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Comparing the Performance of Granular and Extracted Binder from Buton Rock Asphalt

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Abstract: Buton Rock Asphalt (BRA) is natural rock asphalt found in Buton Island, Northwest Sulawesi, Indonesia. This study compares the performance of asphalt concrete made by two different methods of BRA binder preparation. The first method heats and crushes the rock into granular asphalt, while the second method extracts and recovers the bitumen out of the rock to produce pure BRA bitumen. Petroleum bitumen is used as a control. Rheological properties of pure BRA bitumen, a blend of petroleum bitumen, and pure BRA bitumen were determined. The properties of these binders were used to quantify the contribution of binder in resisting permanent deformation and fatigue cracking. Bituminous mixtures of different BRA binders and petroleum bitumen were prepared. Ordinary bitumen was added to the mixture of granular BRA to achieve the optimum bitumen content. It was found that BRA binders yield mixtures with better stiffness modulus, rate of permanent deformation, and creep stiffness compared to petroleum bitumen mixture. Mixtures with a higher percentage of granular BRA yield a better performance when compared to the mixture of pure BRA bitumen. It may be concluded that granular BRA would be the best alternative, provided that the transportation cost of the material from Buton Island can be competitive.

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***Key words**: Buton rock asphalt; Creep stiffness; Extracted binder; Granular asphalt; Stiffness modulus.*

Introduction

Buton Rock Asphalt (BRA) is natural rock asphalt from Buton Island, Northwest Sulawesi, Indonesia. Basically, BRA is bitumen impregnated limestone. Consistency of its bitumen varies from low to high penetration grades. The deposits are located in different places along the island. The biggest deposit was found in the Lawele Region. Total BRA deposits on the island are estimated at 677,247,000 tons, while the Lawele region alone contains around 210,283,000 tons [1]. At present, the transportation cost as well as the purification cost of the BRA bitumen restrained the utilization of BRA mostly to the area close to the island. However, efforts to improve the technology of producing BRA as an asphalt binder of high quality are continuously evolving. It is believed that with such a large reserve of natural asphalt and steadily increasing crude oil price, BRA is an attractive alternative source of bituminous binder of the future.

Two different methods of BRA binder preparation can be applied. The first method involves heating and crushing the BRA to decrease its water and volatile oil content and to reduce the size of granular rock asphalt to 9.5 mm maximum size. The second method involves extracting and recovering the bitumen out of the rock to produce pure bitumen. The granular BRA is easier to produce; hence, the production cost is relatively low. However, because its mineral content is high, the handling and application are comparatively more difficult than normal hot mix asphalt. Transportation cost is critical for granular BRA, especially if the bitumen content is low. Only BRA, which contained more than 20 percent of bitumen is currently considered as commercially viable. Pure BRA bitumen is identical to petroleum bitumen; therefore, its application and handling is similar to that of the ordinary bitumen. Nevertheless, the high bitumen extraction and recovery costs may cause this product to be less competitive at present.

This study compares the performance of asphalt concrete made by the two different methods of BRA binder preparation, namely granular BRA and pure BRA bitumen. BRA from the Lawele region is used; it contains 70-80% mineral, 20-30% bitumen, and 2-10% water. The bitumen has an initial penetration value around 180 dmm and contains around 7% volatile oil. Penetration grade 80/100 petroleum bitumen is used as a control.

Materials and Methods

Materials used in this study are petroleum bitumen penetration grade 80/100, a raw BRA, and aggregate. Flowchart of the laboratory tests performed is shown in Fig. 1. The raw BRA was processed to produce both granular BRA and pure bitumen of BRA. The characteristics of the petroleum bitumen, granular BRA, and pure BRA bitumen are exhibited in Tables 1 to 3, respectively.

Table 2 indicates that raw BRA has high water and volatile oil contents, flash point close to mixing temperature of hot mix asphalt, and high penetration, which means it is too soft, especially for the tropical climate where bitumen with penetration grade 60/70 or 80/100 are normally preferred.

In order to use BRA as an asphaltic binder that is suitable for hot mix asphalt, the raw material was heated until 120-130° C to reduce water and volatile oil contents. In addition, the heating processes loosened the internal bonding of lumped raw BRA and crumbled the lumps into the size of fine to medium aggregate fractions with the

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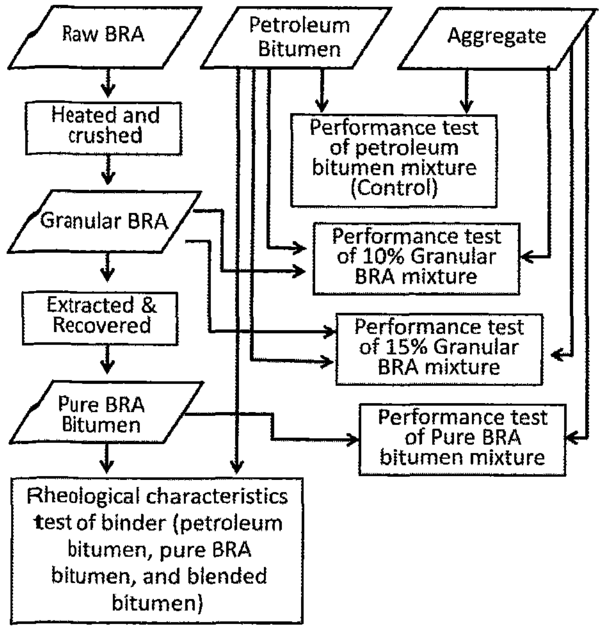

Fig. 1. Flow Chart of the Laboratory Tests Performed.

maximum size of 9.5 mm. Characteristics of BRA after pre-processing are also shown in Table 2.

Pure bitumen of BRA was produced by extracting and recovering the bitumen out of the granular BRA. The procedures are described in ASTM D2172 and ASTM D5404 respectively. The characteristics of pure BRA bitumen are exhibited in Table 3.

Table 1. Characteristics of the Petroleum Bitumen.

No.	Characteristics	Test Results	Specification (ASTM D946)
1.	Penetration at 25°C, 100 g, 5 Sec; dmm	95	80 - 100
2.	Softening Point; °C	46.2	-
3.	Flash Point (Cleveland Open Cup); °C	259	200
4.	Ductility at 25° C, 5 cm/minute; cm	> 140	Min. 100
5.	Water Content; %	0.00	-
6.	Solubility in C_2HCl_3; %	99.5	Min. 99
7.	Loss on Heating (TFOT); %	0.035	Min. 0.8
8.	Penetration after TFOT, % Original	76.9	Min. 47

The results show that the pure BRA bitumen met all the requirements of penetration grade bitumen of 80/100, except for the loss on heating. A relatively high figure for loss on heating indicated that the volatile oil content of the bitumen was still reasonably high. As a consequence, the flash point and the penetration after the loss on heating were slightly low compared to the ordinary petroleum bitumen. Nevertheless, both values were still within the specifications.

The rheological characteristics of the binders and the performance of the mixtures were investigated. Rheological characteristics of the binder, *i.e.* complex modulus (G^*) and phase

Table 2. Characteristics of the BRA.

No.	Characteristics	Raw Materials	Granular BRA (after processing)	Specification*)
1.	Bitumen content, %	35.3	29.4	25-40
2.	Water content, %	11.8	1.1	Max. 2
3.	Loss on heating (TFOT)	7.9	2.13	Max. 2
4.	Flash point, °C	178	205	Min. 200
5.	Penetration of impregnated bitumen at 25°C, 100g, 5 sec; dmm	183	85	60-70 or 80-100
6.	Maximum size; mm	-	9.5	9.5
7.	Gradation of extracted mineral:	-		-
	• 1.180 mm (% loss)	-	100	-
	• 0.600 mm (% loss)	-	98.7	-
	• 0.300 mm (% loss)	-	90.8	-
	• 0.075 mm (% loss)	-	51.7	-

*Directorate General of Highway (2009) [2]

Table 3. Characteristics of the Pure BRA Bitumen.

No.	Characteristics	Test Results	Specification (ASTM D 946)
1.	Penetration at 25°C, 100 g, 5 sec; 0,1; mm	85	80 - 100
2.	Softening Point; °C	46.8	-
3.	Flash Point (COC); °C	243	232
4.	Ductility at 25°C, 5 cm/minute; cm	>140	Min. 100
5.	Water Content; %	0.00	-
6.	Solubility in C_2HCl_3; %	99.2	Min. 99
7.	Loss on Heating (TFOT); %	1.53	Min. 0.8
8.	Penetration after (TFOT; % Original)	65.2	Min. 47

angle (δ) were determined by using Dynamic Shear Rheometer (DSR). These properties were used to quantify the contribution of binder in resisting permanent deformation and fatigue cracking. The binders consisted of pure BRA bitumen, petroleum bitumen, and composites of the two with the proportion of 1:3, 1:1, and 3:1. Each binder was tested at unaged, after the Rolled Thin Film Oven Test (RTFOT)-aged, and after the Pressure Aging Vessel (PAV)-aged conditions. These conditionings represent the fresh, short-term, and long term aging conditions respectively.

Four groups of bituminous mixture with different binder composition were prepared. The binder of each group was: (i) all petroleum bitumen; (ii) all pure BRA bitumen; (iii) blend of pen grade bitumen with 10% granular BRA; and (iv) blend of pen grade bitumen with 15% granular BRA. The percentage of granular BRA of the last two types of binder was equivalent to 3.0% and 4.5% of pure bitumen correspondingly. Filler content of mixtures with granular BRA were slightly high due to the high filler fraction of the granular BRA. Filler content of petroleum bitumen and pure BRA bitumen mixtures was 6.9%, while mixtures with 10% and 15% granular BRA had a filler content of 7.4% and 8.8% respectively. Typical aggregate gradation of the mixtures is shown in Fig. 2. Performance of the bituminous mixture in terms of stiffness and resistance to permanent deformation were determined according to British Standard DD 231 [3] and British Standard DD 226 [4], respectively.

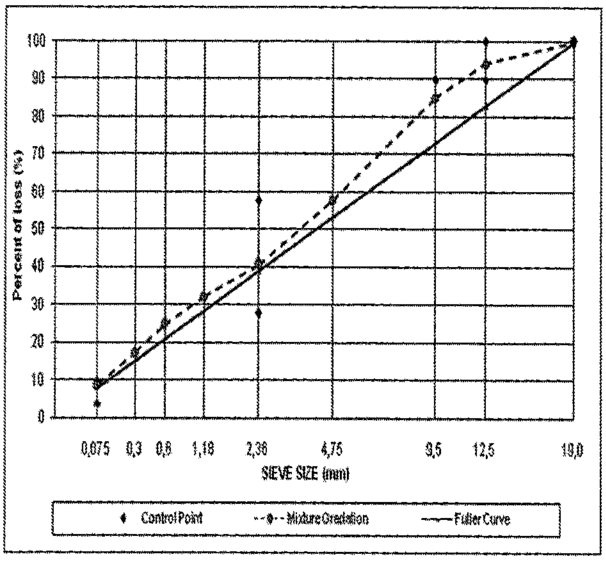

Fig. 2. Typical Aggregate Gradation of the Mixtures.

Results and Discussion

Rheological Characteristics of Binder

Dynamic Shear Rheometer (DSR) measured the complex shear modulus (G^*) and phase angle (δ) at the desired temperature and frequency of loading. These two parameters are used to indicate the ability of binder to resist the permanent deformation and fatigue due to traffic loading at in-service-temperature. Performance Grade, or Superpave binder test and specification, uses DSR to determine complex shear modulus and phase angle to control two specific type of asphalt concrete distress, i.e. permanent deformation and fatigue cracking at intermediate temperature. The requirement of the physical properties (e.g. rheology) of binder remain constant for all performance grades, but the temperature at which the related properties must achieved varies from grade to grade depending on the climate in which the binder is expected to perform [5].

Rutting Parameter

$G^*/\sin[\delta]$ parameter was chosen for Superpave binder specification to minimize rutting [5]. In the specification, the in-service-pavement-temperature, whereby a binder is considered as suitable, is a temperature at which $G^*/\sin[\delta]$ is equal to or more than 1,000 Pa for unaged condition and 2.200 Pa for RTFOT-aged condition. Rutting factors of the petroleum bitumen, pure BRA bitumen, and the blended binder at un-aged and aged conditions are shown in Figs. 3 and 4 respectively. Overall, the petroleum bitumen exhibited the lowest rutting factor, while the pure BRA bitumen yielded the highest rutting factor. The rutting factor of the blended binders was in between.

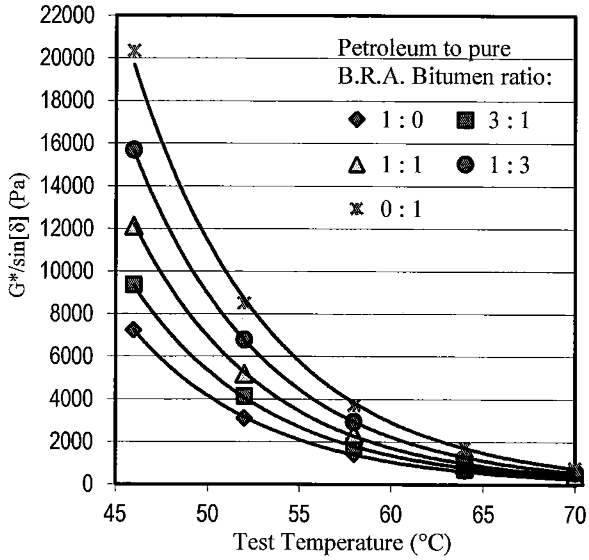

Fig. 3. The Effect of Test Temperature on Rutting Factor of Binder at Un-aged Condition.

Performance Grade, or suitable maximum design temperature of fresh and RTFOT-aged BRA blended bitumen, is shown in Fig. 5. The figure shows that while the threshold values of the rutting factor were achieved, the critical temperature for each increment of additional pure BRA bitumen increased accordingly. It means that the addition of pure BRA bitumen into the petroleum bitumen improves the rutting factor of the binder.

Fatigue Parameter

$G^*\sin[\delta]$ was selected in binder Performance Grade Specification to minimize fatigue cracking. Since asphalt concrete is more susceptible to crack after a number of years of pavement in service,

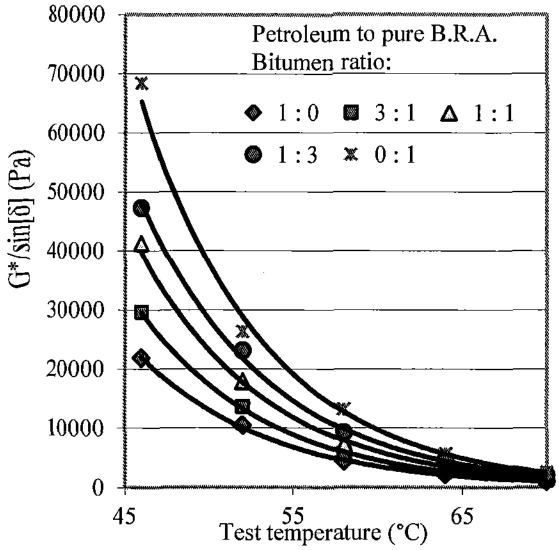

Fig. 4. The Effect of Test Temperature on Rutting Factor of Binderat RTFOT-aged Condition.

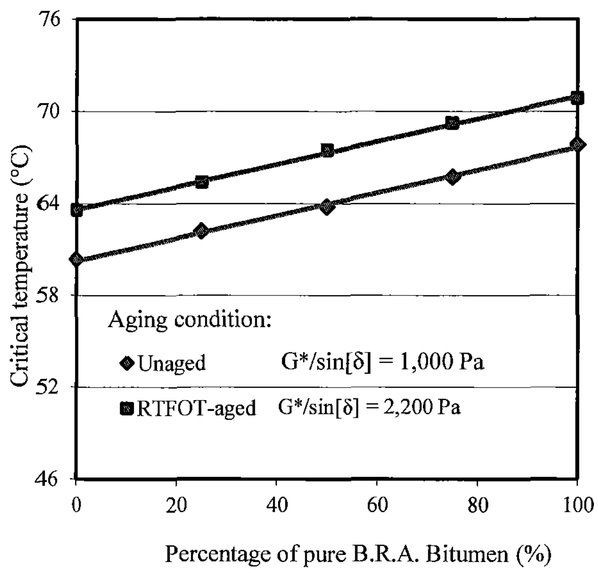

Fig. 5. The Effect of Pure BRA Bitumen on the Critical Temperature for Rutting Factor of Blended Binder.

the tested samples of binder were aged in Pressure Aging Vessel (PAV) to simulate the long-term aging condition. The binder Performance Grade Specification limit of fatigue parameter, $G^*\sin[\delta]$, at the intermediate in service temperature is set by consensus as maximum 5,000 kPa [5].

Fig. 6 shows fatigue parameters of the petroleum, the pure BRA bitumen, and the blended binder at different test temperatures. Theoretically, as temperature increased, complex modulus (G^*) of binder decreased, meaning that the binder became less stiff. Additionally, the phase angle (δ) is increased which indicates that the binder is less elastic as well. Since fatigue parameter is the product of G^* times sin[δ], the value of fatigue parameter at

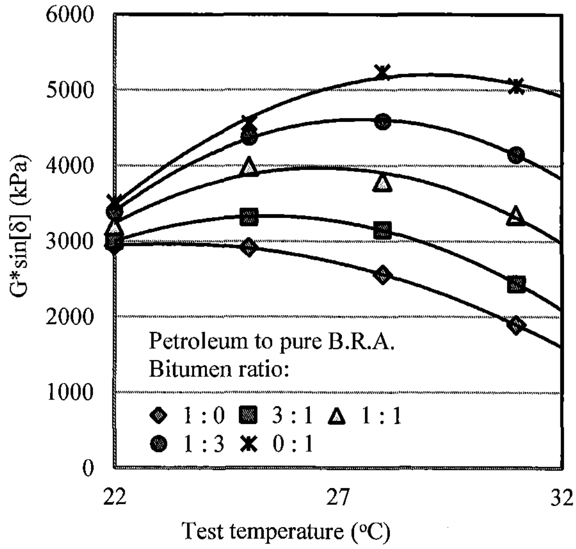

Fig. 6. The Effect of Test Temperature on Fatigue Factor of Binder at PAV-aged Condition.

different temperatures may initially increase up to a certain value and then decrease depending on the magnitude of G^* and δ at the related temperature.

Fig. 6 shows that the petroleum bitumen has the lowest fatigue parameter, while the pure BRA bitumen yields the highest. The fatigue parameter increased in line with the increment of pure BRA bitumen addition. Nevertheless, within the range of test temperatures, all of the binders passed the limited maximum value of the fatigue parameter set in the binder Performance Grade Specification.

Performance of BRA Bituminous Mixtures

Indirect Tensile Stiffness Modulus

Indirect tensile stiffness modulus (ITSM) test was used to measure the stiffness modulus of the mixture. The test was conducted according to British Standard DD213 [4]. The tests were carried out at three different temperatures (i.e. 30°C, 40°C, and 50°C). The test parameters were: 124 milli seconds of loading rise-time, 5 μm of peak transient horizontal deformation, and 0.35 of assumed Poisson's ratio. The result is shown in Fig. 7.

The figure indicates that mixtures with granular BRA binders yield a higher stiffness compared to the mixture with the petroleum or pure BRA bitumen. This is because the mineral filler fraction of granular BRA increased the filler to bitumen ratio of the mixtures. In addition, the pure bitumen content of granular BRA increased the stiffness of the blended binder.

Dynamic Creep Test

The British DD 226: 1996 test procedure was carried out to assess the performance of the mixture in terms of resistance to permanent deformation. The tests were conducted at 45°C and 3,600 seconds or

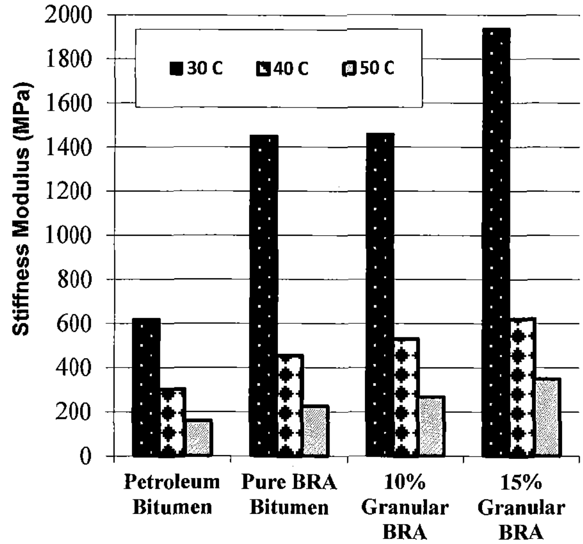

Fig. 7. Indirect Tensile Stiffness Modulus of the Mixtures.

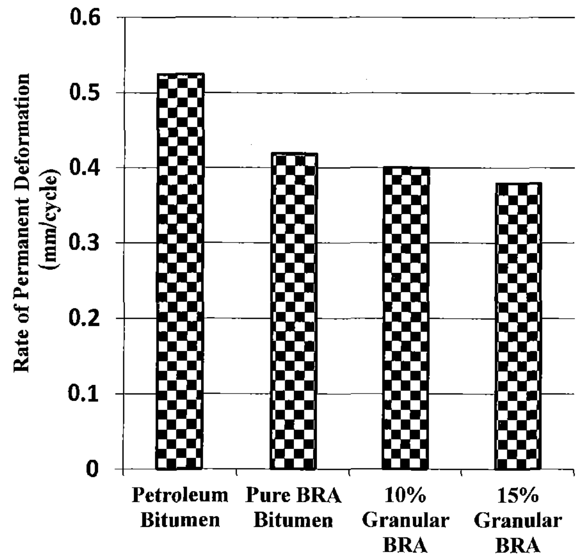

Fig. 8. Permanent Deformation Rate of the Mixtures at 45°C.

1,800 cycles test duration with a load pattern of one second load of each application period followed by one second off or rest period. The axial stress of 100 kPa was applied at 50 kPa of confining pressure. Prior to the measurement, each sample was subjected to a 10 kPa for 600 seconds of conditioning stress. The results in term of the rate of permanent deformation and the dynamic stiffness are shown in Figs. 8 and 9.

As was expected, mixture with pure BRA bitumen yields a lower rate of permanent deformation and a higher creep stiffness when compared to mixture with petroleum bitumen. This is in-line with the bitumen rheology test results that indicated the pure BRA bitumen yields a higher rutting factor. For mixture with granular BRA, the resistance to permanent deformation was improved further

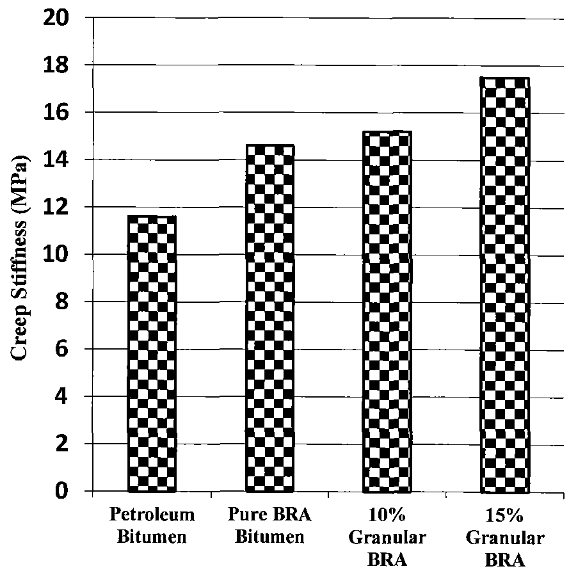

Fig. 9. Creep Stiffness of the Mixtures at 45°C.

due to the existence of mineral filler of BRA. This mineral filler increased the filler to bitumen ratio of the mixture, which increased the stability of the mixture [6].

Conclusions and Recomendation

This paper presents a laboratory experimental investigation aimed at assessing the performance of asphalt concrete with Buton Rock Asphalt (BRA) as the binder. Prior to its use as a binder, the raw BRA must be pre-processed to reduce its high water and volatile oil contents. After pre-processing, it was found that the extracted or pure BRA bitumen was equivalent to 80/100 pen grade petroleum bitumen.

Two different methods of BRA binder preparation were applied, i.e. in the form of granular and extracted, or pure, bitumen. Both methods yield mixtures with better performance in terms of stiffness and resistance to permanent deformation compared to mixture with petroleum bitumen of the same penetration grade. Nevertheless, mixture with granular BRA yields a higher stiffness as well as resistance to rutting. It is believed that such performance was achieved due to the existence of the higher natural filler fraction of granular BRA.

At present, the pure BRA bitumen is not available in the market, most likely because of the high BRA bitumen extraction and recovery costs. However, this study indicates that BRA in granular form can also be utilized as a good binder, but the transportation costs may restrict its application to the areas close to Buton Island, where the application may be considered as economically feasible.

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References

1. Directorate General of Highway, (2006), *Guidelinefor Road Construction – Book 1 General Specification,* The Ministry of Public Work Indonesia, Jakarta.
2. British Standard DD 231, (1993), *Methodfor Determination of Indirect Tensile Modulus Stiffness of Bituminous Mixtures,* The British Standard Institution, London, UK.
3. British Standard DD 226, (1996), *Method for Determining Resistance to Permanent Deformation of Bituminous Mixtures Subject to Unconfined Dynamic Loading,* British Standard Institution, London, UK.
4. Roberts, F. L., Kandhal, P. S., Brown, E. R., Lee, D. Y., Kennedy. T. W., (1996), *Hot Mix Asphalt, Mixture Design and Construction,* Second Edition, NAPA Education Foundation Lanham, Maryland, USA.
5. Brown, E.R., Mc Rae, J.L., and Crawley, A.B., (1989), *Effect of Aggregates on Performance of Bituminous Concrete,* ASTM Special Technical Publication 1016, Philadelphia, PA, USA.
6. Directorate General of Highway, (2009), *Interim Technical Specification,* The Ministry of Public Work Indonesia, Jakarta.