The influence of vehicle speed changes at mechanistic performance of asphalt mixture

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Abstract. Asphalt mixture is a viscoelastic material. Several factors affect the behavior of a viscoelastic material. Temperature and loading time are the most critical of these parameters. Vehicle speed affects time loading, therefore it's very important to know the influence of vehicle speed changes in mechanistic performance of bitumen and asphalt mixture with different aggregate gradation types, namely dense graded and gap graded. Based on data of bitumen penetration, bitumen softening point, volume of bitumen, volume of aggregate and volume of voids, mechanistic performance of bitumen and asphalt mixture influenced by vehicle speed changes can be predicted using the software BANDS 2.0. The variation of vehicle speed will be carried out to see its significance. The results of the BANDS 2.0 simulation show that vehicle speed changes influence bitumen stiffness, asphalt mix stiffness and fatigue life asphalt mix. The higher the vehicle speed is, the higher bitumen stiffness and asphalt mix stiffness will be, but fatigue life asphalt mix will be lower. At the same vehicle speed, asphalt mix stiffness of dense graded mixture will be higher than gap graded mixture. The other way for fatigue life asphalt mix.

1 Introduction

Asphalt mixture is a viscoelastic material. The behavior of this material combines two parts: elastic behavior and viscous behavior. Materials with elastic behavior return to their initial state after removal of the applied loads, whereas permanent deformations remain under applied loads for viscous behavior. Several factors affect the behavior of viscoelastic material. Temperature and loading time are the most critical of these parameters. A viscoelastic material has more elastic behavior at low temperatures and is more viscous at high temperatures. Asphalt mixture as a viscoelastic material behaves as a viscous liquid at long times of loading and behaves like an elastic solid at short times of loading [1–7]. Vehicle speed affect time loading, therefore it is very important to know the effect of vehicle velocity changes in mechanistic performance of bitumen (for example: bitumen stiffness) and hotmix asphalt (such as asphalt mix stiffness and fatigue life asphalt mix) with different aggregate gradation types, namely dense graded and gap graded.

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The type of asphalt mixture frequently used for wearing course in Indonesia is Asphalt Concrete-Wearing Course (AC-WC) and Hot Rolled Sheet-Wearing Course (HRS-WC) [8]. Nevertheless, those two types of hot mix asphalt have different gradation, in which AC-WC is a dense graded mixture while HRS-WC is a gap graded mixture.

Gradation is the distribution of aggregate based on size. Particle size or grain size can be obtained through sieve analysis. Aggregate gradation can be classified into dense graded and poor graded. The first is an aggregate which particle size is evenly distributed in a range of particle sizes. The second is an aggregate which does not meet the requirements of good gradation, consisting of uniform graded, open graded and gap graded. Uniform graded is composed of aggregates which have the same or nearly the same size particle size. Open graded is aggregate that has a particular particle size distribution in which the pores are not well filled. Meanwhile, gap graded is an aggregate that has uneven particle size distribution, or there is a particle size that does not exist and if there are some, only a very small amount is present [9].

Aggregate gradation determines stability, permeability, density and voids/pores in asphalt mixtures [9-15]. Previous studies indicate that aggregate gradation affects the degree of degradation more than any other factors [16-19]. The gap graded asphalt mixture experienced a greater amount of aggregate degradation after compaction compared to the continuously graded mixture [20].

In Indonesia, the testing of asphalt mixture is performed through Marshall Test. It was initially developed by Bruce Marshall and continued by the US Corps Engineer. It was then standardized by ASTM and AASHTO through several modifications, namely ASTM D 1559-76 and AASHTO T-245-90. The test is frequently employed to determine the performance of the asphalt concrete mixtures, such as the test specimen volume, stability, flow, Marshall Quotient, and voids (VIM, VMA, VFWA) in asphalt concrete mixtures [9,21].

Mechanistic performance of bitumen (for instance: bitumen stiffness) and hotmix asphalt (such as asphalt mix stiffness and fatigue life asphalt mix) can be measured quickly and easily using a test. For examples, indirect tensile stiffness modulus test can be carried out (ITSM test) to determine bitumen stiffness and asphalt mix stiffness, and by using fatigue test one could find out the fatigue life asphalt mix. However, when testing is not feasible, then the stiffness of a particular mixture at any temperature and time of loading can be estimated by empirical methods [3]. In 1977, Shell produced a nomograph to predict the stiffness of an asphalt [22]. These nomographs can be simulated by the software BANDS 2.0. This study aimed to know the effect of vehicle speed changes in mechanistic performance of bitumen (for example: bitumen stiffness) and hotmix asphalt (such as asphalt mix stiffness and fatigue life asphalt mix) with different aggregate gradation types, namely dense graded and gap graded using the software BANDS 2.0 based on data of bitumen penetration, bitumen softening point, volume of bitumen, volume of aggregate and volume of voids.

2 Materials and method

The materials are bitumen penetration 60/70 (penetration = 60,5 (in 0,1 mm), softening point = 51,5°C), coarse aggregate and fine aggregate based on the Bina Marga specification (2010). Subsequently, the dense graded asphalt concrete-wearing course (AC-WC) and gap graded hot rolled sheet-wearing course (HRS-WC) are also prepared. The AC-WC and HRS-WC specifications also refer to Bina Marga [23]. Specifically, the gradations of AC-WC and HRS-WC are presented in Table 1. These hotmix asphalts are tested using Marshall test to find the optimum bitumen content and Marshall properties. The optimum bitumen content for AC-WC was 5.80% and for HRS-WC it was 6.35%. Vehicle speeds are

40, 50, 60, 70, 80, 90, 100 km/h. Time loading is determined based on the Groenendijk formula [24]: $\log t_b=0,5h-0,2-0,94\log v$ [25] , where t_b : *loading time (s)*, h: surface course thickness (m), and v: vehicle speed (km/h). Based on the results of the bitumen test and the Marshall test, mechanistic performance of asphalt and hotmix asphalt influenced by vehicle speed changes are predicted by the software BANDS 2.0 simulation.

Table 1. Gradation envelop of AC-WC and HRS-WC based on Bina Marga (2010) specification.

Ø sieve	AC-WC			HRS-WC		
	Specification	Medium specification	Actual	Specification	Medium specification	Actual
3/4 "	100	100	100	100.00	100	100
1/2 "	90-100	95	92.31	90-100	95	90.07
3/8 "	77-90	83.5	83.53	75-85	80	79.85
No. 4	53-69	61	60.85	-	-	-
No. 8	33-53	43	41.92	50-72	61	61.20
No. 16	21-40	30.5	30.05	-	-	-
No. 30	14-30	22	21.30	35-60	47.5	35.31
No. 50	9-22	15.5	14.62	-	-	-
No. 100	6-15	10.5	10.19	-	-	-
No. 200	4-9	6.5	6.50	6-10	8	8.52
Pan	0	0	0	0	0	0

3 Marshall properties

Based on the optimum bitumen content of several AC-WC and HRS-WC asphalt mixtures, specimens are made to reveal the Marshall properties. The properties are presented in Table 2.

Table 2. Marshall properties of AC-WC and HRS-WC asphalt mixture from Marshall test.

Marshall Properties	Unit	AC-WC		HRS-WC	
		specification	actual	specification	Actual
Marshall Stability	Kg	≥ 800	1412.31	≥ 800	1319.51
Flow	mm	2≤4	3.57	≥ 3	3.77
VIM (Void in the mix)	%	3≤5	4.54	4 ≤ 6	5.46
VMA (Void in mineral aggregate)	%	≥14	17.53	≥ 18	19.61
VFWA (Void filled with asphalt)	%	≥65	74.14	≥ 68	72.25
Marshall Quotient (MQ)	Kg/mm	≥250	402.03	≥ 250	356.37

4 The influence of vehicle speed changes at mechanistic performance of asphalt mixture

The influence of vehicle speed changes at mechanistic performance of hotmix asphalt are simulated by the software BANDS 2.0. Bitumen stiffness (Sbit) is obtained by input data of bitumen penetration and bitumen softening point. Asphalt mix stiffness (Smix) is derived from data of Sbit, volume of bitumen, volume of aggregate and volume of hotmix asphalt,

while fatigue life asphalt mix (NFAT) from data of Smix and the volume of bitumen of each hotmix asphalt mixture. The results from the simulation of the software BANDS 2.0 are shown in Table 3 and Table 4.

Table 3. Bitumen stiffness (Sbit), Asphalt mix stiffness (Smix) and Fatigue life asphalt mix (NFAT) at variation of vehicle speed from BANDS 2.0 simulation.

No	V (km/h)	Loading		Sbit (MPa)		Smix (MPa)		Nfat (x1000)	
		Time (s)	Temperat ure (°C)	AC- WC	HRS- WC	AC-WC	HRS- WC	AC-WC	HRS- WC
1	40	0.0208	20	21.8	21.8	7890	6590	0.396	0.797
2	50	0.0169	20	24.7	24.7	8400	7030	0.354	0.709
3	60	0.0143	20	27.3	27.3	8830	7410	0.323	0.645
4	70	0.0123	20	29.5	29.5	9170	7710	0.302	0.600
5	80	0.0108	20	31.4	31.4	9470	7970	0.285	0.565
6	90	0.0079	20	36.5	36.5	10200	8610	0.249	0.492
7	100	0.0071	20	38.5	38.5	10500	8850	0.238	0.464

Table 4. Bitumen stiffness (Sbit), Asphalt mix stiffness (Smix) and Fatigue life asphalt mix (NFAT) at variation of temperature and V= 50 km/h from BANDS 2.0 simulation.

No	V (km/h)	Loading		Sbit (MPa)		Smix (MPa)		Nfat (x1000)	
		Time (s)	Temperatu re (°C)	AC- WC	HRS- WC	AC-WC	HRS- WC	AC-WC	HRS- WC
1	50	0.0169	15	49.5	49.5	11900	10100	0.190	0.371
2	50	0.0169	20	24.7	24.7	8400	7030	0.354	0.709
3	50	0.0169	25	11.3	11.3	5710	4700	0.709	1.460
4	50	0.0169	27	8.1	8.1	4830	3950	0.957	2.000

Based on the tables above, the effect of vehicle speed changes at mechanistic performance of asphalt mixture are presented in Figure 1, Figure 2 and Figure 3

Fig. 1. Graph of relation between vehicle speed and bitumen stiffness (Sbit) from BANDS 2.0 simulation.

Fig. 2. Graph of relation between vehicle speed and asphalt mix stiffness (Smix) from BANDS 2.0 simulation.

Fig. 3. Graph of relation between vehicle speed and fatigue life asphalt mix (NFAT) from BANDS 2.0 simulation

The mechanistic properties of bitumen and hotmix asphalt influenced by vehicle velocity speed simulated by software BANDS 2.0 are that the higher the vehicle speed is the the higher bitumen stiffness (Sbit) will be. While mechanistic performance of hotmix asphalt at variation of vehicle speed with different gradation asphalt mixtures, namely dense graded and gap graded are as follows:

- **Asphalt mix stiffness (Smix).** Asphalt mix stiffness is used to assess the resistance asphalt mix to deformation. The higher the vehicle speed is the higher the asphalt mix stiffness (Smix) will be. At the same vehicle speed, AC-WC mixture has a higher Smix than HRS-WC mixture. Dense graded has a higher Smix than gap graded, therefore dense graded is more rigid than gap graded and more stable to support traffic load.
- **Fatigue life asphalt mix (NFAT).** Fatigue in bituminous pavement is the phenomenon of cracking that is caused by tensile strains generated in the pavement by traffic loading, temperature variations and construction practices. Fatigue life is the number of load applications to initiate a fatigue crack. The higher the vehicle speed is the lower the fatigue life asphalt mix (NFAT) will be. At the same temperature, AC-WC mixture has lower NFAT than HRS-WC mixture. Dense graded has lower NFAT than gap graded, so dense graded has fatigue resistance lower than gap graded. AC-WC is a dense graded mixture, HRS-WC is a gap grade mixture. Dense graded has lower NFAT than gap graded, so AC-WC has a lower fatigue resistance than HRS-WC. The higher speed (less loading time) will be faster to initiate cracks because asphalt mixtures with less loading

time has a high stiffness mixture (Smix), which means it is more rigid. Rigid tends to initiate cracks faster than flexible.

5 Conclusions

Mechanistic performance of bitumen and hotmix asphalt are influenced by vehicle speed changes sensitively. The higher the vehicle speed is the higher the bitumen stiffness (Sbit) will be. The higher the vehicle speed is the higher the asphalt mix stiffness (Smix) will be, while fatigue life asphalt mix (NFAT) will be lower. At the same temperature, dense graded mixture has a higher value of bitumen stiffness (Sbit) and a lower value of fatigue life asphalt mix (NFAT).

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