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Permanent Deformation and Fatigue of Semi Flexible Pavement Incorporating Waste Tire Rubber and Natural Zeolite

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Abstract. Due to repeated loads, the pavement structures will experience repeated stresses and strains resulting in permanent deformation even though the working loads are still smaller than the design load. The permanent deformation will lead to cracking and fatigue failure with the life of the pavement. This phenomenon can be reduced by increasing the stiffness, flexibility, durability, stability and water absorption of the pavement. Material modification including the utilization of waste tire rubber (WTR) and natural zeolite is one of the efforts to increase those parameters in semi flexible pavement (SFP). The aim of this study therefore, to assess the deformation and fatigue failure of SFP incorporating WTR and natural zeolite under cyclic loading. The WTR was used as an additive at the level of 3% of asphalt content while natural zeolite was used as cement replacement at the 0, 5, 15 and 25% replacement levels. Permanent deformation tests were conducted by applying wheel tracking loads with the pressure of 6.4 ± 0.15 kg/cm^2 on the surface of the specimens with 1260 cycles per hour while fatigue tests were conducted on the simple supported beams with the span length of 30 cm by applying forth point loading at the frequency of 10 Hz. The test results showed that the best performance in sustaining cyclic loading was achieved at the zeolite content of 5%.

Introduction

The pavement structures when sustain the vehicle wheel loads will experience stresses and strains both in tension and compression around the vehicle wheel axles. Of the two stress behaviors, tensile stress has the most dominant influence on the pavement performance that occurs at the bottom of the pavement layer, causing cracks which are the initial failure of the pavement layer. In addition, the pavement structures are maintained the repeated loads causing the permanent deformation, cracking and fatigue failure of the pavements even though the working loads are still smaller than design load. The sufficient of stiffness, flexibility, durability, stability and water absorption are needed to avoid the failure of the pavements before design life [1]. In recent years, the use of waste tire rubber (WTR) as an additive to asphalt has been widely studied. Many aspects of WTR on the properties of the asphalt mixture were studied such as durability, stability and resistance to damage. Most importantly, the presence of WTR can significantly improve the physical properties of asphalt mixtures [2-4]. The use of natural pozzolan such as zeolite and diatomite has also intensively studied [5-11]. Incorporating of waste tire rubber (WTR) as an additive and natural zeolite as cement replacement in semi flexible pavement has shown to increase those parameters [12,13].

Many studies have been conducted on the prediction of permanent deformation and fatigue failure of pavement structures [14-20]. However, none of them studied the parameters on the semi flexible pavements (SFP) especially with using WTR and natural zeolite. This study therefore was conducted to obtain the permanent deformation and fatigue life of SFP incorporating WTR and natural zeolite. Fatigue failure of SFP can be estimated by applying cyclic loading on the SFP specimens [21]. Testing of fatigue life using the flexural testing method is one of the most preferred methods because in addition to the uniform stress distribution it also simulates the actual conditions of the asphalt mixture in the field. In this test, the loading can be carried out with three points or four points loading under stress or strain controls.

Materials and Method

SFP is a porous asphalt where its pores were grouted by cement mortar in an attempt to increase the stiffness of the mixture. The porous asphalt material consists of coarse aggregate, fine aggregate, asphalt and WTR powder, while the grouting material in the form of mortar is made by mixing cement, natural zeolite, fine aggregate and water. The use of WTR powder in this research is as an additive while the natural zeolite is to partially cement replacement in a mortar.

Coarse aggregate was used in the form of open graded stone split with a maximum grain size of 19 mm in accordance with the AAPA 2004 specification [22]. As fine aggregate the river sand with a maximum diameter of 4.75 mm was used. The physical properties of the coarse and fine aggregates are shown in Table 1 while the gradations of mixed aggregates are shown in Table 2 the gradations of mixed aggregates are shown in Table 2.

Table 1 Physical properties of aggregates

Materials	Bulk density (kg/m^3)	Specific gravity	Absorption (%)
Fine Aggregate	2520	2.60	1.89
Coarse Aggregate	2340	2.47	1.94

Table 2 Gradations of aggregates

Sieve size (mm)	Cumulative passing (%)	
	Tested aggregates	AAPA 2004 Requirements
19.0	100	100
12.7	95	85-100
10.0	50	45-70
5.0	15	10-25
2.0	10	7-15
1.0	8	6-12
0.6	7	5-10
0.3	5	4-8
0.15	3	3-7
0.075	2	2-5

Asphalt binder used in this study was 60/70 penetration bitumen made by PT Pertamina with a specific gravity of 1.00, the softening point of 48 °C and the flash point of 232 °C. The WTR powder used was the one available in the market. The cement used is Portland cement type II made by PT Semen Andalas Indonesia with a specific gravity of 3.16. The zeolite used is a natural zeolite from Ujong Pancu Village, Aceh Besar District, Indonesia. The use of zeolite was through the process of grinding and sieving so that it passes the sieve # 200. Furthermore, the zeolite powder was activated using 30% hydrochloric acid (HCl) and washed with distilled water to clean the dirt. Before its use, zeolite powder was dried at the room temperature. The chemical compositions of the zeolite power are 46.57% SiO_2, 16.58% Al_2O_3, 10.21% Fe_2O_3, 8.77% CaO, 4.81% MgO, 2.97% Na_2O, 0.87% K_2O, 0.14% MnO, 0.83% TiO_2, 0.14% P_2O_5 and 7.75% loss of ignition.

The optimum asphalt content (OAC) was determined using the AAPA 2004 method. OAC was obtained through Marshall tests using a 102 mm diameter and 64 mm high cylinder specimens with asphalt content of 3%, 3.5%, 4%, 4.5% and 5%. For each level of asphalt, 3 specimens were prepared. Marshall tests were then carried out, and the average test results along with the AAPA 2004 requirements are shown in Table 3. Based on these data, the OAC was determined as 3.5%.

Table 3 Marshall test results for determining of AOC

Marshall Parameter	Alphalt Content (%)					AAPA (2004) Requirements
	3.0	3.5	4.0	4.5	5.0	
Stability (kg)	503	512	470	362	356	≥ 500
Flow (mm)	3.97	5.60	4.00	5.78	5.53	2-6
Void in the mix, VIM (%)	24.95	24.70	22.64	18.43	13.88	18-25

WTR powder used in this study was 3% of asphalt content. The determination of 3% of WTR powder was based on the previous studies conducted by the authors which the results showed that the use of 3% WTR lead the best SFP performance [5,6]. The penetration bitumen was heated at the temperature of 160 ºC then the WTR powder was added on the hot asphalt and mixed for about 5 minutes. On the other hand, the aggregates were also heated at the temperature of 170 ºC and added on the asphalt mixture and mixed for about 15 minutes at the temperature of 160 ºC. The hot mixture was then poured in the mould and compacted at the temperature of 140 ºC to produce the porous asphalt specimens. The specimens for permanent deformation test were the cylinders with the diameter of 15 cm and height of 5 cm while the specimens for fatigue test were the rectangle slab with the size of 35 cm x 30 cm x 5 cm.

After 3 days age, the porous asphalt specimens were grouted with the cement mortar to produce SFP specimens. The mortar was the mixture of cement, zeolite, sand and water. The zeolite was used as cement replacement. Four replacement levels were used which were 0%, 5%, 15% and 25%. The amount of water used was justified by the fluidity test that meets the requirement of Road Engineering Association of Malaysia (REAM). Grouting mortar into the porous asphalt specimens was carried out by pouring the mortar into the container then the porous asphalt specimens were inserted into the mortar and vibrated using a portable mortar vibrator so that the mortar enters into the pores of the porous asphalt specimens. For each different zeolite content three SFP specimens were prepared for each permanent deformation and fatigue test. The SFP specimens were then cured in the room temperature until the specimens' age of 14 days.

The permanent deformation test was carried out by applying wheel tracking loads with the pressure of 6.4 ± 0.15 kg/cm^2 on the flat cylinder surface of the specimens. The pressure of 6.4 ± 0.15 kg/cm^2 which is equivalent to a single axle load of 8.16 tons (Japan Road Association, 1998) was applied. Each specimen was passed by 1260 wheel-cycles per hour, or 21 cycles per minute, and the test was carried out at a temperature of 60 ºC. The data of deformation, permanent deformation, deformation rate as well as dynamic stability were then obtained.

The specimens for fatigue tests were cut into beams with the size of 35 cm x 5 cm x 5 cm. The beams were supported by two simple supports with the span length of 30 cm. Bending tests were applied on the beams by applying forth point loading with the distance between the supports and the loading points were 10 cm. The sinusoidal cyclic loading was applied on the specimens with the frequency of 10 Hz through a servo hydraulic actuator in control room with room temperature of 25 ºC. The loading was applied under stress control until the specimens were failed. At every cycle, the deflection, load, stress and strain developed in the specimens were recorded and the stiffness of the specimens can be later calculated.

Results and Discussion

Wheel Tracking Test Results. The wheel tracking test results are shown in Table 4. From the test results, the relationship between the deformation and the number of wheel tracking passing is presented in Figure 1. This figure shows that after about 1000 cycles, the SFP containing 5% zeolite had the smallest deformation. This means that the SFP with 5% zeolite content had a best performance compared to the other mixtures. The low deformation rate of SFP with 5% zeolite content as shown in Figure 2 is the evidence that the mixture had a best performance. This is also supported by a large dynamic stability of SFP with 5% zeolite content compared to the other mixtures as shown in Figure 3. Dynamic stability in the wheel tracking test is used as a basic index of rut-resistance for asphalt mixtures. In general, the deeper rut depth is obtained from the weaker mixture, resulting in the lower dynamic stability. The higher dynamic stability of SFP with 5% zeolite content shows that the mixture was very stiff leads in almost no rutting when the pavement is passed by the vehicle wheels. However, as shown in Figure 4, the permanent deformations of all mixtures were almost the same.

The presence of zeolite as a cement replacement in a mortar that is grouted into porous asphalt causes the mortar to become denser, so that its stiffness increases. This is due to the active reaction of silica in the zeolite with carbon hydroxide as a byproduct of cement hydration to form calcium silicate hydrate. However, the need for silica to react with calcium hydroxide is not much as can be seen from the results of this study, where the best performance is obtained at a zeolite content of 5%. For zeolite contents above 5%, the amount of silica has exceeded that required to react with calcium hydroxide, leaving unreacted zeolite granules which causes the SFP stiffness to decrease, and finally results in a large deformation.

Table 4 Results of wheel tracking test

Time (minutes)	Number of wheel-track passing	Deformation (mm)			
		Zeolite=0%	Zeolite=5%	Zeolite=15%	Zeolite=25%
0	0	0	0	0	0
12	250	0.81	1.29	1.01	0.97
24	500	0.99	1.42	1.39	1.31
36	750	1.37	1.50	1.76	1.78
45	945	1.54	1.55	2.22	2.09
60	1260	1.75	1.62	2.91	2.48
71	1500	2.00	1.69	3.35	3.49
83	1750	2.46	1.75	3.79	4.10
95	2000	3.10	1.87	4.12	4.69
107	2250	3.70	2.02	4.42	5.19
120	2500	4.24	2.22	4.70	5.68
Permanent deformation (mm)		1.38	1.32	1.30	1.37
Dynamic stability (cycles/mm)		3000	9000	913	1615
Deformation rate (mm/minute)		0.0140	0.0047	0.0460	0.0260

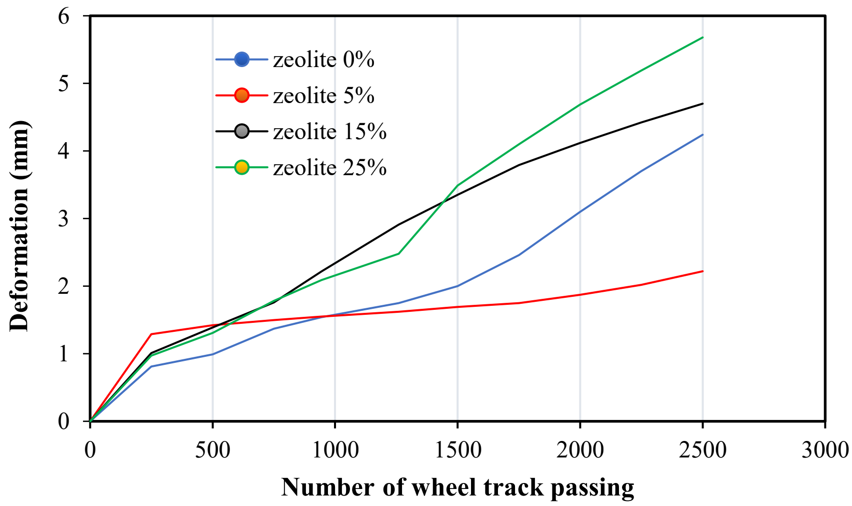

Fig. 1 Relationship between deformation and number of wheel track passing

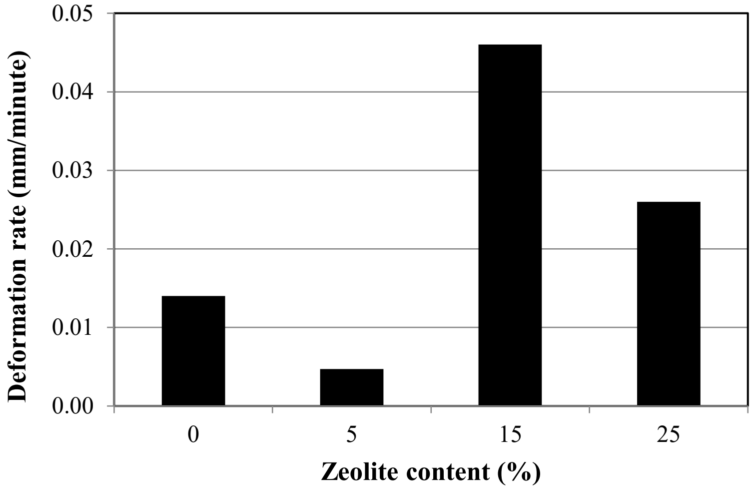

Fig. 2 Deformation rate of tested SFP

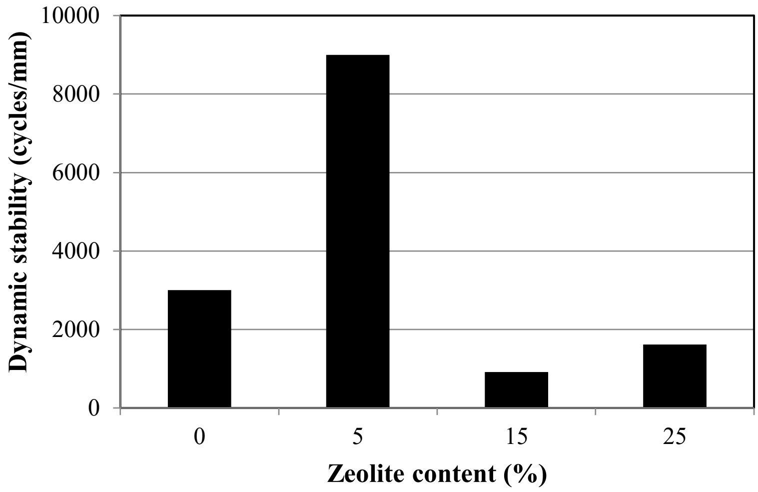

Fig. 3 Dynamic stability of tested SFP

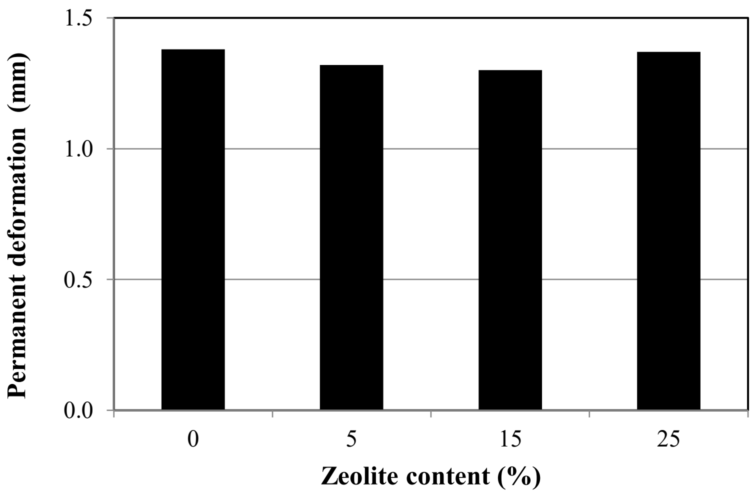

Fig. 4 Permanent deformation of tested SFP

Fatigue Test Results. From the fatigue test results the relationship between flexural stiffness and the number of loading cycles for all SFP mixtures can be drawn as presented in Figure 1. This figure shows that the highest initial flexural stiffness was reached by SFP with 15% zeolite content, followed by 5%, 0% and 25%. The stiffness of SFP with 5% and 15% zeolite content decreased with increasing in number of loading cycles up to 50 cycles. After 50 cycles the SFP with 5% zeolite content had the highest flexural stiffness. These results are in line with the results of wheel tracking test. After 50 cycles, the stiffness of SFP became constant until its failure. The fatigue failure occurred suddenly after the SFP mixtures lost their stiffness. In this study, the number of loading cycles at the SFP mixtures have no more stiffness denotes as fatigue life. The fatigue life of SFP mixtures tested in this study is shown in Figure 6. From this figure, it can be seen that the SFP with 5% zeolite content had higher fatigue life which means that this mixture had better performance in maintaining fatigue loading. From the observation during testing, a horizontal crack was first occurred in the bottom part of the beams followed by some vertical cracks. The vertical cracks then propagated to the middle part of the beams. By increasing the loading cycles, the cracks propagated more to the upper part of the beams which caused the fatigue failure of the beams.

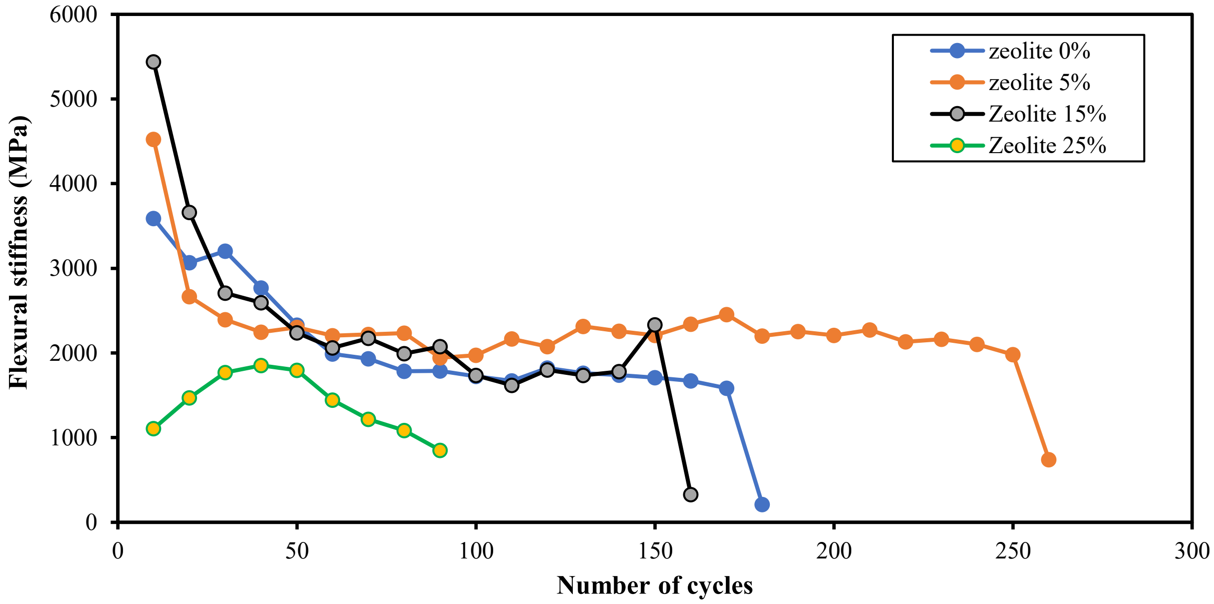

Fig. 5 Relationship between flexural stiffness and number of cycles

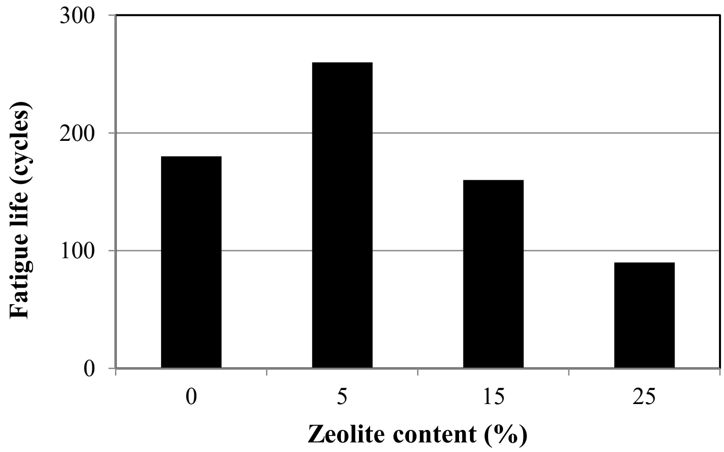

Fig. 6 Fatigue life of tested SFP

Conclusions

The performance of semi flexible pavements (SFP) incorporating waste tire rubber (WTR) and natural zeolite in sustaining cyclic loading was studied. The WTR was used as additive with content of 3% of asphalt. The zeolite was used as cement replacement in production of mortar which was grouted into the porous asphalt to product SFP. The replacement levels were 0%, 5%, 15% and 25%. Wheel tracking and flexural fatigue tests were performed on the SFP specimens. The test results showed that at the replacement level of 5% the SFP mixture had the highest dynamic stability, lowest deformation rate and highest fatigue life. However, the permanent deformations of all mixtures were almost the same. These results indicate that the SFP with 5% zeolite content had the best performance in sustaining repeated loading compared to the other mixtures.

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References

[1] R.A. Yamin and B.I. Siswosoebrotho, Karakteristik mortar semen untuk cement treated asphalt mixture, J. Teknik Sipil ITB. 9(3) (2002).

[2] J. Zhang, J. Cai, J. Pei, R. Li and X. Chen, Formulation and performance comparison of grouting materials for semi-flexible pavement, Constr. Build. Mater. 115 (2016) 582-592.

[3] D. Ge D, K. Yan, Z. You and H. Xu, Modification mechanism of asphalt binder with waste tire rubber and recycled polyethylene, Constr. Build. Mater. 126 (2016) 66–76.

[4] N.M. Noor, H. Hamada and Y. Sagawa, Rubberized concrete durability against abrasion, Matec Web of Conf. 47 (2016) 01006.

[5] Y.T. Tran, J. Lee, P. Kumar, K.H. Kim and S.S. Lee, Natural zeolite and its application in concrete composite production, Compos. Part B: Eng. 165 (2019) 354-364.

[6] T. Saidi and M. Hasan, The effect of partial replacement of cement with diatomaceous earth (DE) on the compressive strength and absorption of mortar, J. King Saud Univ. Eng. Sci. in press (2020)

[7] M. Hasan and T. Saidi, Properties of blended cement paste with diatomite from Aceh Province Indonesia, IOP Conf. Ser.: Mater. Sci. Eng. 796 (2020) 012034.

[8] T. Saidi, M. Hasan, A.D.D. Riski, R.R. Ayunizar and A. Mubarak, Mix design and properties of reactive powder concrete with diatomaceous earth as cement replacement, IOP Conf. Ser.: Mater. Sci. Eng. 933 (2020) 012007.

[9] M. Hasan, A. Muyasir, T. Saidi, Husaini, R. Azzahra, Properties of high strength concrete with calcined diatomaceous earth as cement replacement under compression, Defect and Diffusion Forum 402 (2020) 7-13.

[10] M. Hasan, A.D.D. Riski, T. Saidi, Husaini, P.N. Rahman, Flexural and splitting tensile strength of high strength concrete with diatomite micro particle as mineral additive, Defect and Diffusion Forum 402 (2020) 50-55.

[11] M. Hasan, S. Husin and C. Nursaniah, Mechanical properties of concrete in compression exposed to sulfuric acid, Key Eng. Mater. 711 (2016) 302-309.

[12] Hamzani, Munirwansyah, M. Hasan and S. Sugiarto, Determining the properties of semi-flexible pavement using waste tire rubber (WTR) powder and natural zeolite, Constr. Build. Mater. 266 (2021) 121199.

[13] Hamzani, Munirwansyah, M. Hasan and S. Sugiarto, The influence of the using waste tire rubber and natural zeolite as asphalt and cement replacement to compressive strength of semi-flexible pavement, IOP Conf. Series: Mater. Sci. and Eng. 523 (2019) 012034.

[14] D. Kim, B. Han, Y. Kim and S. Mun, A study of reliability of predictive models for permanent deformation and fatigue failure related to flexible pavement design, Int. J. Highw. Eng. 16(6) (2014) 105-113.

[15] M. El-Basyouni and M.G. Jeong, Effective temperature for analysis of permanent deformation and fatigue distress on asphalt mixtures, Transp. Res. Rec. 2127 (2009) 155-163.

[16] I. Isailovic, M.P. Wistuba and C.F. Augusto, Permanent deformation of hot mix asphalt under compression and tension, Proc. of the 6th Eurasphalt & Eurobitume Congress, Prague. Czech Republic, 2016.

[17] F.L. Villacorta, A.V. Nordcbeck and J.P.A. Moya, Permanent deformation and deflection relationship from pavement condition assessment, Int. J. Pav. Res. Tech. 10 (2017) 352-359.

[18] M.J. Khattak and G.Y. Baladi, Fatigue and permanent deformation models for polymer-modified asphalt mixtures, Transp. Res. Rec. 1767 (2001) 135-145.

[19] J.T. Harvey, I. Guada, D. Hung and C.L. Monismith, Permanent deformation and fatigue evaluation of asphalt concrete mixes, Proc. of the 6th RILEM Symposium PTEBM'03, Performance Testing and Evaluation of Bituminous Materials, Zurich, 2003.

[20] E.O. Ekwulo and D.B. Eme, Fatigue and rutting strain analysis of flexible pavements designed using CBR methods, African J. Env. Sci. Tech. 3(12) (2009) 412-421.

[21] S.F. Said, H. Hakim, E. Oscarsson E and M. Hjort, Predicting of flow rutting in asphalt concrete layers, Int. J. Pav. Eng. 12(6) (2011) 519-532.

[22] AAPA, Open graded asphalt design guide, Australian Asphalt Pavement Association, Australia, 2004.