Pulse repetition period (ms)	Temperature (°C)				
		5	15	25	40	60
40	1000	1.38	1.38	1.65	2.15	2.06
40	2000	1.39	1.41	1.77	2.16	2.05
40	3000	1.38	1.44	1.78	2.17	2.01
60	1000	1.39	1.41	1.73	2.21	2.04
60	2000	1.40	1.44	1.82	2.17	2.05
60	3000	1.39	1.47	1.83	2.16	2.06
80	1000	1.41	1.42	1.79	2.26	2.02
80	2000	1.41	1.46	1.85	2.17	2.07
80	3000	1.39	1.49	1.86	2.15	2.09
	Average	1.39	1.44	1.79	2.18	2.05

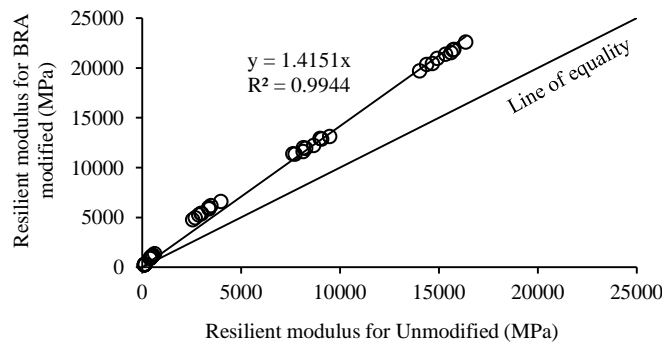


Figure 4 Relationships between resilient modulus of unmodified and BRA modified asphalt

From the previous investigation [8], stiffness modulus values converge at test temperature of 25°C and 40°C. Similarly, this study found that the stiffness modulus tends to converge at test temperature of 15, 25, 40 and 60°C. The results show a decrease in resilient modulus for both asphalt mixtures due to the increase in test temperature. The resilient modulus values decreased by about 39-85% and 39-82% for

unmodified and BRA modified asphalt mixtures, respectively, between two adjacent temperatures. This shows that the resilient modulus is highly dependent on temperature as a result of the softening point of asphalt binder. As expected, the results of this study showed that the resilient modulus of asphalt mixtures decreases as temperature increases. The resilient modulus of unmodified mixtures decreased by 2-3% more than the BRA modified asphalt mixtures tested at the same rise time and repetition period conditions. These results confirmed that BRA modified asphalt mixtures are less sensitive to temperature change than unmodified asphalt mixtures. Increasing temperature led to an increase in the deformation of asphalt mixtures due to a lower base asphalt binder viscosity in higher temperatures.

3.3. Effect of rest period ratio on resilient modulus of asphalt mixtures

The rest period ratio is obtained by dividing the rest period by the loading time (R/L), while the resilient modulus ratio is defined by dividing the resilient modulus in a given rest period ratio with the resilient modulus under a standard loading time of 100 ms and repetition period of 3000 ms at the same temperature [9, 24]. Figure 5 shows the resilient modulus ratio for unmodified and BRA modified asphalt mixtures increased with an increase in the R/L ratio at 5°C. However, by contrast, the resilient modulus ratio for both asphalt mixtures decreased with an increase in the R/L ratio at other test temperatures. Law [25], and Shafabakhsh and Tanakizadeh [9] have concluded that a lower R/L ratio will yield greater resilient modulus values under the same loading period.

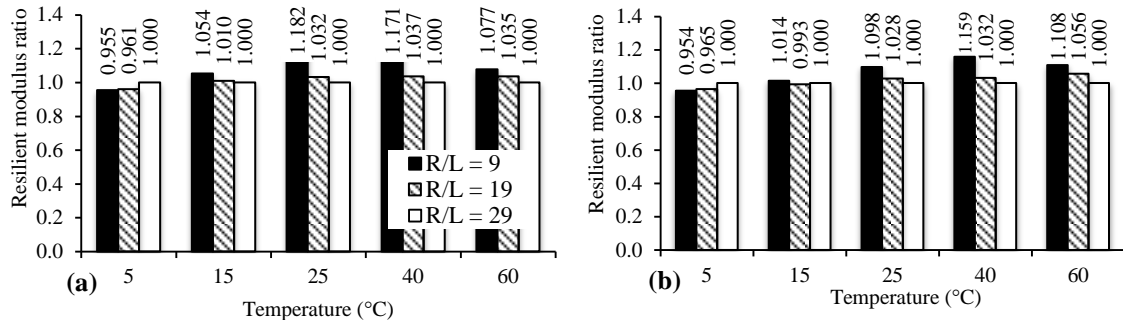


Figure 5 Effect of rest period ratio on resilient modulus of (a) unmodified asphalt mixtures, (b) BRA modified asphalt mixtures

A lower R/L ratio resulted in a higher resilient modulus ratio of up to 1.182 and 1.159 for unmodified asphalt mixtures at a test temperature of 25°C and BRA modified asphalt mixtures at a test temperature of 40°C, respectively. This shows that the resilient modulus increases when the frequency of load cycle increases from 0.33 Hz or 0.5 Hz to 1.0 Hz. A shorter rest period resulted in less time for strain recovery to occur under a higher load cycle frequency, resulting in a higher resilient modulus [26]. Kim *et al.* [24] have showed that the rest period ratio has a direct effect on the recovery strain of asphalt mixtures. A greater resilient modulus value is obtained from a smaller recoverable strain. However they found that a R/L ratio approaching 8 and higher had only minor effect on the resilient modulus. The resilient modulus of asphalt mixtures decreases as the R/L ratio increases. Moreover, the dependency of R/L ratio decreases with a decrease in temperature. Monismith [27] reported that an R/L ratio of 8 and higher does not show the beneficial effect of a longer R/L ratio. Similarly, Barkdale *et al.* [28] showed that the R/L ratio of 4 to 27 bring about less variation in the resilient modulus.

3.4. Effect of traffic volume on resilient modulus of asphalt mixtures

The repetition period of 1000 ms and 3000 ms were used to simulate a high and low volume of traffic, respectively. It can be seen in Figure 6(a) that at a test temperature of 5°C, the unmodified and BRA modified asphalt mixtures under low traffic volume conditions had a resilient modulus higher than that of asphalt mixtures under high traffic volume conditions. By contrast, at other test temperatures, the resilient modulus values for both mixtures under a low volume of traffic were lower compared with those mixtures under a higher volume of traffic. Furthermore, the increase in rise time from 40 ms to 80 ms resulted in a decrease in the resilient modulus.

The resilient modulus for both asphalt mixtures decreased by up to 8.6% as the repetition period decreased from 3000 ms to 1000 ms at a test temperature of 5°C. However, at other test temperatures, the resilient modulus of both asphalt mixtures increase by up to about 17% - 18% when the repetition period decreased from 3000 ms to 1000 ms especially at a moderate temperature (25°C) and high temperature (40°C) [18]. Similar finding was reported by Tayfur *et al.* [8]. In addition, the effect of loading frequency on the resilient modulus of unmodified and BRA modified asphalt mixtures is illustrated in Figure 7.

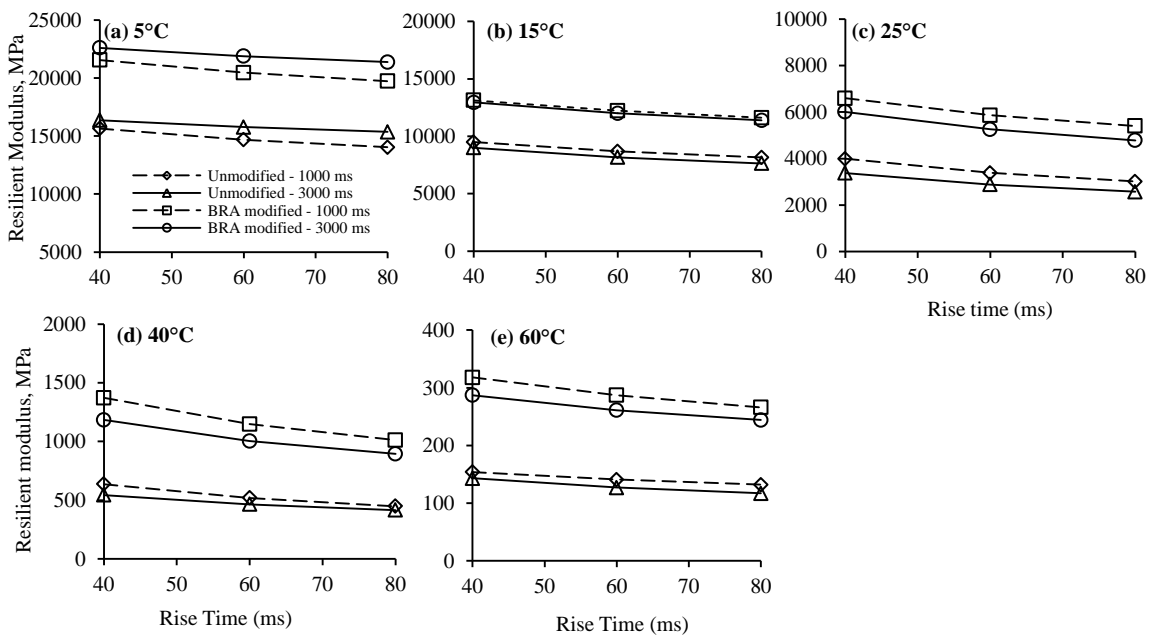


Figure 6 Resilient modulus for asphalt mixtures at variation of test temperatures

The constant coefficients obtained from fitting Figure 7 to the data using a linear relationship for unmodified and BRA modified asphalt mixtures are listed in Table 7. As can be seen, at a temperature of 5°C, the constant coefficient “a” is a negative value, indicating that an increase in loading frequency results in a decrease in the resilient modulus of unmodified and BRA modified asphalt mixtures.

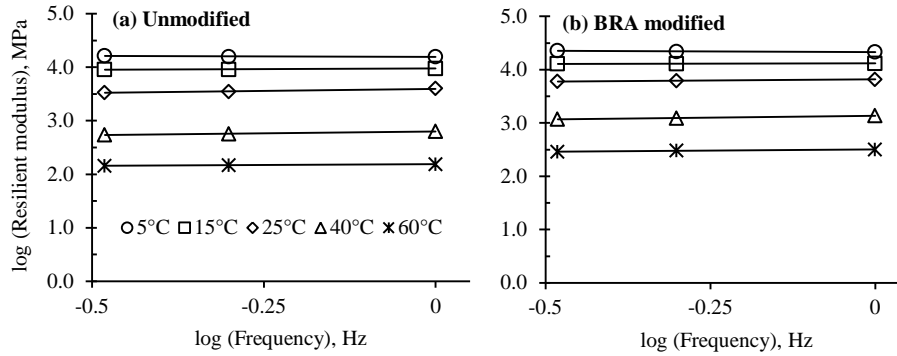


Figure 7 Effect of loading frequency on resilient modulus of asphalt mixtures

Table 7 Coefficient of linier relationship of frequency – resilient modulus

Temperature (°C)	Unmodified			BRA modified		
	<i>a</i>	<i>b</i>	R ²	<i>a</i>	<i>b</i>	R ²
5	-0.0382	4.1916	0.7318	-0.0400	4.3317	0.8296
15	0.0485	3.9761	0.9573	0.0142	4.1170	0.5691
25	0.1550	3.5977	0.9600	0.0852	3.8184	0.9923
40	0.1458	2.8017	0.9746	0.1365	3.1345	0.9697
60	0.0659	2.1882	0.9897	0.0902	2.5041	0.969

However at other test temperatures, constant coefficient “*a*” is a positive value, demonstrating that the resilient modulus for both unmodified and BRA modified asphalt mixtures increases with an increase in the loading frequency. According to Fakhri and Ghanizadeh [11], the constant coefficient “*a*” indicates the change in modulus rate corresponding to the change of loading frequency. The results show that the minimum value of coefficient “*a*” is at the temperature of 5°C and increases as the temperature increases. The maximum value of this coefficient was recorded at the temperature of 25°C and 40°C for unmodified and BRA modified asphalt mixtures, respectively. Similar observations was reported by Fakhri and Ghanizadeh [11]. At the same test temperature, the constant coefficient “*a*” values for unmodified asphalt mixtures was higher than for the BRA modified asphalt mixtures. This confirms that BRA modified asphalt mixtures are less sensitivity to changes in the frequency than unmodified asphalt mixtures. Moreover, the constant coefficient “*b*” for both unmodified and BRA modified asphalt mixtures decreased with an increase in test temperature, indicating that the resilient modulus values for both asphalt mixtures decreases when temperature increases.

3.5. Effect of loading time on resilient modulus of asphalt mixtures

The resilient modulus ratio was defined as the resilient modulus for a given loading time divided by the resilient modulus for a standard loading time of 100 ms and a repetition period of 3000 ms [9]. Figure 8 presents that the resilient modulus ratio for unmodified asphalt mixtures decreased by up to 0.76 at a test temperature of 25°C and 40°C as the loading time increased to 200 ms, while for BRA modified asphalt mixtures, the resilient modulus ratio decreased by up to 0.76 at test temperature of 40°C. Furthermore, at a low temperature (5°C), the effect of loading time on resilient modulus was less significant. At this temperature, the behaviour of the asphalt mixtures is close to elastic and therefore the materials are largely independent of the change in loading time. Similar observations have been reported by other researchers [8, 25, 28]. However, at moderate temperature (15°C and 25°C) and high temperature (40°C and

60°C), the resilient modulus decreased significantly as loading time increased to 200 ms. According to other researchers [28, 29], at these temperatures there is great deformation with less recovery from deformation when a high loading time is applied. It was observed the resilient modulus decreased in about 24% - 26% for BRA modified asphalt mixtures and 24% - 29% for unmodified asphalt mixtures [18]. Generally, the decrease in resilient modulus ratio due to the increase in loading time for unmodified asphalt mixtures was greater than for the BRA modified asphalt mixtures. Similar observation have been reported by Kamal *et al.* [29]. Tayfur *et al.* [8] reported that the resilient modulus values for modified mixtures increased by about 25% when the loading time decreased from 80 ms to 40 ms. Shafabakhsh and Tanakizadeh [9] observed that the effect of loading time on the resilient modulus of asphalt mixes was significant. They stated that with an increase in loading time from 100 ms (for R/L of 9) to 1000 ms at 40°C, the resilient modulus ratio decreased by about 0.16 for haversine loading and 0.21 for square loading, and vice versa; with a decrease in loading time to 50 ms, the resilient modulus ratio decreased by about 1.45 for haversine loading and 1.41 for square loading. In addition, the loading time of 100 ms and 200 ms were chosen for simulating the high and low vehicle speed respectively. The results show that the resilient modulus for unmodified and BRA modified asphalt mixtures decreased as loading time increased to 200 ms under various temperature and pulse period conditions. The decrease in resilient modulus for BRA modified was lower than for with the unmodified asphalt mixtures tested at various temperature and pulse period.

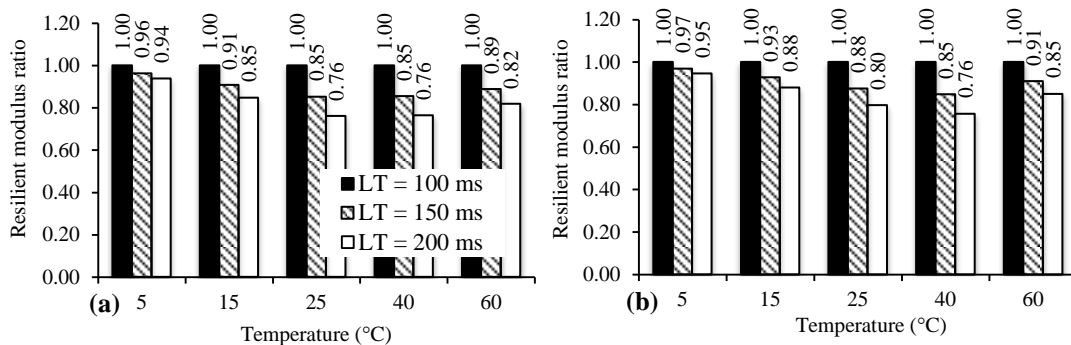


Figure 8 Effect of loading time on resilient modulus of asphalt mixtures

4. Conclusion

Indirect tensile stiffness modulus test were performed on dense graded 10 mm and 14 mm in this study to evaluate the effect of granular BRA modifier binder on resilient modulus of asphalt mixtures. Based on the results of this study, it is important to note that the type of bitumen used in asphalt mixtures has an important effect on resilient modulus of asphalt mixtures. The BRA modified asphalt mixtures have much higher resilient modulus that of the unmodified asphalt mixtures. Considering the temperature, rest period ratio, traffic volume, and loading time effect on resilient modulus showed that BRA modified asphalt mixtures with 20% BRA modifier binder enhanced to be better performance on those factors.

References

- [1] S. Zoorob and L. Suparma, "Laboratory design and investigation of the properties of continuously graded Asphaltic concrete containing recycled

- plastics aggregate replacement (Plastiphalt)," *Cement and Concrete Composites*, vol. 22, pp. 233-242, 2000.
- [2] M. S. Pourtahmasb, M. R. Karim, and S. Shamshirband, "Resilient modulus prediction of asphalt mixtures containing Recycled Concrete Aggregate using an adaptive neuro-fuzzy methodology," *Construction and Building Materials*, vol. 82, pp. 257-263, 2015.
- [3] V. Venudharan and K. P. Biligiri, "Estimation of phase angles of asphalt mixtures using resilient modulus test," *Construction and Building Materials*, vol. 82, pp. 274-286, 2015.
- [4] S. J. Ji, "Investigation of factors affecting resilient modulus for hot mix asphalt," Master, Department of Civil Engineering, University of Canterbury, Christchurch, New Zealand, 2006.
- [5] A. M. Hartman, M. D. Gilchrist, and G. Walsh, "Effect of Mixture Compaction on Indirect Tensile Stiffness and Fatigue," *Journal of Transportation Engineering*, vol. 127, pp. 0370-0378, 2001.
- [6] B. V. Kok and N. Kuloglu, "Effects of Two-Phase Mixing Method on Mechanical Properties of Hot Mix Asphalt," *Road Materials and Pavement Design*, vol. 12, pp. 721-738, 2011/01/01 2011.
- [7] A. Mokhtari and F. Moghadas Nejad, "Mechanistic approach for fiber and polymer modified SMA mixtures," *Construction and Building Materials*, vol. 36, pp. 381-390, 2012.
- [8] S. Tayfur, H. Ozen, and A. Aksoy, "Investigation of rutting performance of asphalt mixtures containing polymer modifiers," *Construction and Building Materials*, vol. 21, pp. 328-337, 2007.
- [9] G. Shafabakhsh and A. Tanakizadeh, "Investigation of loading features effects on resilient modulus of asphalt mixtures using Adaptive Neuro-Fuzzy Inference System," *Construction and Building Materials*, vol. 76, pp. 256-263, 2015.
- [10] M. Lavasani, M. Latifi Namin, and H. Fartash, "Experimental investigation on mineral and organic fibers effect on resilient modulus and dynamic creep of stone matrix asphalt and continuous graded mixtures in three temperature levels," *Construction and Building Materials*, vol. 95, pp. 232-242, 10/1/ 2015.
- [11] M. Fakhri and A. R. Ghanizadeh, "An experimental study on the effect of loading history parameters on the resilient modulus of conventional and SBS-modified asphalt mixes," *Construction and Building Materials*, vol. 53, pp. 284-293, 2014.
- [12] B. S. Subagio, B. Siswosoebrotho, and R. Karsaman, "Development of laboratory performance of indonesia rock asphalt (ASBUTON) in hot rolled asphalt mix," in *Proceeding of the Eastern Asia Society for Transportation Studies*, 2003, pp. 436-449.
- [13] B. S. Subagio, H. Rahman, H. Fitriadi, and L. Lusiana, "Plastic Deformation Characteristics and Stiffness Modulus of Hot Rolled Sheet (HRS) containing Buton Asphalt (ASBUTON)," in *Proceedings of the Eastern Asia Society for Transportation Studies*, 2007, pp. 262-262.
- [14] K. A. Zamhari, M. Merhadi, and M.H. Ali, "Comparing the Performance of Granular and Extracted Binder from Buton Rock Asphalt," *International Journal Pavement Research Technology* vol. 7, pp. 25-30, 2014.
- [15] Australian Standard, "Residual bitumen for pavements," in *AS 2008-1997*, ed. New South Wales, Australia, 1997.

- [16] *Bitumen content and particle size distribution of asphalt and stabilised soil: centrifuge method*, Main Roads Western Australia, 2011.
- [17] Main Road Western Australia, "Asphalt Wearing Course," in *Specification 504*, ed. Perth, 2010, pp. 1-45.
- [18] M. Karami and N. Hamid, "The effect of granular BRA modifier binder on the stiffness modulus of modified asphalt," in *Advances in Civil Engineering and Building Materials IV*, ed: CRC Press, 2015, pp. 345-349.
- [19] M. Karami and H. Nikraz, "Using Advanced Materials of Granular BRA Modifier Binder to Improve the Flexural Fatigue Performance of Asphalt Mixtures," *Procedia Engineering*, vol. 125, pp. 452-460, // 2015.
- [20] Australian Standard, "Methods of sampling and testing asphalt - Method 2.2: Sample preparation - Compaction of asphalt test specimens using a gyatory compactor," in *AS 2891.2.2-1995*, ed. New South Wales, Australia, 1995, pp. 1-8.
- [21] Australian Standard, "Methods of sampling and testing asphalt - Methods 13.1: Determination of resilient modulus of asphalt - Indirect tensile method," in *AS 2891.13.1-1995*, ed. New South Wales, Australia 1995, pp. 1-8.
- [22] H. Lee, S. Kim, B. Choubane, and P. Upshaw, "Construction of dynamic modulus master curves with resilient modulus and creep test data," *Transportation Research Record: Journal of the Transportation Research Board*, pp. 1-14, 2012.
- [23] Main Road Western Australia, "Procedure for the Design of Road Pavements," in *Engineering Road Note 9*, ed. Perth, 2012.
- [24] Y. Kim, K. Shah, and N. Khosla, "Influence of test parameters in SHRP P07 procedure on resilient moduli of asphalt concrete field cores," *Transportation Research Record*, 1992.
- [25] T. L. Law, "Resilient modulus of asphalt concrete mixtures," 2004.
- [26] C. Fairhurst, N. Kosla, and Y. Kim, "Resilient modulus testing of asphalt specimens in accordance with ASTM D4123-82," in *Mechanical Tests for Bituminous Mixes. Characterization, Design and Quality Control. Proceedings of the Fourth International Symposium held by RILEM*, 1990.
- [27] C. Monismith, "Resilient modulus testing: interpretation of laboratory results for design purposes," in *Proceedings of the Workshop on Resilient Modulus Testing*, 1989.
- [28] R. D. Barksdale, J. Alba, N. P. Khosla, R. Kim, P. C. Lambe, and M. Rahman, "Laboratory determination of resilient modulus for flexible pavement design," 1997.
- [29] M. Kamal, F. Shazib, and B. Yasin, "Resilient behaviour of asphalt concrete under repeated loading & effects of temperature," *Journal of the Eastern Asia Society for Transportation Studies*, vol. 6, pp. 1329-1343, 2005.

Laboratory experiment on resilient modulus of BRA modified asphalt mixtures

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