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Laboratory investigation of the performances of cement and fly ash modified asphalt concrete mixtures

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Abstract

The influence of filler materials on volumetric and mechanical performances of asphalt concrete was investigated in this study. The AC60/70 asphalt binder incorporating with cement and fly ash as filler materials was mixed with limestone following the Marshall mix design method. The filler contents of cement and/or fly ash were varied. The non-filler asphalt concrete mixtures of the AC60/70 and the polymer modified asphalt were prepared for the purpose of comparison. The investigation programme includes the indirect tensile test, the resilient modulus test and the dynamic creep test. The tests are conducted under the humid temperate environments. All tests were then carried out under standard temperature (25 °C) and high temperature (55 °C) by using a controlled temperature chamber via the universal testing machine. The wet-conditioned samples were prepared to investigate the moisture susceptibility. Results show that cement and/or fly ash were beneficial in terms of improved strength, stiffness and stripping resistance of asphalt mixture. In addition, the combined use of cement and fly ash can enhance rutting resistance at wet and high temperature conditions. The results indicate that the strength, stiffness and moisture susceptibility performances of the asphalt concrete mixtures improved by filler are comparable to the performance of the polymer modified asphalt mixture.

Keywords: Asphalt concrete; Filler; Resilient modulus; Dynamic creep test; Moisture susceptibility

1. Introduction

Materials broadly employed to construct the surface layer of flexible pavement is an asphalt concrete, which is the composite material mixed from aggregates and asphalt binder. While the aggregates conduce resistance to support traffic loads, the asphalt binder contributes viscous-elastic behaviour to help with the adhesion of aggregate particles. The practicable size range of aggregate is from 50 mm to 0.075 mm. From this range the fine aggregates are defined to be smaller than 4.75 mm and the coarse aggregates are bigger than 4.75 mm. Even though particle size of the filler is less than 0.075 mm, it is well-known that the filler plays an important role in providing better packing conditions between the coarse and fine aggregates. It also leads to the greater stability within asphalt concrete and the reduction of optimum asphalt content.

Filler is categorised as a fine material which can be used to modify the properties of asphalt binder and asphalt concrete mixture. To this point, Portland cement, hydrated lime, fly ash, limestone dust, and clay particles are counted as fillers. The filler is not considered as a part of the aggregates. It is a modifier to improve the temperature susceptibility and durability of the asphalt binder as well as the asphalt concrete mixture [1]. The moisture susceptibility

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can be reduced by using the mineral fillers, for instance, hydrated lime [2,3]. In addition to utilisation of mineral fillers, the strength and stiffness of asphalt concrete can be increased [4]. The purpose of studying the characteristics of mineral filler is to enhance the performance of asphalt concrete in particular to increase the stability and durability against rutting and shoving. Lesueur et al. [3] presented that the durability of asphalt concrete mixtures can be increased by 2–10 years when the 1–1.5% of hydrated lime is used in the mixture. It is also found that Portland cement utilised as the filler can improve the anti-stripping properties of asphaltic concrete [5,6]. Additionally, the significant improvement on the moisture resistance characteristics can be observed when fly ash is employed to replace the cement and hydrated lime in producing asphalt concrete mixtures [7,8].

The key factors separating the fillers are particle shape and size, void content, surface area, mineral, chemical properties, and other physical properties [9]. By this reason different kinds of fillers replaced in the asphalt mixture lead to various asphalt mixture performances. This research aims to study the influence of filler types and fractions on the asphalt concrete mixture's properties. The materials selected to be the filler for this study are cement and fly ash. The contents of cement, fly ash and their combination were varied in the mixtures. The performance characteristics of the asphalt concrete mixture containing different types and fractions of filler were evaluated by various laboratory tests. The tests are conducted under the humid temperate environments of Thailand. To reach the standard test requirement, a minimum of three specimens was evaluated in each test.

2. Materials and testing programme

2.1. Materials

Most pavements in Thailand are constructed using asphalt mixes, consisting of AC60/70 penetration grade asphalt cement and aggregates. Mineral fillers such as limestone dust and cement are used to enhance the stability and durability of the asphalt concrete mixture. There is still no specification of filler material approved by the Thailand's Department of Highways (DOH). In the study, a local asphalt mix design based on the standard of the DOH commonly used in a flexible paving project was employed. In order to compare the performance of filler mixtures, the typical hot mix asphalt (HMA) without fillers and the polymer modified asphalt (PMA) mixtures were also prepared. Therefore, the locally-produced AC60/70 asphalt binder and the polymer modified asphalt were chosen in this study. The limestone aggregate used in the lab mixes was also obtained from an approved paving project. The aggregate particles were sieved according to the required size ranges in preparation to blend the considered asphalt mix with the approved gradation as shown in Fig. 1. Basic properties of aggregate were tested and summarised in Table 1. The two main variables in the specimens are the type and content of the filler. The filler used in this research are Portland cement type I and fly ash class C. The Portland cement type I is a common construction material locally made and consumed in the country. The fly ash is a by-product of lignite-fired power generation from the Mae Moh Power Plant in Lampang province. The chemical component and physical properties of cement and fly ash are summarised in Tables 2 and 3, respectively. The results of scanning electron micrograph of cement and fly ash are presented in Fig. 2.

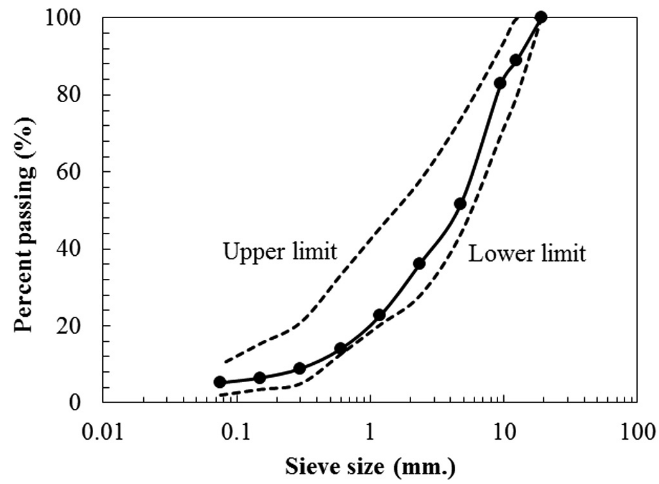


Fig. 1. Grain size distribution of aggregate.

Table 1
Properties of aggregate.

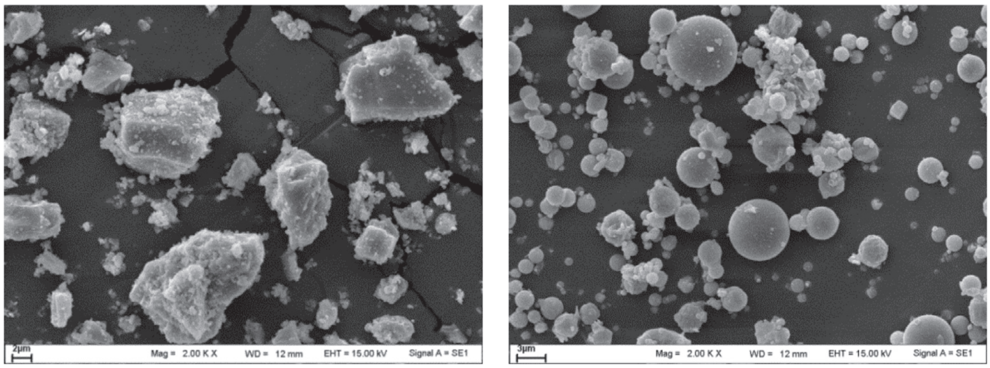
Aggregate type	Limestone
Bulk specific gravity	2.70
Flakiness index (%)	33
Asphalt absorption (%)	0.25
LA abrasion value (%)	
Aggregate 3/4″	22.70
Soundness (%)	
Weight loss aggregate 3/4″	1.0
Fine aggregate	3.2
Sand equivalent	64

Table 2
Chemical composition of materials from X-ray fluorescence (XRF) test (after Ref. [10]).

Chemical composition (%)	Portland cement	Fly ash
SiO_2	20.90	30.90
Al_2O_3	4.76	17.60
Fe_2O_3	3.41	14.80
CaO	65.41	23.24
MgO	1.25	2.12
SO_3	2.71	3.87
Na_2O	0.24	1.50
K_2O	0.35	2.73
LOI	0.96	1.20

Table 3
Basic properties of Portland cement and fly ash.

Material	Retained on sieve #325 (%)	Blaine fineness (cm^2/g)	Mean particle size (d_{50}, μm)	Specific gravity
Portland cement	13	3,420	11	3.15
Fly ash	29	3,602	19	2.12



(a) Portland cement (b) Fly ash

Fig. 2. Scanning electron micrographs of fillers with 2000× magnification (after Ref. [10]).

2.2. Asphalt concrete mixture preparation

Asphalt cement together with a 12.5-mm nominal maximum aggregate size of limestone were employed to prepare asphalt mixes. The mixture specimens were designed according to the Marshall method which is also used by the Thailand's Department of Highways. In this study, a total of 11 mixtures were prepared as summarised in Table 4. The HMA and PMA are the mixtures without filler, which are fabricated from the AC60/70 and the polymer modified asphalt binder, respectively. The letter C and F refer to the mixtures with cement and fly ash added as filler, respectively, and the number after the letter means the percentage of filler by weight of the aggregate. For example, C1.5F1.5 refers to the mix with 1.5% cement + 1.5% fly ash added by weight of the aggregate. The optimum asphalt content of 5% was determined from the HMA mix according to the Marshall design method [11]. In this study, the asphalt content of 5% was fixed for all mixes.

All materials were prepared in accordance the Marshall method (ASTM D6926) [12]. Before the mixing process, the aggregates were heated at 100 °C for 24 h to ensure moisture-free conditions and continued to be heated for 2 h at a mixing temperature of 150 °C. The asphalt was also heated at 150 °C in the oven. The specimens with dimensions of approximately 102 mm (4 inch) diameter and 64 mm (2.5 inch) height were compacted by using Marshall hammer compaction at 135 °C. The specimens were compacted at 75 blows per side according to heavy traffic conditions. After a 24-hour curing period for the Marshall specimens, volumetric measurement was conducted for all specimens. The results of volumetric properties of all mixes are summarised in Table 4.

Table 4
Volumetric properties of all mixtures.

Mix	Bulk specific gravity (G_{mb}, −)	Voids in the total mix (VTM, %)	Voids in the mineral aggregate (VMA, %)	Voids filled with asphalt (VFA, %)
HMA	2.418	4.0	14.7	72.8
C1	2.461	2.5	13.3	81.2
C3	2.462	2.8	13.4	79.1
C5	2.453	3.5	13.9	74.8
F1	2.467	2.0	12.8	84.4
F3	2.468	1.7	12.3	86.2
F5	2.471	1.3	11.7	88.9
C0.5F0.5	2.465	2.2	13.0	83.1
C1.5F1.5	2.466	2.2	12.8	82.8
C2.5F2.5	2.470	2.1	12.5	83.2
PMA	2.419	4.0	14.7	72.8

Remark: HMA = Hot Mix Asphalt (without filler), PMA = Polymer Modified Asphalt (without filler), C = Cement, F = Fly ash (e.g. C1.5F1.5 = 1.5% cement + 1.5% fly ash mixture).

2.3. Testing programme

The experimental tests including the Marshall stability (ASTM D6927) [13], the indirect tensile test (IDT) (ASTM D4867) [14], the resilient modulus (Mr) test (ASTM D4123) [15], and the dynamic creep test (BS DD226) [16] were carried out through this research as summarised in Table 5. Following the Marshall stability test, the specimens were soaked at 60 °C for 24 h, and then the conditioned specimens were loaded to failure at a constant rate of 1.65 mm/min. The ratio of the stability to flow, which is stated as the Marshall quotient (MQ), indicates the stiffness of the specimen. For the indirect tensile, the resilient modulus, and the dynamic creep tests, a controlled temperature and humidity chamber is used to manage the

Table 5
Experimental programme.

Test	Temperature (°C)	Mix	Conditions
Stability and flow (ASTM D6927)	60	HMA, PMA, C1, F1, C0.5F0.5, C3, F3, C1.5F1.5, C5, F5, C2.5F2.5	Wet
Indirect tensile test (ASTM D4867)	25, 55	HMA, PMA, C1, F1, C0.5F0.5, C3, F3, C1.5F1.5, C5, F5, C2.5F2.5	Dry/Wet
Resilient modulus test (ASTM D4123)	25, 55	HMA, PMA, C1, F1, C0.5F0.5, C3, F3, C1.5F1.5, C5, F5, C2.5F2.5	Dry/Wet
Dynamic creep test (BS DD226)	25, 55	HMA, PMA, C1, F1, C0.5F0.5, C3, F3, C1.5F1.5, C5, F5, C2.5F2.5	Dry/Wet

temperatures desired for the testing samples at 25 °C and 55 °C. In order to examine the moisture sensitivity, the conditioned specimens were soaked at 55 °C for 24 h prior to the test started. The details of testing conditions are summarized in Table 5.

For the indirect tensile test, the cylindrical specimens are subjected to monotonically compressive loads, which act parallel to the vertical diametric plane, by using the 200 kN Universal Testing Machine (UTM). This type of loading produces a relatively uniform tensile stress acting perpendicular to the applied load plane and the specimen usually fails by splitting along with the loaded plane. The indirect tensile strength (ITS) is then defined as the maximum strength. The test method has been carried out similar to the previous research by the authors [17]. The 14 kN cyclic UTM was employed in the resilient modulus and the dynamic creep tests. To evaluate the mixture's resilient modulus, 10% of indirect tensile strength (ITS) values at each temperature are used for the resilient modulus test. The specimens are continuously loaded by 1 Hz frequency (loading period for 0.1 s and rest period for 0.9 s) with 155 cycles, which the first 150 cycles are for preloaded conditions and the last 5 cycles are for measuring the resilient modulus. The dynamic creep test or the permanent deformation test was performed according to the British Standard [16], a deviator stress of 100 kPa was used in the unconfined test, and the loading frequency of 1 Hz (loading period for 0.5 s and rest period for 0.5 s) with 1800 cycles or until the specimen is failed was applied.

3. Results and discussion

3.1. Material characterisation

The limestone used for coarse and fine aggregates was relatively clean and free from deleterious material, and the particle shape was relatively flaky and irregular. The properties of limestone such as flakiness index, LA abrasion, soundness and sand equivalent satisfy the Thailand's Department of Highways requirement for asphalt concrete mixture application [18]. It is noted that the Thailand's Department of Highways standards are rather similar to the ASTM and AASHTO standards [19–21]. The properties of cement and fly ash are shown in Table 3. The specific surface area (the surface area per unit mass) was tested by Blaine fineness. The specific surface area of fly ash is slightly higher than that of cement. The fine particle size (i.e., sieve No.325 with an opening size of 0.044 mm) and the mean particle size (d_{50}) were tested and reported. The particle size of fly ash is higher than that of cement. The specific surface can be correlated with particle size and linked to physical and mechanical properties of the mixture. The specific gravity of cement is greater than that of fly ash. The particle shape, size and morphology of the cement and fly ash were examined by using scanning electron microscopy (SEM) as shown in Fig. 2. The SEM images show that the cement is irregular in shape and its particle size is around 2 μm, whereas the fly ash shape is relatively spherical and approximately 3 μm in size. It is because the specific gravity of fly ash is lower than cement. It can be deduced that the fly ash particle is bigger and has a more specific surface area than cement particle. Therefore, the information shown in SEM images is consistent with the Blaine fineness test and d_{50} data in Table 3.

3.2. Volumetric properties of the mixture

In this study, the effect of the amount and type of filler on the volumetric properties of the mixture was examined. The asphalt content of 5.0% was fixed for all the mixes. The results of volumetric properties of all specimen designs are summarised in Table 4. The bulk specific gravity (G_{mb}) values of the mixtures with filler added are higher than those of the HMA and PMA mixes. The HMA and PMA specimens have higher the total voids in the mix (VTM) and the voids in mineral aggregate (VMA), but lower the voids filled by asphalt (VFA) than those of the mixtures with filler added. This is because the filler can fill the void and increase the density of the mixture.

Comparing among the mixtures with filler added, the fly ash provides the denser properties than the cement, in which the mix with 5% fly ash has the highest G_{mb} and lowest the VTM. The mix with both cement and fly ash has the intermediate values of the volumetric properties. It is possible that filler, for a certain size range, would fill up voids among the aggregates, thereby decreasing the VMA. The decrease in the VMA could indirectly lead to the decrease in the VTM even though the asphalt content of all mixes is fixed. Certain fillers require more asphalt to wrap onto its surface because of the relatively higher specific surface area, thus resulting in a higher VFA.

3.3. Strength and stiffness of the mixture

3.3.1. Marshall stability

The Marshall stabilities and flows of all asphalt concrete specimens were tested. The ratio of stability (kN) to flow (mm), stated as the Marshall quotient (MQ), and as an

Table 6
Experimental results.

Specimen	MQ (kN/0.25 mm)	ITS (kPa)			TSR 55 °C (%)	Mr (MPa)			Accumulated strain @ 1800 cycles (%)			Accumulated strain rate		
		dry		wet		dry		wet	dry		wet	dry		wet
		25 °C	55 °C	55 °C		25 °C	55 °C	55 °C	25 °C	55 °C	55 °C	25 °C	55 °C	55 °C
HMA	0.74	603	86	57	66.28	3,247	240	153	1.43	1.62	2.38	0.1004	0.1954	0.2172
C1	0.74	683	109	119	109.17	3,372	344	163	1.18	1.28	1.23	0.0902	0.1479	0.1342
C3	0.79	687	120	126	105.00	3,553	399	193	1.16	1.12	1.00	0.1059	0.1378	0.0851
C5	0.87	684	129	138	106.98	3,280	396	192	0.65	1.20	1.14	0.0651	0.1291	0.0878
F1	0.72	631	112	91	81.25	4,005	340	224	1.12	1.37	0.98	0.1114	0.1612	0.1004
F3	0.75	657	127	126	99.21	3,325	324	174	0.55	1.50	0.94	0.0611	0.1593	0.0948
F5	0.72	663	132	125	94.70	3,284	334	149	1.31	1.25	1.26	0.1511	0.1447	0.1310
C0.5F0.5	0.75	647	95	94	98.95	3,758	310	225	1.38	1.45	1.39	0.1162	0.1755	0.1267
C1.5F1.5	0.91	653	132	110	83.33	4,005	368	354	0.47	1.35	0.92	0.0546	0.1599	0.0918
C2.5F2.5	0.93	675	159	132	83.02	3,967	309	275	0.81	1.11	0.94	0.0938	0.1144	0.0870
PMA	0.99	747	165	130	78.79	3,839	439	377	0.62	0.80	0.83	0.0594	0.0493	0.0546

empirical indication of the stiffness of the mixes is reported in Table 6. It is well-recognised that the MQ is a measure of the material's resistance to shear stresses, permanent deformation, and hence rutting. The high MQ values indicate a high stiffness mix and resistance to creep deformation. Fig. 3 illustrates the MQ for all mixtures. The results indicated that the PMA has highest MQ value and the more cement added the higher MQ can be observed. Conversely, the fly ash has less influence to the MQ value. However, the combination of cement and fly ash as fillers can significantly increase the MQ value of the mixture. The filler content is in the range of 3–5%, in which the mixture with 2.5% cement + 2.5% fly ash provides the MQ value almost closed to the PMA mix.

3.3.2. Indirect tensile strength

The indirect tensile tests (IDT) were carried out on unconditioned (dry) and conditioned (wet) specimens at standard temperature (25 °C) and hot temperature (55 °C). The test results are summarized in Table 6 and plotted as shown in Figs. 4 and 5. The IDT is normally conducted to determine the tensile properties of the asphaltic concrete, which can be further related to the cracking properties of the pavement. Fig. 4 illustrates the average indirect tensile strength (ITS) under dry conditions of the asphalt specimens treated with filler material. The result indicates that the use of cement and fly ash result in increasing in the ITS comparing to the HMA mix around 10–15% at 25 °C and almost 50% at 55 °C. However, the ITSs of all filler mixtures are still lower than the ITS of PMA mix.

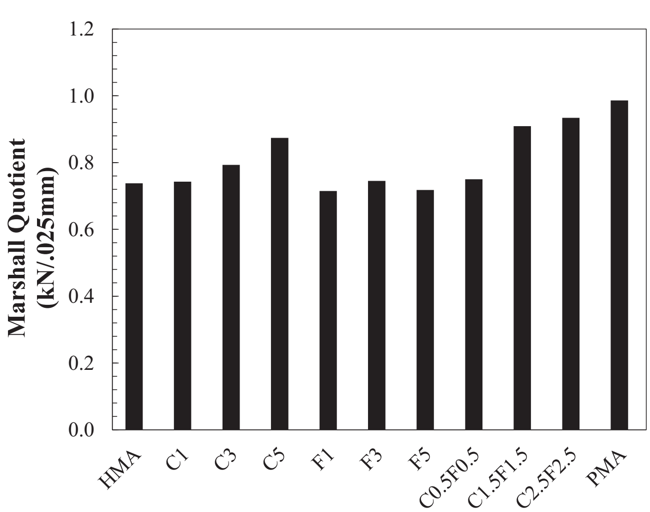


Fig. 3. Marshall quotient values of asphalt mixtures.

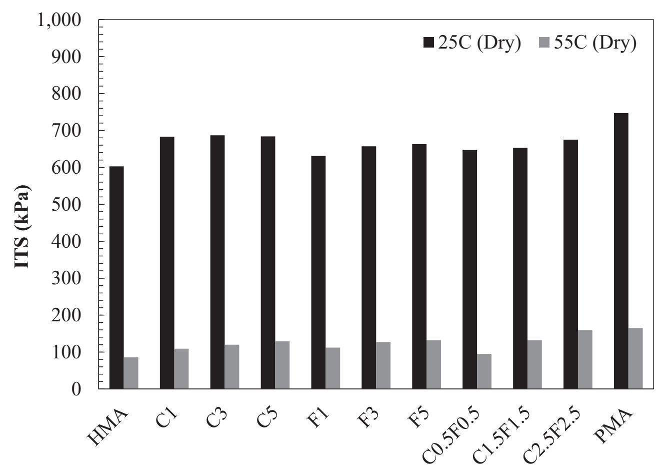


Fig. 4. Indirect tensile strength (ITS) values of asphalt mixtures in dry conditions.

Fig. 5 presents a comparison of the average ITS of the unconditioned and conditioned specimens at 55 °C. The tensile strength ratio (TSR), defined as the ratio between the ITS of conditioned and unconditioned sample at 55 °C, is an indicator for moisture susceptibility. The results show that both cement and fly ash can significantly increase the ITS of conditioned specimens at 55 °C, especially the 5% cement and 5% fly ash specimens offer the ITS values as good as the PMA specimen. It is noted that the TSR at 55 °C for the mixes C1, C3 and C5 are slightly greater

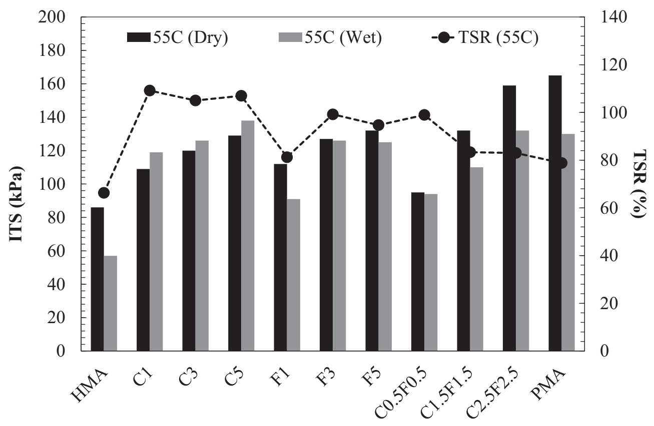


Fig. 5. Indirect tensile strength (ITS) and tensile strength ratio (TSR) values of asphalt mixtures at 55 °C.

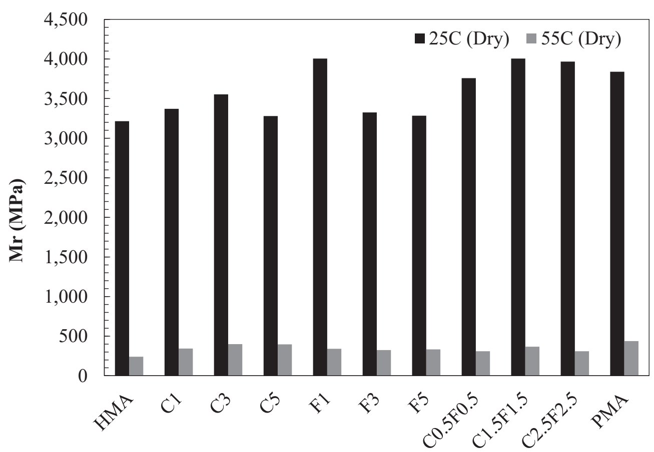


Fig. 6. Resilient modulus (Mr) values of asphalt mixtures in dry conditions.

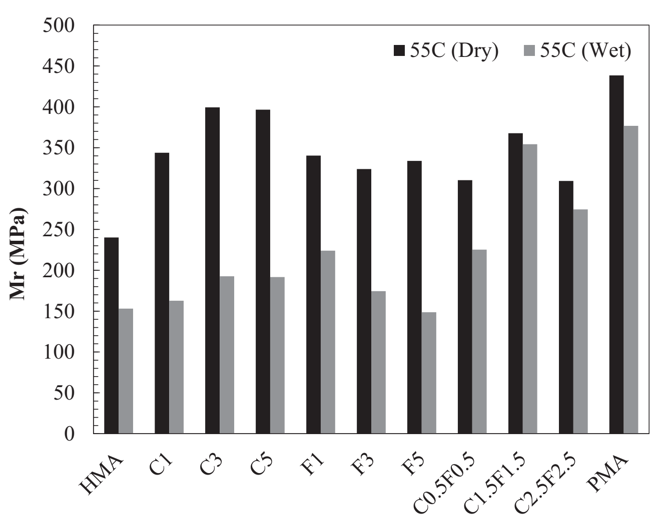


Fig. 7. Resilient modulus (Mr) of asphalt mixtures at 55 °C.

than 100%. This might be from the influence of cementation in the first 24 h. The samples were better curing when soaked in the water than air-dried conditions.

3.3.3. Resilient modulus

Similar to the ITS, the cement and fly ash can improve the stiffness of asphalt concrete. The resilient modulus (Mr) is a significant parameter for pavement design as indicated by the material stiffness. The test results of resilient modulus are also summarised in Table 6 and plotted as shown in Figs. 6 and 7. Fig. 6 shows that the Mr values are increased by cement and fly ash. The presence of filler may modify the viscoelastic properties of the asphalt mastic and affect the mixture's stiffness. However, an excessive amount of filler could reduce the viscous behaviour of asphalt mastic and result in decreasing the Mr value. In this study, the suitable amount of cement and/or fly ash was found to be in the range of 1–3%.

3.4. Dynamic creep performance

Rutting is the major distress found in flexible pavement. It is the permanent deformation in the transverse profile in the wheel patch, starting at zero rut depth and increasing with the number of loading repetitions. A repetitive uniaxial compressive load on cylindrical specimen from the dynamic creep test provides a reasonable simulation of asphalt pavement subjected to repetitive axle loads. In this study, all mixture specimens were firstly performed in dry conditions at 25 °C according to BS DD226 [16]. To evaluate the moisture susceptibility, the dynamic creep tests for all mixture specimens were conducted in dry and wet conditions at hot temperature (55 °C). The dynamic creep test results known as creep curves were plotted as shown in Figs. 8–10 for dry-conditioned at 25 °C, dry-conditioned at 55 °C and wet-conditioned at 55 °C, respectively. Two parameters, the accumulated strain at 1800 cycles and the accumulated strain rate, were determined from the curves as reported in Table 6.

The results indicate that the cement and fly ash can improve the resistance to performance deformation. The 5% cement, 3% fly ash and 1.5% cement + 1.5% fly ash are the mixtures that can provide resistance to permanent deformation as similar to the PMA mix. The fillers can

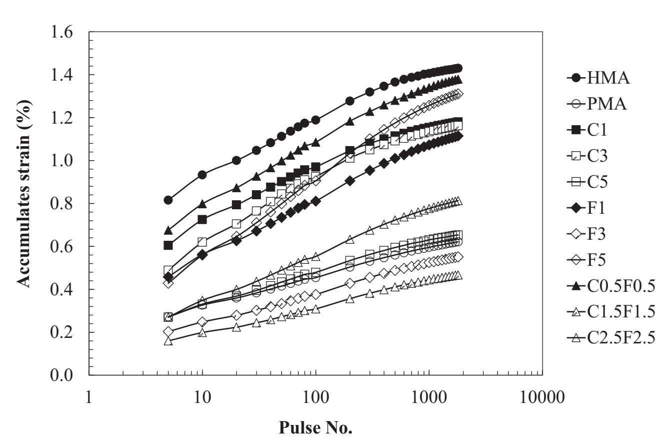


Fig. 8. Creep behaviour of asphalt mixture at 25 °C under dry conditions.

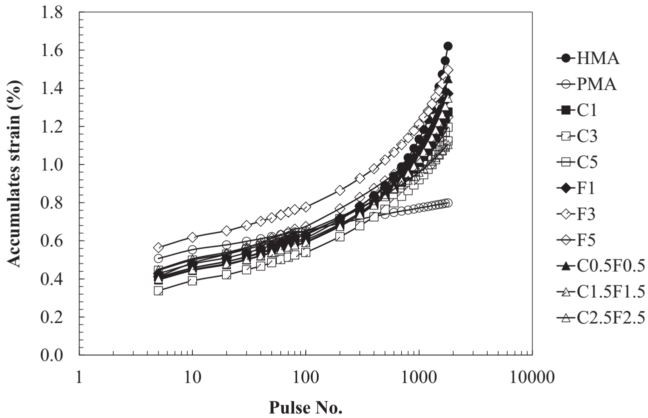


Fig. 9. Creep behaviour of asphalt mixtures at 55 °C under dry conditions.

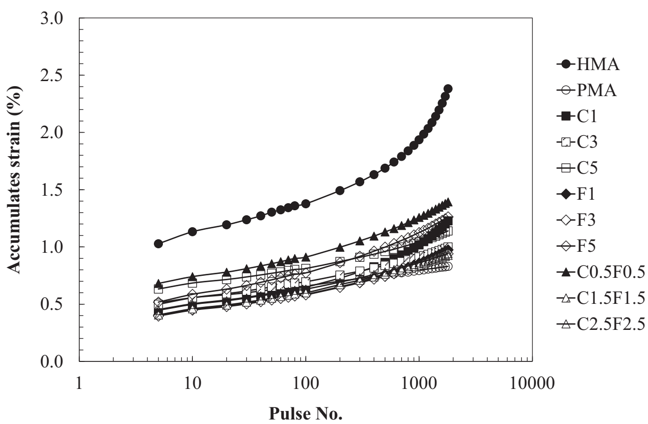


Fig. 10. Creep behaviour of asphalt mixtures at 55 °C under wet conditions.

enhance the rutting resistance of asphalt concrete, especially at high temperature, when the asphalt behaves softly.

3.5. Moisture susceptibility

In tropical countries like Thailand, moisture susceptibility is one of the most important distress mechanisms leading to premature failure of asphalt pavements. There are many researchers trying to study and develop the methods of testing [11,22]. In this study, the test results of the conditioned specimens can be used to indicate the moisture susceptibility. Basically, higher values of ITS, Mr and accumulated strains of conditioned samples may indicate greater resistance to moisture damage. The indirect tensile strength ratio (TSR) is a common parameter to evaluate moisture susceptibility. The TSR for all mixes are reported in Table 6 and Fig. 5. The results indicate that the cement and fly ash as filler can enhance the moisture susceptibility of the asphalt concrete. The 1% cement mixture gives the highest number of the TSR. However, the 1.5% cement + 1.5% fly ash mixture offers the highest Mr and accumulated strain values in wet conditions, which is similar to the values of PMA mix. It seems that the combination of the cement and fly ash as filler can increase the moisture susceptibility of the HMA as good as the PMA mix.

4. Discussion and conclusion

Filler is usually added to asphalt concrete mixtures as a stiffening and void-filling material. This study evaluated totally 11 groups of specimens with various cement and/or fly ash contents and a 5% asphalt content. The hot mix asphalt (HMA) and polymer modified asphalt (PMA) mixtures without filler added were prepared for a sake of comparison. The mechanical properties of these mixtures were determined at 25 °C and 55 °C and moisture susceptibility tests were conducted at 55 °C to determine their moisture damage potential. The influence of cement and fly ash as filler materials on the performance of asphalt concrete can be discussed as follows:

(1) It is obvious that the filler can fill the void and increase the density of the mixture. It is resulting in increasing the bulk specific gravity (G_{mb}) and reducing the voids in the total mix (VTM). However, the fly ash provides denser properties than cement because the fly ash has greater specific surface area. The more specific surface area the more asphalt to wrap its surface, thus resulting in a higher void filled with asphalt (VFA). Moreover, the filler can perform as a tiny roller during the compaction process. If the filler has a large enough diameter and a regular shape, it will act as a friction-lubricating agent [9]. The relationship between types of fillers and voids of mineral aggregates directly affects the work ability of the mixture. The bigger size and more regular shape of fly ash particle may act as rollers that facilitate less friction in the mastic during compaction, thereby resulting in a tighter packing and a lower void in the mineral aggregate (VMA).

(2) Results from this study shows that cement and/or fly ash were beneficial in terms of improved strength, stiffness and stripping resistance of asphalt mixture. Mechanical properties and moisture damage testing results indicated that the use of 1.5% cement + 1.5% fly ash improves the resilient modulus (Mr) of the mix at low and high temperature. Since cement increases the strength of asphalt concrete [4] and fly ash increases the stripping resistance of mix [23], the combined use of both cement and fly ash might be the optimum filler solution.

(3) For pavement distress, the addition of cement and/or fly ash in asphalt concrete mixture significantly reduces the permanent deformation of the mix, especially in wet and high temperature. The results show that the mix of 1.5% cement + 1.5% fly ash provides the best rutting resistance.

In this study, investigation of volumetric and mechanical properties of asphalt concrete mixtures revealed that cement and/or fly ash imparted different enhancements to mixtures. It is concluded that the filler interacted with other constituent materials in the asphalt concrete mixture contributes to the mixture's performance. The combination of cement and fly ash mixture exhibited better strength, stiffness and moisture damage resistance. It is well-known that the PMA considerably increases mechanical performances and work ability of the asphalt concrete mixture [22,24]. Therefore, an alternative of using filler to improve the conventional HMA might be the optimal solution in the practice. It is noted that some more research would be suggested to be conducted in future, such as the influence of the optimum asphalt content and the fatigue performance.

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References

[1] C. Gorkem, B. Sengoz, Predicting stripping and moisture induced damage of asphalt concrete prepared with polymer modified bitumen and hydrated lime, Constr. Build. Mater. 23 (6) (2009) 2227–2236, http://dx.doi.org/10.1016/j.conbuildmat.2008.12.001.

[2] R. Taha, A. Al-Rawas, A. Al-Harthy, A. Qatan, Use of cement bypass dust as filler in asphalt concrete mixtures, J. Mater. Civ. Eng. 14 (4) (2002) 338–343, http://dx.doi.org/10.1061/(ASCE)0899-1561(2002) 14:4(338).

[3] D. Lesueura, J. Petitb, H.J. Ritterc, The mechanisms of hydrated lime modification of asphalt mixtures: a state-of-the-art review, Road Mater. Pavement Des. 14 (1) (2013) 1–16, http://dx.doi.org/10.1080/14680629.2012.743669.

[4] A.H. Aljassar, S. Metwali, M.A. Ali, Effect of filler types on Marshall stability and retained strength of asphalt concrete, Int. J. Pavement Eng. 5 (1) (2004) 47–51, http://dx.doi.org/10.1080/10298430410001733491.

[5] S.D. Ramswamy, M.A. Aziz, Assessment of effect of filler on the stripping of bituminous mix, The 4th Conference of the Road Engineering Association of Asia and Australasia, 1983, pp. 159–170.

[6] S.D. Ramswamy, M.A. Aziz, Effect of filler type and shape of aggregates on the stability of bituminous mixes, The 4th Conference of the Road Engineering Association of Asia and Australasia, 1983, pp. 171–177.

[7] J.C. Rosner, R.D. Pavlouich, J.G. Chehovits, Fly ash as a mineral filler and anti-strip agent for asphalt concrete, Report No. FHWA-AZ-81/173, 1981, USA.

[8] M. Pasetto, N. Baldo, Resistance to permanent deformation of road and airport high performance asphalt concrete base courses, Adv. Mater. Res. 723 (2013) 494–502, 10.4028/www.scientific.net/AMR.723.494.

[9] A. Zulkati, Y. Diew, D.S. Delai, Effects of fillers on properties of asphalt–concrete mixture, J. Transp. Eng. 138 (7) (2012) 902–910, http://dx.doi.org/10.1061/(ASCE)E.1943-5436.0000395.

[10] T. Chompoorat, S. Likitlersuang, Assessment of shrinkage characteristic in blended cement and fly ash admixed soft clay, 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Japanese Geotechnical Society Special Publication 2(6), 2015, pp. 311–316. doi: http://doi.org/10.3208/jgssp.THA-01.

[11] T. Chompoorat, S. Likitlersuang, Laboratory investigation of hot mix asphalt behaviour for mechanistic-empirical pavement design in tropical countries, Geotech. Eng. J. SEAGS AGSSEA 46 (1) (2015) 37–44.

[12] ASTM D6926, American Society for Testing and Materials, Standard practice for preparation of bituminous specimens using Marshall apparatus, 2010, Washington, DC.

[13] ASTM D6927, American Society for Testing and Materials, Standard test method for Marshall stability and flow of asphalt mixtures, 2015, Washington, DC.

[14] ASTM D4867, American Society for Testing and Materials, Standard test method for effect of moisture on asphalt concrete paving mixtures, 2009, Washington, DC.

[15] ASTM D4123, American Society for Testing and Materials, Standard test method for indirect tension test for resilient modulus of bituminous mixtures, 1995, Washington, DC.

[16] BS DD226, Method for Determining Resistance to Permanent Deformation of Bituminous Mixtures Subject to Unconfined Dynamic Loading, British Standards Institution, UK, 1996.

[17] T. Chompoorat, S. Likitlersuang, An influence of asphalt binder on time-temperature shift function for asphalt concrete at large strains, KSCE J. Civil Eng. (Online) (2016), http://dx.doi.org/10.1007/s12205-016-0665-4.

[18] DH-S 408, 2532, Asphalt Concrete or Hot-Mix Asphalt, Standard of the Department of Highways, Thailand, 1989 (in Thai).

[19] ASTM D692, American Society for Testing and Materials, Standard specification for coarse aggregate for bituminous paving mixtures, 2015, Washington, DC.

[20] M. Aashto, American Association of State Highway and Transportation Officials, Standard specification for fine aggregate for bituminous paving mixtures, 2012, Washington, DC.

[21] M. Aashto, American Association of State Highway and Transportation Officials, Standard specification for mineral filler for bituminous paving mixtures, 2011, Washington, DC.

[22] K. Kanitpong, N. Charoentham, S. Likitlersuang, Investigation on the effects of gradation and aggregate type to moisture damage of warm mix asphalt modified with Sasobit, Int. J. Pavement Eng. 13 (5) (2012) 451–458, http://dx.doi.org/10.1080/10298436.2011.565058.

[23] N. Ali, J.S. Chan, S. Simms, R. Bushman, A.T. Bergan, Mechanistic evaluation of fly ash asphalt concrete mixtures, J. Mater. Civ. Eng. 8 (1) (1996) 19–25, http://dx.doi.org/10.1061/(ASCE)0899-1561.

[24] M. Pasetto, N. Baldo, Influence of the aggregate skeleton design method on the permanent deformation resistance of stone mastic asphalt, Mater. Res. Innovations 18 (S3) (2014) S96–S101, http://dx.doi.org/10.1179/1432891714Z.000000000588.