Future roads and mobility

Application of bitumen products for next-generation airports

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Abstract

The rapid growth in the commercial aviation sector in recent decades has caused more than 40% of existing airports to operate above their planned capacity and will result in many new airports and upgrading projects in the next 5 to 10 years. Over this time, many airport owners are aiming to develop the so-called next generation airport to face challenges such as the operation of New Large Aircrafts (NLAs), increased air traffic volumes and to deliver positive impacts to airport users, neighbors and the environment in an affordable and sustainable manner. However, airfield infrastructure such as runways, taxiway and aprons, is struggling to keep pace with this new trend. The existing bituminous material requirements are lagging against the expectations of airport designers, consultants and operator/management teams. In this paper, the performance requirements for bituminous pavements for next generation airports are analyzed and proposed from different perspective, i.e. durability and sustainability, environmental-friendliness and reduced adverse user/neighbor impact, which are then compared against the existing requirements for bituminous materials from airport projects in the Asia Pacific region.

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1. INTRODUCTION

Commercial aviation has been the preferred mode of transportation for medium- to long-distance travel for the past few decades. Current global passenger traffic is around 4.1 billion passengers annually with steady growth averaging 5.5% per year over the last decade and forecasted to be 4.3% per year in the next 15 years [1]. Traditional markets like the United States and Europe, while currently dominating passenger traffic, have steady annual growth rates of 4% and 6.1% respectively. The Asia-Pacific region, currently with 1/3 of global air traffic market share, has average annual traffic growth exceeding 8% in the past 10 years and forecasted to be 5.1% in the next 15 years [1]. Thus, by 2022 air passenger traffic from emerging Asia Pacific markets, should those from developed countries [2]. This will be accompanied by a doubling in global aviation fleet by 2035 as forecasted by Boeing. However, such up-trending demand forecast as well as the aviation fleet growth are not aligned with the airport infrastructure capacity, with more than 40% of existing airports already operating above their planned capacity [3].

In response to the rapid air traffic growth, merely in the Asia Pacific 350 new airports have been planned to be built within the next decade, while many existing airports will undertake major upgrades for both landside and airside capacities [4]. However, most Asian airports are still designed and constructed according to older aircraft references and material requirements. On the other hand, alongside the environmental & operational challenges, as well as the increase in New Large Aircrafts (NLAs) in service in the region, better material performance is required for better airport pavement performance. Preferred solutions in enhancing bituminous pavement performance include the development of superior-performing materials (e.g. Polymer Modified Bitumens (PMBs) & Performance Grade (PG) binders).

2. AIRPORT PAVEMENT PERFORMANCE REQUIREMENTS

Airport and road asphalt pavements share similarities, but also some significant differences, one of which is in terms of types and frequencies of loads that are experienced in service. Even though both pavement types are typically designed for 20 to 30 years of service life expectancy, the approach on how to translate traffic frequency and intensity to design load is different.

Road pavement design considers traffic frequencies or load repetitions in the length of pavement design life and traffic load based on standard axle or Equivalent Single Axle Load (ESAL), with such load repetitions summing up to millions or tens of millions and impacting pavement performance significantly; on the other hand, for airport pavements, load repetitions range from tens of thousands to millions and the load repetition factor is not as crucial as for road pavements. Airport pavement design or airport pavement performance is critically affected by the maximum axle load and tire pressure that it can support. As shown in Table 1, both loading gear configurations and tire pressures of commonly-used aircrafts greatly exceed the standard axle load and tire pressure for roads. The Boeing B777-200B is shown to have the highest gross load on its main landing gear group, while the Boeing B787-8 shown to have the highest tire pressure.

Table 1. Aircraft Loads vs Road Traffic Loads [5]

Traffic Load		Gross Load Main Landing Gear Group for aircraft or axle load for truck (lb)	Tire Pressure (psi)
Commonly used Aircraft Load	Airbus A-300 B2	304,000	168
	Airbus A-330	460,000	200
	Airbus A-380	942,700	194
	Boeing, B-737-100	100,000	148
	Boeing, B-747-200	833,000	200
	Boeing, B-777-200B	634,500	215
	Boeing, B-787-8	478,325	228
Standard Road Axle Load		18,000	100

From the application or operational perspective, the performance requirements of airport pavements are also different compared to road pavements. Both pavements require deformation resistance characteristics, but for airport pavements, additional concerns include prevention of groove closure and rutting/shearing/shoving associated with aircraft turning in place. Groove closure can lead to reduced surface friction that will affect stopping distance during aircraft landing or emergency braking. Rutting and shoving affect surface evenness, risking aircraft overruns at high speed during take-off or landing. These are especially important for safe aircraft operations, especially on runways.

All pavements require surface friction and in-service texture, critically when wet. But since typical ground roll speeds during aircraft take-off or landing range much higher (e.g. 240-285 kmph) compared to top highway speeds, having and maintaining skid resistance for airport pavements are regulated more stringently and frequently. For airport runways, the minimum friction level is 0.42 when tested at 65 kmph using the Mu-meter trailer [6]. In contrast, the minimum friction level required for toll roads in Indonesia is 0.33 when tested using the same equipment with the same condition [7]. The friction level for airport pavements is evaluated at least once every six months [6], while for toll road is required annually [7].

In terms of cracking, highway pavement cracking is usually taken to initiate from the bottom of the asphalt layer where tensile stresses are the greatest and then progress up to the surface. But for airport asphalt pavements, top down cracking frequently happens because aircraft tire pressures are much higher compared to the typical truck tire pressure shown in Table 1.

Airport pavements also require pavement surface integrity to avoid material disintegration that will lead to Foreign Object Damage (FOD) which can lead to catastrophic aircraft incidents. Thus, asphalts for airports must have good component adhesion and cohesion. A summary comparing the performance requirements between airport and highway pavements is shown in Table 2.

Table 2. Summary of Airport vs Highway Asphalt Performance Requirements [8]

Physical Requirement	Protects against	Level of Importance	
		Airport	Highway
Deformation resistance	Groove closure	High	N/A
	Rutting	High	High
	Shearing/Shoving	High	Moderate
Surface friction and texture	Skid resistance	High	High
	Compliance requirement	High	Moderate
Fracture resistance	Top down cracking	Moderate	Low
	Fatigue cracking	Moderate	High
Durability	Pavement generated FOD	High	N/A
	Resistance to moisture damage	High	Moderate
	Resistance to fuel corrosion	High	N/A

Although bitumens typically constitutes around 5% by mass in asphalts, their characteristics and performance dominate the overall mixture performance as well as economic significance in terms of repair costs for rework needed when asphalt failures occur.

To ensure that asphalts have high stiffness and fatigue resistance, bitumens also need to have high stiffness moduli and reduced hardening over time and load repetitions. As a viscoelastic material, bitumens also need to be stiff at elevated temperatures but not to be excessively stiff when aged to ensure groove integrity.

For the prevention of stripping in asphalts, bitumens need to have good cohesion and adhesion. Further, some airport segments like aprons, holding positions, turning bays, or even the whole taxiway itself, where aircraft are typically slow moving, fuel-resistant binders may be required to prevent FOD due to fuel spills.

Traffic in many major airports is such that only very short time windows are typically allowed for paving work, thus requiring fast asphalt installation and curing, and/or having good workability at low temperatures. Thus, the latest bitumen development is to have suitable viscosity ranges for good paving workability.

Asphalt performance and bitumen characteristic requirements related to airport pavement functions are summarised in Table 3.

Bitumen solutions to meet specific airport requirements will vary from location to location as they are very dependent on local climate, traffic intensity, types of aircraft, etc. Bitumen offers great flexibility in terms of composition and physical characteristics and can be specifically designed to meet particular airport specifications. It can be designed to improve rut resistance performance, crack resistance at low temperatures, fatigue resistance, durability against climatic challenges, as well as to address fuel spillage problems.

Asphalt specifications for many airports have also shifted from traditional Marshall and volumetric requirements to further include performance criteria such as rutting- & cracking- resistances.

Table 3. Asphalt and Bitumen Requirements for Airport Pavement Functions [9]

Pavement Function	Airport Segment	Asphalt Performance Requirement	Bitumen Characteristic Requirement
Structural load bearing capacity	Apron, Taxiway, Runway	• High stiffness modulus • Fatigue-Resistance	• High stiffness modulus • Fatigue-Resistance
Permanent deformation (rut) resistance	Apron, Taxiway	• Stone-to-stone contact for high internal friction and load transfer	• Stiff at elevated temperatures • Elastic
Surface shear-resistance	Apron, Taxiway	• Fatigue Resistance	• Less hardening over time and loading • High ductility
Skid resistance	Runway	• High micro/macro texture depth • Grooving if required	• Cohesion • High stiffness when fresh, not excessively stiff when aged for groove integrity
Water dispersion	Apron, Taxiway	• Grooving if required	• High stiffness when fresh, not excessively stiff when aged for groove integrity
Foreign object damage (FOD) prevention	Taxiway, Runway	• Anti-stripping • Good component adhesion • Crack-resistance	• Cohesion • Adhesion
Fuel-Resistance	Apron, taxiway	• Closed surface with low void content	• Fuel-resistance
Operational time constraint	Apron, taxiway, runway	• Fast installation and curing • Good workability at lower temperatures	• Suitable viscosity for good workability

3. AIRPORT PAVEMENT SOLUTION CASE STUDIES

This section collects three examples of airport projects in the Asia Pacific region with various climatic conditions under high air traffic volumes.

3.1. Tropical Airport A

Airport A is located in the tropics with annual temperatures ranging from 21ºC to 35ºC and about 70 rainy days yearly, of which 27 days are classified medium (20-50 mm/day) to very heavy rain (>100 mm/day). It served more than 60 million passengers and 400,000 aircraft movements in 2017 as a main hub for domestic as well as international flights, growing 10% annually on average.

Airport A used to operate with two concrete runways. After more than 30 years in service the airside concrete pavements needed to be rehabilitated in order to:

- repair deteriorated concrete pavement and lower FOD risk; and
- improve airport pavement capacity by overlaying asphalt on top of existing concrete runway and taxiway pavements.

The rehabilitation work was also intended to increase its Pavement Classification Number (PCN) from 114 to 131 to accommodate the Maximum Take-Off Weight (MTOW) of the Boeing B777-300ER aircraft as well as to widen the runway width from 45 m to 60 m to accommodate the Airbus A380 aircraft.

A 190 mm thick asphalt overlay comprised 140 mm of binder course under 50 mm of wearing course. A tack coat layer was specified to provide adequate bonding of a minimum 0.41 MPa between the existing layers and the overlay.

The bitumen selected for this project was a PG76 PMB in consideration of the design aircraft and the 7 days highest pavement temperature. Fuel resistant performance was further specified to ensure the asphalt's capability to deal with fuel leaks and jet blast. The details of the PG76 fuel resistant PMB specified for this project is shown in Table 4 while the asphalt specifications are shown in Table 5.

Table 4. Airport A PMB Specifications

Test Property	Method	Value
Penetration Test (dmm)	ASTM D5	Report
Softening Point Test (ºC)	ASTM D 36	Report
Dynamic Viscosity @135ºC (Pa.s)	ASTM D 4402	<3.00
Dynamic Viscosity @170ºC (Pa.s)	ASTM D 4402	<0.80
Elastic Recovery, 25ºC, 10 cm elongation (%)	ASTM D6084	>75.00
Flash Point (ºC)	ASTM D 92	>230.00
Dynamic Shear G*/sinδ @10rad/sec, 76ºC (kPa)	AASHTO T315	>1.00
Rolling Thin Film Oven Test		
Loss of Mass (%)	ASTM D2872	<1.00
Increase in Softening Point (ºC)	ASTM D36	<10.00
Elastic Recovery, 25ºC, 10cm elongation (%)	ASTM D6084	>75.00
Dynamic Shear G*/sinδ @10rad/sec, 76ºC (kPa)	AASHTO T315	>2.20
PAV aging after RTFOT @ 100ºC		
Dynamic Shear G*sinδ @10rad/sec, 31ºC (kPa)	AASHTO T315	<5,000
Storage Stability after 72 hours storage @180 ºC		
Evolution of Softening Point (ºC)	ASTM D36	<5.00
Evolution of Penetration (dmm)	ASTM D5	<9.00
Fuel Resistance by weight loss of Marshall block with unaged PMB (%)	In-house Kerosene Immersion Test (KIT) method	<1.00

Table 5. Airport A Asphalt Specifications

Mixture Properties	Binder Course	Wearing Course	Tack Coat
Number of blows on each face (Marshall)	75	75	-
Stability (lb)	Min 1800	Min 2200	-
Flow (mm)	2 – 4	2 – 4	-
Voids total mix (%)	3 - 5	3-4	-
Voids Filled with Bitumen (%)	76 - 82	76 - 82	-
Interlayer Shear Strength (MPa)	-	-	0.41

3.2. Tropical Airport B

Airport B is another major hub in the tropics with annual temperatures ranging from 23ºC to 33ºC and relative humidity frequently reaching 100% during prolonged periods of rainfall. It served more than 60 million passengers with 6% growth and 2 million tonnes of cargo in 2017. This airport has two asphaltic runways of 4 km length and 60 m width. From 2008 to 2016, aircraft movements served by Airport B not only increased by almost 50%, but also accompanied by more heavier wide-body aircraft movement, e.g. Airbus A380 and Boeing B777. This significant traffic increase resulted in longer operation hours with a corresponding reduction in the daily maintenance work time window from 8 hours to 5.5 hours.

To address expected future traffic, environmental, and operational challenges, Airport B upgraded their PMB grade requirement from PG76 to PG82 in their asphalt, thereby improving material strength, rut resistance and weathering resistance. In addition to the PG82 high temperature requirements, elastic recovery and storage stability specifications were also mandated. More details of the PMB and asphalt requirements are shown in Tables 6 and 7 below.

Table 6 Airport B PMB Specifications

Test Property	Method	Value
High temperature Performance Grade	AASHTO M320	PG 82
Softening Point (ºC)	ASTM D36	> 80
Viscosity at 135 ºC (Pa.s)	ASTM D4402	< 3
Flash Point (ºC)	ASTM D92	> 230
Elastic Recovery at 25 ºC & 10cm elongation (%)	ASTM D6064	> 75
Dynamic Shear G*/sinδ tested @82ºC & 10rad/sec (kPa)	AASHTO TP5	> 1.0
Rolling Thin Film Oven Test		
Mass loss (%)	ASTM D2872	< 1.0
Dynamic Shear G*/sinδ tested @82ºC & 10rad/sec (kPa)	AASHTO TP5	> 2.2
Storage Stability after 72 hours storage @180 ºC		
Softening Point Evolution (ºC)	ASTM D36	< 5.0

Table 7 Airport B Asphalt Specifications

Mixture Properties	Test Method	Requirement
Number of blows on each face (Marshall)	ASTM D1559	75
Stability (N)	ASTM D 1559	Min 9600
Flow (mm)	ASTM D1559	2.5 – 3.5
Air voids (%)	ASTM D3203	2.8 – 4.2
Void in Mineral Aggregate (%)	ASTM D2726	Min 15
Tensile Strength Ratio (%)	ASTM D4867	Min 80
Wheel Tracking Rate (mm/hr)	BS 598-110	Max 2.0
Wheel Tracking Depth (mm)	BS 598-110	Max 4.0

3.3. Desert Airport C

Airport C is also an Asian hub used by almost 90 million passengers in 2017. A few years ago, when Airport C needed to upgrade and resurface its two runways, one of the main challenges was to ensure that this project would follow its timeline and not risk any downtime impacting the planned operations of the airport. The paving works were planned to be completed within 6 months and the large PMB volume of 30,000 tonnes to be supplied within this timeframe necessitated on-site production.

A PG76-10 grade PMB was specified for the project. Elastic recovery and low temperature binder performance were specified to ensure that PMB was supplied instead of merely a harder grade bitumen that might also have achieved a similar stiffness. The details of the PMB requirements are as shown in Table 8.

Table 8 Airport C PMB Specifications

Test Property	Method	Value
Penetration Test (dmm)	ASTM D5	>25.00
Softening Point Test (ºC)	ASTM D 36	>65.00
Viscosity @135 ºC (Pa.s)	ASTM D 4402	<3.00
Viscosity @165 ºC (Pa.s)	ASTM D 4402	<0.80
Viscosity @195 ºC (Pa.s)	ASTM D 4402	Report
Flash Point (ºC)	AASHTO T48	>230.00
Dynamic Shear G*/sinδ @10rad/sec, 76ºC (kPa)	AASHTO TP5	>1.00
Elastic Recovery, 25ºC, 10cm elongation (%)	ASTM D6084	>75.00
Rolling Thin Film Oven Test		
Loss of Mass (%)	ASTM D2872	<1.00
Elastic Recovery, 25ºC, 10cm elongation (%)	ASTM D6084	>75.00
Dynamic Shear, G*/sinδ @10rad/sec, 76ºC (kPa)	AASHTO T315	>2.20
PAV aging after RTFOT @110ºC		
Dynamic Shear G*sinδ @10rad/sec, 34ºC (kPa)	AASHTO T315	<5,000
Storage Stability after 48 hours Storage @163ºC	ASTM D7173	
Softening Point difference (ºC)	ASTM D36	<4.00
Separation Ratio on G*	ASTM D5	0.8 – 1.2
Creep Stiffness, S, max 300 MPa min m-value 0.3, test temperature @60 s (ºC)	AASHTO T313	0.00
Direct Tension, Failure Strain min 1.0%, test temperature @ 1.0 mm/min (ºC)	AASHTO T314	0.00

For asphalt performance, Airport C also specified moisture resistance, rut resistance and jet fuel resistance performances beyond Marshall mixture characteristics and volumetric requirements. Further, even though the asphalt Dynamic Modulus did not have a specified limit, it was required to be measured and reported as shown in Table 9.

Table 9 Airport C Asphalt Specifications

Mixture Properties	Test Method	Requirement
Number of blows (Marshall)	ASTM D1559	75
Stability (N)	ASTM D1559	>10,000
Flow (mm)	ASTM D1559	2.5 – 3.5
Air voids (%)	ASTM D3203	3 - 7
Voids Filled with Bitumen (%)	ASTM D2726	60 - 70
Voids in Mineral Aggregate (%)	ASTM D2726	> 14 (19mm NMAS) > 15 (12.5mm NMAS)
Air voids at Refusal (%)	BS 598-104	> 2
Retained Marshall Test after 24 hrs immersion @60ºC (%)	ASTM D1559	> 75
Marshall Quotient (N/mm)	ASTM D1559	> 4900
Moisture Resistance (%)	AASHTO T283	> 80
Jet-Fuel Resistance (%)	24 hr Kerosene Immersion	< 2% Mass loss
AMPT Dynamic Modulus (MPa)	AASHTO TP-79	Report
Rut Resistance + Moisture Susceptibility (mm)	AASHTO T324 @ 60 ºC	< 5 @10.000 passes < 12.5 @20,000 passes

3.4. Performance Comparison

From the case studies, Table 10 summarizes asphalt and bitumen requirements; while all of these airports still use the Marshall mixture design method, Airport C had already explored to further check against the Superpave mixture design method. Airports B and C also included asphalt performance requirements (e.g rut resistance and moisture resistance) to their specification and Airport A already included a tack coat / interlayer strength requirement. All these airports had specified higher grade bitumens to address traffic and environmental challenges as well as to prolong the maintenance cycle in expectation of narrowed operational windows. Fuel resistant bitumens were also specified to improve safe flight operations by reducing FOD.

The above three airports selected PMBs of grades PG76 or PG82 as per their climatic & traffic requirements; in addition to the PG high temperature requirements, these airports also included extra requirements to the PMB specifications such as elastic recovery, storage stability, fuel resistance, etc. to ensure that high quality bitumens for airport applications. Nonetheless, the quality of the bitumen is only one part contributing to airport pavement performance, it is also very important to check the performance of asphalts at both the mixture design stage and construction stage.

Table 10 Comparison of PMB & Asphalt Requirements for Airports

Airport Pavement	Airport A	Airport B	Airport C
No. of Runways	2	2	2
Dimension	Runway North: 3660 x 45m Runway South: 3600 x 45m	Runway 1: 4000 x 60m Runway 2: 4000 x 60m	Runway 1: 4000 x 60m Runway 2: 4450 x 60m
Pavement structure & thickness	Asphalt over concrete 50 mm Surface Course 140mm Base Course	Asphalt over Cement Treated Base (CTB) 75mm Surface Course 75mm Binder Course 350mm CTB	Asphalt 50mm Surface Course 200mm Base Course
Binder Grade Requirement	PG 76	PG 82	PG76 - 10
Fuel Resistant	Yes	No	Yes
Mixture Design Method	Marshall	Marshall	Marshall / Superpave
Asphalt Stiffness Modulus	No	No	Yes
Rutting Performance	No	Yes	Yes
Moisture Resistant	No	Yes	Yes
Tack Coat Bonding Strength	Yes	No	No

4. AIRPORT PAVEMENT PERFORMANCE ENHANCEMENT

Following the three case studies in the previous section, this section presents a Warm Mix Asphalt (WMA) technology that enhances the performance of airport pavements with respect to workability and sustainability without compromising on mechanical (stiffness and deformation resistance) and durability (moisture resistance) performances. While WMA mixes have been used for airport pavement applications for a number of years already in various parts of the world, they are still not commonly-used in the Asia Pacific region. WMA technology can be especially relevant to hub airports as described in the case studies that typically require fast installation and curing in order to fit tight operational time constraints.

4.1. WMA PMB Properties

The test properties of the WMA PMB are compared to a reference PG76 PMB as summarised in Table 11.

Table 11. Comparison of PMB Properties

Property	Method	PG 76 PMB	WMA PMB
Penetration @ 25 ^{0}C (dmm)	ASTM D5	45	40
Softening Point (^{0}C)	ASTM D36	93	90.9
Dynamic Viscosity @135 ^{0}C (Pa.s)	ASTM D4402	1.607	1.187
Dynamic Shear G*/sin δ at 76 ^{0}C & 10rad/s (kPa)	AASHTO T315	1.86	2.35
Rolling Thin Film Oven Test	AASHTO T240		
Dynamic Shear G*/sin δ at 76 ^{0}C & 10rad/s (kPa)	AASHTO T315	3.29	3.50
PAV aging after RTFOT @100ºC	AASHTO PP1		
Dynamic Shear, G*sin δ at 31 ^{0}C & 10rad/s (kPa)	AASHTO T315	1673	2450
Storage Stability after 72 hours storage @180 ºC			
Difference in Penetration (dmm)	ASTM D5	1	1
Difference in Softening Point (^{0}C)	ASTM D36	1.0	1.5

The penetration and dynamic shear values indicate that the WMA PMB is stiffer than the reference PG76 PMB at service temperatures, and yet is less viscous at the typical asphaltic paving materials' working temperature of 135^{0}C.

4.2. Volumetric Analysis

Three Marshall test specimens following a typical Stone Mastic Asphalt (SMA) gradation were prepared as per ASTM D6926 for the asphalt mixture of each PMB in order to analyse their volumetric properties as well as Marshall stability and flow values as per ASTM D6927 (refer to Table 12). To demonstrate the improved workability of the WMA, the mixing and compaction temperatures for the bituminous mixture of each PMB was differentiated, namely 180^{0}C and 160^{0}C respectively for the HMA with PG 76 PMB, and 160^{0}C and 140^{0}C respectively for WMA. These temperatures also applied to the preparation of test specimens for the other laboratory tests.

Table 12. Volumetric Analysis Summary

Property	Limits	PG 76 HMA	PG76 WMA
Marshall Density (t/m^3)	Report	2.325	2.329
Air Voids (%)	3.0 – 5.0	4.7	4.5
VMA (%)	Min 14.0	15.02	14.85
VFB (%)	Report	68.9	69.8
Stability (kN)	Min 12	16.95	19.59
Flow (mm)	2.0 – 4.0	3.29	2.77

Comparing the reference HMA against the WMA, the WMA was better compacted based on its 4.5% air voids against the corresponding 4.7% for the reference HMA, despite lowering the WMA's mixing and compaction temperatures by 20°C each. The WMA also gave higher stability and lower flow than the reference HMA

4.3. Indirect Tensile Stiffness Modulus (ITSM)

The ITSM tests were conducted in accordance with EN 12697-26, with three test specimens of each of the reference HMA and the proposed WMA tested at 25°C, 35°C and 45°C. The test results are summarised in Figure 1.

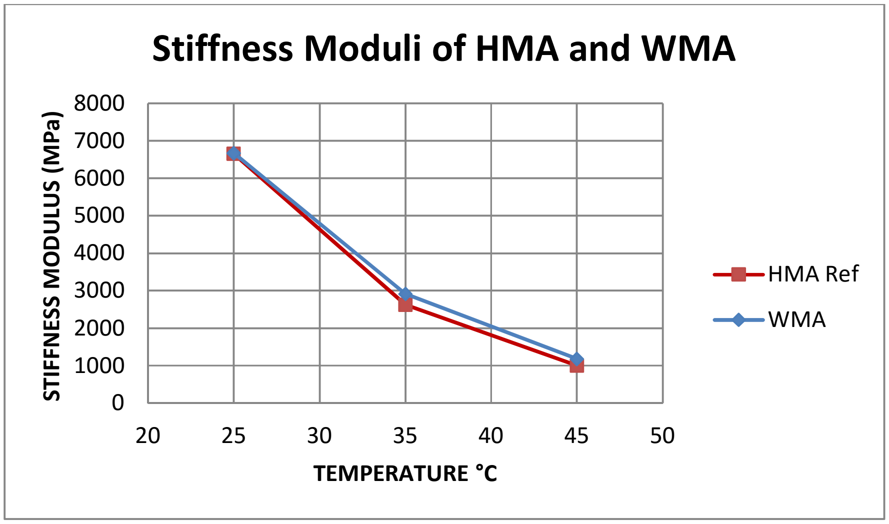

Figure 1: Average Stiffness Moduli at 25°C, 35°C and 45°C

In line with the higher Marshall stability and lower flow reported in the previous section, the WMA was slightly stiffer than the reference HMA at all three temperatures.

4.4. Water Sensitivity

The water sensitivity tests were conducted in accordance with AASHTO T283, with three test specimens each for the dry and wet sub-sets. The results of the subsequent Indirect Tensile Strength (ITS) test are summarised in Table 13.

Table 13. Summary of Indirect Tensile Strength Results for Water Sensitivity Analysis

Specimen	Dry 1	Dry 2	Dry 3	Dry Ave		Wet 1	Wet 2	Wet 3	Wet Ave	ITS Ratio
Specification		≥ 0.75		≥ 1.0			≥ 0.65		≥ 0.80	≥ 0.80
ITS HMA (MPa)	1.02	1.00	0.98	1.00		0.77	0.88	0.75	0.80	0.80
ITS WMA (MPa)	1.22	1.10	0.91	1.08		0.86	0.91	0.82	0.86	0.80

From the results above, the proposed WMA satisfied the five specification requirements in terms of the dry and wet individual and average ITS values as well as the ITS ratio. In addition, the ITS of both the dry and wet specimens of the WMA are slightly higher than those of the reference HMA, in line with the Marshall and ITSM results reported in the previous sections.

4.5. Deformation Resistance

The deformation resistance was assessed via a Wheel Tracking Test (WTT) conducted in accordance with AASHTO T324 with the test specimens submerged under water in the Hamburg Wheel-Tracking Device, under the specific conditions as stated in Table 14.

Table 14. Test Conditions for WTT

Condition	Parameter
Number of test specimens	2 per mixture
Test specimen thickness	50 mm
Test temperature	50°C
Temperature conditioning	Place test specimen in water at 50°C for minimum one hour after reaching temperature equilibrium.
Wheel load applied	705 N steel wheel
Wheel speed	50 passes/min
Load cycles	20,000 passes

The results of the WTT in terms of the rut depths at corresponding numbers of wheel passes are plotted in Figure 2 together with a reference maximum rut depth limit of 4.5 mm as specified for heavy-duty pavements for the Hamburg Container Port. Compared against the reference specification, it is evident that both the reference HMA and the proposed WMA had very low rut depths, indicating good deformation resistance. The tests were conducted under immersion in water heated at 50°C, so such low rut depths and the absence of any stripping inflection points indicated the good moisture/stripping resistance of both materials. In addition, the rut depth of the WMA was slightly lower than that of the HMA, in line with the Marshall, ITSM and ITS results reported in the previous sections.

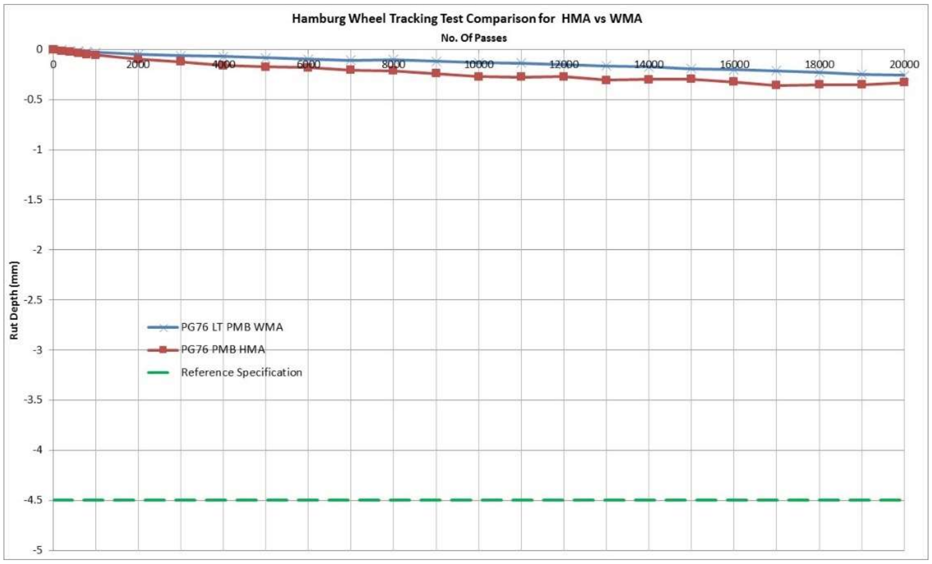

Figure 2: Rut Depths of the HMA vs. WMA

4.6. Sustainability Enhancement

By enabling the reduction in production temperatures, the fuel oil usage to produce the WMA instead of HMA at the asphalt plant is decreased by 1.1 L per tonne (from 10.7 L per tonne to 9.6 L per tonne) of asphalt mixture produced, yielding approximate savings of 10.3%. This also represents a reduction in CO_2 emissions of 32600 kg per 100,000 L of fuel [10], clearly demonstrating the environmental benefits of fuels savings and emission reductions at the asphalt plant in addition to the operational improvements.

5. CONCLUSION

As air traffic in Asia Pacific is expected to continue to grow, the market demands safe and continual airport operations with less disruptions, particularly those caused by maintenance works. Thus, more durable and better pavement performances are important factors to be considered when selecting pavement materials in constructing or maintaining an airport.

Most of the major hubs in Asia Pacific are located in warmer climates with high maximum temperatures in summer. Combined with more NLAs operating in the region, selecting suitable PG binders is one of the critical factors to have durable and better pavement performance. In addition, specifying particular PMB properties presents the possibility to further enhance binder performance. To ensure more durable and better performing airport pavements, it is beneficial for asset owners to include HMA performance criteria in their specifications.

More durable and sustainable pavement also must be considered to optimize natural resources usage (e.g. aggregates and fuels) as to align with sustainable development agenda in the region. The WMA technology described in this paper demonstrates that durable and sustainable bituminous pavement with improved workability and reduced energy consumption can be achieved without compromising on mechanical performance. Such a technology is especially relevant to airports that typically require fast installation and curing in order to fit tight operational time constraints.

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