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Improvements of TPS-Porous Asphalt Using Wax- Based Additives for the Application on Malaysian Expressway

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ABSTRACT

Porous asphalt provides a sustainable approach to reduce traffic noise at source, while at the same time offering storm-water management systems which promote infiltration and often reduce the need for a detention pool. However, porous asphalt is prone to premature deteriorations, in terms of ravelling, and air voids clogging, rendering its unpopularity as the road surfacing material for expressways construction. In this research, the comparative influences of Tough Fix (TF) and Tough Fix Hyper (TFH) additives incorporation were evaluated on the performance of Tafpack-Super modified porous asphalt mixtures (TPS-PA). The Tafpack-Super (TPS) as a modifier at 20%, and anti-stripping additives (TF and TFH) with dosages used in this study were 0.3%, and 0.15% based on the weight of asphalt binder, respectively. Initially, the PA mixtures were prepared according to a predetermined mix design, and verified based on the percentage of air voids, permeability, and connected air voids. Comprehensive experimental tests of Marshall stability, permeability, Cantabro loss, rutting resistance, and moisture induced damage resistance were performed to assess the mechanical performance of the TPS-PA mixtures. Moreover, the Texas boiling test was employed to assess the stripping potential of loose TPS-PA mixtures. The experimental results revealed that both TF and TFH are capable of improving the PA resistance against rutting, ravelling, and moisture damage. In addition, the porous asphalt with TFH anti-stripping agent incorporation exhibited a superior overall performance as compared to the PA with TF.

Keywords: Abrasion resistance; asphalt-aggregates bonding; moisture damage; porous asphalt pavement, ravelling

INTRODUCTION

Porous asphalt (PA) is a type of asphalt mixture with 20% or more air voids content after being compacted. The nature of high porosity is an important criterion to the ecological functions of porous asphalt mixture in water drainage, noise reduction, and water purification (Larsen & Bendtsen 2002; Hwee & Gwee 2004; Alvarez et al. 2006; Zhang et al. 2018). Nonetheless, PA is prone to premature deteriorations, in terms of rutting, ravelling, and void clogging, which render it as an unpopular option for high-speed roadways. In most countries, due to heavy precipitation during the year, porous asphalt pavement is gradually exposed to wet conditions and high-volume water seepage. This phenomenon contributes to the deterioration of the pavement surfacing layer. Moisture damage poses great influences for pavement deterioration through air void, pavement structural integrity, precipitation intensity, and age of pavement along with repetitive loading stress by vehicles (Lu & Harvey 2006; Behiry 2013). The stripping process which is usually triggered by the water infiltration into asphaltic mixtures eventually weakens the mortar and aggregate-mortar bonds. Therefore, progressive dislodgement of aggregates may occur due to the continuous dynamic action of water infiltration and traffic loading (Dawson et al. 2009). Mohd Hasan et al. (2015) revealed that the sensitivity of asphalt mixtures to moisture degradation can be improved by incorporating additive that acts as an anti-stripping agent in order to overcome the rheological weakness in conventional asphalt binders. The incorporation of additive in an asphalt mixture leads to strong bond coating behaviour at the asphalt-aggregate interface. The improved behaviour of asphalt-aggregate interface reduces the possibility of aggregate stripping, which leads to enhanced asphalt mixture performance and prolonged service life.

Moisture damage can be defined as the loss of strength and durability in asphalt mixtures due to precipitation and infiltration of water. The infiltration of moisture could damage PA in two ways: (1) Reduction of adhesive bond strength between mastic asphalt and aggregate (fine or coarse aggregate), or (2) Deterioration of mastic asphalt due to the presence of moisture from precipitation intensity. There are six factors that could influence the mechanisms of moisture damage in PA pavements, namely, displacement, spontaneous emulsification, detachment, hydraulic scour, pore pressure, and environmental effects. However, not one of the above-mentioned factors necessarily works alone in damaging PA pavement, as usually the deterioration of asphalt pavement occurs due to the combination of processes. This prompted the researchers to adopt a method to handle the phenomenon. Zhang et al. (2018), established that a thorough assessment needs to be carried out on the adhesive interface between aggregate and asphalt, as well as the durability of mastic and the cohesive strength. This is because the stripping process and ravelling mechanism which are caused by a loss of the adhesive bond between asphalt and aggregate in addition to the cohesive strength can lead to weaken pavement performance (Canestrari et al. 2009; Zhang et al. 2018). Based on previous studies, almost all case studies aimed to measure the comparative moisture damage either through the means of visual observations on raw field data, laboratory examination tests, or wet-versus-dry mechanical evaluation which yields the moisture damage index parameter (Kringos & Scarpas 2005; Masri et al. 2019). Moreover, Dawson et al. (2009) reported that open-graded mixtures are purposely designed and laid to help in draining surface water. This mechanism appears to allow some water to penetrate into PA mixtures that eventually lead to water induced damage formation. The physical processes known as the key contributors to water damage are the molecular diffusion of water via the PA mixture portion, and mortar 'washing away' due to water infiltration via connected macro pores. Despite the fact that PA mixtures have been developed for more than six decades, their application as a surface layer is yet unconvinced due to their premature ageing and ravelling damage which restricts their usage over time (Alvarez et al. 2006). The introduction of polymer modifications using bituminous mixtures and other additives has led to the development of new generation PA mixtures with improved engineering characteristics. Therefore, based on the previous studies, the incorporations of recycled materials, crumb rubber, Tafpack-Super, nano-silica, Styrene Butadiene Styrene (SBS) or Styrene Butadiene Rubber (SBR) polymers, low density polyethylene, and other different kinds of fibre into PA mixtures have significantly improved their strength and durability (Oiu et al. 2009; Lyons & Putman 2013; Shirini & Imaninasab 2016; Ranieri et al. 2017; Tanzader & Shahrezagamasaei 2017; Jiao et al. 2019).

Tafpack-Super (TPS) is an asphalt modifier manufactured in the form of a 2–3 mm diameter pellet. This is an important additive used to manufacture an asphalt binder with high in viscosity. The modified asphalt binder with TPS displays greater resistance to shear creep than the SBS modified asphalt binder (Caro et al. 2008). Chen & Wong (2013) demonstrated the effect of TPS on PA with 100% recycled concrete aggregate (PAM-RCA). The study revealed that the PAM-RCA without TPS addition is appropriate for low strength applications, while the PAM-RCA with TPS incorporation can fulfil the requirements of normal highways application. Cao et al. (2009) indicated that a PA mixture with TPS modification is less prone to permanent deformation at high temperatures and cracking at low temperatures.

Therefore, in this study, TPS modified PA mixtures with the incorporation of either Tough Fix (TF) or Tough Fix Hyper (TFH) as the anti-stripping agents at respective concentrations of 0.3% and 0.15% were introduced. Further evaluations to ascertain the resistance of the asphalt mixtures to ravelling, rutting, moisture susceptibility, permeability, and stripping were also conducted. Thus, this will give clear understanding of the various additives influence on TPS modified PA.

MATERIALS AND METHODS

MATERIALS

Conventional bitumen of 60/70 penetration grade was used throughout this study. Tafpack-Super (TPS) in pellets form that obtained from Japan were used as modifier. Table 1 illustrates the properties of the asphalt binder. The physical characteristics of the TPS, Tough Fix (TF), and Tough Fix Hyper (TFH) utilised in this study are as displayed in Figure 1. The TF and TFH which are wax-based additives were selected to serve as anti-stripping agents in the asphalt mixtures. The wax additives were supplied by Taiyu Kensetsu Co. Ltd., Japan. Table 2 demonstrates the physical and chemical properties of the additives (Taiyu 2018). In accordance with the manufacturers' recommendations as well as previous literatures (Sani et al. 2019; Nakanishi et al. 2019; Sani et al. 2020), the contents of the TPS, TF, and TFH used in this study were 12%, 0.3%, and 0.15% respectively by weight of asphalt binder. Granite aggregate was acquired from KUAD Sdn. Bhd., Malaysia was used in this study. The coarse granite aggregates, which are cubical in geometry were crushed using a Vertical Shaft Impact (VSI) crusher at the quarry. Likewise, the fine aggregates used which are of quarry dust were also supplied by the same quarry.

PREPARATION OF ASPHALT SPECIMEN

Porous asphalt mixtures were prepared using materials with properties as described in Table 3. Aggregates (VSI 14mm & quarry dust) and fillers (calcium carbonate) were batched to produce specimens of individual weight range of approximately 1020-1786g. The aggregates batches were placed in an oven at the desired mixing temperature for a minimum period of 4 hours. Prior to mixing, the asphalt binder was heated into a flowable state and intimately blended with each respective additive and TPS by weight ratio of the asphalt binder. The binder was thoroughly mixed using a shear mixer at 180°C. Marshall and wheel tracking test specimens were also prepared based on the aggregates gradation demonstrated in Figure 2. The pre-heated batches of aggregates and the designated amount of flowable binder were thoroughly mixed at 180℃. Prior to compaction, the

TABLE 1. Physical properties of 60/70 asphalt binder

Properties	Result	Limiting Value	Standard
Penetration (25 °C)	66 dmm	Min. 60	ASTM D5
Flash point	310 °C	Min. 250	ASTM D92
Softening Point	45.5 °C	Min. 40	ASTM D36
Ductility (5cm/min)	>100 cm	Min. 100	ASTM D113
Specific gravity	1.03	-	ASTM D70

a. Tafpack-Super (TPS)   b. Tough Fix Hyper (TFH)   c. Tough Fix (TF)

FIGURE 1. Physical appearances of additives used

TABLE 2. Properties of wax-based additives

Properties	Description	
	Tough Fix Hyper	Tough Fix
Appearance	Flaky	Flaky
Colour	Yellow	White
Solubility in water	Insoluble	Insoluble
Density	0.870g/cm^3	0.955g/cm^3
Flash point	286 °C	199 °C
Melting point	125 °C	70 °C
pH	9.6 (1% suspension)	2.3 (1% suspension)
Viscosity	300 mPa.s	100 mPa.s

asphalt mixtures were transferred into trays and conditioned for two hours at 165°C to mimic the short-term ageing process. The samples were then compacted using either the Marshall or Servopac Gyratory compactors, depending on the parameters considered. Marshall compactor was used for the preparation of Cantabro, Permeability, and Marshall stability test samples. Whereas Servopac Gyratory compactor was used specifically for compacting samples for the wheel tracking, and moisture damage tests. All compacted specimens were carefully transferred onto a smooth, flat surface and allowed to cool to ambient temperature before being tested or placed in an incubator to prevent ageing.

MIXTURE PERFORMANCE

WATER PERMEABILITY TEST

A falling head water permeameter was used to evaluate the permeability coefficient (k) of porous asphalt mixtures (Li et al. 2013). The k value reflects the hydraulic conductivity of the compacted porous asphalt specimens. Prior to the test, after sealing the orifice with rubber bung, water is poured into an acrylic perspex tube with two designated points. The duration taken for water to fall between the two designated points of the acrylic perspex tube was recorded. The coefficient of permeability was computed using Equation 1.

$$k = \frac{aL}{At}\ln\frac{h_1}{h_2} \tag{1}$$

Where k is the permeability coefficient (cm/s); A is the cross sectional area of specimen (cm^2); a is the cross sectional area of permeameter tube (cm^2); L is the height of specimen (cm); t is the duration taken for water to flow between two points (s); h_1 is the initial water level marked on permeameter tube; h_2 is the final water level marked on permeameter tube.

INDIRECT TENSILE STRENGTH (ITS) TEST

The indirect tensile strength (ITS) test was performed based on the ASTM D6931 method. The procedure was performed by creating tensile stresses along the test specimens diametral axis. The compacted specimens were diametrically loaded along and parallel to their vertical diametric planesat a constant deformation rate of 50.8 mm/min according to ASTM D6931, which eventually force the specimens to split or crack. The specimens were cured in an incubator for 4 hours at 20°C prior to the test. The specimen dimensions and peak load (recorded load at failure, P) were used by Equation 2 to calculate its indirect tensile strength (failure strength).

$$ITS = \frac{2000P}{\pi HD} \qquad (2)$$

where, P is the maximum applied load (N); H is the specimen thickness (mm); and D is the specimen diameter (mm).

WATER SENSITIVITY TEST USING DYNAMIC ASPHALT STRIPPING MACHINE (DASM)

The performance and durability of asphalt mixtures are interrelated with the moisture sensitivity in view of its service life (Oliveira et al. 2013). In this study, the DASM which was developed by Hamzah et al. (2012) was used to condition the PA samples. In DASM, six sets of porous asphalt were conditioned to assess water sensitivity by allowing water at 40°C temperature to continuously shower and permeate through the non-extruded samples at an intensity equivalent to 5400 mm/hr through water sprinklers. The other remaining sets were stored under dry condition at an ambient temperature (Hamzah et al. 2016). After 3 days of conditioning in DASM, both sets of specimens were extruded and conditioned in an incubator before being individually tested for the indirect tensile strength (ITS) at 15°C. Their stripping resistance was measured from the ratio of the wet ITS (after conditioning in DASM) to the dry ITS. The ITSR value can be determined from the dry and wet samples and was subsequently calculated using Equation 3.

$$ITSR = \frac{S_2}{S_1} \qquad (3)$$

Where, ITSR is the tensile strength ratio; S_1 is the dry sample average strength; and S_2 is the conditioned sample average strength.

HAMBURG WHEEL TRACKING TEST

The dynamic stability (DS), which can be measured using a wheel tracking machine, is considered as the most crucial property of a porous asphalt mixture. The Hamburg wheel tracking (HWT) test was used to assess the rutting performance of asphalt mixtures and their resistance to moisture degradation. The HWT test demonstrates susceptibility to premature failure of porous asphalt mixtures due to inadequate binder stiffness, poor aggregate packing, moisture damage, and insufficient adhesion between the aggregate and binder. An HWT machine with steel wheel was used to test 8-shaped sample dimension at a constant temperature of 50 ± 1°C. The device is capable of concurrently examining a pair of specimens. The steel wheel has a diameter of 203 mm and a width of 47 mm, which oscillates at 42 ± 2 passes per minute. In this case study, the number of wheel passes after 45 and 60 minutes were 1890 and 2520 passes, respectively. Dynamic stability was calculated by dividing the number of wheel passes to the deformation difference between 45 and 60 minutes oscillation as shown in Equation 4.

$$DS = \frac{(2520 - 1890)}{(Rut\,at\,2520 - Rut\,at\,1890)} \qquad (4)$$

CANTABRO TEST USING LOS ANGELES ABRASION MACHINE

Cantabro test was conducted to evaluate the resistance of the mixtures to particle loss in accordance to ASTM D7064, or in other words to determine the abrasion resistance of the Marshall compacted specimens. The specimens were subjected to test after the compaction protocols by considering two conditions: with and without conditioning. Each specimen was categorised into three conditioning protocols (standard, water immersion, and ageing) prior to the Cantabro test to assess the rutting and ravelling resistance of the PA mixtures. Under standard protocol, the test was conducted by immersing the samples in water bath at 20°C for a period of 20 hours. Likewise, for water immersion protocol, the samples were immersed in 60°C water bath for a duration of 48 hours. Prior to testing, the samples were placed indoor in room temperature for 24 hours. For ageing condition, the samples were placed in an oven at 60°C for 7 days prior to the Cantabro test. Both conditioned and unconditioned compacted samples were tested using a Los Angeles abrasion machine. All the loose materials broken off from the surface of the test specimens were discarded at the end of testing. The mass of the specimens was recorded before and after tests. This was determined the percentage loss of each original specimen which represents the Cantabro abrasion loss. The reduction of specimen weight is expressed as a percentage weight ratio of disintegrated particles to the initial weight of the specimen, as shown in Equation 5.

$$\%\ \mathrm{L.A} = \frac{M_1 - M_2}{M_1} x100 \qquad (5)$$

Where, % L.A is the abrasion loss in percentage; M_1 is the initial weight of specimen (g); and M_2 is the final weight of specimen (g).

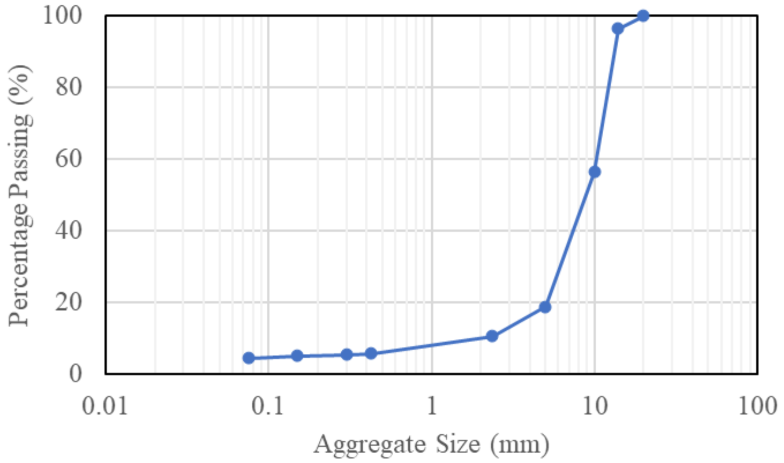

FIGURE 2. Aggregates gradation (masuk di sini)

DYNAMIC CREEP TEST

Rutting takes place due to the accumulation of un-recoverable strain in asphalt pavements due to vehicle loading. Dynamic creep test was carried out to evaluate the resistance of the asphalt mixtures to permanent deformation. Prior to testing, specimens were pre-conditioned for 4 hours at 60°C. Loading was uniformly applied onto the surface of the asphalt specimens to a conditional stress of 9 kPa with a cycle count of 10000, rest period of 900 ms, pulse width of 100 ms, and test deviator stress of 207 kPa. Haversine loading was applied without impact and with load of 100 kPa.

TEXAS BOILING TEST

The Texas boiling test was performed in compliance with ASTM D3625 to determine the stripping potential of uncompacted bituminous-coated aggregate mixtures due to the boiling water dynamic action. In this test, 250 g of loose asphalt mixture was boiled for 10 min. The boiling water could cause the binder film on the aggregate surface to strip. The samples were then left for 24 hours to cool down under ambient temperature. Later, visual observation and image acquisition were carried out to distinguish the stripping rates of the loose asphalt mixtures.

RESULTS AND DISCUSSION

COEFFICIENT OF PERMEABILITY

The most important index in the functionality of a porous asphalt is the permeability coefficient. The influence of anti-stripping agent addition on the permeability of TPS-PA was investigated. The minimum requirement for acceptable coefficient of permeability (0.01 cm/sec) was satisfied by both mixtures as shown in Figure 3. The results from the laboratory falling-head permeability test indicated that the coefficient of permeability of the mixtures reduced with the incorporation of TF additive in comparison with the TFH addition. The mixture with TF additive is more water flow resistant than that with TFH additive due to the very high interconnected air voids in the TPS+TFH mixture. Therefore, TFH additive in comparison with TF additive exhibited a better performance in terms of permeability behaviour.

MARSHALL STABILITY AND FLOW

The durability of PA mixture is rated according to the results of its Marshall test. From this test two key indices were obtained, i.e. Marshall stability and flow value. The overall strength of a porous asphalt is dependent on the occlusion of aggregates and its additive. A type B grading as specified in the Malaysian Guide for Porous Asphalt REAM-SP 5/200 shows that the Marshall stability of a porous asphalt mixture is the lowest among all types of mixtures, with a standard stability requirement of less than 3.5 kN. In this study, an average Marshall stability of 11.0 kN was obtained for TPS+TFH, which is higher than the TPS+TF (8.07 kN), as demonstrated in Table 3. While, the flow values, for both mixes exhibited comparable result.

This indicates that the incorporation of TFH contributes to a stiffer PA mixture with higher Marshall stability. However, the PA with TF addition promoted a slightly lower stability compared to the TPS+TFH mixture. It can be deduced that the TF additive has lower compatibility with TPS compared to TFH. Likewise, Air void and interconnected air void show little distinction between different types of PA mixtures.

ABRASION LOSS CHANGE VIA CANTABRO TEST – (UNCONDITIONED & CONDITIONED)

Ravelling test is applied in determining the degree of aggregates stripped from the road surface under the influence of repeated traffic loads. The Los Angeles abrasion testing machine was used to determine the ravelling potential due to multiple rotating and striking of Marshall standard test. Figure 4 illustrates the Cantabro test results of the PA mixtures with the incorporation of different additives at different conditions. The incorporation of Tough Fix Hyper in the unconditioned PA mixture has drastically reduced the Cantabro loss in comparison with the unconditioned TPS+TF mixture. However, for the conditioned samples, an increase in the Cantabro loss was observed for the TPS+TFH mixture which is due to moisture and oxidation effects. The mixture of TPS+TF also follows the same loss trend as TPS+TFH, but loss is more pronounced in the conditioned TPS+TF sample. Furthermore, under ageing condition, the Cantabro losses of both TPS+TFH and TPS+TF mixtures significantly reduced with a slight difference. This deduces that the presence of additives in the PA mixtures improves their ageing and ravelling resistance. Similar trend has been observed in a study conducted by Kline and Putman, (2011), and it is somewhat expected since the binder oxidises during the ageing process and becoming stiffer. Theoretically, stiffening is a characteristic of asphalt binders due to ageing process. This phenomenon was also reported in a study conducted by Mo et al. (2010), where the asphalt binder oxidation was found to increase the abrasion resistance of a sample in warm weather condition, but substantially decreases in cold weather since the elasticity of the binder is compromised. Generally, the incorporation of Tough Fix Hyper additive yields a better adhesion and improved ravelling resistance in PA mixtures. This concludes that a PA mixture with Tough Fix Hyper additive has a better ravelling resistance than PA with Tough Fix additive.

DYNAMIC STABILITY VIA HAMBURG WHEEL TRACKING TEST

Dynamic stability (DS) is measured using a wheel tracking machine and is considered as a crucial property of a porous asphalt mixture. The Hamburg wheel tracking test was used to assess the dynamic stability and permanent deformation of the TPS-PA mixtures. The test was conducted using a 150 mm diameter compacted specimen which was subjected to 20,000 cycles of loading. Figures 5 and 6 display the rut test results of the mixtures. The asphalt mixture with the incorporation of TF showcased a better rutting resistance than the asphalt mixture with TFH. The dynamic stability results shown in Figure 6 reveal that all the mixtures have exceeded the minimum requirement of 3000 passes/mm as stipulated by the Japanese Standard (Japan Road Association, 2006). Nevertheless, the mixture with TFH exhibited a better stability compared to that with TF.

WATER SENSITIVITY VIA DYNAMIC ASPHALT STRIPPING

Indirect tensile strength test approach was employed to evaluate the moisture susceptibility of modified TPS-PA based on the indirect tensile strength ratio (ITSR). The TSR serves as an index to determine the mixture susceptibility to moisture damage. A minimum ratio of 0.80 is desired for asphalt mixtures to have a better resistance to moisture degradation. Likewise, the porous asphalt mixtures fracture resistance was determined by comparing the indirect tensile strength of each mixture at different conditions. Figure 7 compares the dry and wet conditioned specimens based on the indirect tensile strength (ITS) values. The findings reveal that the incorporation of additives poses significant effects on the ITS. PA with TFH incorporation exhibited improved strength at both conditions compared to the TF mixtures. This is because TFH increases the stiffness of the TPS-PA, which better improves its resistance to potential cracking. However as shown in Figure 8, the average ITSR of TFH incorporated TPS-PA (0.87) is slightly lower compared to

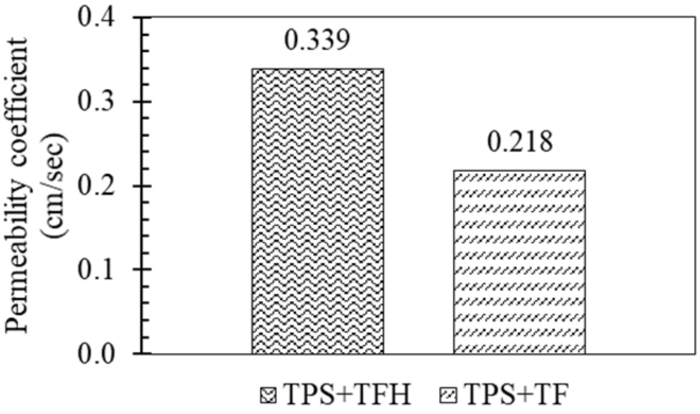

FIGURE 3. Permeability coefficient of PA mixtures

TABLE 3. Marshall stability and flow of PA mixtures

Mixture Type	Interconnected Air Void (%)	Air Void (%)	Stability (kN)	Flow (mm)
TPS	18.5	20.3	8.89	3.5
TPS+TFH	15.1	19.6	11.0	3.0
TPS+TF	14.7	20.0	8.07	2.8
Min.Std.*	13.0	20	3.43	2.0

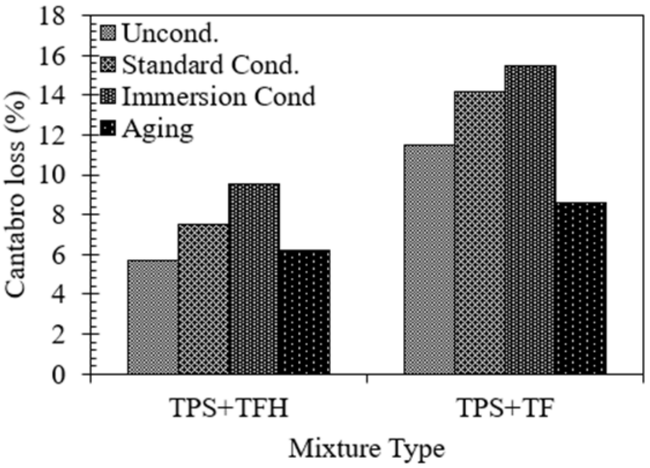

FIGURE 4. Cantabro loss of PA mixtures at different conditions

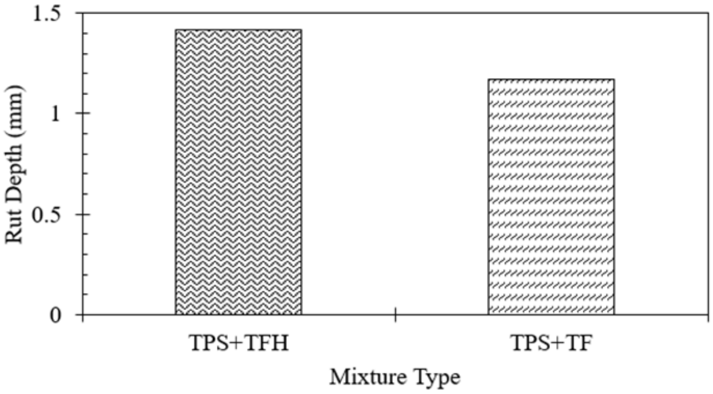

FIGURE 5. Rut depth of PA mixtures

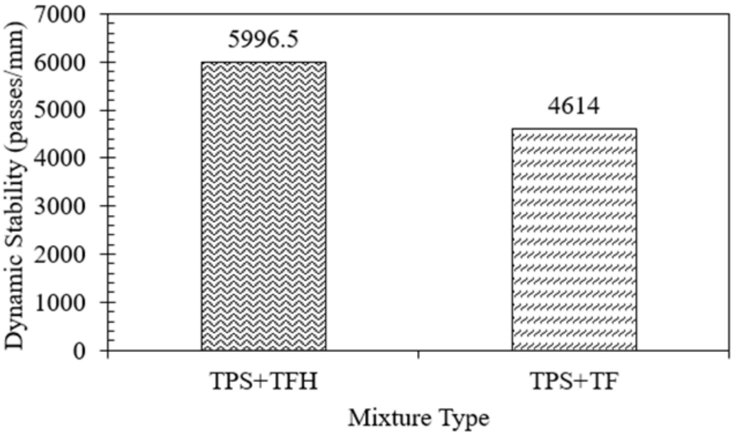

FIGURE 6. Dynamic stability of PA mixtures

TPS-TF (0.88). These values are regarded high, and also proved that the Tough Fix additive has better ability to resist moisture induced damage than the Tough Fix Hyper additive. The results of this test revealed that the ITSR values of all the mixtures were well above the standard minimum value of 0.80, which indicates that under the influence of moisture, these mixtures are expected to showcase better performance.

DYNAMIC CREEP

The dynamic creep stiffness modulus represents the ratio of applied stress to the total axial strain acted on a specimen after specific load cycles. The TPS-PA mixtures with additive of either TFH or TF were tested at 40°C. Figures 9 and 10 illustrate the results of the creep stiffness and permanent deformation of the PA mixtures. The figures clearly reveal

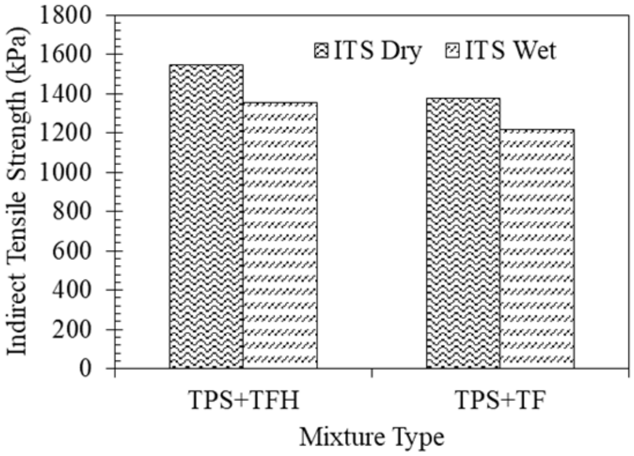

FIGURE 7. ITS of PA incorporating additives at dry and wet conditions

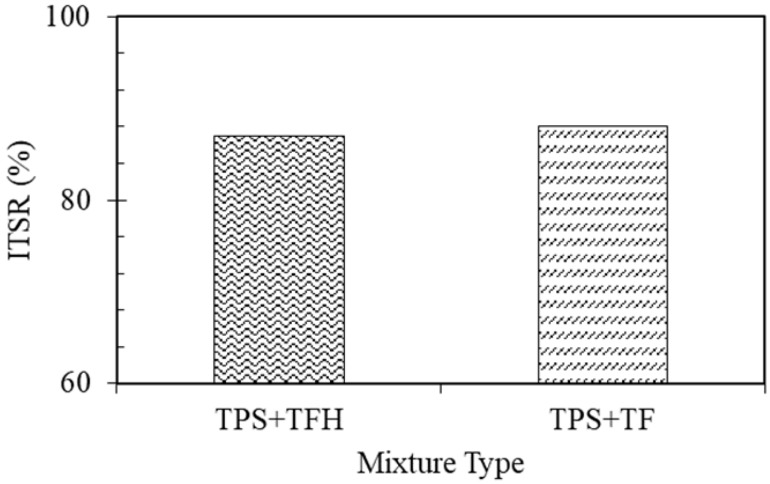

FIGURE 8. ITSR of PA mixtures

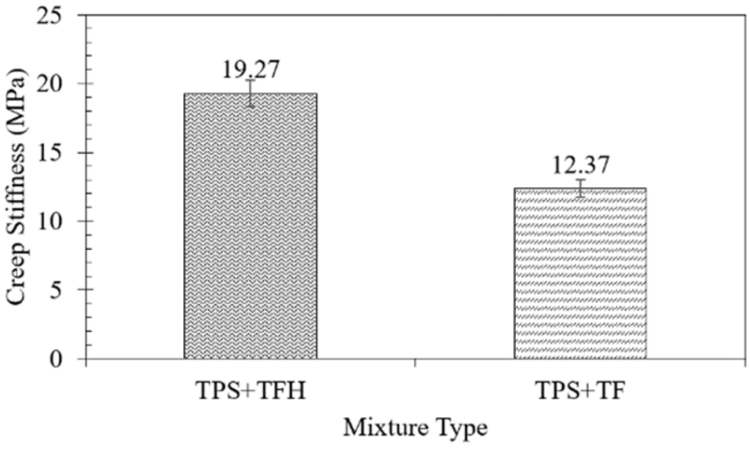

FIGURE 9. Creep stiffness of PA mixtures

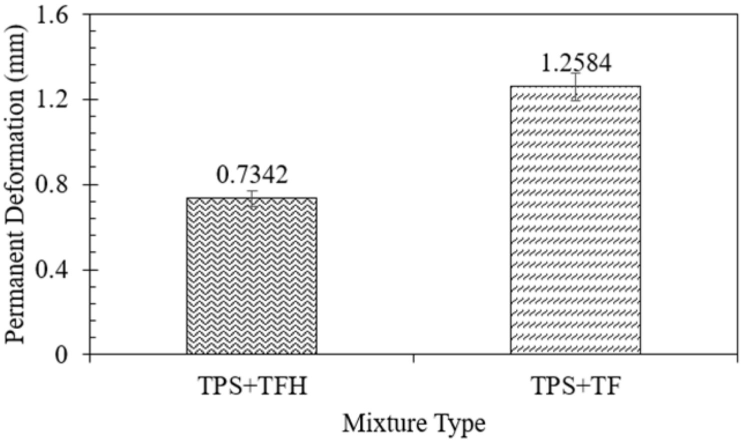

FIGURE 10. Permanent deformation of PA mixtures

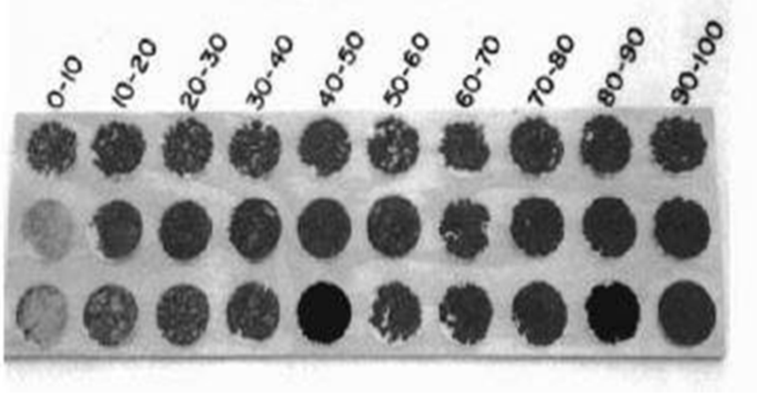

FIGURE 11. Texas boiling test rating board (Kennedy et al. 1984)

(a)

(b)

FIGURE 12. PA incorporating: (a) TFH; (b) TF for Texas boiling test

that the creep stiffness of the mixture with TFH showcased a better rutting resistance than the mixture with TF. This can be inferred due to the addition of TFH additive which better improved the performance of the TPS-PA mixture compared to TF addition.

TEXAS BOILING TEST

The amount of stripping that takes place on aggregates particles is determined by visual rating and expressed in terms of percentage of asphalt coating (scale of 0 to 100 percent coating). Such rating is subjective and varies with time and different operators. To standardise the evaluation, a standard rating board (Figure 11) comprising of 10 intervals from 0 to 100 percent coating was adopted in this study (Kennedy et al. 1984). This scale was constructed using a set of selected specimens to provide visual examples of varying degrees of stripping for comparison with all the test specimens. The mixtures were evaluated after air-dried in laboratory to examine the stripping behaviour of the asphalt binders from coated aggregates. Figure 12 (a) and (b) display the digital images of loose mixtures after undergoing the boiling test. The loose mixtures fall within the range of 90 - 100% scale. This indicates that the incorporation of either TFH or TF may improve the stripping resistance of the TPS-PA mixtures. These findings coincide with the results obtained from the ITSR approach conducted in this study, where the PA mixtures with additives have greater ITS ratios than 80%.

CONCLUSION

This study presents an investigation on the application of wax-based additives in porous asphalt mixtures. Two sets of specified porous asphalt mixtures were studied and tested: TafPack-Super mixture (TPS-PA) with Tough Fix Hyper (TFH) additive, and TPS-PA with Tough Fix (TF) additive. The mixtures were produced at different ageing and moisture conditioning approaches in order to evaluate the influence of temperature on the performance of the mixtures. The asphalt mixture performance tests conducted included tests of Cantabro (conditioned & unconditioned), wheel tracking, indirect tensile strength (ITS), dynamic creep, and Texas boiling. The following observations were made from the experimental data analysis:

1. The TPS-PA mixture with TF additive incorporation is more water flow resistant than that with TFH additive, as a result of very high connected air voids present in the TPS-PA mixture with TFH. Therefore, TFH additive in comparison with TF exhibits a better performance in terms of k coefficient and volumetric behaviour.
2. By incorporating TPS as the bitumen modifier and TF as the anti-stripping agent, the ravelling resistance of a PA mixture is improved notably. This is due to the ageing process that results in a stiffer and more brittle asphalt binder. It is postulated that the stiffening effect exerts much greater influence than the increase in the brittleness of an asphalt binder.
3. The PA mixture incorporating TPS as the bitumen modifier and Tough Fix Hyper as the anti-stripping agent shows a better dynamic stability than the PA mixture with Tough Fix additive. However, the PA mixture with Tough Fix additive shows a slightly better rutting resistance than the PA mixture with Tough Fix Hyper.
4. The ITS of the TPS-PA mixture incorporating Tough Fix Hyper is generally higher for both conditioned (wet) and unconditioned (dry) samples. However, it is learnt from the ITSR that both mixtures with Tough Fix Hyper and Tough Fix portray excellent moisture resistance.
5. The TPS-PA mixture with TFH additive has a better creep stiffness compared to the TPS-PA with TF additive. This indicates that TFH additive reduces the mixture susceptibility to creep deformation more than the TF additive. A higher value of creep stiffness indicates a better rutting resistance.
6. Moisture sensitivity was evaluated through the boiling test, where the incorporation of either TFH or TF improves the stripping resistance of the TPS-PA mixtures. It is proven through the ITSR that asphalt mixtures with additives have higher ratios than 0.80.

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DECLARATION OF COMPETING INTEREST

None.

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