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Assessment of Fatigue Characteristic of Asphalt Mixture with the Existing of Moisture: A Review

Nor Najiha Izzati Mat Nor[1], Mustafa Kamal Shamshuddin[2]*,

[1,2] Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: Fatigue is one of the most common distress mode of asphalt pavement that cause by the number of load repetitions with high axle loads, environmental conditions, construction quality and design errors. The objectives of this study is to assess the effect of moisture on fatigue characteristic and evaluate the capability of additives in asphalt mixture to resist the effect of moisture. This paper aims to highlight the previous study on the fatigue characteristics and effectiveness of asphalt mixture with the existing of moisture. From the observation of the previous study, the fatigue characteristic of asphalt mixture could be improved by utilization of additives materials such as polyethylene terephthalate, fly ash, polyethylene, silica fumes, nano silica, hydrated lime and asphlatite. Experimental study need to be conducted according to the specification and standard of test method that was stated in the previous study to establish confirmation and verification of their result while the findings show that the uses of additives in asphalt mixture can improve the fatigue characteristic and prolong the performance of the asphalt pavement.

Keywords: Fatigue Characteristic, Asphalt Mixture, Effect of Moisture, Additives

1. Introduction

Road pavement is one of the most essential modes of transportation system and plays a vital role in economic and social development of the country. However, there are few factors that will affect the life performance of the pavement which can cause failure or damage. Moisture damage is one of the factor that can affect the asphalt pavement and known as the main factor of pavement failure. Modified asphalt mixture is assumed as one of the most important solutions for pavement distress by using waste material as additives [1]. Additives that most commonly used based on previous study that have been conducted to modify AC mixture consist of polyethylene terephthalate, fly ash, polyethylene, silica fumes, nano silica, hydrated lime and asphlatite [1-5]. By using the waste products as an additive on asphalt mixture, it can improve fatigue characteristics and prolong the performance of asphalt pavement. Besides that, its also able to reduce the environmental waste issue and control the disposal area.

*Corresponding author: mkamal@uthm.edu.my

1.1 Fatigue

Fatigue is one of the most common distress mode of asphalt pavement that cause by the number of load repetitions with high axle loads, environmental conditions, construction quality and design errors [6]. Fatigue cracking tends to occur if the pavement is at moderate temperatures while at the high temperature it can cause rutting. The fatigue cracking is cause by horizontal tensile strain at the bottom of the asphalt pavement that can shortening the life span and increase the number of maintenance cost. According to [7], there are two principal solutions in improving the durability of the pavement which is by applying a thicker asphalt pavement and making an asphalt mixture with modified characteristics.

1.2 Asphalt Mixture

Asphalt mixture was commonly used material in road construction. It can provide driving comfort, stability, durability and water resistance. Asphalt mixture contain both bitumen and mineral aggregate and the behaviour of the mixture is affected by the properties of the individual components and how they react with each other in the system.

1.3 Moisture damage

Moisture damage in asphalt mixture refers to loss in strength and durability due to the presence of water and can be classified in two mechanisms which is loss of adhesion and loss of cohesion. The durability of an asphalt mixture depends on the degree of adhesion between bitumen and aggregate. The presence of moisture is the major factor of asphalt pavement damage that can affect the durability of asphalt mixture.

2. Materials and Methods

Nowadays, natural resources are being quickly depleted due to the enormous amount of raw materials that being consumed worldwide and with the growth in population, there are concomitant increases in waste generated by the increasing demand of new agricultural, manufacturing and construction industries, which results in a large amount of waste materials that being deposited in landfills every year [8]. The application of waste materials as an additive in asphalt mixture can leads to green, sustainable, environmental friendly and able to preserve the nature besides minimize the construction costs. The use of additives in asphalt mixture has increased considerably and it was found that it is able to strengthen the asphalt mixture against the dynamic loads [8]. In this study, the additives that was selected from the previous research consist of polyethylene terephthalate, fly ash, polyethylene, silica fumes, nano silica, hydrated lime and asphaltite [1-5].

2.1 Indirect Tensile Strength (ITS) test

In ITS test, the cylindrical specimens were subjected to compressive loads, which act parallel to the vertical diametral plane, by using the Marshall loading equipment. This type of loading will produce a relatively uniform tensile stress, which acts perpendicular to the applied load plane and the specimen usually fails by splitting along with the loaded plane [9]. The higher the tensile strength, the more is the resistance against rutting and cracking and change in tensile strength under environmental conditions such as moisture is used for evaluation of the durability of asphalt mixture [5]. The ITS was calculated according to the Equation 1 in kPa unit.

$$\mathrm{ITS} = \frac{2\mathrm{F}}{\pi \mathrm{LD}} \quad Eq.\ 1$$

where,
F = Peak value of the applied vertical load (kN)
L = Mean thickness of test specimen (m)
D = Specimen diameter (m)

In order to evaluate the moisture resistance of asphalt mixture, the Tensile Strength Ratio (TSR) is been evaluated by Equation 2.

$$TSR = 100(ITS_{cond.} / ITS_{uncond.}) \quad Eq.\ 2$$

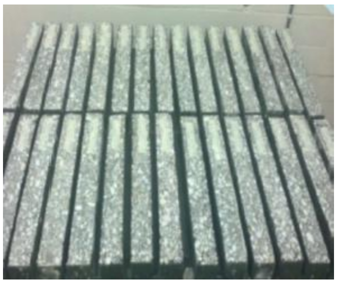
where,
$ITS_{cond.}$ = ITS of wet specimens
$ITS_{uncond.}$ = ITS of dry specimens

2.2 Beam Fatigue test

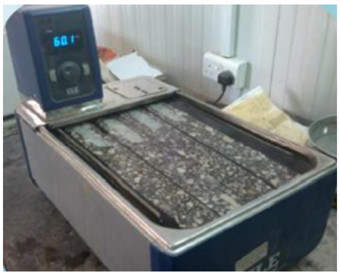
The mixtures were heated and compacted using the Rolling Wheel Compactor (RWC) device which is one progressive way that simulates field compaction to compact the slab-shaped specimens into asphalt mixture beams. Vertical pressure towards the specimens was applied by means of a rolling wheel with the moving table. The volumetric for each compacted beam were checked to determine the air voids. Then, the specimens will be removed from the mold and been cut to obtain beam-shaped specimens [2]. The preparation process of fatigue test as shown in Figure 1.

a. Preparation of roller compacted slab

b. Sawing beam specimens from slab



c. Part of the sawed beams



d. Conditioning the beams in water bath

Figure 1 (a-d): Preparation of beam fatigue test sample

The specimens were tested by placed in a 4-point bending loading machine for unconditioned specimens which subjected the beam to a repeated load in evaluate the fatigue characteristics of asphalt concrete. The fatigue test was performed by placing the beam in repetitive four points loading as shown in Figure 2 at a specified strain level and the beam is held in place by four clamps and a repeated haversine (sinusoidal) load was applied to the inner clamps while the outer clamps provide a reaction load [5].

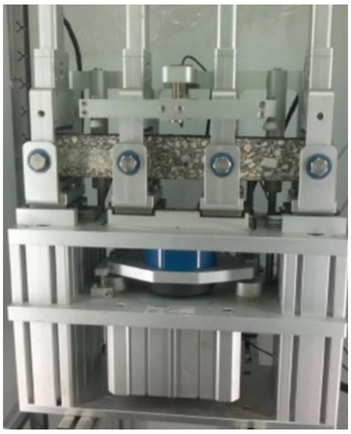


Figure 2: Close-up of beam with 4 clamps in place [5]

3. Results and Discussion

3.1 ITS test

The ITS test was used to evaluate the effects of saturation and accelerated water conditioning with a freeze-thaw cycle in asphalt mixture. The tensile strength of mixtures consists of unconditioned (dry) and conditioned (wet), that will be compared to assess the potential of moisture damage in asphalt mixture.

Asphalt mixture with the additive of Nano-Silica (NS) and Hydrated Lime (HL) is been evaluated their tensile strength [5]. The percentage of nano-silica additives consist of 0%, 2%, 4% and 6% and the hydrated lime consists of 1.5%, 2% and 2.5% and the result of the ITS is shown in Table 2 [5]. The results of unconditioned mixtures show that the ITS of the asphalt mixture that been added by NS and HL was higher and indicating the resistance against cracking compare to the control mixture which is not been added by any percentage of additives. The effectiveness of NS was higher than HL since the ITS of the asphalt mixture that containing 6% of NS in dry condition was 89% higher than the control mixture, while the asphalt mixture containing 2.5% of HL had an ITS 86.5% which higher than the control mixture. The ITS of the asphalt mixture after conditioning under one, three and five freeze-thaw cycles which contain NS and HL was decrease with the increasing of the freeze-thaw cycles numbers. From this result it can be concluded that, the effect of moisture will reduce the strength of the asphalt mixture.

Table 2: Indirect Tensile (IT) strength test result [5]

	Control mixture (C)	2% NS	4% NS	6% NS	1.5% HL	2% HL	2.5% HL
ITS - Dry	560	612	707	765	635	683	714
1 cycle	359	465.1	593.68	680.85	486.25	564.15	617.61
3 cycles	297	429.6	563.83	650.25	438.15	530.34	585.54
5 cycles	224	401.47	519.64	612	382.58	471.27	523
TSR (%)	64.1	76	84	89	76.5	82.6	86.5

Other investigation of an additive mix with asphalt mixture is using the asphaltite [9]. The study used 25%, 50%, 75%, and 100% of asphaltite which consists of high amount of sulfur to study the effectiveness of this additive against fatigue characteristics with the existing of moisture. The TSR values for both dry and wet condition increase with the increasing of asphaltite content. 100% of this additive in asphalt mixture shows the highest TSR value which is 87% compare to the control mixtures which only 65% as shown in Table 3.

Evaluation of reclaimed polyethylene mix with asphalt mixtures also been evaluated [3]. The ITS was compared between unconditioned and conditioned with the percentage of polyethylene additives consist of 2.5%, 5%, 7.5% and 10%. Conditioning sample was conducted by keeping the specimens in water and the temperature been maintained at 60°C for 24 hours and by curing at 25°C for 2 hours before commencing the test at 25°C. TSR value for 5% of polyethylene that was added in asphalt mixture achieved 96% which is the highest value when compare to 2.5%. However, TSR values shows the reduction since the percentage of polyethylene increase into 7.5% and 10%. Table 3 shows the ITS and TSR values for each usage of additives of the selected previous study.

Table 3: Indirect Tensile Strength (ITS), % and Tensile Strength Ratio (TSR), % of the selected previous study

No.	Journal	Author	Type of additives in AC	Percentage of additives (%)	Indirect Tensile Strength, ITS (kPa)		Tensile Strength Ratio, TSR (%)
					Unconditioned	Conditioned	
1	Comparing the effects of nano-silica and hydrated lime on the properties of asphalt concrete	(Taherkhani & Tajdini, 2019)	Control mixture (C)	0	560	359	64
			Nano silica (NS)	2	612	465.1	76
				4	707	593.68	84
				6	765	680.85	89
			Hydrated lime (HL)	1.5	635	486.25	77
				2	683	564.15	83
				2.5	714	617.61	87
2	Effects of using asphaltite as filler on mechanical properties of hot mix asphalt	(Yilmaz et al, 2011)	Control mixture (C)	0	446	290	65
			Asphaltite	25	500	360	72
				50	550	400	73
				75	580	445	77
				100	630	550	87
3	Evaluation of reclaimed polyethylene modified asphalt concrete mixtures	(Punith et al, 2011)	Control mixture (C)	0	550	420	76
			Polyethylene	2.5	750	650	87
				5	900	860	96
				7.5	830	760	91
				10	730	650	89

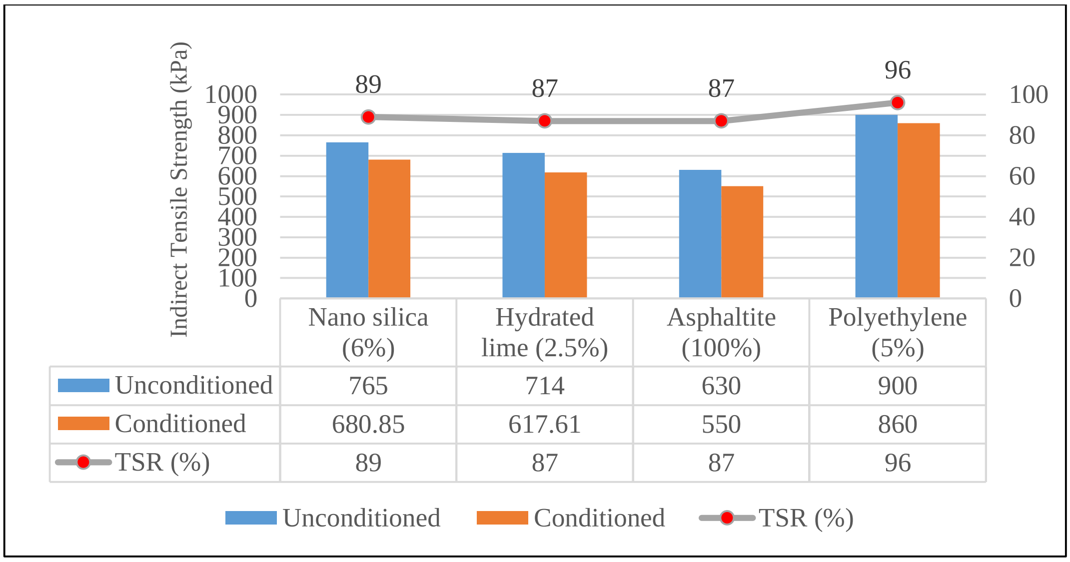


Figure 3: Indirect Tensile Strength (ITS), kPa from the selected previous study based on the highest TSR value of each type of additives

Figure 3 shows the comparison of ITS test based on the highest TSR value according to the percentage of nano-silica, hydrated lime, asphaltite and polyethylene. It shows that 6% of nano-silica as an additive in asphalt mixture indicate 89% of TSR value while for the 2.5% of hydrated lime and 100% of asphaltite were 87%. The other additive of polyethylene with the percentage of 5% indicate that 96% of TSR value which this is the highest value among the others additives. From this observation, it shows that by using 5% of polyethylene in asphalt mixture has a potential to be most effective additive. It can improve the fatigue characteristic and moisture resistance compared if compared to the other additives of nano-silica, hydrated lime and asphaltite.

3.2 Beam Fatigue test

Beam Fatigue test was carried out to the asphalt mixture to evaluate their engineering properties of fatigue life cycle at certain temperature under constant frequency and strain level by using a Universal Testing Machine (UTM-14) [1-4]. The result of the studies are as shown in Table 4.

Table 4: Collected data of Beam Fatigue test from the previous study

No.	Journal	Author	Type of additives	Test Temp. (°C)	Microstrain level (με)	Fatigue life cycle at percentage of additives						
						Control mix.	1%	1.50%	2%	4%	5%	6%
1	Evaluating the fatigue properties of hot mix asphalt reinforced by recycled PET fibers using 4-point bending test	(Dehghan & Modarres, 2017)	Polyethylene terephthalate (PET)	20	300	161252	209121	242198	125441	-	-	-
					500	19645	39693	19567	22845	-	-	-
					700	50003	6092	6987	6028	-	-	-
2	Fatigue life assessment of modified asphalt concrete	(Sarsam & AL-Lamy, 2015)	Fly ash (FA)	20	250	16212	-		22448	31549	-	28690
					400	2722	-	-	5809	8729	-	6975
					750	563	-	-	788	973	-	869
3	Evaluation of reclaimed polyethylene modified asphalt concrete mixtures (2011)	(Punith et al., 2011)	Polyethylene (PE)	20	400	283548	-	-	-	-	374627	-
					700	184892	-	-	-	-	136865	-
				30	600	137849	-	-	-	-	282946	-
					650	129341	-	-	-	-	241895	-
4	Assessing fatigue life of reclaimed asphalt concrete recycled with nanomaterial additives	(Sarsam & Al-shujairy, 2015)	Silica fumes (SF)	20	250	1535	-	-	-	1422	-	-
					750	236	-	-	-	83	-	-

The use of polyethylene terephthalate (PET) as an additive in asphalt mixture was also been observed [2]. The 4-Point bending test was conducted to evaluate the fatigue properties of the asphalt mixture. The fatigue test was performed under influence of three levels of micro-strain which are 300με, 500με and 700με at a constant temperature of 20°C by using Universal Testing Machine (UTM-14). Fatigue characteristics of asphalt mixture with 1.5% of PET shows the highest number of repetitions which is 242,198 cycles under 300με compared to the control mixture and others percentage of PET. However, the increase of PET content to 2% had an opposite effect and led to the reduction in fatigue life for each level of microstrain 300με, 500με and 700με which is 125,441, 22,845 and 6,028 cycles respectively as shown in Figure 4. Therefore, the increase of additive content in asphalt mixture with the increment of micro-strain level can led to the drop of fatigue life cycle of asphalt mixture.

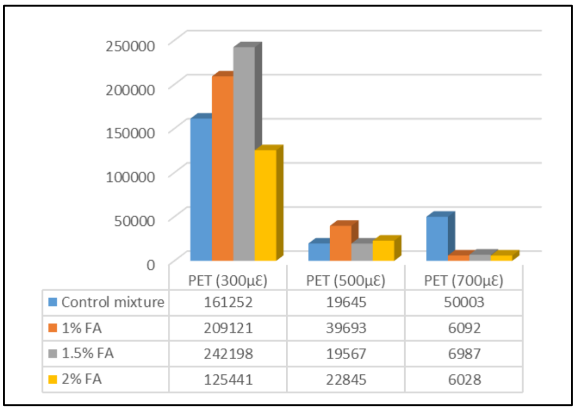


Figure 4: Effect of PET content and level of microstrain towards fatigue life cycle.

Fatigue life assessment of modified asphalt mixture by using Fly Ash (FA) as an additive also been conducted [1]. The strain that been induce during the test is 250µƐ, 400µƐ and 750µƐ respectively at a constant temperature of 20°C and 5 Hz of frequency level. FA with different percentage has been used and beam specimens were tested at optimum bitumen content to determine optimum percentage of additive. Figure 5 depicts the effect of FA content on fatigue life at 250µƐ, 400µƐ and 750µƐ strain level. It was found that, the fatigue life was increase from 22,448 cycles to 31,549 cycles then reduce to 28,690 cycles respectively when the percentage of fly ash increase from 2% to 4% and 6% as compared to the control mixture at strain during the test is 250µƐ. Then, the fatigue life also tends to show the higher value than the control mixture at level strain of 400µƐ and 750µƐ during the test with the increasing of FA content. From this results, it shows that the increasing of strain level during the test will reduce the fatigue life cycle and FA content obviously has significant effect on fatigue characteristic of asphalt mixture.

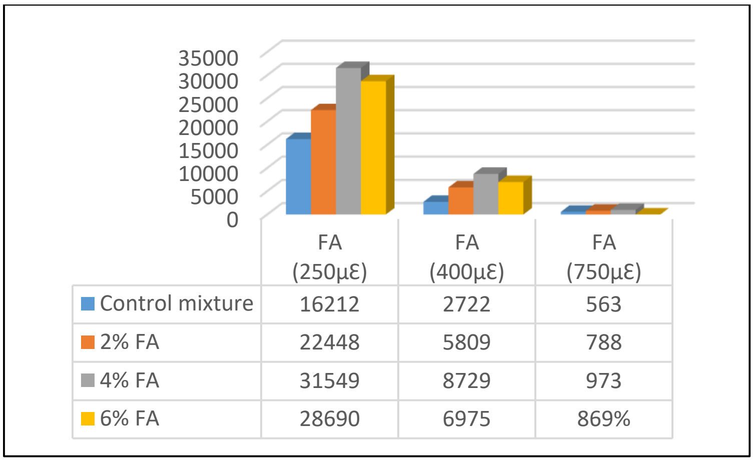


Figure 5: Effect of FA content and level of microstrain towards fatigue life cycle.

A study on evaluation of reclaimed polyethylene (PE) modified asphalt mixtures also been conducted to investigate their fatigue characteristics [3]. In this study, 5% of PE has been used as an additive at two different temperature of 20°C and 30°C. The strain level for 20°C test temperature was 400µƐ and 700µƐ. From Figure 6, the fatigue life of asphalt mixture increased to 374,627 cycles compare to the control mixture with only 283,548 cycles at 20°C under 400µƐ of strain level. However, the fatigue life reduced to 136,865 cycles compare to the control mixture which have 184,892 cycles at 700µƐ of strain level. However, by adding 5% of polyethylene in asphalt mixture and tested at 30°C improving the fatigue life for each level of strain induced during the test as shown in Figure 7.

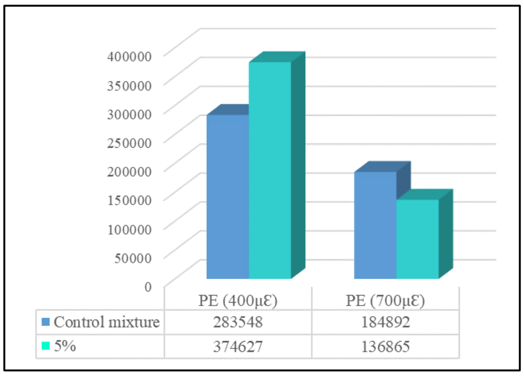


Figure 6: Effect of PE content and strain level towards fatigue life at 20°C.

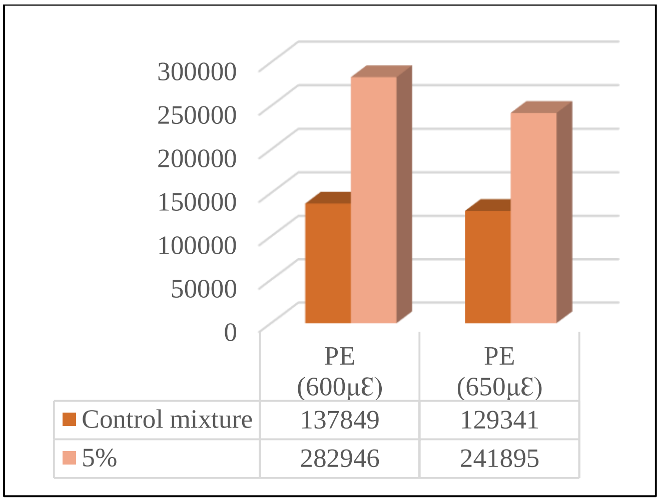


Figure 7: Effect of PE content and level of microstrain towards fatigue life cycle at 30°C.

In other study, fatigue life of Reclaimed Asphalt (RAP) was measured at strain level of 250με and 750με with the frequency level of 5 Hz and test temperature of 20˚C by an additive of nanomaterials [4]. The 4% of silica fumes (SF) was implemented as nanomaterial additives. From the test result, the fatigue life of modified asphalt mixture is 1,422 cycles. The fatigue life is smaller than the control mixture which is 1,535 cycles at 250με strain level. The same result at 750με of induced strain during the test, the fatigue life of control mixture also greater than modified mixture which contain 5% of silica fumes which is 236 and 83 respectively as shown in Figure 8. Therefore, the increasing of strain induced during the test definitely reduce the fatigue life cycle of asphalt mixture.

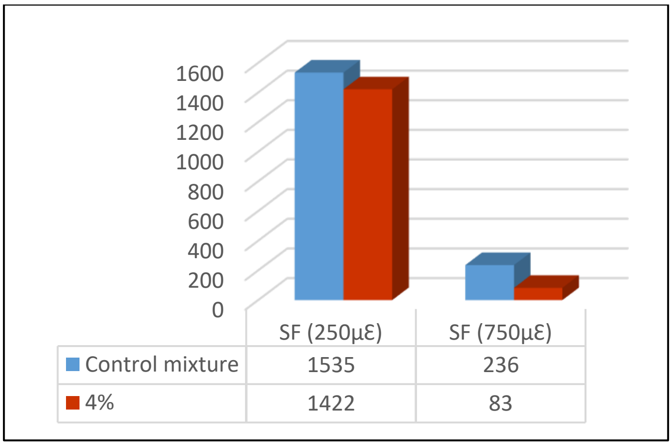


Figure 8: Effect of SF content and level of microstrain towards fatigue life cycle.

4. Conclusion

It was found that the effectiveness of the additives potentially improved the fatigue characteristic and life performance of asphalt mixture. This situation will reduce the maintenance costs as well as construction costs. From the observation, the most effective additive was polyethylene since it significantly less susceptible to moisture induced damage compared to the control mixture. Polyethylene indicated higher Tensile Strength Ratio (TSR) and able to improve the fatigue characteristic of asphalt mixture compared to the control mixture and others type of additives. Besides that, the use of polyethylene as an additive in asphalt mixture potentially able to reduce waste material and control the environmental impact. This will contribute to the effort of producing sustainable road construction materials.

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