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PERFORMANCE EVALUATION OF KOREAN MODIFIED ASPHALT BINDER UNDER VIETNAM CONDITIONS

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Abstract. In recent years, study on asphalt binder that provide strong rutting and cracking resistance is considered of great significance as it can help provide extended pavement life and significant cost savings in pavement construction in Vietnam. The purpose of this paper is to evaluate the performance characteristics of Korean modified asphalt binder in hot mix asphalt (HMA) mixture under Vietnam condition. To accomplish this objective, the mechanical properties of Korean modified binder in AC mixtures were evaluated using tests such as the Marshall stability and flow, indirect tensile (IDT), moisture resistance, and Wheel Tracking. It was found that the Korean modified binder can improve significantly not only the rutting performance but also the moisture damaged resistance of asphalt pavement. Furthermore, the performance life of Korean modified binder for AC mixtures was evaluated through the mechanistic- empirical pavement design guide (MEPDG) program. Based on the results of the study, it can be concluded that the Korean modified asphalt binder can enhance the performance of asphalt mixtures significantly under Vietnam conditions.

Keywords: Korean modified asphalt binder, hot mix asphalt, rutting resistance, moisture resistance, mechanistic empirical pavement design guide (MEPDG).

1. INTRODUCTION

Rutting and cracking distresses are related to the viscoelastic behaviour of asphalt binder which plays an important role in determining the pavement performance life. The conventional asphalt binder is not able to sustain the performance criteria in rutting deformation and cracking due to increase in heavy loading and busy traffic as well as high temperatures. The conventional asphalt binder is generally characterized by higher brittleness temperature and lower softening temperature, leading to cracking and rutting distresses often occur during its serving life. In order to solve these problems, the polymer modified asphalt is used generally to enhance the pavement performances in terms of permanent deformation at high temperatures and cracking at low temperatures.

In Vietnam, a lot of research efforts have been made to investigate the use of different additives in improving binder characteristics for HMA mixtures [1-4]. The effect of carbon nanotubes (CNTs) as binder modifier for asphalt mixtures was evaluated on the performance of asphalt mixtures [1]. It was found that the use of CNTs as binder additive increases significantly to rutting resistance at high temperature and cracking resistance at intermediate temperature. The study results [2] showed that use of Toughfix additive for HMA mixture can improve the Marshall stability, rutting resistance and tensile strength. The use of Zycotherm to modify asphalt binder can increase the softening temperature and the penetration *PI* index [3]. Finally, the study results [4] indicates that there are six additive types including lime hydrate, cement, Wetfix Be, Zycotherm, Tough Fix, and Tough Fix Hyper which can apply to enhance binder characteristics for AC mixtures in Vietnam. However, these additives may increase price of asphalt binders and thus in the price of HMA as well. Currently, the temporary technical guide of design, construction, and specification for HMA using the Styrene - Butadiene – Styrene (SBS) additive mixed with aggregate at HMA plant according to Decision No. 3904/QĐ-BGTVT [5] which was done in Vietnam**.** Although the rutting resistance is good and the price of HMA is reduction comparing with the polymer asphalt concrete, the cracking performance is need to be considered the long-term pavement. Hence, further studies may be needed to investigate other modified binders which can improve binder properties and affordable cost.

In this study, the performance characteristics of Korean modified asphalt binder in hot mix asphalt (HMA) mixture under Vietnam condition was investigated. For this purpose, The Marshall stability (MS) test, wheel tracking (WT) test and indirect tensile (IDT) tests were carried out to evaluate the performance characteristics of AC mixtures. Finally, the performance life of AC mixtures was simulated and evaluated using the mechanistic - empirical pavement design guide (MEPDG) program.

2. EXPERIMENTAL PROGRAM

2.1. Aggregates

The dense gradation with nominal maximum aggregate size of 12.5mm was used for the control and modified asphalt mixtures. Fig. 1 shows the aggregate gradation used for asphalt mixtures in this study.

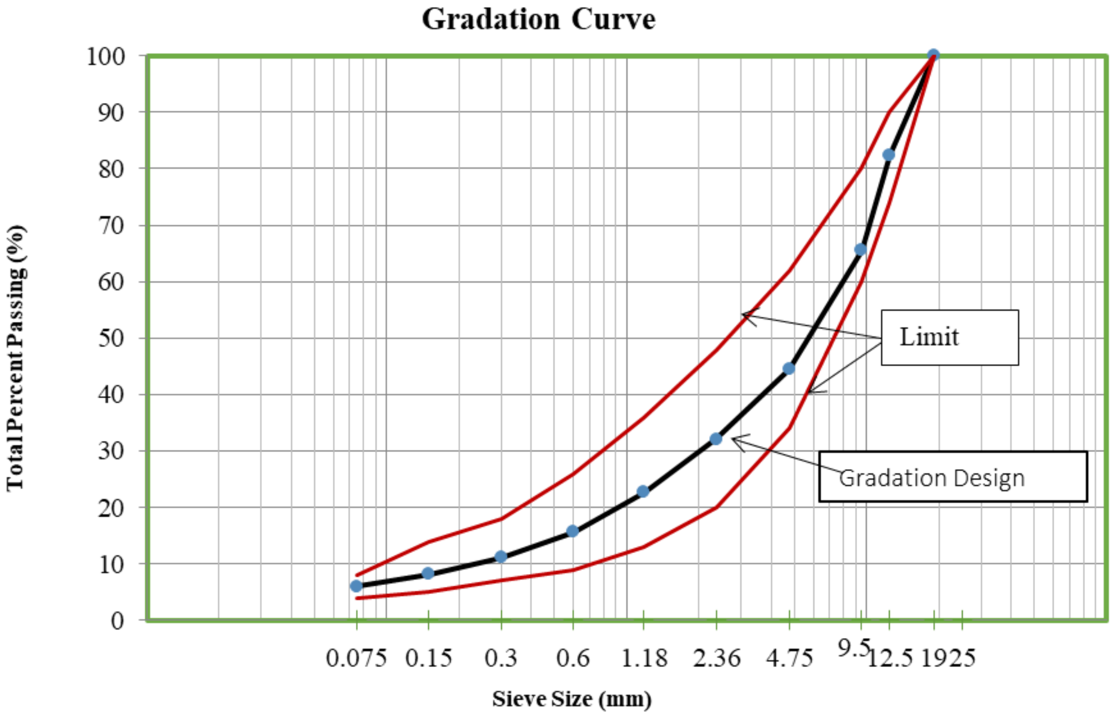

Figure 1. Aggregate gradation used for this study.

2.2. Asphalt Binder

In this paper, a 60/70 bitumen was used as control asphalt binder. The properties of conventional binder and Korean modified binder are presented in Table 1.

Table 1. Physical properties of conventional binder and Korean modified binder.

No.	Test Name	Unit	60/70 Binder	Korean modified binder
1.	Penetration at 25°C, 0.1 mm	1/10mm	61.2	58
2.	Softening Point (Ring and Ball Method)	°C	48.6	90
3.	Density at 25°C	g/cm^3	1.035	1.034
4.	Coated Aggregate Using Boiling water	level	3	4

2.3. Mix Design

The Marshall mix design was used to produce asphalt mixtures. The compacted samples were conducted at different binder contents to determine the optimum bitumen content, the optimum binder content value of the AC mixture was found to be 4.8% by mass of the total mixture for the control and modified mixtures based on the target air void of 4.0%±0.5%.

2.4. Mixture tests

The HMA mixture tests were carried out such as the MS test, IDT test, and WT test to evaluate the performance of asphalt binder in asphalt concrete (AC) mixtures. In the MS test, the resistance to plastic deformation of a compacted cylindrical sample of asphalt mixtures is measured when the sample is loaded at a constant speed rate of 50mm per minute according to TCVN 8860-1:2011 [6]. The MS of the HMA mixture is defined as the maximum load carried by the sample at a standard test temperature of 60°C. Meanwhile, the flow value is the deformation that the compacted sample undergoes during loading up to the maximum value. Moreover, Marshall Stability Ratio (MSR) were tested to evaluate moisture damage resistance of HMA mixtures according to TCVN 8860-12:2011 [7], the MSR is computed using equation (1):

$$MSR = \frac{MS_{wet}}{MS_{dry}} \times 100 \quad (1)$$

where

MSR = Marshall stability ratio,

MSdry = Marshall stability value of the dry samples at 25°C, and

MSwet = Marshall stability value of the conditioned sample at 60°C for 24h and 25°C for 2h.

The IDT test was performed at a constant displacement rate of 50mm/min under temperature condition of 20 · C. The peak compressive load was measured to calculate the indirect tensile strength of all the specimens using the following equation:

$$\sigma_{IDT} = \frac{2000 P_{\max}}{\pi t D} \quad (2)$$

where

σ_{IDT} = indirect tensile strength (kPa),

$P_{\max}$ = peak load (N),

t = specimen thickness (mm), and

D = specimen diameter (mm).

The wheel tracking tester developed by Hamburg Wheel Tracker made in Germany was used in accordance with EN 12697-22 [8]. Steel wheels were used for experiments in water. The wheel diameter and width are 203mm and 50mm, respectively. The wheel tracking machine and testing samples as shown in Figure 2.

Figure 2. Wheel tracking machine and testing samples.

3. RESULTS AND DISCUSSION

3.1. Marshall Stability Test

In this study, the MS and MSR were done to evaluate the performance characteristics of Korean modified asphalt binder in AC mixtures. As shown in Table 2, The MS of Korean modified asphalt mixtures are 12 kN which is 14.3% higher than that of the control AC mixture (10.5kN). Meanwhile, the MSR of Korean modified asphalt mixtures is 6.1% higher than that of control mixture.

Table 2. The results of Marshall stability test.

Binder type	**Air Void (%)**	**Marshall stability (MS) (KN)**	**Flow (mm)**	**Marshall Stability Ratio (MSR) (%)**
60/70	4.3	10.5	3.82	87.0
Korean modified binder	4.2	12	3.71	92.3

An analysis of variance (ANOVA) was applied to determine whether significant differences among sample means existed on marshall stability test. Based on the ANOVA testing as shown in Table 2, The p-value was greater than 0.05 where have not a significant difference among samples with the measured IDT at 5% level of significance.

Table 2. Results of ANOVA on effects of test samples on Marshall stability.

Source	F	p-value	Significant
MS	0.0004369	0.95047>0.05	No
Flow	3.055667	0.15537>0.05	No

3.2. IDT test

The IDT test was done to compute the IDT strength at intermediate temperature of 20°C of the mixtures. The IDT strength were used to evaluate crack initiation behaviour of asphalt mixtures. In order to have good cracking resistance, a material must be both strong and ductile. The IDT strength was calculated using Eq. (2). The IDT strength test results at 20 °C are shown in Fig. 3. The maximum tensile strength of SBS modified asphalt mixtures is 965.8 kPa which is 2.7% higher than that of the control asphalt mixture (940kPa). Polymer creates a three-dimensional network within base asphalt phase resulting in improvement of bonding strength to aggregates which leads to high cracking resistance.

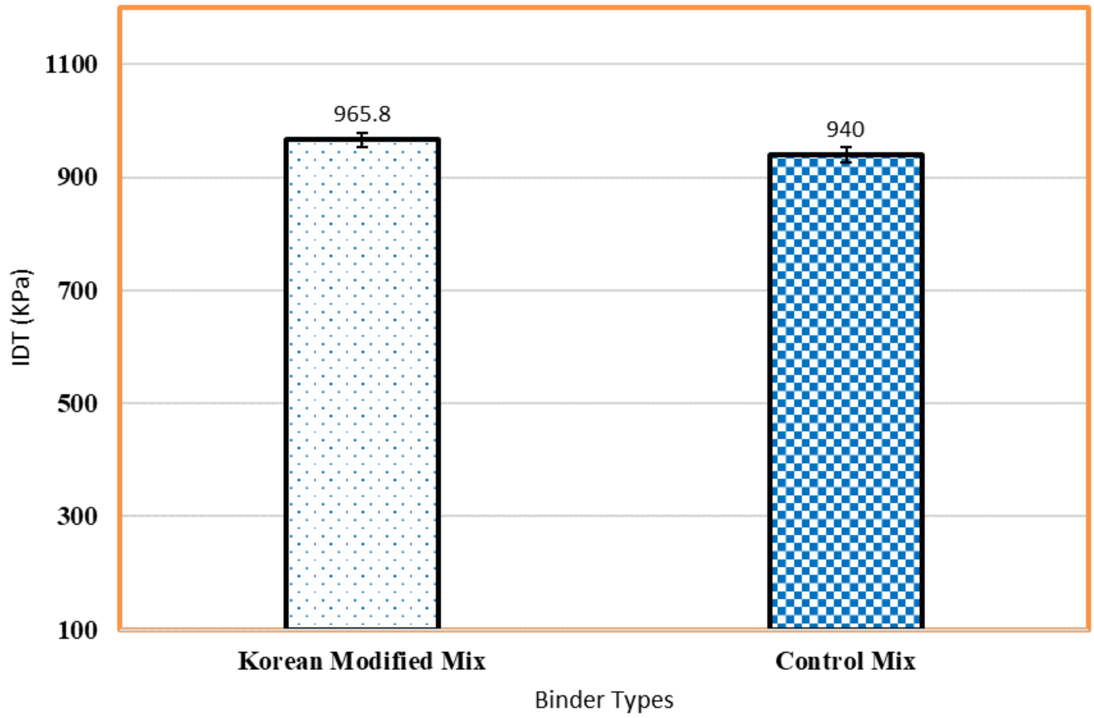

Figure 3. The comparison of IDT strength.

Similarly, an analysis of variance (ANOVA) was applied to determine whether significant differences among sample means existed on measured IDT. Based on the ANOVA testing as shown in Table 3, The p-value was greater than 0.05 where have not a significant difference among samples with the measured IDT at 5% level of significance.

Table 3. Results of ANOVA on effects of test samples on IDT strength.

Source	F	p-value	Significant
IDT	7.2512	0.0544>0.05	No

3.3. Wheel tracking test

In order to evaluate the rut resistance of Korean modified asphalt mixtures, the WT tests for the control mixture and Korean modified mixture were conducted using Method A according to Decision No. 1617/QD - BGTVT. The wheel load of 0.7MPa was applied to the 320mm x 260mm x 50 mm slab specimens, submerged in water. The wheel passes 50 times per minute at the centre of the specimen. The wheel tracking tests were conducted at the temperature of 50°C to evaluate the permanent deformation characteristics of asphalt mixtures. Fig. 4 shows the rut depth versus loading cycles of control mixture and Korean modified asphalt mixture. Compared to the controlled asphalt mixture, the Korean modified asphalt mixtures have rut depths of 1.83mm which is 81.6% higher than that of the control mixture at 15,000 loading cycles. This is because that Korean modified asphalt binder has the formation of critical network between the binder and modifier resulting in improvement of rutting resistance. Therefore, using the Korean modified binder can improve significantly the rut resistance of asphalt mixtures in constructing asphalt pavement in the field under high temperature conditions.

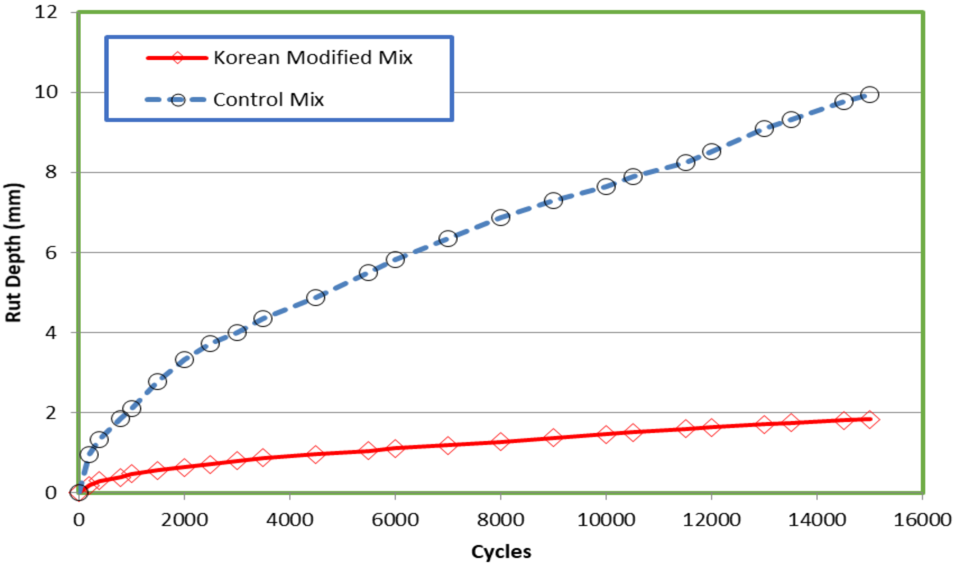

Figure 4. Rut depth versus loading cycles for AC mixtures.

4. PERFORMANCE EVALUATION USING MEPDG PROGRAM

The dynamic modulus of AC layer was estimated using Hirsch model [9,10] for the control mix and Korean modified mix to be used as input in the MEPDG program in Fig.5.

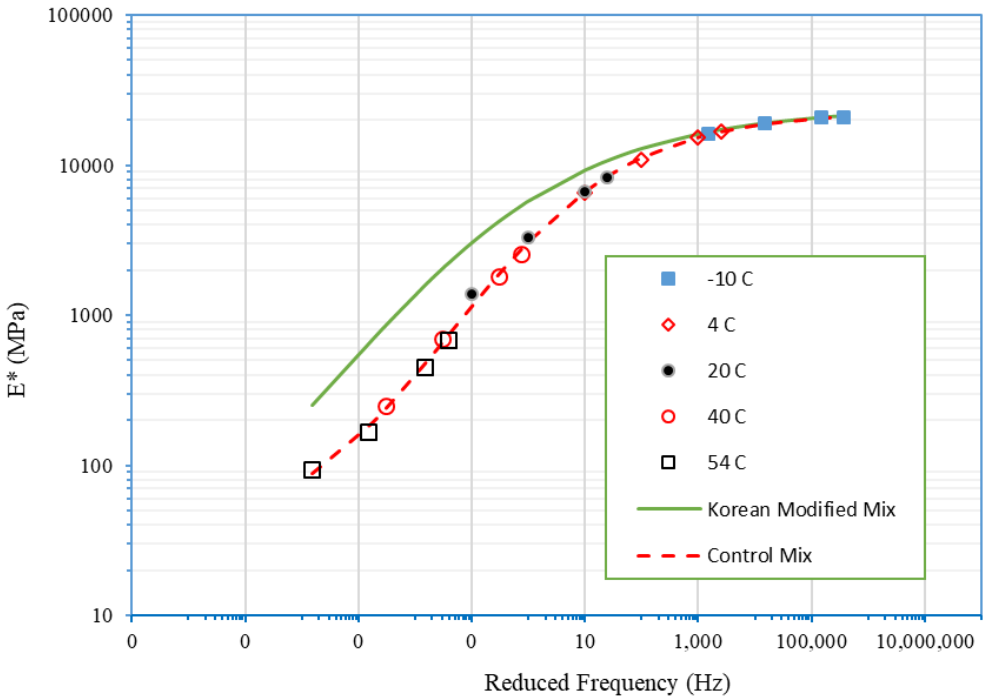

Figure 5. The dynamic modulus of the control mix and Korean modified mix.

Fig.6 shows pavement geometric information and material properties used for MEPDG analysis. Resilient moduli of 180 MPa for the aggregate subbase for all the sections and a modulus value of 75 MPa for subgrade were used. Poisson's ratio values of 0.35, 0.4 and 0.45 were assumed for asphalt layer, aggregate subbase and subgrade, respectively.

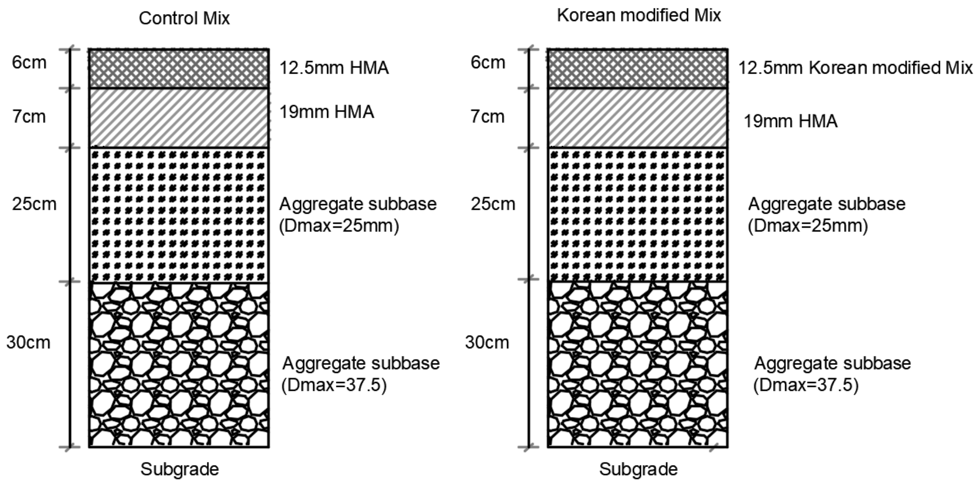

Figure 6. The AC pavement geometric information.

The climatic data of Ho Chi Minh city was got from MERRA of NASA [11] to be used in the MEPDG and the vehicle distribution for class 4, class 6 and class 13 as input for MEPDG is assumed 2%, 62%, and 36%. Moreover, failure criteria for AC design were selected based on four types of pavement distresses namely top-down (TD) cracking, bottom-up (BU) cracking, permanent deformation of the AC layer and total permanent deformation based on AASHTO specifications [12]. The distress performances for the control mixture and Korean modified mixtures were compared using the MEPDG program for given pavement thicknesses, material properties, climate conditions, and failure criteria as shown in Fig. 7.

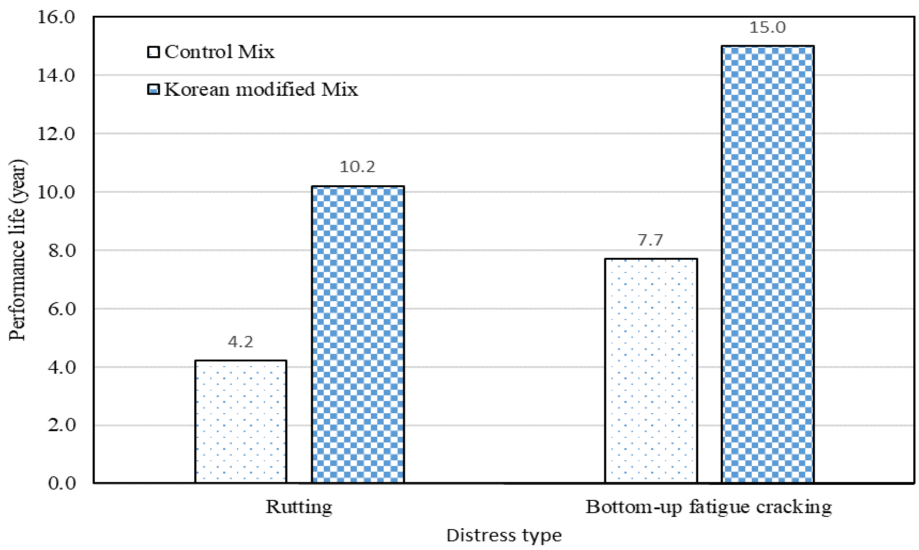

Figure 7. Comparison of performance life for control mix and Korean modified mix.

It can be seen clearly from Fig. 7 that the rutting performances of Korean modified asphalt mixtures is significantly better than the control mixture. For example, compared to the control mix, the rutting performance life of the modified mix increases about 6 years based on 20mm (0.75in) of rut depth criteria. This is due to the dynamic modulus of Korean modified asphalt mixtures is higher than the control HMA mix at high temperature as shown Fig. 4. Moreover, it was noted that the cracking performance life of Korean modified mix is significantly higher than that of the control mix based on 25% of bottom-up fatigue cracking criteria. However, this study evaluated only the performance life of HMA mixtures using MEPDG program, it is recommended to test the effect of the Korean modified mixtures on rutting and cracking performance asphalt mixtures under actual field pavement conditions.

5. CONCLUSIONS

The current study was mainly focused on evaluating the performance characteristics of Korean modified asphalt binder in hot mix asphalt (HMA) mixture under Vietnam condition. Based on the results obtained from experimental testing, the following conclusions are made:

- Results of moisture susceptibility testing showed that application of Korean modified binder can improve the moisture susceptibility of the mixes significantly.
- Based on IDT tests, the use of Korean modified binder in AC mixtures is beneficial in terms of crack initiation.
- The results obtained by wheel track test revealed that the Korean modified asphalt binder led to a significant improvement in rutting resistance of AC mixtures. This might be due to a higher viscosity of the binders, leading to stiffer HMAs of the Korean modified mixtures.
- In order to evaluate the performance life of Korean modified asphalt mixtures using the MEPDG program, the results indicated that the Korean modified AC mixtures can improve significantly its performance in terms of rutting and cracking under Vietnam conditions.
- Further studies are recommended to test the Korean modified binder according to Vietnamese standards. It also is recommended to evaluate the effect of the Korean modified mixtures on rutting and cracking performance asphalt mixtures under actual field conditions.

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