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International Journal of Pavement Research and Technology 11 (2018) 38–46

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Laboratory experiment on resilient modulus of BRA modified asphalt mixtures

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Received 16 March 2017; received in revised form 9 August 2017; accepted 15 August 2017
Available online 24 August 2017

Abstract

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) modified 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 these 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 of improving the resilient modulus values. According to the test results, the resilient modulus of BRA modified asphalt mixtures was higher as compared to the unmodified asphalt mixtures. A higher percentage of BRA modifier binder content resulted in a higher resilient modulus. Furthermore, the unmodified and BRA modified containing only 20% BRA modified binder of DG10 were tested under different conditions of temperature, rise time, and pulse period. The results indicated that the BRA modified asphalt mixtures containing 20% BRA modified 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; Resilient modulus

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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

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Peer review under responsibility of Chinese Society of Pavement Engineering.

http://dx.doi.org/10.1016/j.ijprt.2017.08.005

1996-6814/

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 e.g. 5 °C and high traffic speed e.g. 100 ms rise time, 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 Buton asphalt or materials derived from Buton asphalt 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 Buton asphalt filler conducted by Subagio et al. [13] revealed that the resilient modulus of HRS modified at a test temperature of 25 °C was lower when compared with unmodified HRS mixtures. By comparison, at a 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 the 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 Buton asphalt 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 behaviour of asphalt mixtures. For example, it is still not known how the 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 an 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. Specification of the base bitumen and BRA modified bitumen is given in Table 1. The form of the BRA modifier binder (pellets) with a diameter of 7–10 mm used in this study is shown in Fig. 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 aggregates of 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 2 with the aim of minimizing the variance in the gradation of aggregates.

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

Table 1
Properties of bitumen.

Bitumen property	Standard	Value			
		BRA modifier content			
		0%	10%	20%	30%
Penetration (25 °C; 0.1 mm)	ASTM-D5	67	62	59	57
Softening points (°C)	ASTM-D36	48	51	52.8	55.8
Ductility (25 °C), cm	ASTM-D113	>100	>100	>100	>100
Mass loss (%)	ASTM-D1754	0.19	0.15	0.09	0.10
Ductility after TFOT (25 °C), cm	ASTM-D113	>100	>100	>100	>100

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

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 DG10 and DG14 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 3 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 elsewhere [18,19]. The specimens were cylindrical with dimension of 100 ± 2 mm in diameter and 35–70 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.

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 4. 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 (Fig. 2).

Table 2
Final crushed aggregate gradation used in this study.

Sieve size (mm)	Percent passing								Limit values	
	DG10 (BRA modifier content)				DG14 (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 3
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

Table 4
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, με	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	DG10, DG14	DG10

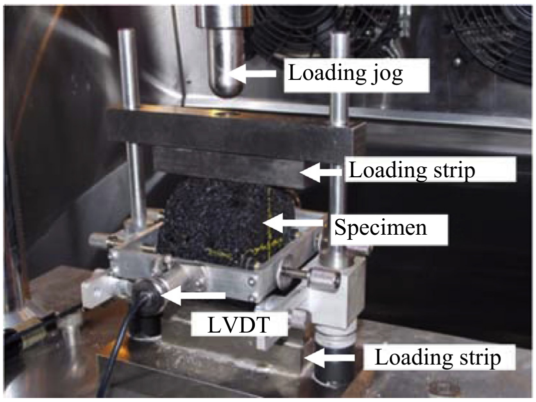

Fig. 2. Set-up the ITSM test.

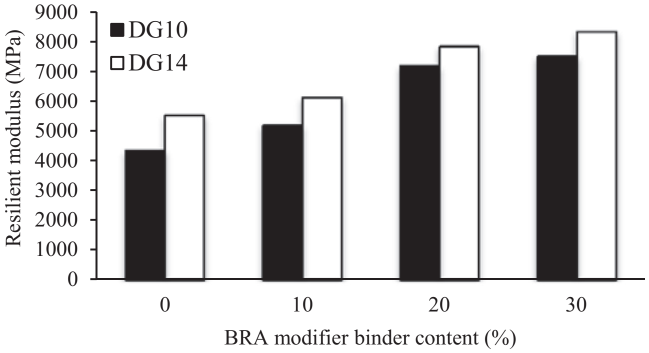

Fig. 3. Resilient modulus of unmodified and BRA modified asphalt mixtures.

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 [9,22]. The resilient modulus of the BRA modified asphalt mixtures at 25 °C was statistically significantly higher than that of the unmodified asphalt mixtures as illustrated in Fig. 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 DG10. 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 DG14, 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.

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 5 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, Fig. 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.

From the previous investigation [8], stiffness modulus values converge at test temperatures of 25 °C and 40 °C. Similarly, this study found that the stiffness modulus tends to converge at test temperatures 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.

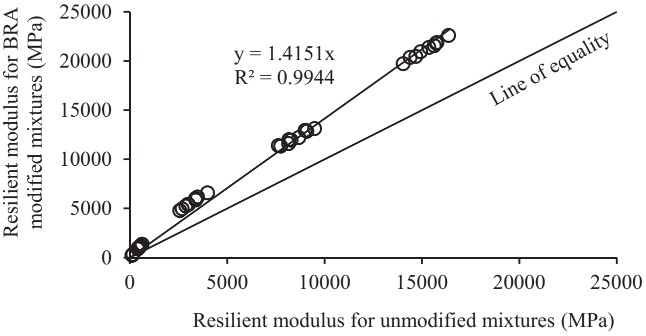

Fig. 4. Relationships between resilient modulus of unmodified and BRA modified asphalt.

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]. Fig. 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.

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

Table 5
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

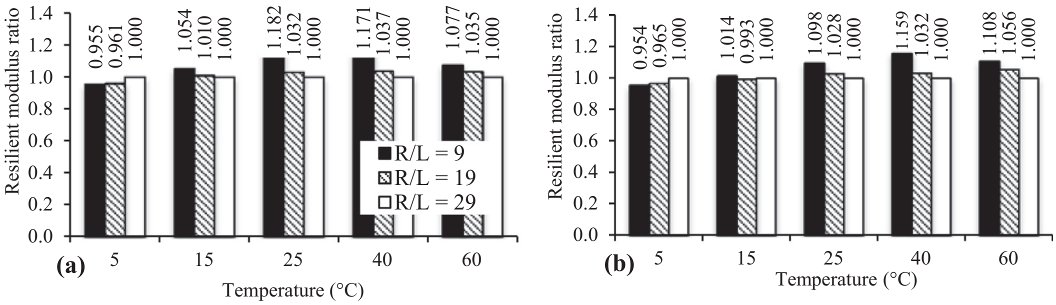

Fig. 5. Effect of rest period ratio on resilient modulus of (a) unmodified asphalt mixtures, (b) BRA modified asphalt mixtures.

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 shown 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 an 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 4–27 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 was used to simulate a high and a low volume of traffic, respectively. It can be seen in Fig. 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 a high temperature (40 °C) [18]. A 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 Fig. 7.

The constant coefficients obtained from fitting Fig. 7 to the data using a linear relationship for unmodified and BRA modified asphalt mixtures are listed in Table 6. 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.

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 in 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 were reported by Fakhri and Ghanizadeh [11]. At the same test temperature, the constant coefficient "*a*" values for unmodified asphalt mixtures were higher than for the BRA modified asphalt mixtures. This confirms that BRA modified asphalt mixtures are less sensitive 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]. Fig. 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

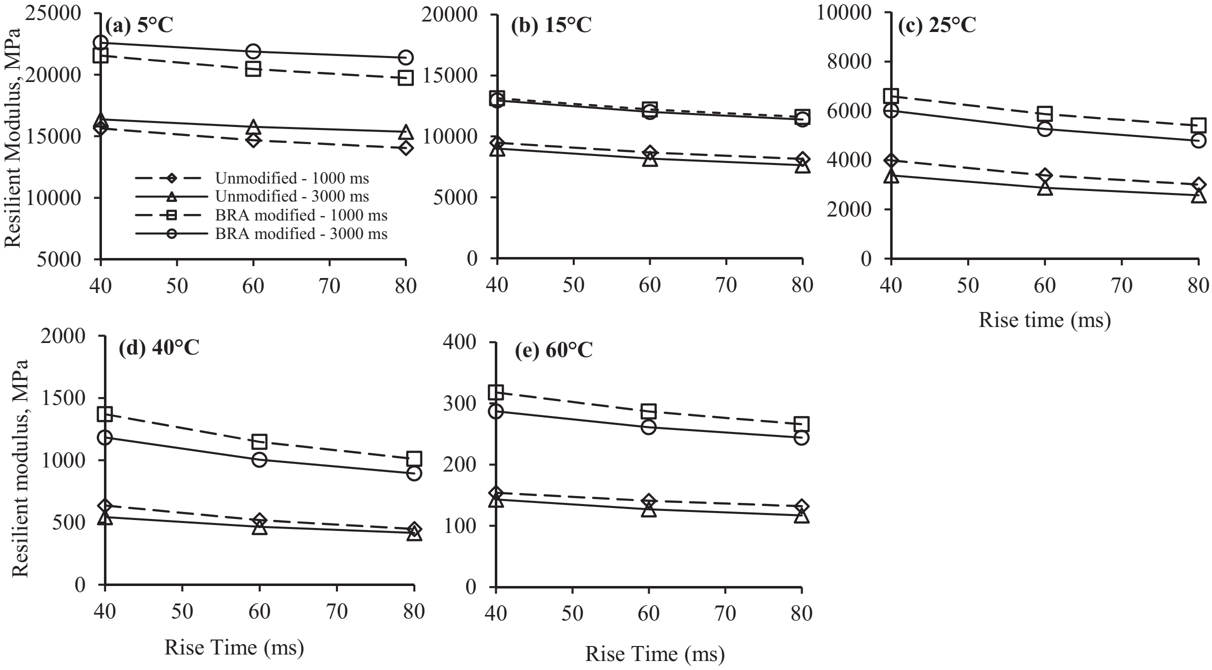

Fig. 6. Resilient modulus for asphalt mixtures at variation of test temperatures.

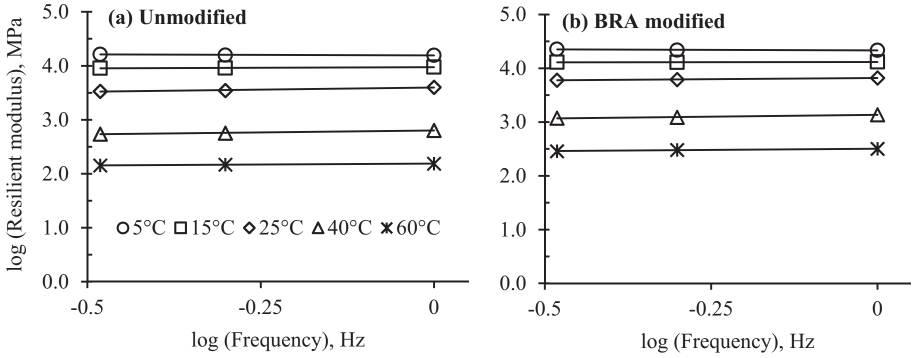

Fig. 7. Effect of loading frequency on resilient modulus of asphalt mixtures.

Table 6
Coefficient of linier relationship of frequency – resilient modulus.

Temperature (°C)	Unmodified			BRA modified		
	a	*b*	R^2	*a*	*b*	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

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 behavior 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%

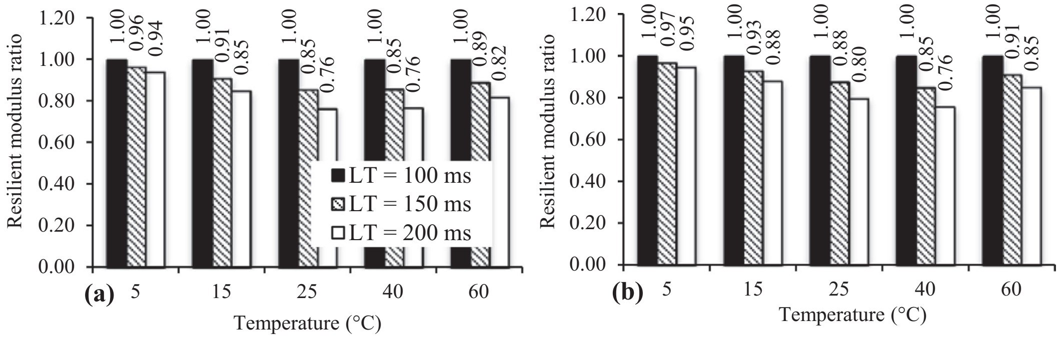

Fig. 8. Effect of loading time on resilient modulus of (a) Unmodified asphalt mixtures, (b) BRA modified asphalt mixtures.

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 observations 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 form 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 temperatures and pulse period conditions. The decrease in resilient modulus for BRA modified was lower than for with the unmodified asphalt mixtures tested at various temperatures and pulse period.

4. Conclusion

Indirect tensile stiffness modulus tests were performed on dense graded aggregates of 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 than 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 as compared to unmodified asphalt mixtures.

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