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Improved Performance of Asphalt Concrete by Concentrated Latex Treatment

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***Abstract---* The increased traffic volume and traffic axel load cause premature failure in the flexible pavement. The premature distress in the asphalt concrete (AC) significantly caused by the development of plastic deformation in the AC layer. Natural rubber is one of thermoplastic elastomers used in asphalt cement modification. With its inherent chemical property as an elastomer, natural rubber has the potential to improve the stability and elastic property of AC materials. This research aims to study performance of natural rubber modified asphalt with various aggregates in Thailand. Three difference types of aggregates, granite (G), basalt (B) and limestone (L) were used in this study. The natural rubber used in this study was in a form of concentrated latex (CL). The effect of CL in the performance of AC mixtures was evaluated by an extensive laboratory testing program, which included Marshall stability, indirect tensile strength (ITS), indirect tensile fatigue (ITF), and dynamic creep. The effectiveness of CL was illustrated by comparing the test results between asphalt mixtures with and without CL modification. The additional 3% of dry rubber of CL by total weight of binder (R/B = 3%) has potential to improve the indirect tensile strength, fatigue life and permanent deformation of all AC mixtures. The properties of the aggregate affect degree of performance improvement. The CL modified AC using limestone aggregate (the lowest ability to absorb asphalt binder) exhibits the lowest degree of improvement when compared with the CL modified AC using granite and basalt aggregates, respectively.**

***Keywords---* Asphalt concrete, Concentrated latex, Aggregate, Natural rubber latex**

I. INTRODUCTION

The rapid growth of cities has resulted in higher requirements for performance and service life for transportation infrastructure. Pavements are now subjected to significant increases in traffic volume and truck loads, causing traditional pavements to fail before reaching the end of their design life. The two principal modes of failure in pavements are fatigue cracking and permanent deformation [1]. Pavement engineers seek to maintain failures within acceptable limits during the design life span of the pavement.

Generally, the flexible pavement construction and service maintenance usually implements the AC 60/70 as the binder. According to the empirical mechanistic design approach, the performance of asphalt concrete essentially depends upon the aggregate type, gradation, and type of asphalt cement. Department of Rural Roads, Thailand revealed that Limestone (L) asphalt concrete presents a high tensile strength, but poor compression and Marshall stability. Meanwhile, the same was not true for Granite (G) and Basalt (B) asphalt concrete due to the high smooth surface of crystal silica [2]. Granite and Basalt aggregates are hydrophilic with high porosity with high ability of absorption, resulting in high bond strength between aggregate and binder, unlike limestone aggregates [3].

To develop the performance of the flexible pavement, the use of synthetic polymer additive is considered as an effective solution to improve the stability of the flexible pavement. The outstanding elastic properties of polymer contribute to resisting the stress-induced fatigue damage. Besides the synthetic polymer, the renewable natural source has been adopted as a biopolymer to enhance the sustainability of the flexible pavement by reducing the life cycle cost and carbon dioxide emission. The natural rubber latex (NRL) has the potential to improve the stability and elastic property of AC materials. In addition, the NRL modified AC reduces the incremental rate of deformation against repetitive loading resulting in a higher ability to withstand the permanent deformation against fatigue damage. [4].

Natural rubber latex (NRL) is the plane material and can be used as an environmental-friendly additive alternative to synthetic polymers. Although the NRL is in the liquid form but presents high elastic properties when it forms a solid-state. In the fresh state, the NRL consists of solid content suspending in the colloidal substances. The composition of NRL solid content composed approximately 94% rubber hydrocarbon and 6% of the non-rubber component. Biological and morphological evidence revealed the spherical molecules of NRL in the range of 0.1 - 2.0 micrometers. NRL are composed of carbon content over 90%, surrounded by the non-rubber compound with protein and phospholipids layers by random packing arrangement. Although the non-rubber substance presents only a few amounts, these compositions cause numerous problems in NRL properties especially the proteins layer. The protein component of NRL causes latex coagulation at room temperature. Therefore, NRL has to be stabilized with the chemical treatment before applying in the engineering approach [5]. Natural rubber latex acts as an elastic band during cold weather, which helps prevent the formation of cracks while at the same time retains asphalt stiffness. During hot weather, natural rubber acts as a film which can improve shear resistance and consequently prevents asphalt flow. The elastomer properties of natural rubber latex contribute significantly to improving long term pavement performance [6].

In addition to its raw rubber compound, water, and minor impurities such as proteins and resins are included in this latex form [7]. This engineering material has been successfully attempted for many years in the production of tires, gloves [8], as well as material for building and road constructions. As road material, with its organic polymer compound behavior, natural rubber becomes one of the alternative solutions in improving the asphalt properties for asphalt pavement. Asphalt, on the other hand, is a natural substance derived from the distillation of crude oil [9] and has a viscoelastic property which is quiet sensitive to temperatures fluctuation [10]. This simply means that conventional asphalt, without any modification, it tends to have high permanent deformation and hence reduces pavement service life and increases expenditures in maintaining road performance [9]. Among the natural rubbers used for asphalt modification, the liquid form is widely implemented in practice due to the most effective mixing [11]. The application of natural rubber in infrastructure increases domestic consumption to balance with its supply in Thailand [12].

Thailand is the largest NRL exporter in the world. Therefore, the use of NRL to improve the stability of the flexible pavement is a sustainable solution. To the best of the authors' knowledge, there has been no research undertaken to date on the application of NRL to improve the performance properties of AC.

Therefore, this research aims to study the performance of natural rubber modified asphalt with various aggregates in Thailand. The natural rubber used in this study was in a form of concentrated latex (CL). The effect of CL in the performance of AC mixtures was evaluated by an extensive laboratory testing program, which included Marshall stability, indirect tensile strength (ITS), indirect tensile fatigue (ITF), and dynamic creep. The test results between asphalt mixtures with and without CL modification were compared to illustrate the effectiveness of CL modification. The outcome of this study will promote the use of natural rubber as a green additive in asphalt pavement applications, which benefits to Thailand and other Southeast Asian countries.

II. MATERIALS

Aggregates

Limestone (L), granite (G), and basalt (B) were used as an aggregate for this study. The aggregates properties are in accordance with the requirement of the Department of Highways standard, Thailand [13]. The properties of aggregates are summarized in **Table 1**.

Concentrated latex

The natural rubber latex for this study is concentrated latex (CL) from Thai Eastern Group Company Limited, Thailand. The non-rubber component of CL was eliminated by using a centrifuge process. The chemical treatments were applied to improve the physical and chemical properties. After the latex stabilization process, the dry rubber content remains approximately 55 - 65% by the total weight of the latex. The CL is classified as medium ammonia n accordance with the TISI. standard [14]. The CL properties are summarized in **Table 2**.

Asphalt binder

Asphalt cement AC60/70 was selected as a binder in this research. It was obtained by Tipco Asphalt, Nakhon Ratchasima Province, Thailand. For the CL modified asphalt, weight of dry rubber/total weight of binder ratio (R/B) was fixed at 3%. To prepare CL modified asphalt, CL and AC60/70 were mixed by using a stirring process at the frequency of 180 rpm and at a temperature of 170°C until binder has smooth surface and no bubble when heat curing at the temperature of 170°C for 30 minutes. The binder properties are in accordance with the requirement of the Department of Highways standard, Thailand [15] as shown in **Table 3**. Higher elastic recovery values are associated with higher ductility contributing to a superior fatigue resistance [16, 17, 18]. According to the rutting resistance factor, the higher rheological properties (G*/sinδ) contribute to superior resistance to permanent deformation due to a higher viscous behavior [19].

Table 1 Properties of aggregates for natural rubber modified asphalt concrete [13]

List of test	Standard	Specification (%)	Results		
			Granite (%)	Limestone (%)	Basalt (%)
Los Angeles abrasion	DH-T 202 [20]	< 35	20.9	24.6	19.1
Soundness	DH-T 213 [21]	< 9	1.9	2.4	1.8
Aggregate crushing value	BS 812 [22]	< 25	14.9	17.6	20.8
Aggregate impact value	DH-T 208 [23]	< 25	16.0	16.1	20.2
Coating and stripping	AASHTO T 182 [24]	>95	98	97	96
Asphalt absorption	DH-T 414 [25]	-	0.25	0.24	0.38

Table 2 Physical and chemical properties of concentrated latex [14]

List	Properties	Specifications	Result
		MA type	
1	Mechanical stability	>650	773
2	Non rubber component	<1.7	1.4
3	Total solids content	>61.0 or depends on the agreement	61.74
4	Alkalinity	0.30-0.59	0.30
5	Dry rubber content	>60.0	60.34
6	KOH number	<0.7 or depends on the agreement	0.60
7	Volatile fatty acid number	<0.06 or depends on the agreement	0.0322
8	Coagulum content	<0.03	0.003
9	Magnesium content	<40 or depends on the agreement	16.26

Table 3 Properties of asphalt cement for natural rubber modified asphalt concrete [15]

No.	Properties	Units	Specification	Result	
				AC60/70	CL modified asphalt
1	Penetration	-	50-70	67	56
2	Softening point	^oC	>50	47.8	59.5
3	Flash point	^oC	>220	332	250
4	Elastic recovery	%	>40	25	380
5	Storage stability	^oC	<4	0.5	4.0
6	Brook field viscosity	mPa-s	200-600	550	585
7	Rheological $G*/\sin\delta$	kPa	>1.0	1.2	6.654
Test on residue from thin film oven test					
8	Weight loss	% by wt.	<1.0	0.12	0.122
9	Penetration	% Initial pen.	>60	71.1	91.89
10	Softening point	^oC	<±6	+8.0	+1
11	Elastic recovery	%	>25	40	26

III. METHODOLOGY

Mix design and sample preparation

To evaluate the effect of aggregate types (G, L, and B) and types of binder (AC60/70 and CL modified asphalt) on performance of asphalt concrete, 6 mixtures of asphalt concrete were prepared according to the Marshall mix design method [26] to determine the optimum binder content of AC material.

Particle-size distribution curves of the mixed aggregates were compared with the upper and lower limits in accordance with Department of Highways standard, Thailand [13] as shown in **Figure 1**.

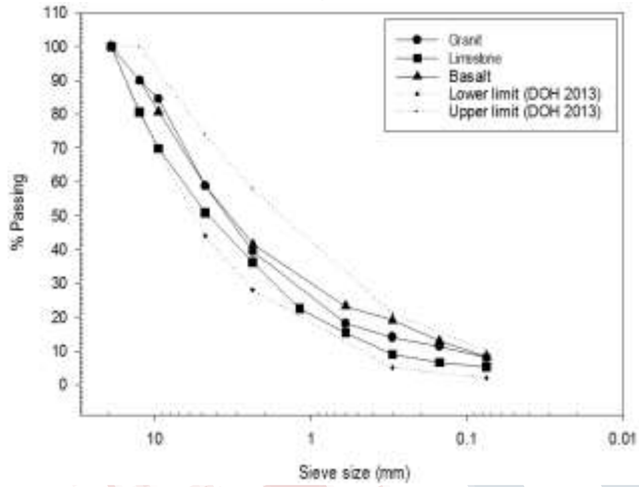

Figure 1 Particle size distribution curves of all aggregates

In this study, air voids were fixed at 4% for all mix proportions because asphalt concretes in Thailand are designed at 4% air voids according to Department of Highway standards. The mix proportions prepared are listed in **Table 4**. Samples for performance tests were prepared at optimum asphalt cement content. The sample dimensions were 63.5 mm height and 101.5 mm diameter.

Table 4 Properties of asphalt concrete

Mix proportion	Binder content	Density	VMA	Air voids	VFB
G + AC60/70	5.1	2.368	14.6	4.0	74.0
L + AC60/70	5.0	2.398	14.8	4.0	71.6
B + AC60/70	5.7	2.389	15.6	4.0	74.3
G + CL modified asphalt	5.5	2.386	15.7	4.0	74.2
L + CL modified asphalt	5.4	2.372	15.4	4.0	73.9
B + CL modified asphalt	5.7	2.387	14.8	4.0	75.9

Note : G = Granite, L = limestone, B = Basalt

Marshall stability

The Marshall stability was measured using the Marshall apparatus in accordance with ASTM 2015 [26]. At least 3 samples were performed to ensure data consistency. The vertical loading was applied at a rate of 50.8 mm/min.

Indirect tensile strength

The indirect tensile strength test was conducted according to ASTM 2017 [27]. The vertical stress was applied at a loading rate of 50.8 mm/min at temperatures of 25°C, 40°C, 50°C, and 60°C, respectively.

Indirect tensile fatigue

The indirect tensile fatigue was performed to evaluate the long-term performance of the AC in accordance with BSI 2004 [28]. The stress control method was selected by using target stress levels of 250, 300, and 350 kPa. A haversine loading pulse was selected to simulate the repetitive traffic loading at a loading frequency of 10 Hz with 0.1s loading period and 0.9 rest period. The experimental programs were performed in an environmental chamber at 25°C. The failure criteria were set at 9 mm vertical deformation.

Dynamic creep test

The dynamic creep test was caried out to evaluate the deformation resistance (rutting susceptibility) of asphalt mixtures in accordance with AS 1995 [29]. The permanent deformation under the repetitive loading is measured by using a linear variable differential transformer (LVDT). The conditioning stress was applied at 10 kPa for the 30s. Thereafter, the square wave was applied at the target stress of 120 kPa for the duration of 1,800 pulses under the environmental temperature of 50°C.

IV. RESULTS AND DISCUSSION

Stability

Figure 2 illustrates the stability of the AC60/70 sample with different aggregate types. According to the Department of Highways standard (DOH 2013) [13], all the stability of AC samples meets the minimum

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requirement (9.8 kN).

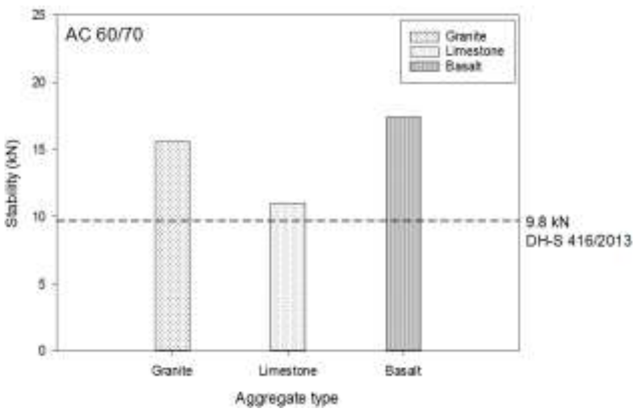


Figure 2 Stability of AC60/70 concrete

The high ability of asphalt absorption contributes to high stability and results in high bond strength between aggregate and binder [2]. Therefore, basalt aggregate (B) exhibits the highest stability value due to highest degree of asphalt absorption, and followed by granite (G) and limestone (L), which are 17.4, 15.6, and 11 kN, respectively. A similar result was reported by Department of Rural Roads [2].

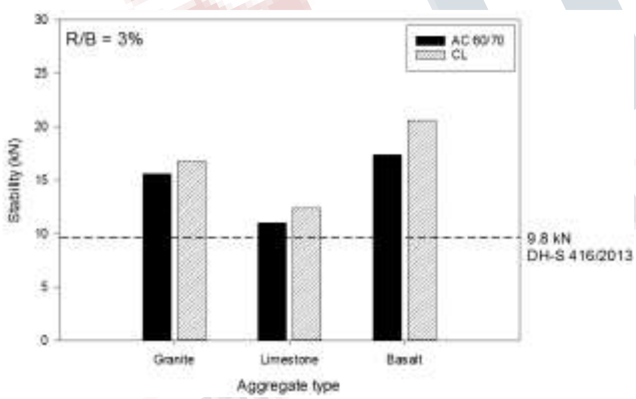


Figure 3 Stability of AC60/70 and CL modified asphalt concretes

CL modified asphalt presents the higher stability for all aggregate types. This is because the lower penetration property of CL modified asphalt enhances the ability to withstand the compressive stress and increase the binder stiffness, causing the higher stability [6]. The CL modified asphalt can improve the stability up to 18.4, 12.7, and 7.7% for B, G, and L aggregates, respectively (**Figure 3**).

Indirect tensile strength

Figure 4 presents the indirect tensile strength (ITS) of AC60/70 concrete under different testing temperatures. The increased temperature reduces ITS of the AC60/70 concrete because the binder is softened. The influence of aggregate types can be observed in that the L provides the highest ITS, followed by G and B, respectively.

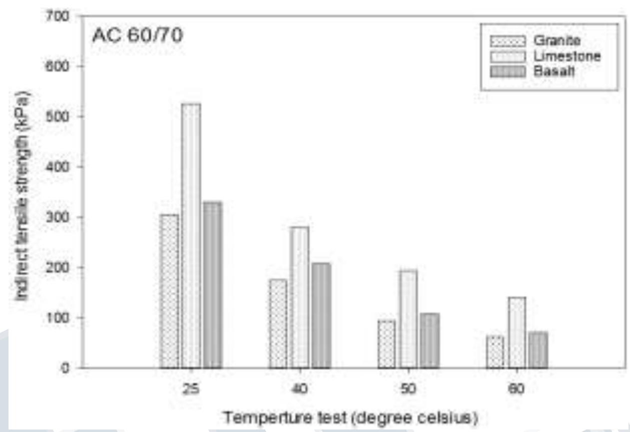
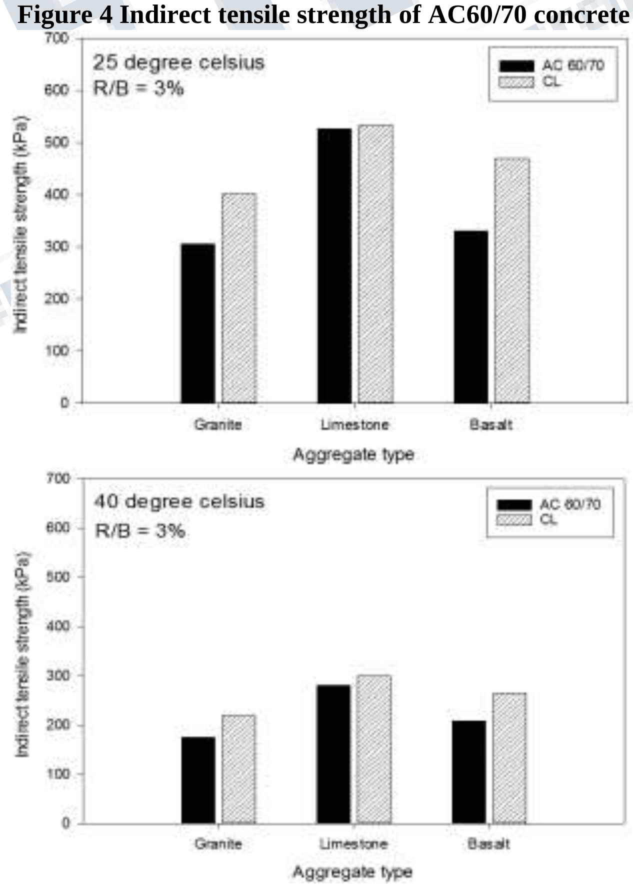


Figure 4 Indirect tensile strength of AC60/70 concrete



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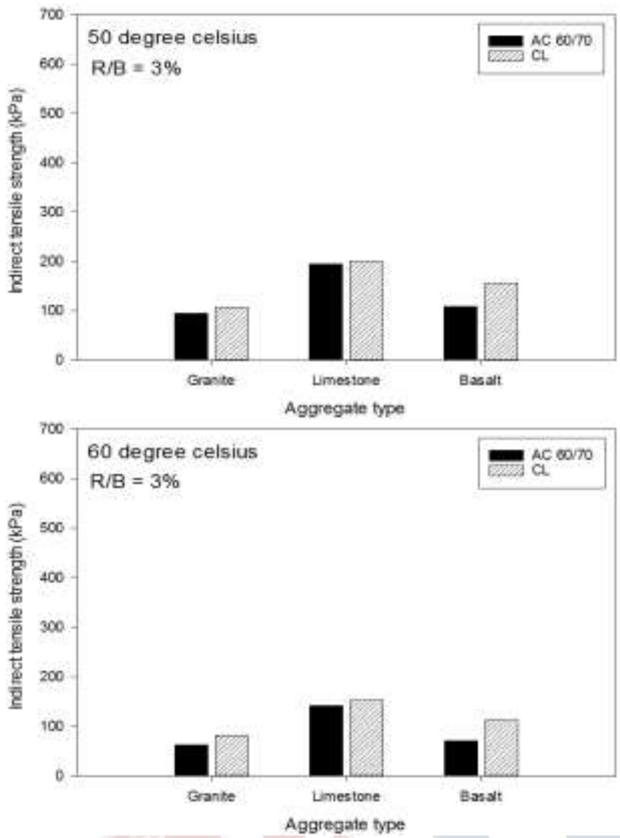

Figure 5 Indirect tensile strength of AC60/70 and CL modified asphalt concretes at 25, 40, 50 and 60 °C

Due to high crystal silica and smooth surface, the G aggregate has a low chemical bonding to the binder, resulting in the lowest tensile strength. However, using CL modified asphalt as a binder can improve the ITS for all types of aggregate (**Figure 5**).

Although the L aggregate presents the highest tensile strength, it exhibits the lowest degree of improvement. ITS improvement is 31.8, 25.7, 12.6 and 30.2% for G aggregate; 1.3, 14.6, 3.1 and 7.8% for L aggregate and 42, 26.8, 43.5, and 59.2 for B aggregate at 25, 40, 50 and 60°C, respectively. Due to a higher elastic recovery, the CL modified AC exhibits a superior ability to withstand the applied tensile stress [16]-[18].

Indirect tensile fatigue

Figure 6 illustrates the relationship between fatigue life (NF) and target stress levels (250, 300, and 350 kPa) of the AC60/70 concrete.

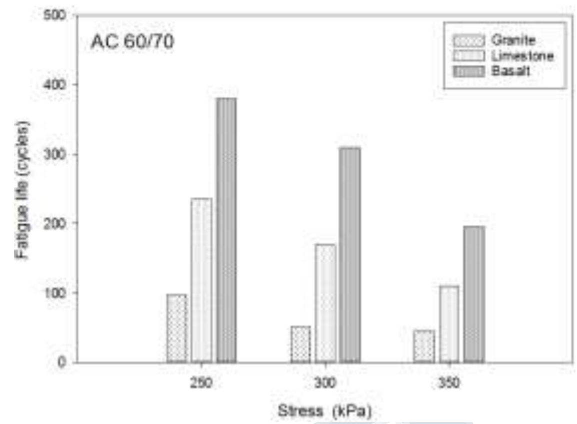

Figure 6 Fatigue life of AC60/70 asphalt concrete

The increased stress level results in the decreased NF because of higher stress-induced damage. Due to the lowest tensile strength, the G asphalt concrete consequently exhibits the lowest NF under ITF with followed by L and B asphalt concretes at the same stress level. The NF values are 97, 51, and 45 pulses for G asphalt concrete, and 235, 170 and 110 pulses for L asphalt concrete, and 380, 310, and 195 pulses for B asphalt concrete at stress levels of 250, 300, and 350 kPa, respectively. It is obvious that CL has the potential to enhance fatigue life of the sample under repetitive indirect tensile stress due to the improved ITS (**Figure 7**).

The lowest NF of CL modified asphalt concrete was alos found for G aggregate. The NF of CL modified asphalt is 212, 330, and 600 pulses for G aggregate, 140, 212, and 470 pulses for L aggregate and 125, 160, and 310 pulses for B aggregates at stress levels of 250, 300, and 350 kPa, respectively. As expected, L aggregate has the lowest degree NF improvement. For instance, at target stress level of 250 kPa, the degree of improvement of CL modified asphalt concrete compared with AC60/70 concrete is 118.6, 40.4, and 57.9% for G, L, and B aggregates, respectively. This indicates that higher elastic recovery property of CL modified asphalt improves the resistance to dynamic force and helps it recover to the original state after the deformation occurs [16]-[18].

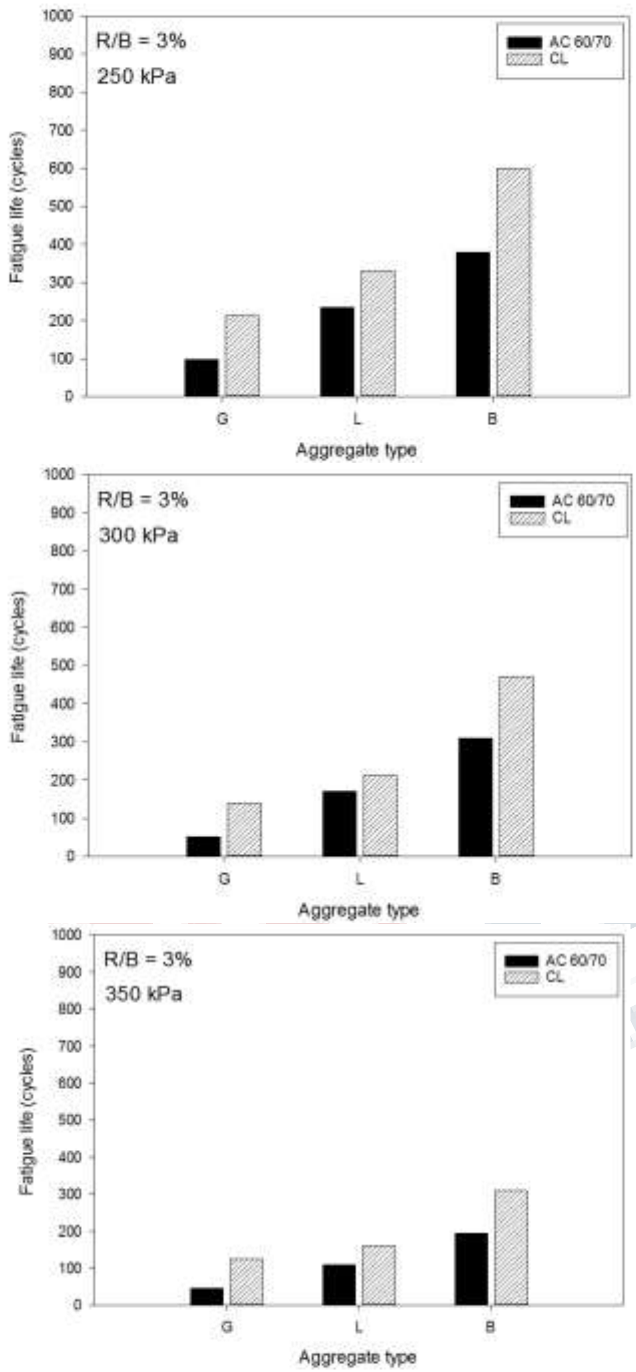

Figure 7 Fatigue life of AC60/70 and CL modified asphalt concretes

Permanent deformation

Figure 8 shows the permanent deformation of the AC 60/70 concrete with different aggregate types. L aggregate exhibits the highest permanent deformation due to the lowest stability and followed by G and B, which is 8,126, 7,796, and 7,396 micro-strains, respectively.

It is evident that the CL modified asphalt can better resist the development of permanent deformation than the conventional one due to the improved stability and tensile strength. The highest permanent deformation for CL modified asphalt concrete is found for L aggregate. The decrease in permanent deformation of CL modified asphalt compared to AC60/70 concrete is 78.8, 55.0, and 16.5% for G, B, and L aggregates, respectively (**Figure 9**). Similar to other test results, the L aggregate exhibits the lowest degree of improvement.

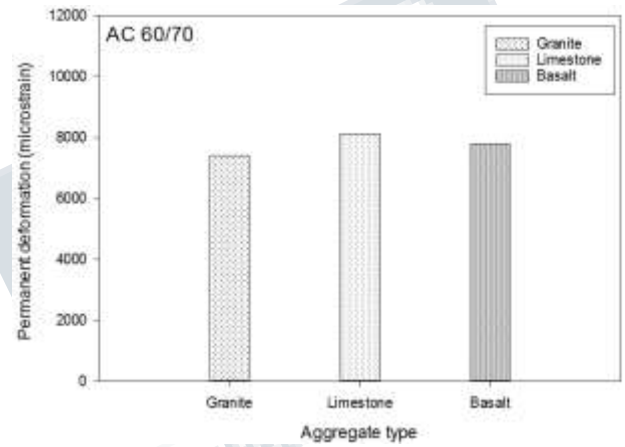

Figure 8 Permanent deformation of AC60/70 concrete

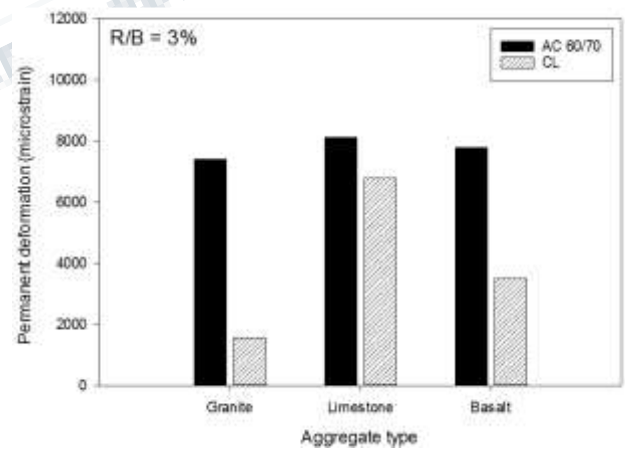

Figure 9 Permanent deformation of AC60/70 and CL modified asphalt concretes

The higher elastic recovery and rheological property of CL modified asphalt improve the permanent resistance of binder material. The properties of the aggregate cause a different degree of improvement. The aggregate with the lowest ability to absorb asphalt binder (L aggregate) has the lowest degree of improvement. The G and B aggregate has a higher potential to absorb CL modified asphalt binder, resulting in stronger particle bonding strength and higher degree of improvement.

V. CONCLUSIONS

Basalt (B) asphalt concrete exhibits the highest stability value due to the high degree of asphalt absorption and followed by granite (G) and limestone (L) asphalt concretes. L asphalt concrete has the highest ITS with followed by G and B asphalt concretes, respectively. Due to high crystal silica and smooth surface, the G aggregate has a low chemical bonding to the binder, resulting in the lowest tensile strength of G asphalt concrete. Due to the lowest tensile strength, the G asphalt concrete consequently exhibits the lowest NF with followed by L and B asphalt concretes at the same stress level. L asphalt concrete exhibits the highest deformation due to the lowest stability and followed by G and B asphalt concretes.

Concentrated latex (CL) has the potential to improve the engineering properties of AC material due to the latex film formation within the AC matrix. CL modified asphalt concretes exhibits the higher stability, ITS, ITF, and lower permanent deformation when compared with AC60/70 concretes.

The aggregate type affects the performance of CL modified asphalt concrete as seen by the different degree of improvement. The CL modified AC using limestone aggregate (the lowest ability to absorb asphalt binder) exhibits the lowest degree of improvement when compared with the CL modified AC using granite and basalt aggregates, respectively.

VI. ACKNOWLEDGEMENTS

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