Rutting performance of Buton rock modified asphalt mixtures

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Abstract. The objective of this research is to determine the effect of granular Buton rock asphalt (BRA) modifier binder on the rutting performance of asphalt mixtures. The wheel tracking tests were performed to examine the rutting performance of unmodified and BRA modified asphalt mixtures for dense graded aggregates of 10 mm. 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 purposes of improving the rutting performance of asphalt mixtures. In this test, four criteria were used to determine the performance of asphalt mixtures, including rut depth, tracking rate, velocity and dynamic stability. According to the test results, the rut depth of BRA modified asphalt mixtures decreased by 16%, 57% and 70% as the percentage of BRA natural binder increased by 10%, 20% and 30%, respectively. The tracking rate of BRA modified asphalt mixtures decreased by 24%, 77% and 86% with an increased in the percentage of BRA natural binder by 10%, 20% and 30%. Furthermore, the velocity for BRA modified asphalt mixtures was lower and the dynamic stability was higher than for unmodified asphalt mixtures.

1. Introduction

Permanent deformation is considered to be one of the common forms of distress associated with load and affects the pavement performance of asphalt mixtures. Generally, permanent deformation consists of a longitudinal settlement in the wheel paths of an asphalt pavement surface. It is believed that permanent deformation, commonly referred to as rutting, is caused by short term loading when vehicles pass over the surface, and results from the accumulation of unrecoverable deformation to the asphalt pavement under repetitive traffic loading over a period of time [1-4].

The internal frictions in the asphalt mixtures provided by aggregates and the cohesion provided by the asphalt binder have a direct effect on permanent deformation. The characteristics of materials such as binder stiffness can help to minimize the rutting. Choi [5] states that an asphalt binder with a higher shear resistance provides better rutting resistance. A study by Little *et al*. cited in Wang [6] showed that some parameters such as the stiffness of asphalt mixtures, mixture volumetrics, and the bonding interaction between asphalt binder and aggregates have an impact on resistance to the permanent deformation of asphalt mixtures. Therefore, the design of the asphalt mixtures is directly linked to plastic deformation, so that improving the material properties and mix characteristics is essential for improving the rutting resistance of asphalt mixtures. Some studies [7-10] have found that temperature has a significant effect on rutting. Asphalt binder tends to flow more easily at high temperatures, with this condition leading to the pavement becoming softer and more liable to rutting. At high temperatures and under long periods of loading, the asphalt binder behaves in a viscous manner, leading to viscous flow and plastic deformation in asphalt mixtures. Furthermore, the need for asphalt modification is caused by limitation in the capability of the base asphalt binder to resist distresses.

Modified bitumen is formulated with additives to improve its service performance. Bahia [11] has explained that the modification of asphalt binder is performed to improve one or more basic properties of asphalt binder related to one or more types of pavement distress. This study, however, deals with the benefit of using granular Buton Rock Asphalt (BRA) modifier binder with the objective of analyzing the potential for using granular BRA modifier binder in asphalt mixtures with the purpose of increasing the rutting performance of asphalt mixtures.

2. Materials and methods

2.1. Materials

Class-170 (Pen 60/80) base asphalt binder was used for the unmodified asphalt mixtures. 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 asphalt binder and BRA modified binder is given in Table 1. The form of the BRA modifier binder (pellets) with a diameter of 7 mm to 10 mm used in this study. Triplicate portions of granular BRA modifier binder were subjected to an extraction process [12]. The bitumen content test results found that, on average, the granular BRA modifier binder consisted of about 70% mineral and 30% binder by total weight of materials. The mean particle size distributions of BRA mineral for each sieve are as follows: 2.36 mm (100%), 1.18 mm (97%), 0.6 mm (92%), 0.3 mm (81%), 0.15 mm (61%), 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 a typical dense graded aggregate with a maximum aggregate size of 9.5 mm (DG 10) based on Specification 504 [13]. In addition, Table 2 shows that in the BRA modified asphalt mixtures, the substitution of the base asphalt binder allowed the proportion of fines passing 2.36 to be adjusted. The total mass of crushed fine aggregate was decreased and replaced with the mineral contained in the granular BRA modifier with the aim of minimizing the variance in the gradation of aggregates.

Table 1. Properties of bitumen

Bitumen property	Standard	BRA modifier content			
		0%	10%	20%	30%
Penetration (25°C; 0.1 mm)	AS 2341.12-1993	67	62	59	57
Softening points (°C)	AS 2341.18-1992	48	51	52.8	55.8
Ductility (25°C), cm	AS 2341.11-1980	>100	>100	>100	>100
Mass loss (%)	AS 2341.10-2015	0.19	0.15	0.09	0.10
Ductility after TFOT (25°C), cm	AS 2341.11-1980	>100	>100	>100	>100

2.2. Mix design and specimen preparation

This study used the Marshall mix design as a method for determining the optimum bitumen content (OBC) of unmodified asphalt mixtures based on specification 504 [13]. Specimens in triplicate with dimension of 101 mm diameter and 63.5 mm height were compacted by applying 75 blows to each side of the specimen using an automatic Marshall compactor for various contents of asphalt binder. The result shows that a void of 5% was chosen to give binder content of 5.4% as the optimum bitumen content (OBC) (by mass of asphalt mixture). The same binder content as for unmodified asphalt mixtures was used for the BRA modified asphalt mixtures in order to maintain consistency for comparison purposes.

Furthermore, after each size of crushed aggregates had been weighed, they were then blended manually in a pan and then heated in an oven at a temperature of 105ºC for 24 hours. After that, the blend aggregates were heated in the same oven at 150ºC prior to mixing with asphalt binder for approximately two hours. In the other side, the base asphalt binder and granular BRA modifier binder (pellets) were placed in the same bowl. The mixture was then put in an oven at a temperature of 150±5 ºC for 30 to 60 minutes with frequent manual stirring intended to blend and incorporate the two binders as BRA modified binder. Then the previously blended aggregates were put in the same bowl as the BRA modified binder and mixed using mixing equipment for 1.5 minutes. Laboratory mixtures were prepared based on AS 2891.1.1-2008 [14], and then were immediately compacted in a slab mould by using a roller compactor in accordance with Austroads standard AG:PT/T220 [15]. The specimens consisted of slabs with dimension of 300 mm in length, 300 mm in width, and 50 mm in height prepared in accordance with the Austroads Standard **[16]**. After 24 hours prior to the compaction process, the slabs were then tested. In total 12 specimens were prepared in this study (triplicate specimens for each percentage of BRA modifier content).

Table 2. Final crushed aggregate gradation used in this study (percent passing)

Sieve size (mm)	BRA modifier content							Limit values
	0%	10%		20%		30%		
	Crushed Aggregate	Crushed aggregate	BRA mineral	Crushed aggregate	BRA mineral	Crushed aggregate	BRA mineral	
13.20	100	100.0		100		100.0		100
9.50	97.5	97.5		97.5		97.5		95-100
6.70	83.0	83.0		83.0		83.0		78-88
4.75	68.0	68.0		68.0		68.0		63-73
2.36	44.0	44.0	100	44.0	100	44.0	100.0	40-48
1.18	28.5	28.5	100.0	28.6	99.9	28.6	99.9	25-32
0.600	21.0	21.1	99.9	21.2	99.8	21.3	99.7	18-24
0.300	14.5	14.8	99.7	15.0	99.5	15.2	99.3	12-17
0.150	10.0	10.5	99.5	11.0	99.0	11.5	98.5	8-12
0.075	4.0	4.9	99.1	5.7	98.3	6.4	97.6	3-5

2.3. Wheel tracking test

Wheel tracking machine (WTM) tests were performed to determine the rutting performance of unmodified and BRA modified asphalt mixtures based on the Austroads standard [16] subject to loaded wheel tracking with the purpose of simulating the effect of traffic at elevated temperatures [17-19]. The WTM tests were performed using a relatively simple testing apparatus. Before testing was started, the specimen was put in the device cabinet at the required test temperature of 60°C for about two hours to allow the specimen temperature to reach equilibrium. The tests were then performed until the wheel travelling stopped automatically after reaching 10,000 loading passes.

3. Results and discussion

3.1. Performance of asphalt mix using the rut depth and tracking rate

A *paired t-test* method with a 95% level of confidence was used to statistically analyse the mean air voids of the wheel tracking test specimens. The results show no significant difference in the void content between unmodified and BRA modified asphalt mixtures. The mean air void content of asphalt mixtures was within the range of 5±1% in accordance with AG:PT/T231 [16].

In the laboratory, the rut was measured automatically by apparatus after chosen cycle intervals in the wheel path by measuring the settlement of the surface of the specimen. Figure 1 presents the relationship between the number of wheel cycles and the rut (mm) for unmodified and BRA modified asphalt mixtures. Figure 1 clearly shows that the rut progression curves for BRA modified asphalt mixtures are very different from unmodified asphalt mixtures. The results obtained for rut depth revealed that BRA modified performs better than unmodified asphalt mixtures after 10,000 cycles.

Based on the tracking depth according to the Austroads method [20], the unmodified asphalt mixtures had a medium performance with an average 7.7 mm rut depth, whereas the 10% BRA modified mixtures had a good performance with an average rut depth of 6.4 mm. For 20% and 30% BRA modified asphalt mixtures, their performance is included as a superior performance with 3.3 mm and 2.3 mm rut depths respectively after reaching the passes limit. It seems that the substitution of BRA modifier binder increases the shear resistance of BRA modified binder resulting in enhanced rut resistance to the mix. This indicated that the use of BRA modifier binder in asphalt mixtures resulted in an increase in resistance to permanent deformation (rutting) in comparison with the unmodified asphalt mixtures. The increase in the BRA modifier binder content resulted in a decrease in the rut depth for the BRA modified asphalt mixtures. In addition, according to Choi [5], a binder with high viscosity will have a higher shear resistance. Accordingly, this binder provides a better rut resistance in asphalt mixtures. It is believed that the role of BRA modifier binder used in BRA modified asphalt mixtures provides enhanced rut resistance compared to base asphalt binder used in unmodified asphalt mixtures.

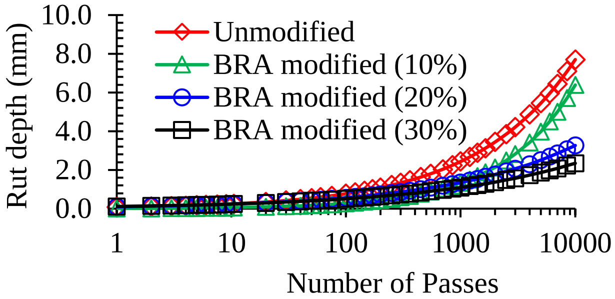

Figure 1. Rut progression curve of wheel tracking test

From the wheel tracking test results, rut resistance can also be represented by tracking rate. The tracking rate is obtained by steady tracking rate over 4,000 to 10,000 loading passes [16]. Figure 2 shows the tracking rate values for unmodified and BRA modified asphalt mixtures. It can be seen in this figure that the BRA modified asphalt mixtures showed a lower tracking rate than the unmodified asphalt mixtures. The tracking rate decreased by about 24%, 77%, and 86% for 10%, 20% and 30% BRA modifier binder, respectively. In addition, statistical analysis was carried out to develop relationship between the rut depth (in mm) as independent variable and tracking rate (in mm/kpass) as dependent variable for the unmodified and BRA modified asphalt mixtures. Figure 3 shows that the correlation between the rut depth and tracking rate for individual specimens was strong ($R^2 = 0.983$). Mixtures with low rut depth exhibit a low tracking rate.

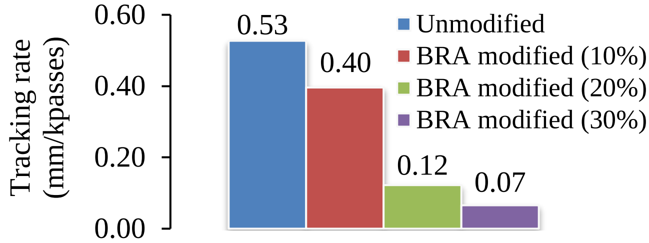

Figure 2. Average tracking rate values for asphalt mixtures

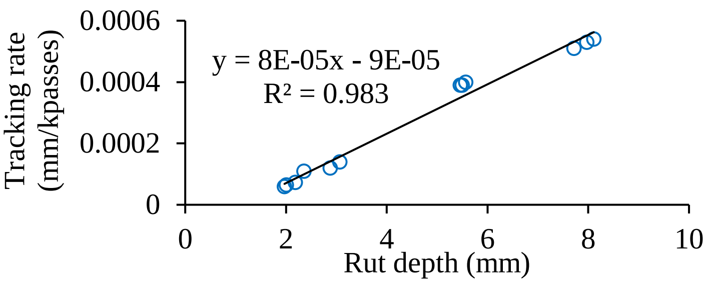

Figure 3. Correlation between rut depth and tracking rate

3.2. Performance of asphalt mix using the velocity

The total rut depths in the wheel path were evaluated after 120 minutes ($R_{d\text{-}120}$) and the rate of deformation was measured between the 105 and 120th minute of testing ($R_{rd\text{-}150/120}$). According to Fontes *et al.* [17] and Dias *et al* [18], based on the LT-173, the average rate is acceptable when the $R_{rd\text{-}105/120}$ is less than or equal to $15x10^{-3}$ mm/min. Figure 4 shows the results of the wheel tracking test, expressed in terms of velocity of deformation of the slab. There were noticeable differences due to the granular BRA modifier asphalt binder used. The velocity of unmodified and 10% BRA modified asphalt mixtures does not pass the criteria in accordance with NLT-173 where the velocity of those mixtures was higher than 0.015 mm/minute. However, the velocity values for 20% and 30% BRA modified asphalt mixtures is much lower than the limit.

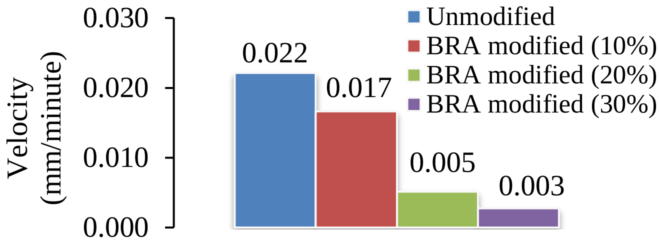

Figure 4. Average velocity for asphalt mixtures

3.3. Performance of asphalt mix using the dynamic stability

The results for dynamic stability were also used to evaluate the rutting characteristics of unmodified and BRA modified asphalt mixtures. In accordance with Chen *et al* [19] and Xu *et.al* [21], the dynamic stability of asphalt mixtures was determined during a test of 45 minutes to 60 minutes to generate a 1-mm rut depth. Figure 5 shows the average dynamic stability of asphalt mixtures. It can be summarized that unmodified asphalt mixtures lead to relatively lower dynamic stability values than BRA modified asphalt mixtures. The increase in the content of BRA modifier binder to 10%, 20%, and 30% resulted in an increase in the dynamic stability by 48%, 197% and 386% respectively. According to Chen *et al* [19], the dynamic stability should be more than 1500 cycles/mm.

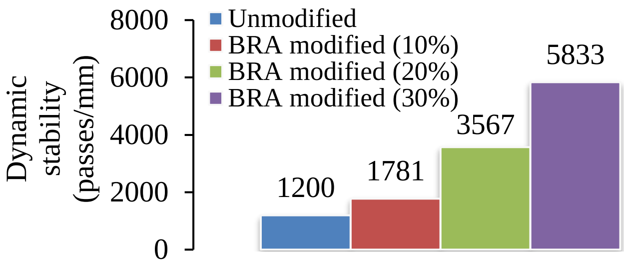

Figure 5. Dynamic stability values for asphalt mixtures

4. Conclusion

The addition of BRA modifier binder in asphalt mixtures increased the resistance of BRA modified asphalt mixtures to rutting depth. The rut depth of BRA modified asphalt mixtures decreased by 16%, 57% and 70% as the percentage of BRA modifier binder increased by 10%, 20% and 30%, respectively. The tracking rate of BRA modified asphalt mixtures measured over 4,000 to 10,000 loading passes decreased by 24%, 77% and 86% with an increase in the percentage of BRA modified binder by 10%, 20% and 30%, respectively. In addition, the velocity for BRA modified asphalt mixtures was lower than for unmodified asphalt mixtures. A higher percentage of BRA modifier binder in asphalt mixtures resulted in lower velocity values for the BRA modified asphalt mixtures. The dynamic modulus of BRA modified asphalt mixtures was higher than for unmodified asphalt mixtures. The dynamic modulus of BRA modified asphalt mixtures increased with an increase in the percentage of BRA modifier binder.

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