Verification of modulus and fatigue cracking models for hot-mix asphalt with asbuton in laboratory scale

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Abstract. Design and analysis of flexible pavement structure using mechanistic approaches require, among other input data, the dynamic modulus of asphalt layer (E*) and it's resistance to fatigue cracking (N_f). These material characteristics can be obtained from both laboratory test results and calibrated against field conditions and from mathematical models, such as the Asphalt Institute's. The two values are to be compared for assessing the applicability of the models for mixes using petroleum bitumen (pen 60/70) and using modified asphalt (with 8% asbuton). The laboratory tests were conducted using Asphalt Mixture Performance Test (AMPT) and Four Point Loading equipment. It was found that the resulting curves are consistent with the Asphalt Institute's model for both types of mixes. Meanwhile, fatigue life model curves show a similar trend to the Asphalt Institute's model on the conservative side. This is explainable the laboratory model needs to be calibrated for variations of wheel track and loading time occuring on site.

1 Introduction

Design and analysis of flexible pavement structure using mechanistic approaches require the dynamic modulus of asphalt layer (E*) and it's resistance to fatigue crack (fatigue life) values.

The dynamic modulus is a stress-strain relationship for a linear viscoelastic material that accepts a sinusoidal load of a certain frequency (N. Suaryana, 2014).

Fatigue cracking is a phenomenon of cracking due to recurrent loads that occur due to repetition of strain still under the strength of the material (E.J Yoder and M.W Witczak, 1975).

The values mentioned above, in addition can be obtained from the test results in the laboratory, can also be obtained from mathematical model.

Models of asphalt mixed modulus have been widely developed, among others modulus models by Witczak (2006), Asphalt Institute (1982), Bonnaure et.al (1977) and Nottingham (Brown, et al., 1984). In this research, the dynamic modulus model used is the Asphalt Institute (AI) model.

The fatigue life (N_f) models is derived based on different laboratory testing methods:

a. Constant Stress : Asphalt Institute (AI), Shell ;
b. Constant Strain : Shell, Austroad, Nottingham, SHRP-Berkeley ;
c. Full Scale: Transport and Road Research Laboratory (TRRL).

This research will use the method (a) constant stress and N_f model by Asphalt Institute. This model is chosen because the parameters in the calculation is complete enough that there is a function of strain (ε), dynamic modulus of asphalt layers (E*) as well as mixed volumetric parameters.

Statistical analysis was performed to verify both models to see consistency between test data and model calculations. Through verification of modulus and fatigue cracking models, the dynamic modulus of asphalt layer (E*) and fatigue life (N_f) values can be obtained with models, without having to carry out expensive and complicated laboratory testing. So that can optimize time and cost when doing the design and analysis of flexible pavement structure using a mechanistic approaches.

2 Theoritical background

2.1 Dynamic modulus (E*) model for asphalt

The Asphalt Institute (1982) states that the dynamic modulus of hot mix asphalt (HMA) is a function of the percentage of aggregates that passes the filter no. 200, loading frequency, air void, asphalt viscosity, temperature and asphalt volume percentage with the following equation:

$$|E^*| = 100{,}000 \times 10^{\beta_1} \quad (1)$$

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With:

$$\beta_1 = \beta_3 + 0.000005\beta_2 - 0.00189\beta_2 f^{-1.1} \quad (2)$$

$$\beta_2 = \beta_4^{0.5} T^{\beta_5} \quad (3)$$

$$\beta_3 = 0.553833 + 0.02882(P_{200} f^{-0.1703}) - 0.003476V_a + 0.070377\lambda + 0.931757 f^{-0.002774} \quad (4)$$

$$\beta_4 = 0.483V_b \quad (5)$$

$$\beta_5 = 1.3 + 0.49825 \log f \quad (6)$$

$$\lambda = 29{,}508.2(P_{77^oF})^{-2.1939} \quad (7)$$

Where,

β1, β2, β3, β4, β5= temporary constants
f = loading frequency, (Hz)
P_{200} = percent of aggregates passed the filter no. 200, (%)
Vb = asphalt volume, (%)
λ = viscosity of bitumen on 70 ^{0}F, (10^6 poises)
T = temperature of asphalt mixture, (^{0}F)

2.2 Fatigue model

Fatigue life (N_f) of HMA can be predicted by performing calculations through a mathematical model. The fatigue model reviewed here is only the Asphalt Institute model with constant stress testing using the Four Point Loading which is calibrated by Witczak and El-Basyouny for *American Mechanistic-Empirical Pavement Design Guide* (MEPDG) are as follows *(J. Yu and G. Zou, 2013)*:

$$N_f = 18.4 \times 0.00432 C \varepsilon_t^{-3.291} |E^*|^{-0.854} \quad (8)$$

Where C is a correction factor, C = 10^M

$$M = 4.84 \left[\frac{Vb}{Va+Vb} - 0.69\right] \quad (9)$$

Where :

N_f = fatigue life to failure, cycle
C = correction factor = 10^M
= function of asphalt volume and volume of air void
ε_t = tensile strain, με
$|E^*|$ = dynamic modulus complex of asphalt mixture, Psi
V_b = percentage of asphalt volume (bitumen) in the mixture, %
V_a = volume of air void in mixture,%

3 Test result and analysis

3.1 Dynamic modulus

The dynamic asphalt mixed modulus testing uses AMPT and making of the sample using a gyratory compactor. Dynamic modulus testing was performed with sinusoidal loading at 20°C, 35°C, 50°C, for each temperature tested at a frequency of 0.01 Hz; 0.1 Hz; 1 Hz; 10 Hz.

The summary of HMA with 8% asbuton, dynamic modulus test results is presented in Table 1, whereas the results for HMA without asbuton show the same behavior. Then for mathematical calculations the modulus model can be seen in Table 2.

To compare the results of the dynamic modulus testing of the AMPT test with the modulus of the Four Point Loading test and the modulus model according to the Asphalt Institute, the first step is to mathematically calculate the model based on equations 1 to 7.

Furthermore, to obtain the relationship between the Four Point Loading modulus test results with the AMPT test results need to adjust the loading frequency, because the Four Point Loading test is done at the frequency of 8.06 Hz, while the AMPT test at the frequency of 0.01; 0.1; 1; 10 Hz. The step taken is to perform a linear interpolation between the AMPT test results and the Four Point Loading test results.

All modulus values are then plotted into the graph of the temperature relation (ºC) with the modulus shown in Figure 2 and 3. To see the consistency between these values, a statistical test is performed, complete verification steps are presented in Figure 1. As for the other mixtures showing the same behavior.

In Figure 2 dan 3, shows of HMA without and with 8% asbuton, at temperature and all frequencies (0.01 Hz; 0.1 Hz; 1 Hz; 10 Hz) for the three variations of asphalt content (5%; 6%; 7%), the value of the test modulus is mostly above the model.

When observed on the graphs of the dynamic modulus, at a frequency of 0.01; 0.1;10 Hz, AI model line and the AMPT test line look consistent, where in the 0.01 Hz and 0.1 Hz frequencies the lines are both concave, as does the AMPT test line. Then for the 10 Hz frequency the AI convex model line, same as the AMPT test line. But somewhat distorted occurs in the frequency of 1 Hz (black line), where the model line tends to convex, while for the AMPT test line tends to be concave. This needs further research to find the cause of the phenomenon.

The dynamic modulus relationship of the AMPT test results and the AI model shown in Figure 4, most of the modulus values of the test results are greater than the model. This, if seen from its influence on flexible pavement design, that the model is safer to use in planning, because it produces a lower modulus, which in fact in the asphalt layers is built has a greater modulus value, indicated by the results of AMPT testing.

Table 1. AMPT test results for HMA with 8% asbuton

Condition		Asphalt Content 5%		Asphalt Content 6%		Asphalt Content 7%	
Temperature	Frequency	Dynamic Modulus	Phase Angle	Dynamic Modulus	Phase Angle	Dynamic Modulus	Phase Angle
ºC	Hz	MPa	(º)	Mpa	(º)	Mpa	(º)
20	0.01	1,907.433	36.58	1,034.300	35.13	828.935	34.46
20	0.1	5,141.885	32.11	3,036.143	35.52	2,312.302	36.70
20	1	10,063.510	22.10	6,816.994	27.24	5,386.530	29.19
20	10	16,153.230	14.24	11,555.780	18.65	9,702.566	19.54
35	0.01	523.316	24.47	292.589	19.44	305.760	19.62
35	0.1	1,294.000	35.30	509.264	32.18	703.296	34.67
35	1	3,444.867	35.09	1,400.384	41.82	2,049.840	38.95
35	10	7,397.912	27.37	4,144.871	37.97	5,052.018	31.54

Condition		Asphalt Content 5%		Asphalt Content 6%		Asphalt Content 7%	
Temperature	Frequency	Dynamic Modulus	Phase Angle	Dynamic Modulus	Phase Angle	Dynamic Modulus	Phase Angle
ºC	Hz	MPa	(º)	Mpa	(º)	Mpa	(º)
50	0.01	281.792	11.29	207.553	11.00	194.003	8.78
50	0.1	352.448	18.60	279.826	21.95	234.765	15.94
50	1	629.325	30.98	563.473	37.91	396.026	29.23
50	10	1,698.911	39.36	1,695.248	42.03	1,102.264	39.67

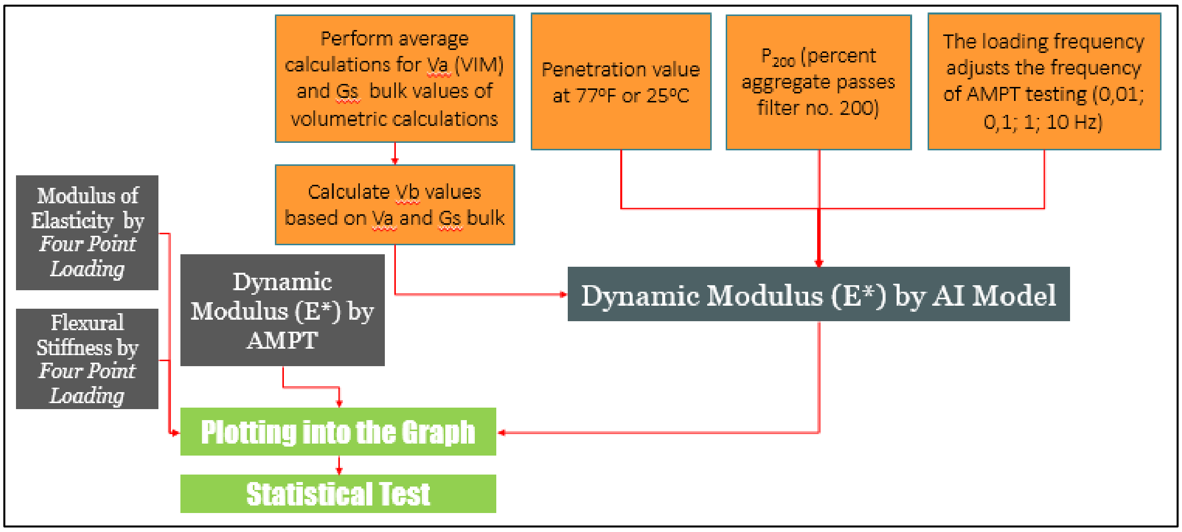

Fig. 1. The steps to verify the AMPT test results on the HMA modulus model

Tabel 2. Results of calculation of dynamic modulus AI model with the frequency according to the modulus testing of AMPT for HMA with 8% asbuton

No.	B1	B2	B3	B4	B5	f (Hz)	Log f	P200	Vv (%) = VIM	VFB (%)	VMA (%)	Vb (%) = Vfb x VMA	λ	P77 ºF (Pen 25 ºC)	E (psi)	E (MPa)	T (ºC)	T (ºF)	AMPT Test	Type HMA
5.1a	0.0467	7.5699	2.3142	4.4244	0.3035	0.01	-2.00000	6.5	8.649	51.444	17.806	9.160	8.4083	41.3	111,356.92	767.78	20	68	1,907.43	Pen 60/70+Asb 8% (5%)
	-0.1955	8.3785	2.3142	4.4244	0.3035	0.01	-2.00000	6.5	8.649	51.444	17.806	9.160	8.4083	41.3	63,757.03	439.59	35	95	523.32	
	-0.3934	9.0393	2.3142	4.4244	0.3035	0.01	-2.00000	6.5	8.649	51.444	17.806	9.160	8.4083	41.3	40,418.17	278.68	50	122	281.79	
5.2a	0.6524	61.5061	2.1155	4.3592	0.8018	0.1	-1.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	449,146.29	3,096.77	20	68	5,141.89	Pen 60/70+Asb 8% (5%)
	0.2025	80.4163	2.1155	4.3592	0.8018	0.1	-1.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	159,418.60	1,099.16	35	95	1,294.00	
	-0.2223	98.2750	2.1155	4.3592	0.8018	0.1	-1.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	59,938.13	413.26	50	122	352.45	
5.3a	1.0151	503.4609	1.9641	4.3592	1.3000	1	0.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	1,035,347.27	7,138.51	20	68	10,063.51	Pen 60/70+Asb 8% (5%)
	0.4984	777.5796	1.9641	4.3592	1.3000	1	0.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	315,044.79	2,172.17	35	95	3,444.87	
	-0.0649	1076.3957	1.9641	4.3592	1.3000	1	0.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	86,119.99	593.78	50	122	629.33	
5.4a	1.2476	4121.1017	1.8457	4.3592	1.7983	10	1.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	1,768,409.27	12,192.83	20	68	16,153.23	Pen 60/70+Asb 8% (5%)
	0.7545	7518.7502	1.8457	4.3592	1.7983	10	1.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	568,183.65	3,917.51	35	95	7,397.91	
	0.1347	11789.6456	1.8457	4.3592	1.7983	10	1.00000	6.5	8.649	51.444	17.544	9.025	8.4083	41.3	136,352.18	940.12	50	122	1,698.91	
6.1a	-0.1352	8.4793	2.4047	5.5512	0.3035	0.01	-2.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	73,244.76	505.01	20	68	1,034.30	Pen 60/70+Asb 8% (6%)
	-0.4065	9.3850	2.4047	5.5512	0.3035	0.01	-2.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	39,218.70	270.41	35	95	292.59	
	-0.6282	10.1252	2.4047	5.5512	0.3035	0.01	-2.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	23,537.58	162.29	50	122	207.55	
6.2a	0.5549	69.4079	2.2060	5.5512	0.8018	0.1	-1.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	358,814.32	2,473.95	20	68	3,036.14	Pen 60/70+Asb 8% (6%)
	0.0472	90.7475	2.2060	5.5512	0.8018	0.1	-1.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	111,488.08	768.69	35	95	509.26	
	-0.4322	110.9005	2.2060	5.5512	0.8018	0.1	-1.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	36,966.95	254.88	50	122	279.83	
6.3a	0.9836	568.1410	2.0546	5.5512	1.3000	1	0.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	962,982.14	6,639.57	20	68	6,816.99	Pen 60/70+Asb 8% (6%)
	0.4005	877.4760	2.0546	5.5512	1.3000	1	0.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	251,490.61	1,733.98	35	95	1,400.38	
	-0.2351	1214.6813	2.0546	5.5512	1.3000	1	0.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	58,195.55	401.25	50	122	563.47	
6.4a	1.2612	4650.5437	1.9361	5.5512	1.7983	10	1.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	1,824,736.33	12,581.19	20	68	11,555.78	Pen 60/70+Asb 8% (6%)
	0.7048	8484.6914	1.9361	5.5512	1.7983	10	1.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	506,708.04	3,493.65	35	95	4,144.87	
	0.0053	13304.2729	1.9361	5.5512	1.7983	10	1.00000	6.5	6.046	65.545	17.535	11.493	8.4083	41.3	101,228.17	697.95	50	122	1,695.25	
7.1a	-0.3014	9.3041	2.4855	6.6837	0.3035	0.01	-2.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	49,953.07	344.42	20	68	828.94	Pen 60/70+Asb 8% (7%)
	-0.5991	10.2979	2.4855	6.6837	0.3035	0.01	-2.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	25,170.39	173.54	35	95	305.76	
	-0.8424	11.1102	2.4855	6.6837	0.3035	0.01	-2.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	14,374.40	99.11	50	122	194.00	
7.2a	0.4751	76.1594	2.2868	6.6837	0.8018	0.1	-1.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	298,613.88	2,058.88	20	68	2,312.30	Pen 60/70+Asb 8% (7%)
	-0.0819	99.5748	2.2868	6.6837	0.8018	0.1	-1.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	82,811.04	570.97	35	95	703.30	
	-0.6080	121.6883	2.2868	6.6837	0.8018	0.1	-1.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	24,662.59	170.04	50	122	234.76	
7.3a	0.9603	623.4065	2.1354	6.6837	1.3000	1	0.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	912,629.72	6,292.40	20	68	5,386.53	Pen 60/70+Asb 8% (7%)
	0.3205	962.8318	2.1354	6.6837	1.3000	1	0.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	209,159.65	1,442.11	35	95	2,049.84	
	-0.3770	1332.8385	2.1354	6.6837	1.3000	1	0.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	41,977.38	289.43	50	122	396.03	
7.4a	1.2764	5102.9215	2.0170	6.6837	1.7983	10	1.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	1,889,727.45	13,029.29	20	68	9,702.57	Pen 60/70+Asb 8% (7%)
	0.6658	9310.0328	2.0170	6.6837	1.7983	10	1.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	463,264.87	3,194.12	35	95	5,052.02	
	-0.1017	14598.4351	2.0170	6.6837	1.7983	10	1.00000	6.5	3.720	78.823	17.556	13.838	8.4083	41.3	79,128.68	545.58	50	122	1,102.26	

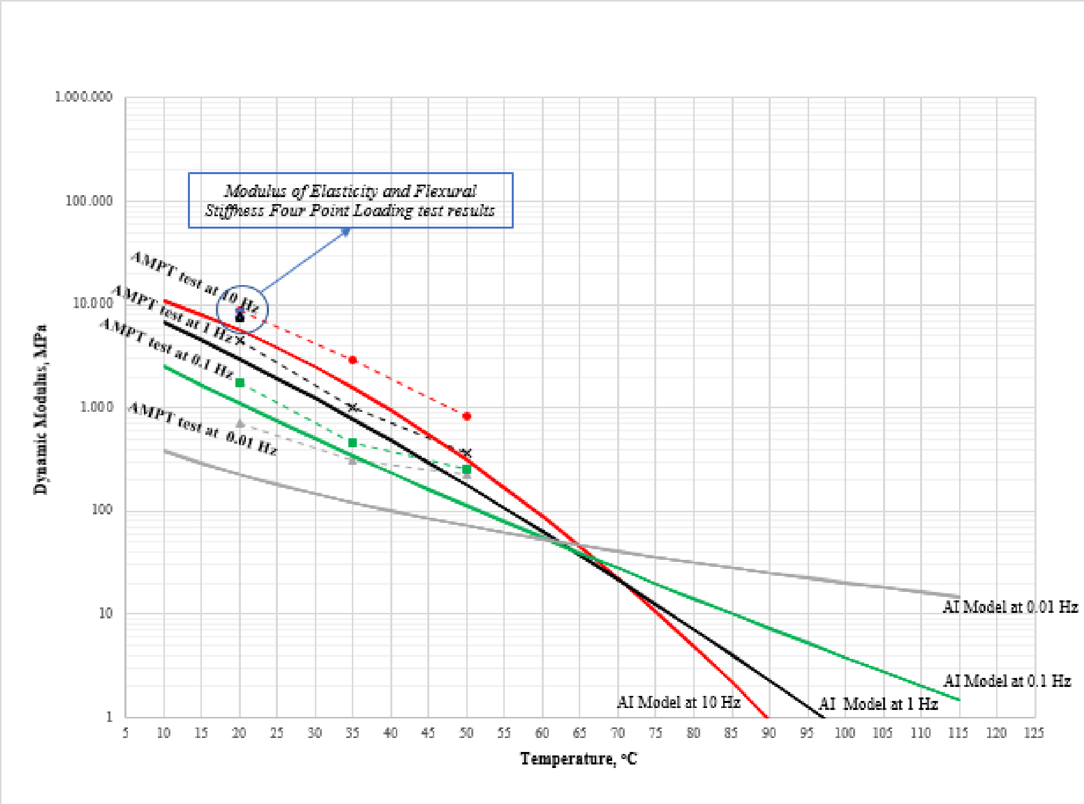

Fig. 2. The dynamic modulus relationship (E*) of AI model with modulus of elasticity and flexural stiffness from four point loading test result and AMPT testing of HMA without asbuton in asphalt content 6%

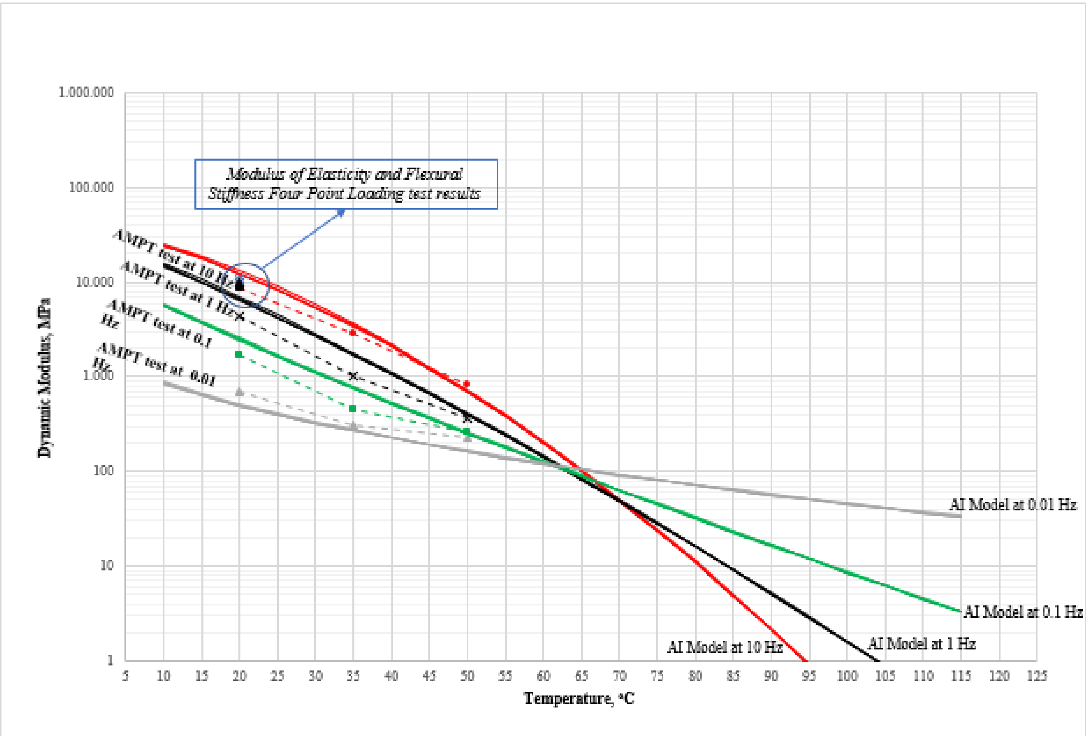

Fig. 3. The dynamic modulus relationship (E *) of AI model with modulus of elasticity and flexural stiffness of four point loading test result and AMPT testing of HMA with 8% asbuton in asphalt content 6%

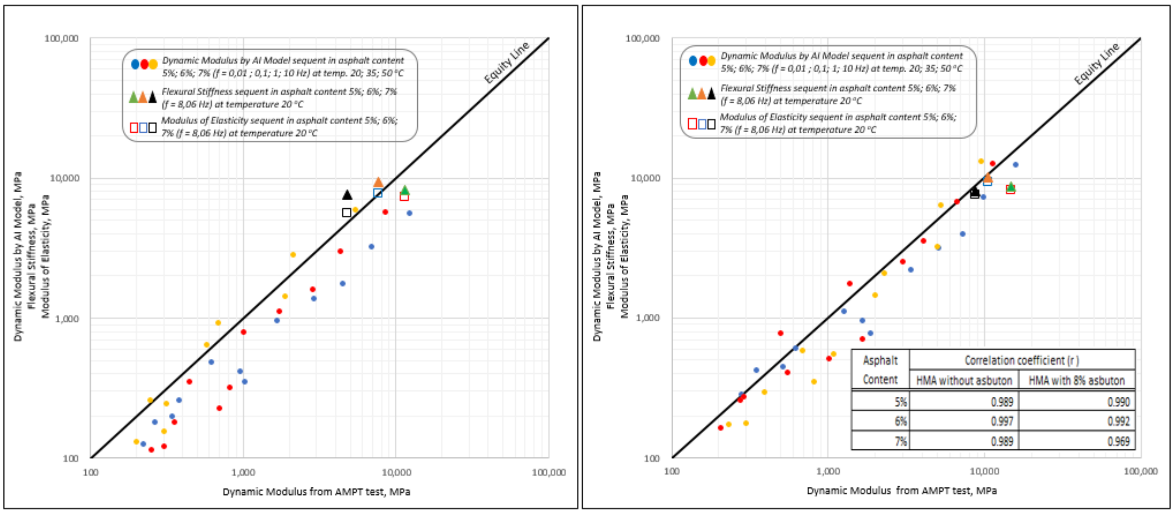

Fig. 4. The dynamic modulus relationship (E*) of AI model with modulus of elasticity and flexural stiffness of Four Point Loading test result and AMPT testing of HMA without and with 8% asbuton

3.2 Fatigue cracking

The test of fatigue crack used is Four Point Loading. This test method refers to ASTM D7460-10 with a frequency of 8.06 Hz (equivalent to vehicle speed of 35.54 km/h) with sinusoidal loading at 20 °C. The concept of constant stress testing using fatigue refers to the AI model, then test results and models are verified by statistical analysis with the steps shown in the Figure 5.

The amount of stress is maintained by maintaining the load, the strain that occurs will be greater as the cycle increases. In this test the fatigue life is achieved when the flexural stiffness has been reduced by 50% of the initial value because at this point it is considered to be a shift of the crack, from microcrack to crack propagation / macrocrack (Rowe and Bouldin, 2000).

Summary of fatigue crack test results of HMA with 8% asbuton is presented in Table 3 and for the other mixtures showing the same behavior.

The result of fatigue crack test for asphalt mixture without and with 8% asbuton were then plotted into fatigue life correlation graph with flexural stiffness, shown in Figure 6 and 7 below this. As for the other asphalt mixture shows the same behavior.

Table 3. Fatigue (N_f) test results of HMA with 8% asbuton

Type of HMA	Asphalt Content (%)	Initial Stress (kPa)	Initial Strain $\mu\varepsilon$	Flexural Stiffness (MPa)			Modulus of Elasticity (MPa)		N_f (Cycles)	Explanation
				Initial	Current	Termination	Initial	Current		
Pen 60/70 + Asb 8%	5	2,065	227	9,093	4,538	4,547	9,661	4,821	102,780	
		2,455	296	8,255	4,056	4,128	8,783	4,.315	20,550	
		2,656	366	7,257	3,449	3,629	7,717	3,667	12,150	
	6	2,064	221	9,351	7,686	4,675	9,953	8,181	312,600	discontinued
									1,111,700	Extrapolation result
		2,453	248	9,883	7,945	4,941	10,515	8,453	175,110	discontinued
									669,510	Extrapolation result
		2,649	292	9,076	7,332	4,538	9,654	7,798	124,920	discontinued
									360,200	Extrapolation result
	7	2,065	272	7,594	3,780	3,787	8,088	4,026	274,320	
		2,445	319	7,668	3,817	3,834	8,164	4,064	157,790	
		2,656	358	7,412	3,684	3,706	7,880	3,917	93,780	

note: * discontinued, because if testing continues it will take a very long time, for it must be extrapolated

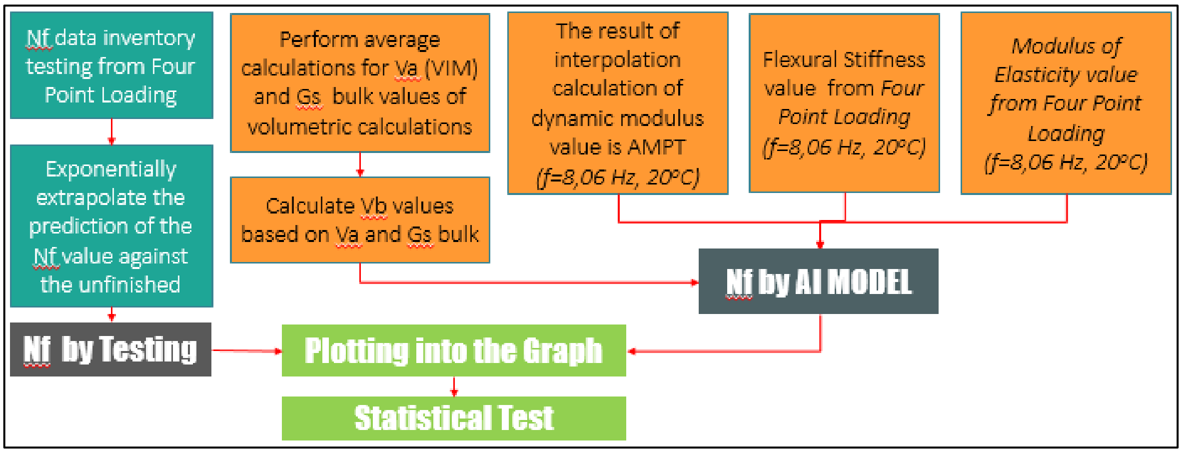

Fig. 5. The steps to verify the Four Point Loading test results on the fatigue life (N_f) AI model

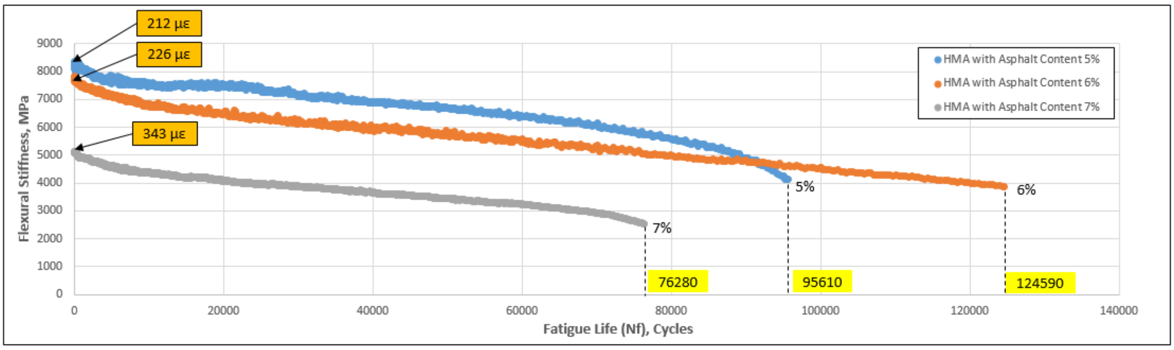

Fig. 6. Relationship of flexural stiffness with fatigue life (N_f) for HMA without asbuton at a stress of 1750 kPa

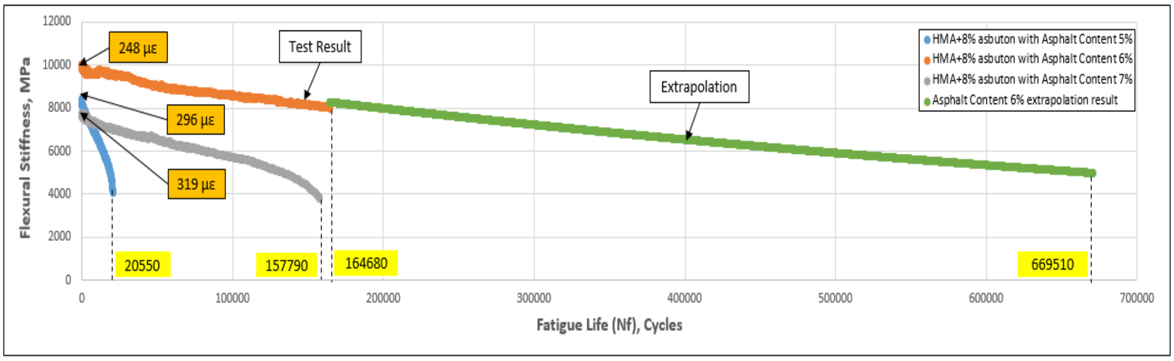

Fig. 7. Test results and extrapolation flexural stiffness vs fatigue life (Nf) for HMA with 8% asbuton at a stress of 2450 kPa

In this study, there were 3 (three) tests of unfinished fatigue life, all three for asphalt mixture 8% asbuton with 6% asphalt content. The tests were carried out at a stress of 2065 kPa, 2450 kPa and 2650 kPa with fatigue life when discontinued respectively were 312,600 cycles, 175,110 cycles and 124,920 cycles which can be seen in Table 3.

The predicted fatigue life can be performed by extrapolating the graph of the decrease in the flexural rigidity modulus to fatigue life to 50% of the initial flexural stiffness modulus (NCHRP, 2010).

If the fatigue life (N_f) values have been calculated based on the AI model and the Four Point Loading test results are plotted into the graph, then the AI model calculation results obtained and the test results show that it is generally adjacent.

The relationship between test results using Four Point Loading and model, can be seen in Figure 8. Generally, from the results of the fatigue crack testing using Four Point Loading, it has been shown that asphalt mixture with 8% asbuton has a fatigue life (N_f) greater than asphalt mixture without asbuton. This illustrates that the asphalt mixture with 8% asbuton is more resistant to fatigue than the asphalt mixture without asbuton.

Verification based on the results of statistical analysis of the fatigue life using the four points loading test results

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with AI Model is good enough in predict fatigue life, with 95% confidence level and significance (error) 5%.

The relationship between the test results and the fatigue crack model is shown in Figures 9. From the analysis showed that the mixture was asphalt without and with 8% asbuton, most of fatigue life (N_f) from Four Point Loading test were lower than model. The laboratory model need to be calibrated for variations wheel track and loading time occuring on site.

Table 4. Result of calculation of fatigue life (Nf) model AI based on dynamic modulus value (E*) from AMPT test interpolated at frequency of 8.06 Hz and temperature 20 °C

Type HMA	Strain ($\mu\varepsilon$)	Dynamic Modulus AMPT (MPa) 20 °C; 8.06 Hz	Dynamic Modulus AMPT (Psi) (x 145)	Va (%)	Vb (%)	M	Nf AI Model (cycles)	Nf from Four Point Loading Testing (cycles)
Pen 60/70 (5%)	212	11,327.17	1,642,439.17	8.32	10.84	-0.60	120,617.11	95,610.00
	283	11,327.17	1,642,439.17	8.32	10.84	-0.60	46,617.73	22,700.00
	374	11,327.17	1,642,439.17	8.32	10.84	-0.60	18,623.44	13,010.00
Pen 60/70 (6%)	226	7,698.22	1,116,241.21	5.84	13.17	0.01	558,008.68	124,590.00
	263	7,698.22	1,116,241.21	5.84	13.17	0.01	338,795.37	117,280.00
	314	7,698.22	1,116,241.21	5.84	13.17	0.01	189,067.27	58,220.00
Pen 60/70 (7%)	343	4,745.24	688,059.82	3.61	15.51	0.59	800,285.83	76,280.00
	307	4,745.24	688,059.82	3.61	15.51	0.59	1,152,724.92	94,350.00
	461	4,745.24	688,059.82	3.61	15.51	0.59	302,453.30	23,380.00
Pen 60/70+8% asbuton (5%)	227	14,840.56	2,151,880.77	8.65	10.78	-0.65	67,602.00	102,780.00
	296	14,840.56	2,151,880.77	8.65	10.78	-0.65	28,224.07	20,550.00
	366	14,840.56	2,151,880.77	8.65	10.78	-0.65	14,035.39	12,150.00
Pen 60/70+8% asbuton (6%)	221	10,534.31	1,527,474.71	6.05	13.11	-0.03	419,568.29	312,840.00
	248	10,534.31	1,527,474.71	6.05	13.11	-0.03	287,115.84	175,110.00
	292	10,534.31	1,527,474.71	6.05	13.11	-0.03	167,734.60	124,920.00
Pen 60/70+8% asbuton (7%)	272	8,772.22	1,271,971.97	3.72	15.46	0.56	960,500.99	274,320.00
	319	8,772.22	1,271,971.97	3.72	15.46	0.56	569,445.64	157,790.00
	358	8,772.22	1,271,971.97	3.72	15.46	0.56	388,897.40	93,780.00

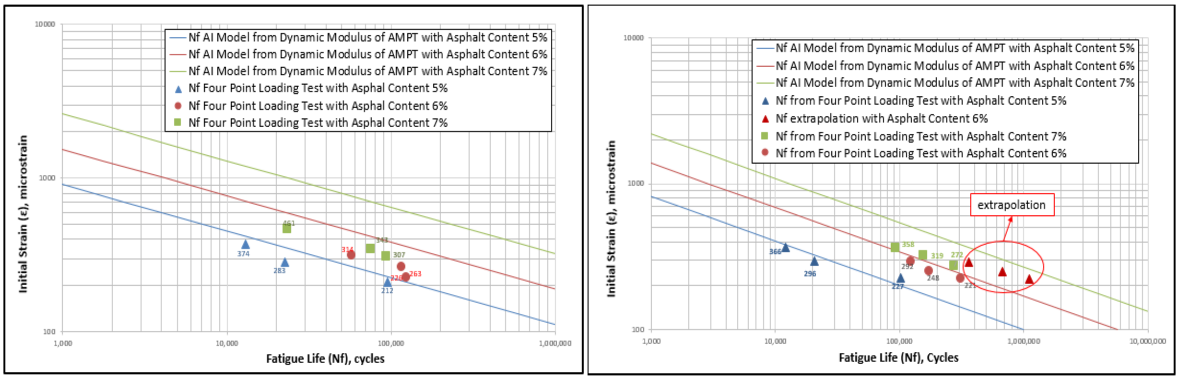

Fig. 8. Fatigue life (N_f) relationship of HMA from four point loading test results and N_f AI model of dynamic modulus (E*) AMPT interpolated for HMA without and with 8% asbuton at frequencies 8.06 Hz and temperature 20 °C

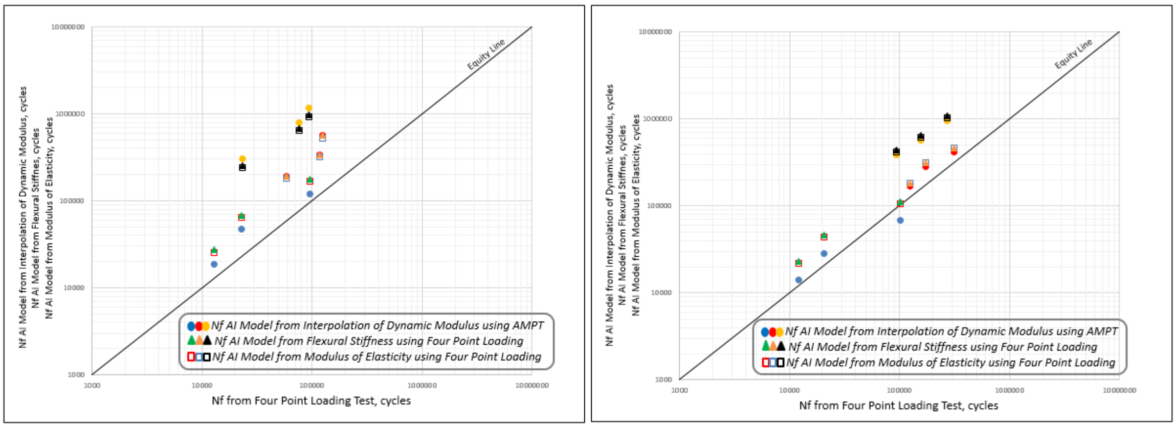

Fig. 9. Fatigue life (N_f) relationship of four points loading test with AI fatigue crack model based on dynamic modulus (E*) of AMPT and flexural stiffness and modulus of elasticity from four points loading for HMA without and with 8% asbuton at frequency 8.06 Hz at 20^{o}C

4 Conclusions

From data analysis explained above some conclusions can be drawn, as follows:

a. The result of verification of relation between dynamic modulus (E*) using AMPT testing with dynamic modulus model by Asphalt Institute, showed fairly consistent result indicated by correlation coefficient (r) which ranged from 0.969 to 0.997.
   Yet, the test results show that most of the modulus values are greater than those computed by the model. This, if seen from its influence on flexible pavement design, that the model is the safe side.
b. The result of verification between fatigue crack/fatigue life (N_f) Four Point Loading with AI Model is good enough in predict fatigue life, with 95% confidence level and significance (error) 5%.
   From the analysis showed that the mixture was asphalt without and with 8% asbuton, most of fatigue life (N_f) using Four Point Loading were lower than model. The laboratory model need to be calibrated for variations wheel tracks and loading time occuring on site. The calibration factor of this model is still to be subject for futher research.

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