Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Enhancing Crack Resistance in Concrete Overlays by Shredded Rubber in Stress Absorbing Membrane Interlayer (SAMI)

Edward Ngii[1], La One[1], Rita Irmawaty[2], Latif Budi Suparma[3]

[1]*Department of Civil Engineering, Faculty of Engineering, Universitas Halu Oleo, Indonesia.*
[2]*Department of Civil Engineering, Faculty of Engineering, Universitas Hasanuddin, Indonesia*
[3]*Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia*
Email: edward.ngii@uho.ac.id

Reflection cracking is one of mayor problem in concrete pavement overlay due to the high volume of heavy vehicle traffic. Using interlayer as a reflection crack control is considered as an efficient method in terms of performance and cost. Stress Absorbing Membrane Interlayer (SAMI) has been developed as controls of cracks in flexible pavement overlay, while the application in concrete pavement is still very low. The use of shredded rubber designing SAMI-SR is intended to make the material resistant to high stress and strain. The purpose of this study was to obtain the rubber content in SAMI-SR and the thickness of the SAMI-SR layer as the interlayer in concrete pavement overlay. In this study, the material SAMI-SR consists of shredded rubber, sand, cement, and asphalt. SAMI-SR test specimen made with dimensions of 200×100×10 mm, with 5 (five) variations of shredded rubber and 3 (three) variations of asphalt. The performance testing of SAMI-SR in concrete overlay is based on shrinkage and cracking observations, density analysis, and the content of rubber in the mixture. Three-point flexural test with load beam centered was carried out to assess the performance of SAMI-SR in retarding crack propagation in the overlay layer. The result was obtained that the shredded rubber content made SAMI-SR by 32.6% to 10% bitumen content and the thickness of 2 cm of SAMI-SR was able to increase the performance of concrete overlay layers to serve the same as a new layer and retarding the crack propagation rate 9 times longer than SAMI without shredded rubber.

Keywords: SAMI; Rubber, Interlayer; Overlay.

1. Introduction

The overlay is the most common method to increase the capacity of the old concrete pavement. However, this method would become a problem if carry out on the damaged concrete pavement structural, e.g., cracks. Crack can quickly spread to the overlay layer due to traffic loading (Fu-Jian et al., 2008; Heath & Roesler, 2000). The potential of reflective cracking on concrete pavement overlay is very high because of the high volume of heavy vehicles (Harrington, 2008).

Using interlayer materials as reflective cracking control has been considered as an efficient method in terms of both performance and cost (Buttlar, 2007). It was recommended to use conventional asphalt mixture as an interlayer 3-5 cm thick to ensure the performance of the concrete overlay work in accordance with the service live (Li et al., 2010; Wilayah, 2003). But, in the process of pavement overlay design, structural contribution or interlayer is not taken into account in the planning process. This result in an overlay layer becomes thicker and incurring additional costs on concrete pavement rehabilitation. Therefore, an attempt to obtain a thinner interlayer material with a low cost needs to be done.

Stress absorbing membrane interlayer (SAMI) is the interlayer material that can reduce stress concentration, resistant to high strain, and can be used in a thin range of 1-2 cm (Vanelstraete et al., 2004). SAMI Performance in flexible pavement overlay shown very well performance. SAMI study of plastic waste (LDPE-SAMI) in the asphalt overlay, showing the efficiency of 62% in retarding the reflective cracking compared to the beam HRA without interlayer (Suparma, 2005). But different SAMI performance when used on the concrete pavement overlay. The results of field investigations show the performance of SAMI on concrete pavement overlay to be very low. This shows that the SAMI is not designed for retarding cracks in concrete pavement (Von Quintus et al., 2010).

The material with stiffness and modulus of elasticity is very small can withstand large horizontal deformation at various temperatures and retard the process of reflection cracking in many cases (Vanelstraete et al., 2004). Using the shredded rubber in the SAMI mixture will make softer the mechanical properties of the SAMI mixture. It was become a SAMI mixture resist to the reflective cracking and had better performance compared to SAMI without the rubber.

This study aimed to obtain the thickness of rubber content and design SAMI-SR as the interlayer in concrete pavement layers.

2. Research Methodology

Material Used

Materials SAMI-SR based on (Ngii & Suparma, n.d.), consists of natural sand (specific gravity = 2.645 gram/cm^3), Portland cement as filler (specific gravity = 3.15 gram/cm^3), bitumen 60/70 penetration (specific gravity = 1.03 gram/cm^3) and shredded rubber, pass sieve no.4 (specific gravity = 1.078 gram/cm^3).

Design of SAMI-SR

SAMI-SR design was based on previous studies (Ngii & Suparma, n.d.). Mortar (sand-filler mixture) in the SAMI-SR is determined by dry compaction test. The percentage of sand to the filler is 70% sand, 30% filler cement, and asphalt content ranges from 8-12% (Suparma, 2005).

The result of the trial experiment by Marshall Testing was obtained 10% maximum asphalt content that was required in the SAMI-SR mixture because of Marshall Quation (MQ) value was not fulfilled in the use of asphalt content above 10 %. Based on this result, variations of asphalt content in the mixture are 8%, 9%, and 10%.

Variations of shredded rubber content in the design of SAMI-SR are 10, 20, 30, 40, and 50% of the aggregate volume, which were presented in Table 1.

Table 1. Composition design of SAMI-SR

Material	Spec. gravity (gr/cm3)	Mix Design				
		1	2	3	4	5
Shredded Rubber	1,078	4,1	8,8	14,3	20,5	28,0
Sand	2,645	67,1	63,8	60,0	55,6	50,4
OPC	3,150	28,8	27,3	25,7	23,8	21,6
Specific gravity of mixed aggregate		2,609	2,439	2,268	2,098	1,928
% of Shredded rubber (by aggregate volume)		10%	20%	30%	40%	50%

Specimens

Three kinds of specimen will be made in this research:

1) Specimens A are SAMI-SR mixture specimens that were made by 3 (three) variations of asphalt content according to the composition in Table 1 with dimensions 200×100×10 mm. Total of these specimens were 15 pieces.

2) Specimens B are beam overlay using interlayer type variations as follows:

- SAMI-NSR interlayer is SAMI interlayer without shredded rubber, 1 cm thick.
- SAMI-SR1 interlayer is SAMI interlayer with shredded rubber, 1 cm thick.
- SAMI-SR1 interlayer is SAMI interlayer with shredded rubber, 2 cm thick.

3) Specimens Care concrete beams without overlay that make in 70 cm thick concrete

Specimens Preparation

For specimen A, the proportions of sand, shredded rubber, and filler were weighed and subjected to the following conditioning procedure before mixing and compaction:

1) The mortar (sand and OPC) was preheated for at least 4 hours prior to mixing at 150ºC. The bitumen was preheated for 2 hours at 150ºC and finally the shredded rubber was preheated for only 1 hour at 125ºC.

2) Mixing and compaction molds were stored at 150 °C for at least 1 hour.

The SAMI-SR specimen was compacted with a hydraulic press with a fixed pressure. On completion of the compaction process, the SAMI-SR specimen was allowed to cool to ambient temperature for at least 24 hours.

Specimen B was made with dimensions 600 mm in length and 150 mm in width. The thickness of the beam is made to simulate a layered overlay, with the existing layer thickness 70 mm and the overlay layer 60 mm. The compressive strength (f'c) that was obtained from the specimen cylinder 150×300mm was 35 MPa. Cracked simulation is made by cutting the transverse direction, depth of 30 mm, and width of 5 mm. Interlayer was installed between existing and overlay layers with 10 mm and 20 mm of thickness. Specimens C was made in the same way as specimen B but without interlayer and overlay layers, with dimensions of 600×150×70 mm.

Testing of Specimen

Testing of SAMI-SR mixture was conducted in the form of observation shrinkage, cracking, and volumetric measurements according to the standard ASTM D 1559-62T. Performance tests on beams overlay interlayer done with setting up testing as in Figure 1.

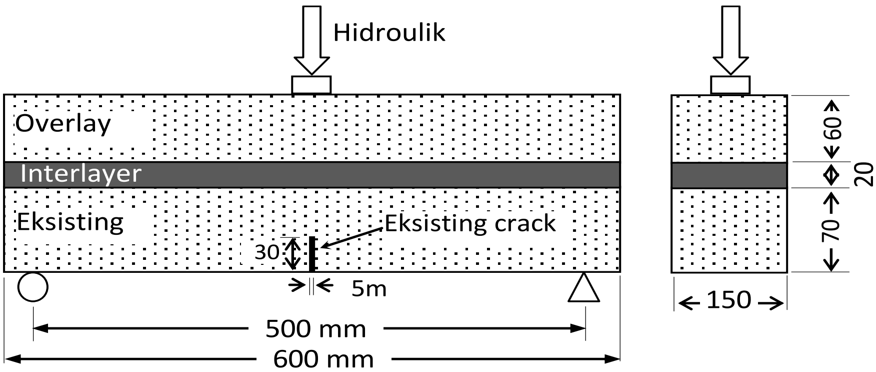

Figure 1. Setup-up of SAMI-SR interlayer performance testing

Maximum load and pattern of progressive crack that reflect to the overlay layer were observed in this performance testing.

Analysis

SAMI-SR mixture analysis was conducted on shrinkage value, porosity, density, and VMA (Voids in Aggregate Mixture) value in accordance with ASTM D 1559-62T and shredded rubber content in the mix. Then the best SAMI-SR performance was selected to the performance of interlayer testing in the overlay beam. Analysis of the beam pattern overlay committed against cracking, maximum load, and flexural strength

3. Results and Discussion

Selected SAMI-SR Mix for Reflective Cracking Test

SAMI-SR mixtures were prepared by composition as shown in Table 1 with dimensions measuring 20×10× 1 cm, as shown in Figure 1 below:

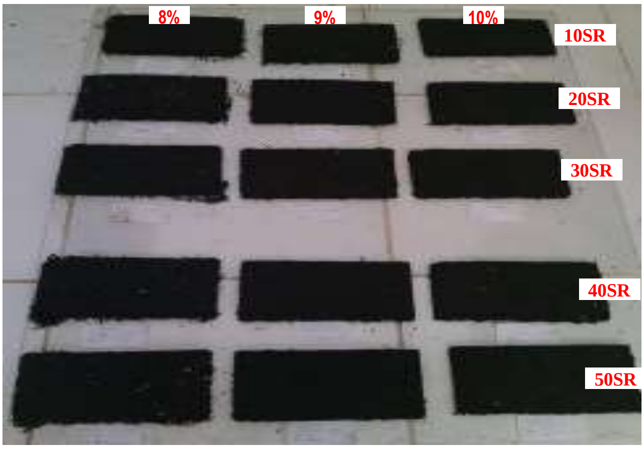

Figure 2. SAMI-SR mixture with shredded rubber variation (10,20,30,40, and 50%) and asphalt content variation 8%,9%, dan 10%

The measure of shrinkage and cracking was conducted to find the potential cracking due to specific gravity differences in SAMI-SR material of. A summary of shrinkage and crack investigation results is given in Table 2.

Tabel 2. Shrinkage and crack result of the SAMI-SR mixture

Coding of mixture	Asphalt content					
	8%		9%		10%	
	Shrinkage %	VMA %	Shrinkage %	VMA %	Shrinkage %	VMA %
SAMI-10SR	crack	19,67	0,50	20,75	1,00	21,80
SAMI-20SR	crack	18,71	1,00	19,70	0,99	20,67
SAMI-30SR	crack	17,72	0,49	18,61	0,00	19,48
SAMI-40SR	crack	16,67	0,50	17,46	0,00	18,23
SAMI-50SR	crack	15,56	1,00	16,24	0,00	16,91

It was shown from Table 2 that shrinkage and cracks not visible on the SAMI-SR mixture using shredded rubber 30%, 40% and 50% of the volume of aggregates and asphalt content of 10% in the mixture. Furthermore mixture volumetric measurement is performed to measure the density of the mixture. Volumetric measurement results are given in Table 3 below:

Tabel 3. Volumetrik test result of SAMI-SR mixture

Coding of mixture	Asphal Content (%)	Weight of Specimen			Volume of specimen (cm3)	Density Value (gram/cm3)	SG of mixture (gram/cm3)	Porosity Value (%)
		Dry (gram)	SSD (gram)	Water (gram)				
SAMI-10SR	8	465,0	468,6	204,5	264,1	1,76	2,32	24,23
	9	457,8	463,3	211,2	252,1	1,82	2,29	20,78
	10	445,2	451,3	217,7	233,6	1,91	2,26	15,74
SAMI-20SR	8	433,3	441,6	170,2	271,4	1,60	2,20	27,37
	9	434,1	441,3	182,9	258,4	1,68	2,17	22,63
	10	427,6	436,5	186,5	250,0	1,71	2,15	20,27
SAMI-30SR	8	408,9	414,8	133,8	281,0	1,46	2,07	29,68
	9	406,1	415,2	146,4	268,8	1,51	2,05	26,19
	10	399,8	407,6	144,1	263,5	1,52	2,02	25,07
SAMI-40SR	8	380,5	394,3	102,7	291,6	1,30	1,94	32,66
	9	382,0	390,6	118,8	271,8	1,41	1,92	26,77
	10	377,0	382,9	130,2	252,7	1,49	1,90	21,53
SAMI-50SR	8	353,9	356,4	95,0	261,4	1,35	1,80	24,89
	9	354,6	362,6	92,6	270,0	1,31	1,79	26,55
	10	350,9	356,1	110,2	245,9	1,43	1,77	19,54

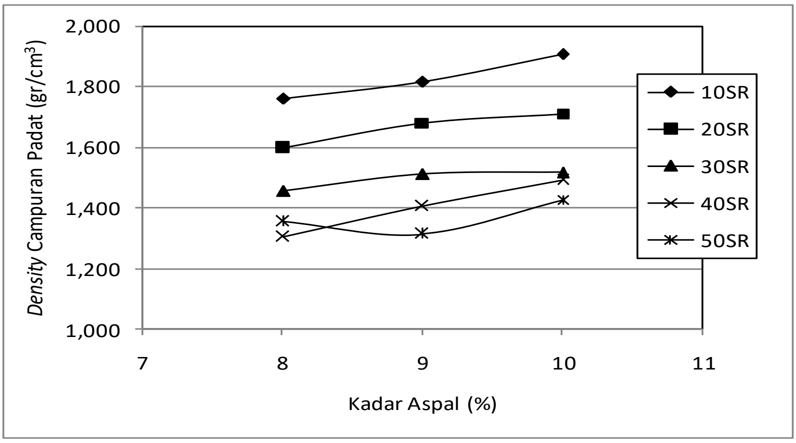

Figure 3. Relationship between Density vs Asphalt content of SAMI-SR

Based on these results, the SAMI-SR mixtures in accordance to the expected criteria were resumed in Table 4 below:

Table 4. Characteristic of SAMI-SR by 30,40 and 50% of shredded rubber content

Coding of mixture	Shredded Rubber (% by volume agg.)	Compacted Density (gr/cm3)	Specific gravity (gr/cm3)	Porosity (%)	Void in the mix (VMA) (%)
SAMI-30SR/10	30	1,5	2,02	25,07	19,5
SAMI-40SR/10	40	1,5	1,90	21,53	18,2
SAMI-50SR/10	50	1,4	1,77	19,54	16,9

For interlayer performance testing, SAMI-SR mixtures were elected based on indicators of the amount of rubber, density, porosity and VMA value. The evaluation results of the SAMI-SR mixture is as follows:

Tabel 5. Result of SAMI-SR election base on priority scale

Indicator	Specimen SAMI-SR		
	30SR/10	40SR/10	50SR/10
Kadar Karet dalam Campuran	3	2	1
Kepadatan (Density)	3	2	1
Porositas	3	2	1
VMA	1	2	3

Ket: 1,2,3 urutan prioritas dari yang tertinggi sampai terendah

Based on Table 5, the SAMI-50SR/10 mixture has the highest priority, but it has the lowest value of VMA (void mix aggregate). Requirements VMA value for SAMI-SR was approached with the requirements Latasir (sand asphalt) with a minimum 20% of VMA value. The lower VMA value can cause asphalt layer covering the aggregate becomes thin and easily oxidized.

SAMI-30SR/10 mixture has VMA value closest minimum requirement, but has low density and use small shredded rubber. SAMI-SR mixture with high porosity can cause air and water easily enter into the mixture so that the mixture is easily oxidized.

Based on the evaluation, the selected mixture to interlayer performance testing was SAMI-SR mixture with 40% shredded rubber in aggregat volume dan 10% asphalt contend in the mixture, with the following characteristics:

Table 6. Composition of the selected SAMI-SR mixture (SAMI-40SR/10)

Item	Specific gravity (gr/cm3)	Aggregate composition (% by mass)	Mixture composition (% by mass)	Volume of material (cm3)	Mixture composition (% by volume)
Shredded Rubber	1,078	20,5	18,49	17,16	32,6
Sand	2,645	55,6	50,05	18,92	36,0
OPC	3,150	23,8	21,45	6,81	12,9
Bitumen	1,030		10	9,71	18,5
Porosity					21,53

As a comparison in measuring the performance of the SAMI-40SR/10 to retard the reflective cracking, the SAMI without rubber (SAMI-NSR/10) was made as a control specimen. The composition of SAMI-NSR/10 mixture (control) refers to SAMI-40SR/10 (Table 6) composition, by eliminating the entire content of shredded rubber in the mix. So that the composition of the mixture SAMI-NSR/10 are as follows:

Table 7. Composition of sand/asphalt-SAMI mixture (control)

Item	Specific gravity (gr/cm3)	Volume of material (cm3)	Mass of material (gr)	Mixture composition (% by mass)
Sand	2,645	36,1	95,43	75,2
OPC	3,150	6,8	21,45	16,9
Bitumen	1,030	9,71	10	7,9

Flexural Strength of Concrete

Interlayer SAMI-40SR/10 will be installed on top of concrete pavement that was designed by 35 MPa of compressive strength of. The concrete mixture consists of split (910.8 kg/m3), sand (653.4 kg/m3), cement (516.4 kg/m3), and water (219.4 liters). Compressive strength test results at 28 days was 35.87 MPa, based on this, the flexural strength of concrete is calculated as follows:

$f_{cf}=0,75\sqrt{(f_c^{'})}$ (MPa)

$f_{cf}=0,75\sqrt{35,87} = 4,491$ MPa.

Kimpraswil (2003) requires about 3-5 MPa of flexural strength, while the AASHTO (1993) set at least 4.5 MPa (Wilayah, 2003). The flexural strength of the concrete used was qualified.

Crack Propagation Pattern

Observation of crack growth and propagation from each beam is described by Figure 2 as follows:

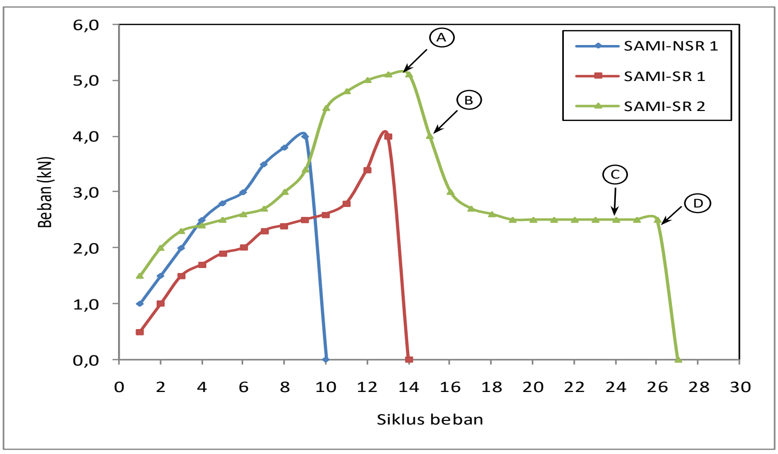

Figure 4. Relationship between load cycle vs maximum load

Based on observations and loading pattern in Figure 3, the condition of crack patterns observed is as follows:

Concrete overlay with SAMI-NSR, 1 cm thick.

Grack growth of existing cracks tends vertically upward and reflects directly to the bottom of the overlay layer. Crack propagates to the surface layer overlay and collapsed simultaneously with layers of interlayer.

Concrete overlay with SAMI-SR, 1 cm thick.

Crack propagation of existing cracks tends to veer to the left, and immediately grow to the bottom of the overlay layer. Cracks quickly propagate to the surface layer and cause the overlay layer to lose its structural strength. In conditions of loss of structural strength, interlayer SAMI-SR 1 cm, is still visible yet collapsed. Time collapse beams overlay with SAMI-SR 1 cm, rose by a factor of 0.4 compared to using SAMI-NSR 1 cm.

Concrete overlay with SAMI-SR, 2 cm thick.

The propagation of cracks in the existing layers has the same pattern of direction that tends to veer to the left and immediately spread to the overlay layer. Observation of crack growth in the test specimen is divided into 4 stages of observation with the following results:

Point A: Cracks began to appear in layers existing

Point B: Cracks immediately spread in the overlay layer, but does not reach the surface.

point C: Interlayer SAMI-SR 2cm, begin to crack

point D: Interlayer SAMI-SR 2 dan Overlay layer failure simultaneously

SAMI-SR layer 2 cm thick, can retard and slow the cracks growth to reach the surface layer of concrete. SAMI-SR layer 2 cm thick make the overlay construction becomes more ductile with the ability to withstand the load (see point B to point C) without collapse. When interlayer SAMI-SR began to crack, the concrete overlay and interlayer still has the ability to simultaneously hold the load until it collapsed. Failure mechanism of interlayer SAMI-SR2 in concrete overalay are shown as follow:

a.*initial crack*

b.*crack spread crack*

c.*cracks in the lining SAMI-SR*

d.*terminal crack*

Figure 5. Crack propagation mechanism on the concrete overlay with interlayer SAMI-SR 2 cm thick.

Effect SAMI-SR to The Maximum Load (Pmax) and Flexural Strength

Using interlayer generally can increase the value of maximum load (Pmax) and flexural strength of concrete structures overlay. The increase of maximum load (Pmax) and flexural strength that occurs in each overlay condition given in Table 8 as follows:

Table 8. Maximum load (Pmax) and flexural strength of overlay beam

Existing Pavement Condition	Repair Method	Pmax		Flexural Strength	
		(N)	%	Mpa	%
Without crack	-	7500	-	7,65	100
Crack, 3 cm deep	-	3000	100	3,06	40
Crack, 3 cm deep	Overlay with SAMI-NSR, t = 1cm	3950	132	5,49	72
Crack, 3 cm deep	Overlay with SAMI-SR, t = 1 cm	4000	133	5,56	73
Crack, 3 cm deep	Overlay with SAMI-SR, t = 2 cm	6000	200	8,33	109

Table 8 shown that the simulation of crack 3 cm deep in existing concrete can affect the remaining life of pavement, where the concrete strength remaining 40% of the initial flexural strength. Using SAMI-SR as an interlayer on the overlay repairing can increase Pmax value and flexural strength of the rigid construction. Using SAMI-NSR interlayer 1 cm thick can increase Pmax by 32%. The value of Pmax increased only slightly in the use of SAMI-SR 1 cm but the interval time to pavement damage can increase by factor 0.4. These results indicate that the SAMI-SR 1 cm has not a significant effect to retard the propagation of reflective cracking.

Adding the thickness of SAMI-SR from 1 cm to 2 cm will increase by Pmax 50% and flexural strength equivalent to the new pavement. This is in accordance with AASHTO (1993), which states that overlay with interlayer system is designed as a new pavement above a base foundation (Li et al., 2010).

4. Conclusion

The main conclusions with respect to the use of shredded rubber in SAMI to prevent reflective cracking are as follows:

a) The quantity of shredded rubber to show no shrinkage was up and including 32.6% by volume of total SAMI mixture (18.49% by weight). However, this is dependent on 10% asphalt content.

b) Design SAMI-SR 2 cm thick, has been able to improve the performance of concrete overlay layers that functions the same as a new layer of concrete with crack propagation rate 9 times longer than using SAMI without rubber (SAMI-NSR 1 cm).

Acknowledgment

This research was supported financially by the Ministry of Research and Technology and Higher Education, Halu Oleo University Kendari.

References

1. Buttlar, B. (2007). Reflective crack relief interlayers. OMG Brown Bag Seminar Series.
2. Fu-Jian, N., Yan, W., & Xiang, M. A. (2008). Analysis on stress of pavement with different crack states in base. Journal of Highway and Transportation Research and Development, 25(12), 65–70.
3. Harrington, D. S. (2008). Guide to concrete overlays for resurfacing & rehabilitating existing pavements: seminar.
4. Heath, A. C., & Roesler, J. R. (2000). Top-down cracking of rigid pavements constructed with fast-setting hydraulic cement concrete. Transportation Research Record. https://doi.org/10.3141/1712-01
5. Li, J., Uhlmeyer, J. S., Mahoney, J. P., & Muench, S. T. (2010). Use of the AASHTO 1993 guide, MEPDG and historical performance to update the WSDOT pavement design catalog. Transportation Research Record, 2776.
6. Ngii, E., & Suparma, L. B. (n.d.). Perancangan Komposisi Bahan Stress Absorbing Membrane Interlayer Menggunakan Serutan Karet Ban Bekas.
7. Suparma, L. B. (2005). Laboratory design and performance of stress absorbing membrane interlayer (SAMI) incorporating waste recycled plastics. Media Teknik, 27(2005).
8. Vanelstraete, A., De Bondt, A. H., & Courard, L. (2004). Characterization of overlay systems. In Prevention of Reflective Cracking in Pavements (pp. 68–87). CRC Press.
9. Von Quintus, H. L., Mallela, J., & Lytton, R. L. (2010). Techniques for mitigation of reflective cracks. 2010 FAA Worldwide Airport Technology Transfer ConferenceFederal Aviation AdministrationAmerican Association of Airport Executives.
10. Wilayah, D. P. D. P. (2003). Perencanaan perkerasan jalan beton semen. Jakarta: Badan Penerbit Pekerjaan Umum.