Application of the Cementitious Grouts on Stability and Durability of Semi Flexible Bituminous Mixtures

Muhammad Karami[1, a)]

[1]Civil Engineering Department, Lampung University, Soemantri Brojonegoro Street No.1, Bandar Lampung 35145, Indonesia

[a)]muhammad.karami@eng.unila.ac.id

Abstract. This paper describes the results of laboratory test for a high durability semi flexible bituminous mixtures (SFBM). The SFBM consists of an open asphalt structure where a high strength mortar is penetrated into the air voids of the bituminous mixtures. The SFBM combines the cement concrete's strength and the asphalt material flexibility. The objective of this study is to involve in the determination of stability and durability of SFBM by located the position of the specimen on an exposed area for 7, 90, 180 and 240 days. The performance of the SFBM was assessed using Marshall and wheel tracking apparatus. Total 18 specimens were prepared and examined for both of test. The Marshall specimens were cylindrical with dimension of 10.16 cm in diameter and 6.35 cm in high. For wheel tracking test, the specimens consisted of slabs with dimension of 30 cm in length, 30 cm in width and 5 cm in height. The results indicated that the first durability index and second durability index increased significantly. For Marshall test, the first and second durability index increased about 0.9% per day and 52.3%, respectively. However, for wheel tracking test, the first and second durability index increased about 1.9% per day and 119%, respectively.

1. INTRODUCTION

One of the major reasons for flexible pavement distress and deterioration of highway serviceability is the low durability of the wearing course. Durability is the property of bituminous mixtures that describes its ability to resist the detrimental effect of air, water, temperature and traffic. Included under weathering are changes in the characteristics of asphalt, such as oxidation and volatilization, and changes in the pavement and aggregates due to action of water. High durability potential usually implies that the mechanical behavior of the mixture will endure for a long service life.

Craus *et al.* [1] defined the durability potential of bituminous mixtures as the resistance of bituminous mixtures on the continous and combined of water and temperature effects. The durability of bituminous mixtures was characterised by the mechanical response under long exposure to water and tempareture [2]. Water is a main cause of failure in bituminous mixtures. Water loss the adhesion between the aggregate and the bitumen, and the cohesion within the bitumen binder resulted in a loss of stiffness and structure strength [3-5]. Hence the adhesion between the aggregate and bitumen is needed if the durabilty performances of bituminous mixture are to be improved. Several methods have been used to increase the adhesion between aggregate and bitumen, including the addition of filler, of polymers and of amine-based anti-stripping agents (ABAA). The beneficial effects of hydrated lime on bitumnious mixtures durability have been reported by Lesueur *et al.* [6]. Cui *et al.* [3] showed that the addition of the ABAA to the bitumen after 3 days of immersion in water improved the interfacial between the bitumen and aggregates. The Styrene-Butadiene-Styrine (SBS polymer) improved the water resistance by increasing the adhesion between the aggregate and the bitumen [3, 7].

Recently the present authors developed semi flexible bituminous mixtures (SFBM) for heavy duty areas [8-11]. SFBM material consists of an open asphalt structure where a high strength mortar is penetrated into the air voids (approximately 20%) of the bituminous mixtures. The SFBM combines the cement concrete's strength and asphalt material flexibility. Setiawan [8] reported that the strenght of SFBM were influenced by the strength of mortar (cementitious grouts), otherwise the compressive strength of SFBM were more affected by the strengths of aggregates and structure of pores. Koting *et al.* [12] examined the effect of superplasticizer type and dosage on the workability and compressive strength of cementitious grouts mixtures. The results show that the type and dosage of superplasticizer influence the flowability of cementitious grouts and the variation of water/cement ratio also influence on the strength and flow of the cementitious grouts. The conventional rigid and flexible pavement contributes the load over the subgrades in the different way. A rigid pavement tends to cause a dispersed spread of pressure over the lower layers, while flexible pavement responds to load near the loading area. Thus, the SFBM spread the pressure over the subgrade tends to become more diffused compared to a conventional flexible pavement [9]. Its stronger rigidity can ensure a higher tolerance of loads without causing any ruts.

Durability of bituminous mixtures is an important characteristic modes since it affects service life of pavement. In this research, therefore, Marshall and wheel tracking (WT) test were performed to undertake the durability performance of SFBM in a period of time. This durability values are under actual service condition, based on the condition of temperature, water and air. The objective of this research is to quantify the durability performance of SFBM asphalt mixtures based on the first and second durability index.

2. EXPERIMENTAL

2.1. Material

A crushed granite aggregate from an aggregate crusher in south part of Lampung, Indonesia was used in all of the mixtures. In addition, the used mineral filler was rock dust, passed through sieve no. 200 (0.075 mm). The properties of aggregates are given in Table 1. An open graded bituminous mixture was used in this investigation and the aggregate grading used are given in Fig. 1. The two curves in the figure show the upper and lower limits of the permitted grading according to highway national code. Aggregate gradation was adopted for the open graded asphalt mixtures used in this investigation. The gradation was selected to result in a compacted porosity in the means of 20%. Asphalt cement pen 60/70 was used for this study, provided from Indonesia oil company (Pertamina). Physical properties of this asphalt cement were provided in Table 2.

The cementitious grout materials used in this study was designed by combined Portland cement (PC) with water. The composition of PC/water ratio was based on wider study conducted to evaluate the strength range 150 to 360 kg/cm^2 on seven days curing.

2.2. Bitumen content and specimen preparation

The mix design procedure for the SFBM followed establishs design guidelines as set in several previous investigations on open graded asphalt design. The optimum bitumen content required is based on a result in a durable mixtures requirements e.g. porosity, cantabro loss and binder drainage. The limit values of porosity, cantabro scattering loss and binder drainage conducted in this study were minimum 20%, maximum 20% and maximum 5%, respectively. Specimen in triplicate with dimension of 101.6 ± 0.5 mm diameter and 63.5 mm height were compacted for each bitumen content and for each requirement. Optimum amount of bitumen was determined to be 4,6% and the results are presented in Fig. 2 and Fig.3.

Table 1. Properties of aggregates.

Properties	Values
Bulk specific gravity of coarse aggregate	2.577
Bulk specigfic gravity of fine aggregate	2.581
Bulk specific gravity of filler	2.777
Water absorption of coarse aggregate (%)	1.546
Water absorption of fine aggregate (%)	2.438
Abration Loss (LA) (%)	13.8
Affinity of bitumen (%)	100

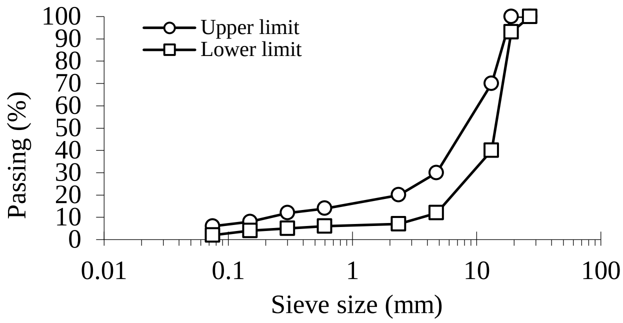

Fig. 1. Crushed aggregate gradation

Table 2. Properties of bitumen

Properties	Test value
Penetration, 100 grams, 25^{o}C, 5 s (dmm)	70
Ductility (cm)	> 140
Softening Point (ring and ball) (^{o}C)	51.5
Rolling Thin Film Oven, 163 ^{o}C, 5 hours	0.26
Specific Gravity	1.04

The mixture of aggregates-filler were heated to 150^{o}C, the binder was heated separately with constant stirring to about 130^{o}C and the required of asphalt cement were added to the hot aggregates and mix thoroughly using a mechanical mixer for 1.5 minutes.

The specimens were prepared by compaction in the Marshall mould, with 50 blows of the 10 lb hammer on each side of the specimen to a final height of 6,35 cm and 10,1 cm in diameter. The specimen are allowed to cool overnight then removed from the mould by using electrical extrusion jack. For the WT test, the specimens were prepared by roller compaction in the WT mould. The dimension of specimens is 30 cm long, 30 cm width and 5 cm thick. The specimens are allowed to cool overnight then removed from the mould.

All open graded bituminous mixes are grouted after 24 hours curing. Penetration of cement fluid was aided by spreading the fluid grout onto the surface of the specimen. The grouts was designed to flow into the pores under the effect of gravitational pull and also helped for vibrations. The grouted bituminous mixtures cylinders and slab were demoulded. For Marshall durability determination, nine specimens were grouped into three. Each group was three specimens and placed in the exposed area for 7, 90 and 180 days. For WT durability test, the specimens were also grouped into three and placed in the expose area for 7, 90 and 240 days.

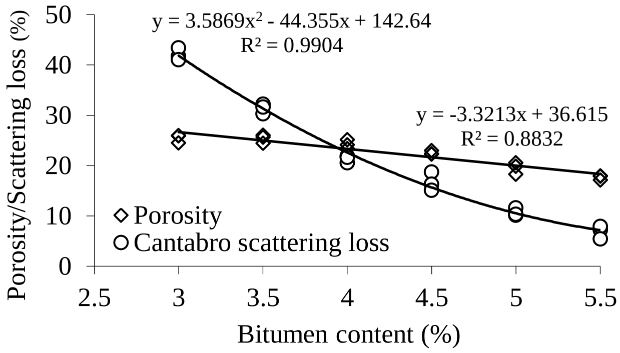

Fig. 2. Porosity and scattering loss determination

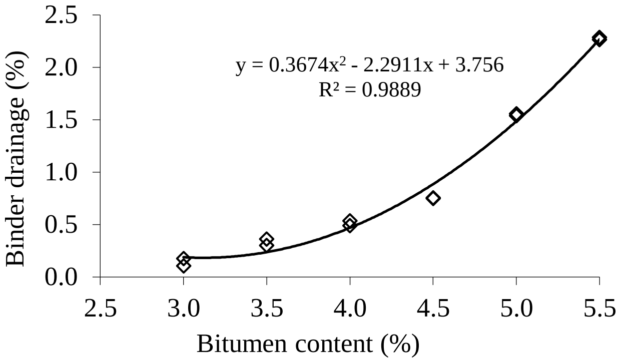

Fig. 3. Binder drainage

2.3. Marshall and wheel tracking test

The Marshall test samples were put in a waterbath at a temperature of 60±1°C for 30 minutes. The samples were then removed from the waterbath and placed centrally in the lower segment of the testing head. The upper segment of the testing head was placed on the test specimen and the complete assembly then placed in position in the testing machine. The base travelling at a rate of 48-54 mm/minute was then applied. An automatic Marshall testing machine was used in this test to find out the stability and flow values of asphalt mixtures.

Furthermore, before WT testing was started, the specimen was put in the device cabinet at the required temperaure of 60°C for about 2 hours to allow the specimen temperature to reach equilibrium. The tests were then performed until the wheel travelling stopped automatically after reaching 60 minutes. The behaviour of asphalt mixtures is generally expressed in term of the number of load repetitions the materials is able to carry before acceptable level of permanen deformations. WT tests were performed using a relatively simple testing apparatus as illustrated in Fig. 4. The apparatus consists of a loaded wheel that bears the specimen held on a table. A vertical load is applied to the top of a specimen with a 200 mm diameter wheel.

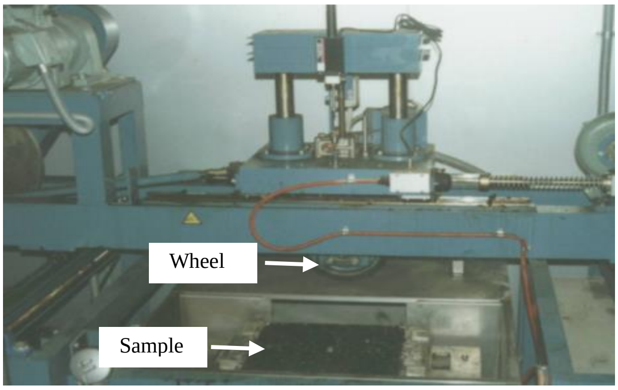

Fig. 4. Set-up of wheel tracking test

3. RESULT AND DISCUSSION

3.1. Ratio of water to cement

Fig. 5 shows the compressive strength of cementitious grouts used in this study for each water-cement ratio tested in 7, 28, 56 and 90 days of curing time.

The results showed that water/cement ratio influenced the compressive strength values. The compressive strength decreases as the ratio of water to cement increases. The ratio of water to cement was 0.5 based on the wider study conducted to evaluate the strength range 150-360 kg/cm^2 on seven day curing. The strength means conducted was 276 kg/cm^2. In addition, increasing the curing time increases the strength of cementitious grouts.

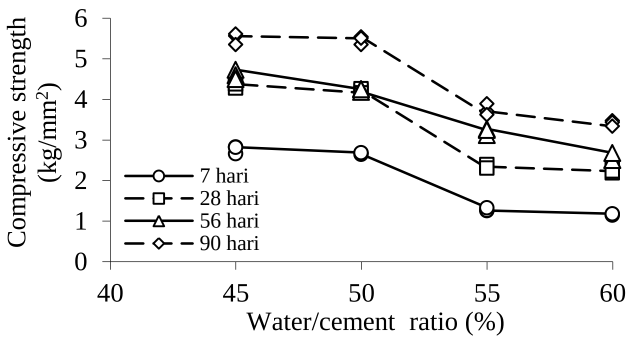

Fig. 5. Compression test values for grouted materials

3.2. Stability

Table 3 and Table 4 show the mean, standard deviation (SD) and coefficient of variation (CV) for Marshall and WT specimens. A *paired sample t-test* with 95% level of confidence was used to statistically analize the mean air voids values for each triplicate group and no significant difference in voids was found between each group.

In addition, Table 5 and Table 6 summarize the Marshall and WT test results, respectively. A longer time to expose resulted in a higher Marshall and WT stability. However, there was no significant difference between the Marshall stability for the 90 and 180 days. The stability of SFBM prepared with 90 and 180 or 240 days was higher than SFBM prepared with 7 days as illustrated in Fig. 6. Thus, the improvement in stability of SFBM is attributed to the stiffer SFBM.

Table 3. VIM and continous void for Marshall specimens

Time (day)	VIM (%)			Continous voids (%)		
	Mean	SD	CV	Mean	SD	CV
7	22	0.8	3.8	16	0.4	2
90	21	0.01	0.1	14	0.8	5
180	22	0.3	1.4	13	0.6	5

Table 4. VIM and continous void for WTM specimens

Time (day)	VIM (%)			Continous voids (%)		
	Mean	SD	CV	Mean	SD	CV
7	20	0.3	1.5	13	1.3	10
90	21	0.8	3.6	12	1.3	11
240	22	0.4	1.8	16	1.2	8

Table 5. Results of Marshall stability of SFBM test

Time (day)	Marshall stability			Flow		
	Mean (kg)	SD (kg)	CV (%)	Mean (mm)	SD (mm)	CV (%)
7	715	4	0.6	2.47	0.3	13
90	1238	14	1.1	2.54	0.3	14
180	1243	4	0.3	2.62	0.3	17

Table 6. Results of dynamic stability test

Time (day)	Dynamic stability (passes/mm)			Rate of deformation (mm/minute)		
	Mean	SD	CV (%)	Mean	SD	CV (%)
7	5624	732	13	0.0076	0.001	13
90	13125	3712	28	0.0033	0.001	28
240	15750	5250	33	0.0029	0.001	35

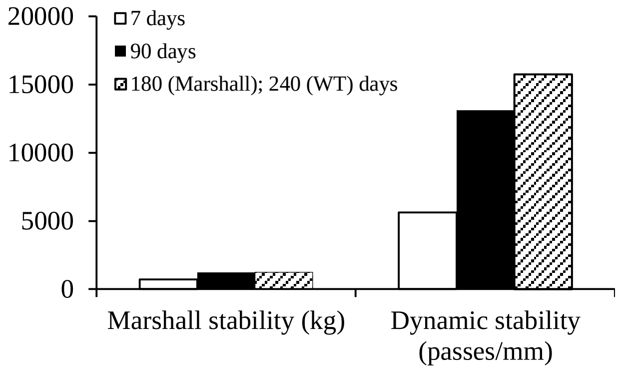

Fig. 6. Marshall and dynamic stability valuse for SFBM

Fig. 7 presents the relationship between the number of wheel cycles and the rut depth (mm) for SFBM obtained from the wheel tracking test. The curve plots the average progression of rut depth from averaging three replicates using a linear regression. Fig. 7 clearly shows that the rut progression curve of SFBM with 7 days curing are very different from SFBM with 90 and 240 days curing. The results obtained for rut depth revealed that SFBM with 90 and 240 days curing perform better than SFBM with 7 days curing after 2520 cycles (60 minutes).

Increasing the curing time tends to increase the Marshall and dynamic stability. Niken *et al.* [13] explained that this process is related to the grouted materials mechanism including solution process and hidration process.

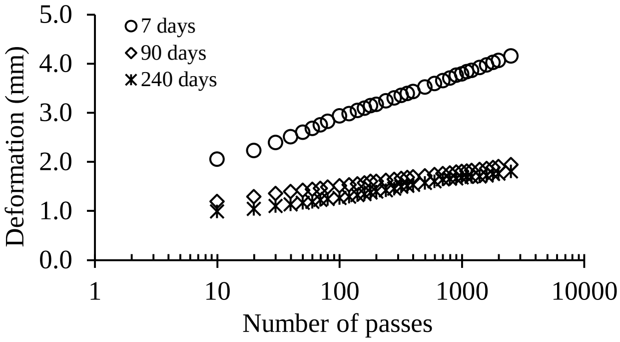

Fig. 7. Rut progression curve of WT test

3.3. Durability potential

Two indices, first durability index and second durability index, were adopted for the analysis of the durability test data. Craus *et al.* [1] proposed the concept of the fist durabilty index (r) as the sum of the slopes of the consecutive sections of the durability curves based upon Equation 1.

$$r = \sum_{i=0}^{n-1} \frac{S_i - S_{i+1}}{t_{i+1} - t_i} \quad (1)$$

where S_{i+1} is percent retained strength at time t_{i+1}, S_i is percent retained strength at time t_i, and t_i, t_{i+1} is immersion period (from beginning of test). The first durability index can be explained with regard to the absolute values of the wighted loss in strengths (R) as shown in Equation 2.

$$R = \frac{r}{100} S_0 \quad (2)$$

where r is the first durability index and S_0 is the absolute value of the initial strength.

In addition, Craus *et al.* [1] and Ishai and Craus [2] defined the second durability index (a) as the average strength area enclosed between the durability curve and the line S_0 = 100% using Equation 4. The second durability index can be defined as the percentage one-day equivalent retained strength ($\bar{s_a}$), the absolute values of the equivalent loss (A) and absolute values of the retained strength ($\overline{S_a}$) presented in Equation 5, Equation 6 and Equation 7, respectively.

$$a = \frac{1}{t_n}\sum_{i=1}^{n} a_i \tag{3}$$

$$a = \frac{1}{2t_n}\sum_{i=0}^{n-1} (S_i - S_{i+1})[2t_n - (t_i + t_{i+1})] \tag{4}$$

$$\bar{s_a} = (100 - a) \tag{5}$$

$$A = \frac{a}{100} S_0 \tag{6}$$

$$\overline{S_a} = S_0 - A \tag{7}$$

Fig. 8 presents the durability curves of SFBM based on Marshall and wheel tracking test. The durability potential of given SFBM was assessed by testing the mixture after 7, 90 and 180 days for Marshall and 7, 90 and 240 days for wheel tracking. The durability behaviour of bituminous mixtures was characterized by testing the mixture after and during longer periods of time (up to 240 days). The relative comparison of the durability curves (retained strength vs. curing time) was used to characterize the durability behavior of the mixtures under Marshall and WT criteria. In general, both tests reflect a similar trend. It can be seen from Fig. 8 that the durability potential of the mixture tested improves with increase in curing time.

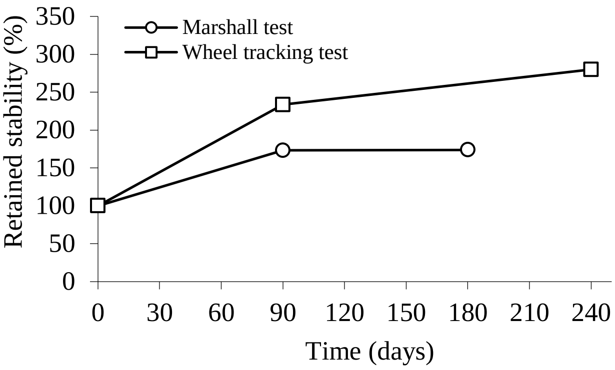

Fig. 8. Durability curves

Table 7 and Table 8 presents the values of two durability indices defined in Equations 1 through Equation 7 and determined from the durability curves representing the Marshall and wheel tracking stability criteria. It can be seen that, in general, both indices reflect a similar trend. For a given testing, however, the second index seems to be more sensitive toward higher values and higher-range strength increased.

Table 7. Values of first durability indices

Criteria	First durability index	
	r	R
Marshall	-0.9%/day	-6.4 kg per day
WT	-1.9%/day	-106 cycles/mm per day

Table 8. Valuse of second durability index

Criteria	Second durability index			
	a	$\bar{s}_a$	A	$\overline{S_a}$
Marshall	-52.3%	152.3%	-374 kg	1089 kg
WT	-119%	219%	-6692 cycles/mm	12316 cycles/mm

The effect of SFBM on the durability potential is basically reflected in the characterization of the durability curves. In general, it can be seen that all types of testing apparatus comply with the durability standard requirement: 75 percent retained strength. This compliance is mainly due to the high quality of bonding, which give the mixture a high initial durability potential. The potential is bound to deteriorate after longer periods of exposing at the open area. Therefore, the influence of SFBM on durability potential is usually increased with curing time. Thus, it can be seen that SFBM maintain a proper retained strength for longer periods at optimum bitumen content.

4. CONSLUSION

Based on the results, penetrating cementitious grouts into open graded asphalt mixtures improved the mechanical properties of semi flexible bituminous mixtures. The stiffness of mixtures is related to the load spreading capacity. Asphalt mixtures with a high stiffness modulus will distribute loads over a wider area. It is expected that semi flexible bituminous mixtures with a higher stiffness would have greater tensile strain and resistance to deformation and cracking.

References

[1] J. Craus, I. Ishai, and A. Sides, *Durability of bituminous paving mixtures as related to filler type and Properties*: Technion-IIT, Transportation Research Institute, 1981.

[2] I. Ishai and J. Craus, "Effects of some aggregate and filler characteristics on behavior and durability of asphalt paving mixtures," *Transportation Research Record: Journal of the Transportation Research Board*, pp. 75-85, 1996.

[3] S. Cui, B. R. Blackman, A. J. Kinloch, and A. C. Taylor, "Durability of asphalt mixtures: Effect of aggregate type and adhesion promoters," *International Journal of Adhesion and Adhesives*, vol. 54, pp. 100-111, 2014.

[4] T. W. Kennedy, F. L. Roberts, and K. W. Lee, *Evaluation of moisture effects on asphalt concrete mixtures*, 1983.

[5] G. Airey, A. Collop, S. Zoorob, and R. Elliott, "The influence of aggregate, filler and bitumen on asphalt mixture moisture damage," *Construction and Building Materials*, vol. 22, pp. 2015-2024, 2008.

[6] D. Lesueur, J. Petit, and H. J. Ritter, "Increasing the durability of asphalt mixtures by hydrated

lime addition: What evidence?," *European Roads Review*, vol. 20, pp. 48-55, 2012.

[7] H. M. Park, J. Y. Choi, H. J. Lee, and E. Y. Hwang, "Performance evaluation of a high durability asphalt binder and a high durability asphalt mixture for bridge deck pavements," *Construction and Building Materials*, vol. 23, pp. 219-225, 2009.

[8] A. Setyawan, "Asessing the compressive strength properties of semi-flexible pavements," *Procedia Engineering*, vol. 54, pp. 863-874, 2013.

[9] P. Solanki and M. Zaman, "Design of semi-rigid type of flexible pavements," *International Journal of Pavement Research and Technology*, 2016.

[10] M. L. Afonso, M. Dinis-Almeida, L. A. Pereira-de-Oliveira, J. Castro-Gomes, and S. E. Zoorob, "Development of a semi-flexible heavy duty pavement surfacing incorporating recycled and waste aggregates–Preliminary study," *Construction and Building Materials*, vol. 102, pp. 155-161, 2016.

[11] J. Pei, J. Cai, D. Zou, J. Zhang, R. Li, X. Chen, *et al.*, "Design and performance validation of high-performance cement paste as a grouting material for semi-flexible pavement," *Construction and Building Materials*, vol. 126, pp. 206-217, 11/15/ 2016.

[12] S. Koting, H. Mahmud, and M. R. Karim, "Influence of superplasticizer type and dosage on the workability and strength of cementitious grout for semi-flexible pavement application," in *Proceedings of the Eastern Asia Society for Transportation Studies The 7th International Conference of Eastern Asia Society for Transportation Studies, 2007*, 2007, pp. 280-280.

[13] C. Niken, Y. Siswanto, and E. Tjahjono, "Cracking of open traffic rigid pavement," in *MATEC Web of Conferences*, 2017, p. 05009.