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FATIGUE PERFORMANCE OF HRA (HOT ROLLED ASPHALT) AND *SUPERPAVE*® MIXES USING INDONESIAN ROCK ASPHALT (*ASBUTON*) AS FINE AGGREGATES AND FILLER

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Abstract: Pursuing our previous research, the fatigue performance of Hot Rolled Asphalt (HRA) mix type C; referred to the British Standard Specification, and ***Superpave*®** Asphaltic Concrete (AC) mix; referred to the Asphalt Institute Specification, both using an ASBUTON (Indonesian Rock Asphalt) as fine aggregates and filler, were investigated. The parameters used to evaluate the fatigue characteristics of Asphalt Concrete mixes were: the number of cycles to failure or Fatigue Life, the Effectiveness Factor, the initial strain, the initial stiffness, the number of cycles for crack initiation, the number of cycles for crack propagation, and the cracking mechanism until failure achieved.
The results of the research showed that the use of Asbuton as fine aggregates and filler in HRA mix type C and ***Superpave*®** AC mixtures, could improve its Fatigue Life, indicated by an increasing of the *Effectiveness Factor*, i.e. the ratio of number of cycle to failure for specimens with and without Asbuton filler, at a given stress level, ranges from 15.71 to 4.90 for HRA mix and from 521.44 to 6.38 for AC mix, depend on its stress level.. The role of Asbuton filler in both asphalt mixture; HRA and AC appears also to decrease the Initial Strain, increase the Initial Stiffness (more than 300% for AC mix) and reduce the mechanism of crack initiation and crack propagation of the specimens.

Key Words: Hot Rolled Asphalt, *Superpave*® Asphalt Concrete, ASBUTON, Fatigue Characteristic, *Effectiveness Factor*.

1. INTRODUCTION

Rock asphalt deposits exist in large quantities in Buton Island, South-East Sulawesi, Indonesia, and it is named locally as Aspal Buton or ASBUTON. Since the deposits are widely variable in both composition and properties, then the production of a consistently uniform material, whose its performance can be predicted with reasonable confidence, is really difficult (McElvaney, J., 1986).Until late 1990s Asbuton was used extensively in its natural state as a surfacing layer for existing road pavements in the highway maintenance and betterment programme in Indonesia.

Use of these materials was then suspended by the Directorate General of Highways, due to "under estimated" performance of the mix, as mentioned above.
On the other hand, extensive maintenance and betterment of the Indonesian road network, involves the use of very large quantities of bitumen-bound materials. Given the relatively high cost of refinery bitumen, much of which is imported from another country, and the existence within the country of large resources of rock asphalt, the outcome of the research of natural rock asphalt becomes significantly important for those involved in the highway maintenance programs.
Pursuing our previous research, the fatigue performances of Hot Rolled Asphalt (HRA) mix type C; referred to the BS 594 part 1-1992 (British Standard,1992) and ***Superpave®*** Asphaltic Concrete (SP-AC) mix; referred to the Asphalt Institute's Specification (Asphalt Institute, 1996), were investigated, both using an ASBUTON (Indonesian Rock Asphalt) as fine aggregates and filler.
The parameters used to evaluate the fatigue characteristics of Asphalt Concrete mixes were: the number of cycles to failure or Fatigue Life, the Effectiveness Factor, the initial strain, the initial stiffness, the number of cycles for crack initiation, the number of cycles for crack propagation, and the cracking mechanism until failure achieved.
The laboratory works were conducted at Highway Engineering Laboratory, Civil Engineering Department, Institute of Technology Bandung (ITB) and Center for Research & Development in Transportation, Ministry of Public Works, at Bandung.

2. MATERIAL PROPERTIES

2.1 Bitumen Properties

Petroleum asphalt called "AC-20" (approximately equivalent to 60/70 pen), produced by Pertamina, was used in the HRA and SP-AC mixture. The laboratory tests performed to evaluate the bitumen properties were: Penetration, Softening Point, Ductility, Flash Point, Solubility, Specific Gravity and Viscosity. The results were shown in table 1.

2.2 Aggregate Properties

The coarse and fine aggregates used were crushed rock from West Java, Indonesia and 2(two) types of filler were used i.e. Asbuton and "normal" filler i.e. stone-ash". The laboratory tests performed to evaluate the properties of coarse aggregates were: Aggregate Impact Value, Aggregate Crushing Value, Water Absorption, Specific Gravity, Flakiness, Elongation and Angularity. The tests conducted for fine aggregates were: Specific Gravity and Water Absorption, while for filler the test performed was only Specific Gravity. The results were shown in table 2.

3. LABORATORY PROCEDURES

3.1 Preparations for Mix design

In this research, mix design were prepared for 2 (two) types of mixture i.e. Hot Rolled asphalt (HRA) type C and Superpave's Asphaltic Concrete (SP-AC) mixture, each type uses either "normal" filler e.g. stone-ash, and Asbuton filler. The percentage of Asbuton filler was different for each mix i.e. 10% by weight for HRS and 6.5% for SP-AC mix.

Table 1
Test results on Bitumen Properties

No	Laboratory Test	Unit	Result	Indonesian Specification	
				Minimum	Maximum
1	Penetration	0.1 mm	52.75	60.00	79.00
2	Softening Point	ºC	51.75	48.00	58.00
3	Burning Point	ºC	350	200	-
4	Ductility	Cm	>100	100	-
5	Solubility	%	99.82	99.00	-
6	Specific Gravity	-	1.04	1.00	-
7	Loss on Heating (TFOT)	%	0.0036	-	0.80
8	Penetration after TFOT	0.1 mm	66.60	80.00	-
9	Viscosity (Saybolt Furol)				
	140ºC	cSt	319.37	-	-
	160ºC	cSt	201.39	-	-
	180ºC	cSt	57.79	-	-

Table 2
Test results on Aggregate Properties

No	Laboratory Test	Unit	Results	Specification	
				Min	Max
Coarse Aggregates					
1	Bulk Specific Gravity	-	2.559	2.5	-
2	SSD Specific Gravity	-	2.639	-	-
3	Apparent Specific Gravity	-	2.781	-	-
4	Effective Specific Gravity	-	2.670	-	-
5	Water Absorption	%	3.11	-	3
6	Aggregate Impact Value	%	17.61	-	30
7	Aggregate Crushing Value	%	19.7	-	25
8	Flakiness Index	%	26.5	-	-
9	Elongation Index	%	25.6	-	40
Fine Aggregates (Asbuton)					
1	Specific Gravity (HRA-C)	-	2.536	-	-
2	Specific Gravity (HRA-F)	-	2.316	-	-
Filler					
1	Specific Gravity (fly-ash)	-	2.531	2.5	-
2	Specific Gravity (Asbuton)		2.092	-	-

According to the British Standard method (BS, 1992), the mixing temperature for HRA mix was 110^{o}C ± 3^{o}C above Softening Point and the tamping temperature was 92^{o}C ± 2^{o}C above Softening Point. The results obtained were: the mixing temperature 159^{o}C~165^{o}C and the tamping temperature 142^{o}C~146^{o}C. While for SP-AC mix, the mixing and tamping temperature were 157^{o}C and 143^{o}C, respectively.

3.2. Marshall tests.

Two types of HRA mix for Marshall test were prepared i.e. using Asbuton filler, bitumen content from 3% to 7% with 1% increment, (namely F_{ab}) and using stone-ash filler, bitumen content from 5% to 9% with 1% increment (namely F_{fa}). While for SP-AC specimens, three types of mix were prepared i.e. using stone-ash filler, using Asbuton filler and using Asbuton as fine aggregates and filler. The bitumen content used was varied from 4% to 8%, with 1% increment.
All specimens of HRA mix were compacted using standard Marshall Hammer i.e. 50 blows for each face of the specimen, while for SP-AC mix the number of compaction was 2x75 blows. The total Marshall specimens were 2x5x3 = 30 samples for HRA mixes and 3x5x3 = 45 samples for SP-AC mixes.

3.3. Fatigue Tests

All beam specimens used for the tests were sawed to the required dimensions from a slab prepared in the rolling wheel compaction apparatus. Beam specimens with 30 cm long, 15 cm wide and 5 cm thickness were used. In order to obtain the same density with Marshall Specimens at OBC, all samples were compacted using wheel-roller compaction with 5.60 kg/cm^2 tire pressure (Fahmi, I., 2003).
The Laboratory fatigue tests were conducted using the Dartec equipment, located in the Laboratory of Highways Engineering at PUSTRANS, Bandung. Because the temperature control facility was not available, all tests were conducted at room temperature.
HRA specimens were tested at three stress levels i.e. 0.26 MPa, 0.39 MPa and 0.51 MPa, that would result in fatigue lives ranging from 1,000 to 120,000 cycles. While for SP-AC, 3(three) stress-levels were used i.e. 0.56 MPa, 0.84 MPa and 1.12 MPa.
All tests were conducted at frequency of 10 Hz (ten cycles per second) under sinusoidal wave loading. The initial peak-to-peak load amplitude and deformation magnitudes were recorded and automatically saved in the computer hard drive. The test terminated when the specimen was completely fractured or when the actuator of the equipment did not respond. Number of cycles to failure (N_f) was defined at the point where there was a significant change in the slope of the deflection curve versus cycles or at intersection of two straight-line of deflection curve.

4. TEST RESULTS AND DISCUSSIONS

4.1 Bitumen

The result of laboratory tests for bitumen was shown in Table L1 and all results could conform to the Specification for each mixture i.e. British Standard and Asphalt Institute’s Specifications. The kinematic viscosity test were also conducted not to determine mixing and compaction temperatures, but to fulfill the test-series for bituminous properties in the laboratory, as mentioned in the Indonesian Specification (Dept. KIMPRASWIL, 2001).

4.2 Aggregates

All results of the laboratory tests for aggregates used in this research was shown in Table L2, and they conformed to the Indonesian specification (SNI M-09-1989-F) and British Standard (BS 812: Part 3 : 1975).
The "gap-graded" gradation curve for HRA mix, as shown in Table 1 and Figure 1, were chosen at the mid-point between those two boundary lines, and referred to British Standard (BS 812, 1975), while for SP-AC mix the "continuous" gradation curve referred to the Asphalt Institute's specification.

4.3 Marshall Test

The results of Standard Marshall Test, as presented in Table 1, were: Stability, Flow, Marshall Quotient (MQ), Density, Voids in Mix (VIM), Voids in Mineral Aggregate (VMA) and Voids Filler with Binder (VFB).
It is shown that Marshall Stability and MQ-value of HRA mix was lower than that of SP-AC mix. The highest Stability obtained was HRA mix using Asbuton filler (2554 kg), and the lowest results were obtained for SP-AC mixes type K (1004 kg). In general, all results of Marshall Stability at OBC, for all types of mix, were higher than the minimum value specified by the Indonesian Standards (Dept. KIMPRASWIL, 2001).

4.4 Optimum Bitumen Content

Referring to the British Standard Specification (BS, 1992), the optimum bitumen of HRA-Asbuton mix shall be determined using 3(three) parameters i.e. Marshall Stability, Density of mix and Density of compacted aggregate. The value of "optimum" bitumen content related to each parameter above should be taken, and the average value was then calculated.
An Optimum Bitumen Content (OBC) obtained for HRA mixes were 4.60% (F_{ab} specimen) and 7.50% (F_{fa} specimen), respectively. While for SP-AC mixes, the OBC obtained were 6.85% (K Specimen), 7.0% (F Specimen) and 7.5% (LF Specimen).
It is shown that the OBC of HRA mix using Asbuton filler was obviously lower than the same mixes using "stone-ash" filler. While for SP-AC mix, the Optimum Bitumen Content was relatively indifferent between 3(three) mix types.

5. FATIGUE TEST RESULTS

The parameters used to evaluate the fatigue characteristics of the mix with and without Latex additive were : the number of cycle to failure (N_f), the Effectiveness Factor (EF), the initial strain (ε_i), the initial stiffness (S), the number of cycles needed to initiate and to propagate cracks (N_i and N_p respectively), and the rate of crack propagation. All the results were given in Table 2 and Table 3.

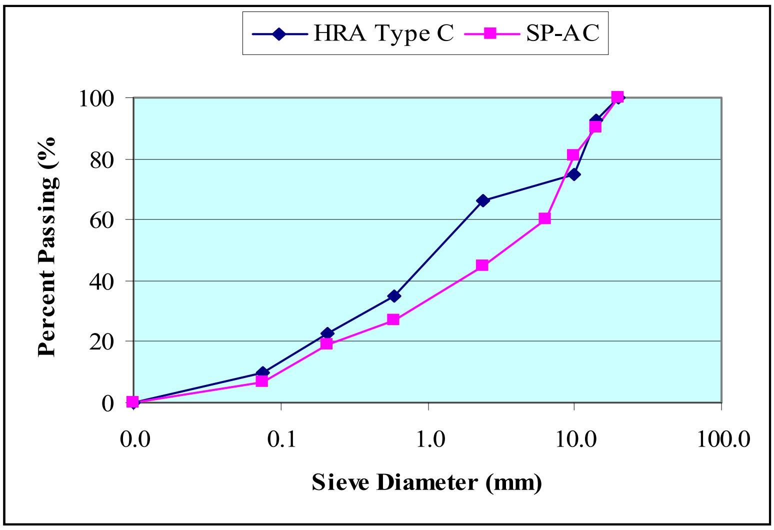

Figure 1
The aggregate gradation curve for HRA and SP-AC mixes

Table 3
Result of Marshall Test

No.	Specimen type (%)	OBC (%)	VIM (%)	VMA (%)	Stability (kg)	Flow (mm)	MQ (kg/mm)
HRA Mix type C							
1	F_{fa}	7.50	-	-	1447	3.25	445.2
2	F_{ab}	4.60	-	-	2554	8.30	307.7
Superpave's AC Mix							
1	K	6.85	4.86	17.83	1004.0	3.58	295
2	L	7.00	4.90	17.86	1032.6	5.25	215
3	LF	7.50	4.97	19.60	1415.0	6.31	210

5.1 Cycles to Failure

The analysis of fatigue data indicates that HRA mix with and without Asbuton filler (F_{ab} and F_{fa}) have significant differences in the number of cycles to failure (N_f). At a given stress level, the number of cycles to failure of F_{fa} specimens is less than that of F_{ab} specimens, for HRA mix and the LF specimens has the highest fatigue life for SP-AC mix (see Figure 2) (Adwang, 2004).
The ratio of cycles to failure for Asbuton specimens (F_{ab}) to that for non-Asbuton specimens (F_{fa}) is described in terms of the *Effectiveness Factor* (EF). The value of EF at each stress level indicates the effect of Asbuton filler and fine aggregates on the fatigue life of the bituminous mixture. The calculation shows that the EF value decreases as the stress-level increases; it ranges from 15.71 ($\Delta\sigma = 0.26$ MPa) to 4.90 ($\Delta\sigma = 0.51$ MPa) for HRA mix, and from 6.38 ($\Delta\sigma = 0.56$ MPa) to 521.44 ($\Delta\sigma = 0.56$ MPa) for SP-AC mix.

The equations obtained which relate variables : Stress to Number of Cycles to failure i.e.
For Hot Rolled Asphalt (HRA) mixes :

a. F_{fa} specimens : $\text{Log}(N_f) = 2.3135 - 2.6130 \log(\sigma)$ .... (1)

b. F_{ab} specimens : $\text{Log}(N_f) = 2.4990 - 4.3403 \log(\sigma)$ .... (2)

For Superpave's AC (SP-AC) mixes :

a. K – specimen : $\text{Log}(N_f) = 2.3180 - 3.51 \log(\sigma)$ .... (3)

b. F – specimen : $\text{Log}(N_f) = 3.1430 - 3.4270 \log(\sigma)$ .... (4)

c. LF – specimen : $\text{Log}(N_f) = 4.9790 - 2.374 \log(\sigma)$ .... (5)

Table 4a
Fatigue Test results for F_{fa} Specimens

Stress Level (MPa)	Initial Strain (10^{-4})	Initial Stiffness (MPa)	$N_{initial}$ (N_i) (cycles)	$N_{propagation}$ (N_p) (cycles)	$N_{failure}$ (N_f) (cycles)
0.26	0.9383	12005	2066	4727	6793
0.39	1.0316	12005	600	2469	3069
0.51	1.0596	12005	340	797	1137

Table 4b
Fatigue Test results for F_{ab} Specimens

Stress Level (MPa)	Initial Strain (10^{-4})	Initial Stiffness (MPa)	$N_{initial}$ (N_i) (cycles)	$N_{propagation}$ (N_p) (cycles)	$N_{failure}$ (N_f) (cycles)
0.26	0.0372	69124	91750	30364	122114
0.39	0.0510	75630	16150	3063	19213
0.51	0.0847	60742	5365	793	6158

Table 5a
Fatigue Test results for K-Specimens

Stress Level (MPa)	Initial Strain	Initial Stiffness (MPa)	$N_{initial}$ (N_i) (cycles)	$N_{propagation}$ (N_p) (cycles)	$N_{failure}$ (N_f) (cycles)
0.56	0.004	49756	550	1007	1557
0.84	0.009	49756	92	309	401
1.12	0.016	49756	43	93	136

Table 5b
Fatigue Test results for F- Specimens

Stress Level (MPa)	Initial Strain (10^{-4})	Initial Stiffness (MPa)	$N_{initial}$ (N_i) (cycles)	$N_{propagation}$ (N_p) (cycles)	$N_{failure}$ (N_f) (cycles)
0.56	0.002	90112	1875	9375	11250
0.84	0.006	90112	175	2535	2710
1.12	0.008	90112	171	880	1051

Table 5c
Fatigue Test results for LF- Specimens

Stress Level (MPa)	Initial Strain (10^{-4})	Initial Stiffness (MPa)	$N_{initial}$ (N_i) (cycles)	$N_{propagation}$ (N_p) (cycles)	$N_{failure}$ (N_f) (cycles)
0.56	0.001	186940	49660	188461	238121
0.84	0.003	186940	36700	194647	231347
1.12	0.004	186940	6150	65869	72019

5.2 The Initial Strain and Initial Stiffness

The initial strain (ε_i) was calculated using the dynamic deflection value at the 50^{th} cycle (SHRP, 1994) and it was recorded for every testing of specimen. Based on the simple equation $\sigma = S.\varepsilon$ and plotting between applied stress (σ) and initial strain (ε_i), then the initial flexural stiffness (S_i) is defined as the slope of the regression line of the stress-initial strain relationship. The results in Table 4 and 5 showed that, for each stress level, the flexural stiffness, either for HRA and SP-AC mixes, was significantly different i.e. 12,005 MPa to 47,127 MPa for HRA mixes and 49,756 MPa to 186,940 MPa for SP-AC mixes. The ratio of this value between SP-AC and HRA specimens is 3.97 to 4.14.

5.3 Cycles to Propagate Cracks

The number of cycles required to propagating cracks (N_p) in HRA and SP-AC mixes, with and without Asbuton filler, was determined based on visual appearance of the initial crack at the bottom of the specimen and it was calculated repeatedly until failure arrived.
This calculation indicates a relatively significant difference in the number of crack propagation cycles (N_p) for mixes with and without Asbuton filler, for both type of mixes (HRA and SP-AC). The results showed that Asbuton filler could increase the number of cycles for crack propagation (N_p).

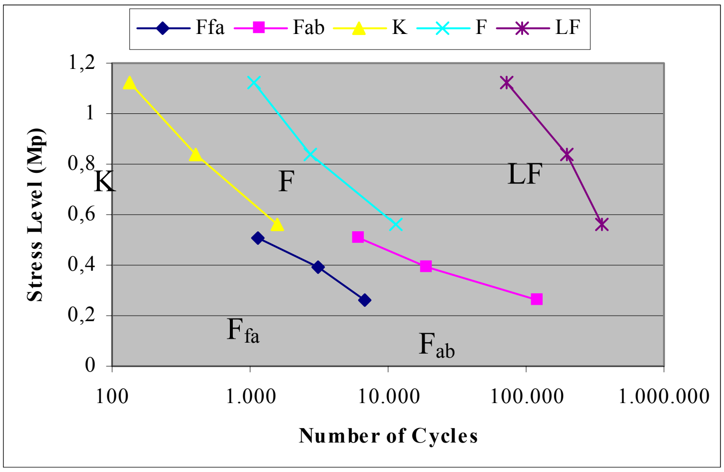

Figure 2
Curves of Fatigue Life

5.4. Rate of Crack propagation

The rate of crack propagation (r_p) is defined as the ratio between the number of cycles required to obtain every 1(one) mm deflection, starting from the first cracking appeared, from one type of specimen to another (Fahmi.I, 2003). This equation is described as follows:

$$r_p = \frac{N_p}{\delta_f - \delta_i} \qquad \text{..............................} \qquad (6)$$

Where : r_p : rate of crack propagation (cycles/mm)
N_p : number of cycles required to propagate cracking
δ_f : cumulative deflection at failure (mm)
δ_i : cumulative deflection at crack initiation (mm).

Using those formulas, the rate of crack propagation could be calculated and the result showed that the higher r_p the slower crack propagates and vice versa. The calculation showed that the use of Asbuton filler would reduce the rate of crack propagation. The values obtained were 31 to 183 (Asbuton filler) and 573 to 10,776 (stone-ash filer).
The initial cracking mechanism of all specimens; with and without Asbuton filler, was not significantly different. The initial cracks start at the bottom area of specimen, at the location of maximum bending moment, and propagate upward to the surface of specimen. The cracks-accumulation continues as the cycle's number increases and at the end, the different type of failure occurred i.e. "brittle failure" for specimen with Asbuton and "ductile failure" for specimen without Asbuton.

6. CONCLUSIONS

Within the limits of this study, the following principal conclusions can be summarized as follows:

a. In the controlled-stress test, the fatigue performances of Superpave's Asphaltic Concrete (SP-AC) mix give a longer N_f (number of cycles to failure) than that of Hot Rolled Asphalt (HRA) mix, although the SP-AC was conducted at a higher stress levels. A more realistic result should be obtained using controlled-strain test with the same strain-level.
b. The use of Asbuton filler in SP-AC and HRA mixes gave a **Stiffening Effect** in both specimens. It is shown by an increasing the (initial) flexural stiffness, decreasing the rate of crack propagation (r_p) and the *Effectiveness Factor* (EF) was greater than 1.0.
c. The inclusion of Asbuton filler in SP-AC and HRA mixes could significantly increase the initial flexural stiffness of specimens i.e. 12,005 MPa to 47,127 MPa for HRA mix and 49.756 MPa to 90.112 MPa for SP-AC mix..
d. The number of cycles for crack propagation (N_p) of the SP-AC and HRA mixes was influenced also by the use of Asbuton filler. A specimen with Asbuton filler give a longer N_p than that without Asbuton filler, particularly at a lower stress-level of fatigue test.
e. The cracking mechanism in SP-AC and HRA specimens; with and without Asbuton filler, is relatively different. The specimens with Asbuton filler tend to failure in "brittle" condition, while for specimens without Asbuton filler, the "ductile" failure was visually appeared.

REFERENCES

Adwang, J., (2004), **Laboratory Evaluation of Asphaltic Concrete Mix with SUPERPAVE's Gradation using Flexure Fatigue test** (in Indonesian), Master's Thesis, ITB, Bandung, Indonesia.

Asphalt Institute, (1996), **Superpave Mix Design (SP-2)**, U.S.A.

British Standard, B.S.594 (1992), **Specifications for Constituent Material and Asphalt Mixtures**, Hot Rolled Asphalt for Roads & Other Paved Areas, London, U.K.

Dept. KIMPRASWIL (2001), **New Specifications for Hot-mix Asphaltic Concrete**, Departemen KIMPRASWIL, Jakarta, Indonesia.

Fahmi, I., (2003), **Laboratory Fatigue Performance of Hot-Rolled Asphalt Mix using Asbuton filler** (in Indonesian), Master's Thesis, STJR-ITB, Bandung, Indonesia.

McElvaney (1986), **Characteristics of Asbuton and Asbuton-Aggregate Mixtures**, Pasca Sarjana Workshop, Bandung.

SNI No. 1737-1989 –F (1989), **Petunjuk Pelaksanaan Lapis Aspal Beton (LASTON) untuk Jalan Raya**, Departemen Pekerjaan Umum, Indonesia.

Strategic Highway Research Program (1994), **Fatigue Response of Asphalt Aggregates Mixes,** SHRP-A-404, University of California, USA.

SUBAGIO, B.S., et al., (2003), **Performance Evaluation of Pavement Structures using ASBUTON as fine aggregates and filler** (in Indonesian), Research's Report, Civil Engineering Department, ITB, Bandung, Indonesia.