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Performance evaluation of stone matrix asphalt using indonesian natural rock asphalt as stabilizer

Nyoman Suaryana

Institute of Road Engineering, Ministry of Public Works, Jl. AH Nasution No. 264, Bandung 40294, Indonesia

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Abstract

One type of road pavement material which is developed to be more resistant to permanent deformation is the SMA (Stone Matrix Asphalt). Utilization of the SMA mix in Indonesia has constraints in gain stabilizer and also difficulty to comply the gradations, mainly because it needs a relatively large amount of filler. Alternative of local materials that can be used is asbuton (natural rock asphalt from Buton Island). Asbuton is expected to act as a stabilizer and simultaneously provides an additional filler. The objective of this research is to evaluate the performance of the SMA that uses the asbuton. The methodology used in this research is the experimental method, its starts from material testing, design mix and performance testing that includes dynamic modulus, permanent deformation and fatigue resistance. The results obtained showed asbuton can prevent asphalt draindown as well as increase the proportion of filler. Draindown asphalt can be prevented by using binder absorbers with fiber cellulose and viscosity boosters with asbuton. Asbuton (LGA 50/25) can behave as a stabilizer as well as cellulose fiber. Addition of asbuton also improves the performance of the SMA mix, as shown with increase in the value of dynamic stability. In terms of resistance to fatigue, SMA with cellulosa as stabilizer and SMA with asbuton as stabilizer, relatively have the same performance. Master curve of dynamic modulus indicates SMA with asbuton as stabilizer is relatively stiffer at high temperatures (more than 4.4 °C), but relatively less stiff (less brittle) at low temperatures.

Keywords: Stone matrix asphalt; Asbuton; Draindown; Dynamic modulus; Permanent deformation

1. Introduction

Permanent deformation or rutting is a surface depression in the wheel path caused by plastic deformation in any or all the pavement layers [1]. The plastic deformation is typically the result of densification or one-dimensional compression and lateral movement or plastic flow of material from wheel loads. The results of investigations on the 15 mixtures used in Strategic Highway Research Project (SHRP) show deformation due to lateral movement much more dominant than the result of compression, these results are similar to the results of the test using the Heavy Vehicle Simulator (HVS) at the University of California as part of the Caltrans project APT, with result that the lateral movement to contribute majorly for permanent deformation, compared with compression [2]. One type of paving materials that is developed to be more resistant to permanent deformation is the SMA (Stone Matrix Asphalt). The SMA mix has been known since the mid 1960s. Dr. Zichner, a German Engineer was its inventor. It was an attempt to solve the problem of the damage to wearing course caused by studded tires and also is durable enough to have a long service life [3]. The type of composition of aggregate blend is typically called a gap-graded mineral mixture.

E-mail address: nyomansuaryana@yahoo.com
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Based on the evaluation results of the use of the SMA mix in the United States of America conducted by NCAT, of the 86 projects that use SMA it was concluded: (i) more than 90% of pavement have ruth depth less than 4 mm, (ii) crack not being a big problem, and (iii) does not prove to cause raveling [4]. Utilization of the SMA mix in Indonesia has started at the end of 90s, but did not develop because of the difficulty in providing the stabilizer that can be spread evenly during the mixing process. The stabilizer is needed to prevent binder draindown during the transport to construction sites. It is also difficult to meet the SMA gradation, especially for aggregate filler which is needed 8–11%, compared with the need for the asphaltic concrete (AC) mix ranging from 4% to 8%, and even then must be added by cement to meet the gradation as required in the specification. Innovation stabilizer that can be suggested is to use Indonesian Rocks Asphalt. It is expected to increase binder viscosity at high temperatures, which in turn reduces the risk of its draindown and also provide additional filler. The natural rock asphalt deposits in Indonesia are found on South Buton Island in southeast Sulawesi island known as Asbuton, abbreviation of Asphalt Batu Buton i.e. Rock asphalt from Buton Island. There is a large reserve of natural rock asphalt in Indonesia containing an asphalt content of 5–30% with an average asphalt content of 20% and asphalt properties as low as 0–0 dmm in Kabungka area and as high as 40–210 dmm in Lawele area [5]. The size of deposit has been variously estimated at up to 677 million tonnes. The deposit is therefore an important national resource with the potential to reduce the need of imported asphalt and generates export income. The types of asbuton product available in the market are granular and refinery asbuton. In the present, the granular type of asbuton product is divided into two types, i.e. Buton Granular Asphalt (BGA) and Lawele Granular Asphalt (LGA). BGA has grain size maximum of 1.16 mm, with penetration asphalt <10 dmm and asphalt content between 18% and 22%, and the LGA has grain size maximum of 9.5 mm, penetration asphalt between 40 and 60 dmm and asphalt content 20–30% [6].

One of the methods to study performance of the hotmix is the complex dynamic modulus testing. The complex dynamic modulus (E^*), is a complex number that relates stress to strain for linear viscoelastic materials subjected to continuously applied sinusoidal loading in the frequency domain. The absolute value of the complex modulus $|E^*|$, is commonly referred to as the dynamic modulus [7,8]. It is perhaps the most important fundamental mix property as it provides information on how the material will deform under the action of a given load. Based on the results of the research at the University of Maryland, the master curve representing the dynamic modulus can be made using a sigmoidal equation [8]. The general form of the master curve of the dynamic modulus is shown as follows:

$$Log|E^*| = \delta + \frac{(\log(|E^*|_{\max}) - \delta)}{1 + e^{\beta + \gamma \log f_r}} \tag{1}$$

where $|E^*|$ = the dynamic modulus, ksi; $|E^*|$max = the limiting maximum modulus, ksi; fr = the reduced frequency, Hz; δ, β, γ = the fitting parameters.

The reduced frequency is computed using the Arrhenius equation and the limiting modulus is estimated from HMA volumetric properties using the Hirsch model [8].

2. Methodology

The methodology used in this research is experimental method, its start from material testing, perform design mix and fundamental test. Design mix is made based on American standards (AASHTO M 325-08). Dynamic modulus test was performed using The Asphalt Mixture Performance Tester (AMPT) device. The test specimens for this test was prepared in the laboratory as at optimum asphalt content, each had a diameter of 100 mm and thickness of 150 mm. The method used was the AASHTO D: PP 61-10, developing dynamic modulus master curves using the Asphalt Mixture Performance Tester (AMPT). A simulative test for evaluating the resistance to permanent deformation is the wheel tracking test. The specimens tested were in a slab form having dimensions of 300 × 300 mm and thickness of 50 mm. The mounted test specimens were conditioned for 10 h at the specified test temperature prior to testing. During wheel tracking test, the specimen was confined in the rigid mold and a loaded wheel with the contact pressure of 6.4 ± 0.15 kg/cm^2 driven backward and forward at 21 ± 0.2 cycles per minute. The depth of tracking was recorded at the midpoint of the sample length. The temperature of testing of the samples was 60 °C. The parameters obtained from the wheel tracking test are t_1, t_2, the Rate of Deformation (RD) and Dynamic Stability (DS). Normally t_1 and t_2 are 45 and 60 min of deformation graph for the test duration of 60 min respectively. In this research the method used for predicting fatigue life was the flexural tests on rectangular specimen tested as a simple supported beam using Beam Fatigue Testing. The mix was compacted using a small steel-wheel roller at 116 °C. After compaction, the slabs were cut into fatigue beams using a wet saw. Fatigue beam dimensions were 380 mm length, 64 mm width, and 51 mm height. The failure criterion used to interpret fatigue test results is controlled strain testing, failure is defined until the flexural modulus reaches 50% of initial flexural modulus. For each set of specimens the magnitude of the target strain level was varied from a high to a small stress. Load pulse width: 100 ms (10 Hz), without rest period. The test was performed at a temperature of 20 °C with a Poission's ratio value of 0.40.

3. Results and discussion

3.1. The physical properties of asphalt

Asphalt is only a minor component of bituminous mixes. But it has a crucial part to play in providing visco-elasticity and acting as a durable binder. The primary or routine physical properties are penetration, softening point and viscosity. The physical properties of asbuton (LGA 50/25) and pure petroleum asphalt 60/70 pen grade are shown in Table 1. Physical properties of LGA and pure petroleum asphalt showed that the asphalt content of asphalt from LGA is 23% and its asphalt is relatively hard as indicated by a penetration value of 41 dmm compare with the petroleum asphalt 60/70 by penetration value of 62 dmm. The softening point of the asphalt of LGA is also higher than the petroleum asphalt, which are 58 °C and 50 °C respectively. The temperature susceptibility is usually described as the change of primary or routine rheological properties of asphalt with temperature. Pleiffer and Van Dormaal defined the temperature susceptibility of asphalt as the Penetration Index [7]. The value of PI ranges from −3 for highly temperature susceptible asphalts to about +7 for highly blown low temperature susceptible (high PI) asphalt. The equation is:

$$PI = \frac{1952 - 500\log Pen - 20(SP)}{50\log Pen - (SP) - 120} \tag{2}$$

where Pen = penetration, SP = softening point.

Based on the data in Table 1 and calculated using Eq. (2), the Penetration Index (PI) of asbuton (LGA) is +0.17 and 60/70 pen grade asphalt is −0.61.

3.2. Properties of the SMA mix

The asphalt content for a particular blend or gradation is determined using the Marshall method. A series of test specimens are prepared for a range of asphalt contents so that the test data curves show well defined relationships. Three test specimens are prepared for each asphalt content. In this study, SMA mix using cellulosa as stabilizer namely as SMA and SMA mix using asbuton as stabilizer namely as SMAB. The aggregate grading for the mix is shown in Table 2.

As presented in Table 1, asphalt content of LGA is about 23% and the rest is the minerals with sizes less than 2.36 mm, that consideration would increase the amount of filler in the mixture. Based on gradation and optimum asphalt content of the SMAB mix was 6.54%, then the additional filler from LGA is 3.7%.

The design asphalt content is selected by considering all of the data properties of the mix. The calculated and measured mix properties at this asphalt content can be evaluated by comparing them to the mix design criteria shown in Table 3. The design asphalt content is a compromise selected to balance all of the mix properties and can be adjusted within the range to achieve properties that will satisfy a requirement for a specific project. Optimum asphalt content of the SMA mix and the SMAB mix are 6.05% and 6.54% respectively. The value of asphalt draindown with stabilizer cellulose fibers and the asbuton (LGA 50/25) produce values below 0.3% as required by the specification. This shows the asbuton (LGA 50/25) can behave as a stabilizer as well as cellulose fibers. Functioning LGA as a stabilizer is predicted because of no mobilization of asphalt in the LGA as a whole, and penetration grade of asbuton asphalt that is relatively lower resulting in increased viscosity of the binder.

3.3. The dynamic modulus

The value of the dynamic modulus and phase angle for the SMA mix using cellulose fiber as stabilizer (namely as SMA) and using Lawele Granular Asphalt as stabilizer (namely as SMAB) is shown in Figs. 1 and 2. In all cases the dynamic modulus decreased as the temperature of test increased and as the loading frequency decreased. At the same loading frequency, the dynamic modulus decreases with increasing temperature to a mixture of the same test. The SMAB mix dynamic modulus value is relatively same than the SMA at all temperatures and the frequency of testing.

Fig. 2 shows that the phase angle will increase in accordance with increasing test temperature, except at loading frequency of 0.1 Hz and 0.01 Hz phase angle down at the test temperature 45 °C. This phenomenon indicates the asphalt mixture at high temperature is dominated by the strength of aggregate interlock.

By referring to Eq. (1) and performing calculations using the "Solver" function in Microsoft Excel, the dynamic modulus master curve as presented in Fig. 3 was obtained. The master curve for SMA and SMAB has been developed with a good degree of accuracy, where the value of the dynamic modulus prediction results with a sigmoidal

Table 1
Physical properties of LGA and pure petroleum asphalt.

No	Property	Asbuton (LGA)	60/70 Pen grade asphalt	Unit
1	Penetration at 25 °C	41	62	0.1 mm
2	Softening Point (R&B)	58.1	50.3	°C
3	Ductility	>140	>140	cm
4	Solubility in C_2HCL_3	–	99.5	%
5	Flash point	–	317	°C
6	Unit weight	1.125	1.035	–
7	Loss on heating TFOT	3.96	0.0041	%
8	Penetration after loss on heating	27.8	47.12	0.1 mm
9	Softening point after loss on heating	68.6	51.3	°C
10	Ductility after los on heating (TFOT)	25	>140	cm
11	Asphalt content	23.3		%

Table 2
Aggregate grading for SMA and SMAB.

Sieve size (mm)	Percent mass passing		
	Specification AASHTO D: M 325-08	Grading of the mixes using cellulosa as stabilizer (SMA)	Grading of the mixes using asbuton as stabilizer (SMAB)
25	–	–	–
19	100	100	100
12.5	90–100	95	95
9.5	50–80	65	65
4.75	20–35	27.5	27.5
2.36	16–24	20	20
0.075	8–11	9.5	5.8 + 3.7 asbuton filler

Table 3
Mix design criteria of the SMA and SMAB mix.

Mix criteria		Specification AASHTO D: M 325-08	SMA Added 0.2% cellulose fibers	SMAB Added 7.5% LGA, without cellulose fibers
Asphalt content	%	6.0 min	6.05	6.54
Void in mix (VIM)	%	4.0	4.0	4.0
Void in mineral aggregate (VMA)	%	17.0 min	17.1	17.9
Void filled asphalt	%	–	76.5	76.8
Marshall stability (kg)	kg	–	634	651
Flow (mm)	mm	–	5.4	4.1
VCA mix	%	Less than VCA_{DRC}	VCA mix = 0.81 VCA_{DRC}	VCA mix = 0.82 VCA_{DRC}
Draindown	%	0.3 max	0.18	0.22

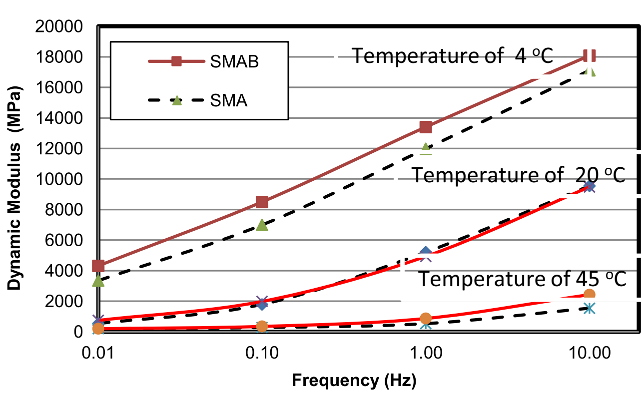

Fig. 1. Plot of dynamic modulus for the SMA mix and SMAB mix [9].

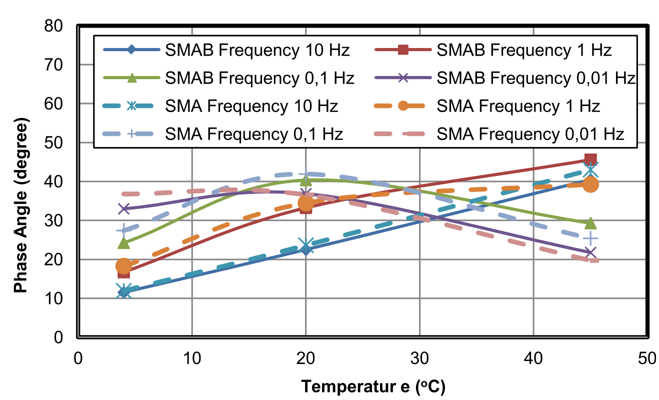

Fig. 2. Plot of phase angle for the SMAB mix and the SMA mix [9].

equation have the explained variance R^2 of 0.98 and the ratio of the standard error of estimate (Se) and the standard deviation of logarithm of the average dynamic modulus value (Sr) is 0.03. Fig. 3 shows that SMAB dynamic modulus was higher than the dynamic modulus of SMA, at a reduced frequency value that is less than about 750 Hz (or at a temperature greater than about 4.4 °C). In contrast, at the reduced frequency over 750 Hz (or temperature less than 4.4 °C), the dynamic modulus of the SMAB mix is less than the SMA mix dynamic modulus. This phenomenon indicates the SMAB mix is relatively stiffer at high temperatures (more than 4.4 °C), but relatively less stiff (less brittle) at low temperatures.

3.4. Permanent deformation

The deformations obtained for the SMA mix with stabilizer 0.2% cellulose and the SMA mix with stabilizer LGA 7.5% are shown in Table 4. From Table 4 it can be seen that the dynamic stability of the SMA mix is smaller then the SMAB mix. This indicates the superiority, in terms of the resistance to permanent deformation, of the SMAB mix. For comparison in the specs ministry of public works, the value of dynamic stability required for heavy traffic is at a minimum in 2500 passes/mm.

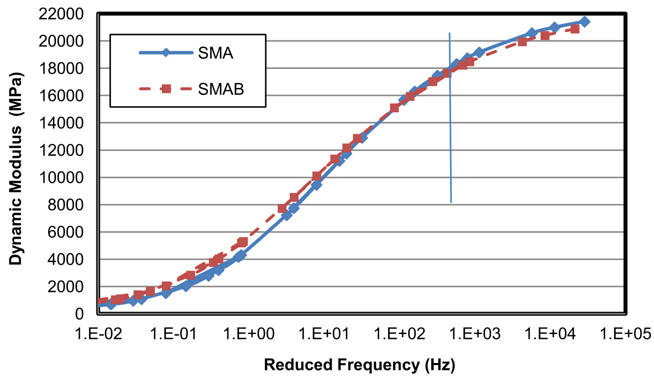

Fig. 3. Plot of dynamics modulus master curve for SMA and SMAB [9].

Table 4
The dynamic stability and rate of deformation of the mixes.

Type of mixes	Dynamic stability passes/mm	Rate of deformation (mm/min)
SMA added cellulosa 0.2%	1145	0.0367
SMA added LGA 7.5% (SMAB)	3938	0.0107

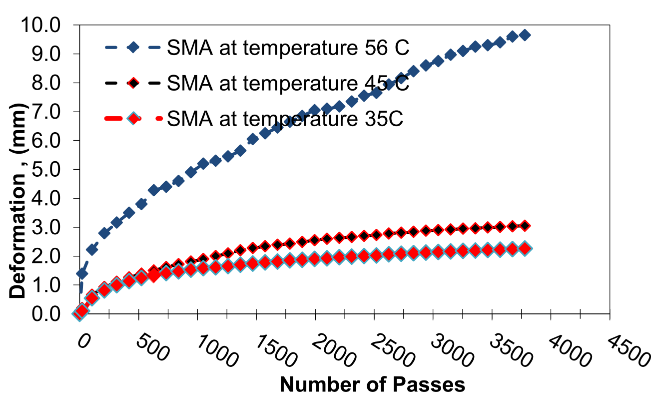

Fig. 4. Plot of dynamic stability for the SMA mix.

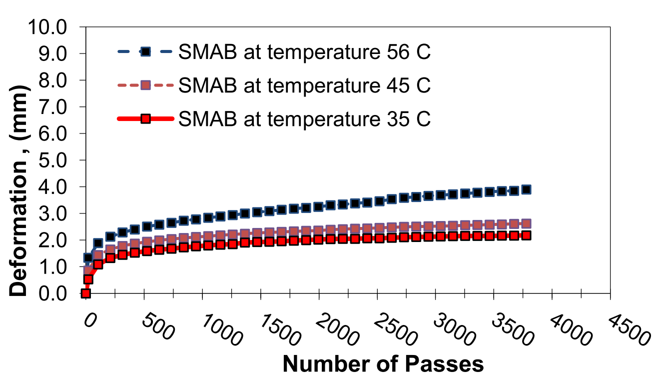

Fig. 5. Plot of dynamic stability for the SMAB mix.

Figs. 4 and 5 shows the effect of temperature on the dynamic stability SMAB value, where the lower the value of the test temperature the dynamic stability will also be greater. After testing for 45 min the rate of deformation has been relatively constant. So that the determination of the value of the dynamic stability from the value of deformation at time 45 min (945 passes) and 60 min (1260 passes) is appropriate.

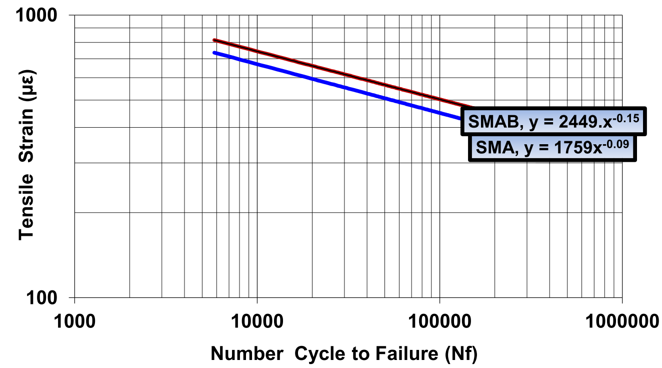

Fig. 6. Plot of trend fatigue's line.

3.5. Fatigue resistance

The fatigue life for those mixes is plotted in Fig. 6. It shows that the resistance to fatigue of the SMAB mix is as good as the SMA mix. Fatigue test results prove that the SMAB is not only resistant to permanent deformation as shown in the value of dynamic stability, but also has enough flexibility as indicated in the relationship between strain and number of cycles to failure.

4. Conclusion

Based on the study conducted, the following conclusions are made:

(1) Asbuton (LGA 50/25) can behave as a stabilizer as well as cellulose fibers. Functioning LGA as a stabilizer is predicted because of no mobilization of asphalt in the LGA as a whole, and penetration grade of asbuton asphalt that is relatively lower resulting in increased viscosity of the binder.
(2) Mineral of asbuton (LGA 50/25) can provide filler in the SMA mix in a fairly significant amounts.
(3) Master curve of dynamic modulus indicates the SMAB mix is relatively stiffer at high temperatures (more than 4.4 °C), but relatively less stiff (less brittle) at low temperatures.
(4) Addition of asbuton also improves the performance of the SMA mix, as shown with increase in the value of dynamic stability.
(5) In terms of resistance to fatigue, SMA with cellulosa as stabilizer and SMA with asbuton as stabilizer, relatively have the same performance. The fatigue performance of the SMA mix and the SMAB mix prove that the SMAB is not only resistant to permanent deformation as shown in the value of dynamic

stability, but also has enough flexibility as indicated in the relationship between strain and number of cycles.

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