Application of high performance PMBs in Asia Pacific Airport Projects

Yandi Nurkama, Jia Lu, Vincent Guwe, Jeyan Vasudevan and Dennis Quek

Abstract— **Asia's rapid growth in the commercial aviation sector in recent decades has positioned the region as the largest and fastest-growing one in the world. However, aviation infrastructure in this region is struggling to keep pace with this growth, with many airports operating above their planned capacity, resulting in many new airports and upgrading projects in the next 5 years. In the face of challenges such as the operation of New Large Aircrafts(NLAs) and increased air traffic volumes, existing bituminous material requirements are lagging the expectations from airport designer, consultants and operator/management teams. This paper analyzes and compares the requirements between bituminous materials applied for airfields and normal highways. It also shares real-life examples of the application of high performance as well as fit-for-function Polymer Modified Bitumen (PMB) in several regional airports. This paper concludes with proposals for new technical specifications that consider the specific climatic conditions for airport projects in the Asia Pacific region.**

Index Terms—**airports, high-performance, PMB, specification**.

I. BACKGROUND

Commercial aviation has been the most preferred mode of transportation for medium- to long-distance travel in the last several decades. Current global passenger traffic is around 4.1 billion passengers annually with steady growth averaging 5.5% per year over the last 10 years and forecasted to be 4.3% per year in the next 15 years and 4.2% per year in the next 25 years(1). Traditional markets like the United States and Europe which currently dominate passenger traffic are on steady annual growth rates of 4% and 6.1% respectively, but Asia Pacific, as a region with a 33.7% air traffic market share, is leading all regions by having average annual traffic growth exceeding 8% in the last 10 years and forecasted to be 5.1% in the next 15 years [1]. Thus, by 2022 air passenger traffic from emerging markets, many in Asia Pacific, will surpass air passenger traffic from developed countries [2].

Aligned with the air passenger traffic data, Boeing, as one of the market leaders in the aviation industry, also forecasted that the world fleet will be doubled by 2035, where the growth driver is the Asia Pacific region that will triple its fleet size while other regions will have lower growth. Such up-trending demand forecast as well as the aviation fleet growth is regrettably not aligned with the airport infrastructure capacity in the region. Many major airports in the region are nearly at full capacity, or have even significantly exceeded the planned capacity [3].

In response to the rapid air traffic growth, 350 new airports have been planned to be built in the region within the next 10 years, while many existing airports will undertake major landside (e.g. terminal, commercial area, land transport system, parking, etc.) and airside (e.g. runway, taxiway, and apron) capacity upgrades [4]. Unfortunately, most of the airports in Asia 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 NLAs in service in the region, better material performance is required for better airport pavement performance. One of the preferred solutions in enhancing Hot Mix Asphalt (HMA) performance is by the development of superior-performing materials (e.g. Polymer Modified Bitumens (PMBs) & Performance Grade (PG) binders).

II. AIRPORT PAVEMENT PERFORMANCE REQUIREMENTS

Airport and road asphalt pavements have many similarities, but also some significant differences. One of the crucial differences is in terms of types and frequencies of loads that are experienced when the respective pavements are 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

Y. Nurkamal is with the PT. Shell Indonesia, Indonesia (e-mail: Yandi.Nurkamal@shell.com)
J. Lu is with the Shell Eastern Petroleum Ltd., Singapore.
V. Guwe is with the Shell Malaysia Trading Sdn. Bhd.
J. Vasudevan is with the Shell Malaysia Trading Sdn. Bhd.
D. Quek is with the Shell Eastern Petroleum Ltd., Singapore.

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 I, both loading gear configurations and tire pressures of commonly-used aircrafts are much higher compared to the standard axle load 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 I
AIRCRAFT LOADS VS ROAD TRAFFIC LOADS [5]

Traffic Load		Gross Load Main Landing Gear Group for aircraft or axle load for truck – Lb (Kg)		Tire Pressure – psi (kPa)	
Commonly used Aircraft Load	Airbus A-300 B2	304,000	(137,892)	168	(1,158.32)
	Airbus A-330	460,000	(208,652)	200	(1,378.95)
	Airbus A-380	942,700	(427,601)	194	(1,337.58)
	Boeing, B-737-100	100,000	(45,359)	148	(1,020.42)
	Boeing, B-747-200	833,000	(377,842)	200	(1,378.95)
	Boeing, B-777-200B	634,500	(287,804)	215	(1,482.37)
	Boeing, B-787-8	478,325	(216,964)	228	(1,572.00)
Standard Road Axle Load		18,000	(8,164)	100	(689.48)

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, deformation resistance is concerned with prevention against groove closure, rutting and shearing/shoving, with particularly high importance for safe aircraft operations, especially on runways. 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.

Traditionally, highway pavement cracking initiates 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 of the tire pressure of the aircraft being that much higher compared to the typical truck tire pressure as seen in Table I.

Both airport and highway pavements require surface friction and texture in service, critically when the asphalt pavement is 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 65kmph using the Mu-meter trailer [6]. For comparison purposes, 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). Airport pavements also require pavement surface integrity to avoid material disintegration that will lead to Foreign Object Damage (FOD) which can then risk aircraft operations. Thus, asphalt mixtures for airports must have good component adhesion and cohesion. A summary comparing the performance requirements between airport and highway pavements is shown in Table II.

TABLE II
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	High
Fracture resistance	Top down cracking	Moderate	Low
	Fatigue cracking	Moderate	Moderate
Surface friction and texture	Skid resistance	High	High
	Compliance requirement	High	Moderate
Durability	Pavement generated FOD	High	N/A
	Resistance to moisture damage	Moderate	Moderate
	Resistance to fuel corrosion	High	N/A

Although the bituminous binder typically constitutes around 5% by mass in asphalt mixtures, its characteristics and performance dominate the overall mixture performance as well as economic significance in terms of repair costs for rework needed when mixture failures occur. To ensure that asphalt mixtures have high stiffness and fatigue resistance, bituminous binders also need to have high stiffness moduli and reduced hardening over time and load repetitions. As a viscoelastic material, bituminous binders 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 asphalt mixtures, bituminous binders 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 allow very short time windows are typically allowed for paving work, thus requiring fast asphalt mixture installation and curing, and/or having good workability at low temperatures. Thus, the latest bituminous binder development is to have suitable viscosity ranges for good paving workability.

TABLE III
HMA & Bituminous Binders Requirements for Airport Pavement Functions [9]

Pavement Function	Airport Segment	Mixture Performance Requirement	Binder 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

Pavement HMA performance requirements, specifically bituminous binder characteristics related to airport pavement functions are shown in Table III.

Bitumen solutions to meet specific airport requirements will vary from location to location as they are very dependent on 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 concrete specifications for many airports have also shifted from traditional Marshall and volumetric requirements to further include rutting- & crack- resistances.

III. Airport pavement Solution Case Studies

This section collects three actual examples of airport projects in the Asia Pacific region with typical climatic conditions as well as aircraft loadings.

A. Tropical airport 1

Airport 1 is located in the tropics with annual temperatures in the range from 21ºC to 35ºC; it typically experiences around 70 rainy days yearly, with around 27 days of medium (20-50mm/day) to very heavy rain days (>100mm/day) per year. As a main hub for domestic as well as international flights, it served more than 60 million passengers and 400,000 aircraft movements in 2017, growing typically 10% annually on average.

Airport 1 operated with two concrete runways, and after more than 30 years in service the airside concrete pavements need to be rehabilitated in order to:

- repair deteriorated concrete pavement and lowering the FOD risk.
- 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 HMA overlay comprised 140 mm of Binder Course and 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 binder selected for this project is a PG76 PMB in consideration of the design aircraft and the 7 days highest pavement temperature in the area. Fuel resistant performance was further specified to ensure the HMA'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 IV while the HMA specification details are shown in Table V.

TABLE IV
AIRPORT 1 BINDER SPECIFICATION

Test Property	Method	Unit	Limit	Value
Penetration Test	*ASTM D5*	*ºC*	*Report*	*Report*
Softening Point Test	*ASTM D 36*	*dmm*	*Report*	*Report*
Dynamic Viscosity @135 ºC	ASTM D 4402	Pa. s	Max	3.00
Dynamic Viscosity @170 ºC	ASTM D 4402	Pa. s	Max	0.80
Elastic Recovery on fresh binder,25ºC, 10cm elongation	ASTM D6084	%	Min	75.00
Flash Point	ASTM D 92	ºC	Min	230.00
Dynamic Shear G*/sinδ @10rad/sec, 76ºC	AASHTO T315	kPa	Min	1.00
Rolling Thin Film Oven Test				
Loss of Mass	ASTM D2872	% w/w	Max	1.00
Increase in Softening Point	ASTM D36	ºC	Max	10.00
Elastic Recovery after RTFOT, 25ºC, 10cm elongation	ASTM D6084	%	Min	75.00
Dynamic Shear after RTFOT G*/sinδ @10rad/sec, 76ºC	AASHTO T315	kPa	Min	2.20
PAV aging after RTFOT				
Dynamic Shear after PAV G*sinδ @10rad/sec, 31ºC	AASHTO T315	kPa	Max	5,000
Storage Stability				
Evolution of Softening Point	ASTM D36	ºC	Max	5.00
Evolution of Penetration	ASTM D5	dmm	Max	9.00
Marshall Block Using Original Binder, Resistance to Kerosene, weight loss	KIT in-house method	% w/w	Max	1.00

TABLE V
AIRPORT 1 HMA MIXTURE SPECIFICATIONS

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

B. Tropical airport 2

Airport 2 is another major hub in the tropics with annual temperatures ranging between 23ºC to 33ºC and relative humidity around 84%, 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 also has two runways, both 4000 m in length, 60 m in width and surfaced with asphalt. From 2008 to 2016, aircraft movements served by Airport 2 increased by almost 50%, accompanied by more wide-body aircraft movement, e.g. Airbus A380 and Boeing B777. This significant increase on traffic resulted in a reduction in the maintenance work time window from 8 hours to 5.5 hours per day.

To address expected future traffic, environmental, and operational challenges, Airport 2 upgraded their PMB grade requirement from PG76 to PG82 in their HMA, 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 HMA and PMB requirements are shown in Tables VI and table VII below.

TABLE VI
AIRPORT 2 HMA SPECIFICATIONS

Mixture Properties	Test Method	Requirement
Number of blows on each face	ASTM D1559	75
Stability, newtons	ASTM D 1559	Min 9600
Flow, mm	ASTM D1559	2.5 – 3.5
Asphalt Content, %		5.0 – 7.5
Air voids, %	ASTM D3202	2.8 – 4.2
Void in Mineral Aggregate (VMA), %	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

TABLE VII
AIRPORT 2 PMB SPECIFICATIONS

Test Property	Method	Value
Fresh Material		
High temperature Performance Grade	AASHTO M320	PG 82
Softening Point, ºC	ASTM D36	Min 80
Viscosity at 135 ºC, Pa.s	ASTM D4402	Max 3
Flash Point, ºC	ASTM D92	Min 230
Elastic Recovery at 25 ºC & 10cm elongation, %	ASTM D6064	Min 75
Dynamic Shear G*/sinδ tested @82ºC & 10rad/sec, kPa	AASHTO TP5	Min 1.0
After RTFOT		
Mass loss, %	ASTM D2872	Max 1.0
Dynamic Shear G*/sinδ tested @82ºC & 10rad/sec, kPa	AASHTO TP5	Min 2.2
After Storage for 72 hours @180 ºC	-	Max 5.0

C. Desert airport 3

Airport 3 is another hub in Asia used by almost 90 million passengers in 2017. A few years ago, when Airport 3 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 the downtime impacting the planned operations of the airport itself. 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 the PMB to be produced to site. 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 harder grade bitumen that might also have achieved a similar stiffness. The details of the PMB requirements are as shown in Table VIII.

In term of HMA, beyond Marshall Mixture characteristics and volumetric requirements, Airport 3 also specified moisture resistance, rut resistance and jet fuel resistance performances. Further, even though the HMA Dynamic Modulus did not have a specified limit, it was required to be measured and reported as shown in Table IX.

TABLE VIII
AIRPORT 2 BINDER SPECIFICATION

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

TABLE IX
AIRPORT 2 HMA SPECIFICATIONS

Mixture Properties	Base Course	Surface Course
Number of blows (Marshall)	2 x 112	2 x 75
Stability (Min)	8,100 (N)	10,000 (N)
Flow	2.5 – 3.5 mm	2.5 – 3.5 mm
Air voids, %	3 – 7	3 - 7
Voids Filled with Bitumen (VFB), %	60 – 70	60 - 70
Voids in Mineral Aggregate (VMA) %	Min. 13	Min. 14 (19mm NMAS) Min 15 (12.5 NMAS)
Air voids at Refusal, %	Min 2	Min 2
Retained Marshall Test after 24hrs immersion @60 ºC, %	Min 75	Min 75
Marshall Quotient, N/mm	Min 4900	Min 4900
Moisture Resistance	AASHTO T283	Min 80%
Jet-Fuel Resistance	24 hr Kerosene Immersion	Max 2% Mass loss
Dynamic Modulus (Asphalt Mixture Performance Tester=AMPT)	AASHTO TP-62	Report
Rut Resistance + Moisture Susceptibility	AASHTO T324 @60 ºC (Hamburg Wheel Tracking Test =HWTT)	Max 0.2” @10.000 passes Max 0.5” @20,000 passes

D. Performance comparison

From the above case studies, Table X summarizes asphalt mixture and binder requirements; while all of these airports still use the Marshall mixture design method, Airport 3 had already explored to further check against the Superpave mixture design method. Airports 2 and 3 already included mixture performance requirements (e.g. rut resistance and moisture resistance) to their specification and Airport 1 already included a tack coat / interlayer strength requirement. All these airports had already implemented higher grade binders to address traffic and environmental challenges as well as to prolong the maintenance cycle in expectations of reduced operational windows. Fuel resistant binders 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 binders for airport applications. Nonetheless, the quality of the binder is only one part contributing to airport pavement performance, it is also very important to check the performance of asphalt mixtures at both the mixture design stage and construction stage.

TABLE X
COMPARISON OF PMB AND HMA REQUIREMENTS FOR AIRPORTS

Airport Pavement	Airport 1	Airport 2	Airport 3
No. of Runways	2	2	2
Dimension	Runway North: 3660 x 45m Runway South: 3600 x 45	Runway 1 4000 x 60m Runway 2 4000 x 60m	Runway 1 4000 x 60m Runway 2 4450 x 60m
Pavement structure & thickness	HMA over concrete 50 mm Surface Course	HMA over CTB 75mm Surface Course 75mm Binder Course 350mm Cement Treated Base (CTB)	HMA 50mm Surface Course 200mm Base

	140mm Base Course	300mm Graded Aggregate Base	Course
Binder Grade Requirement	PG 76	PG 82	PG76 - 10
Fuel Resistant	Yes	No	Yes
Mixture Design Method	Marshall	Marshall	Marshall / Superpave
Asphalt Mixture Stiffness Modulus	No	No	Yes
Rutting Performance	No	Yes	Yes
Moisture Resistant	No	Yes	Yes
Tack Coat Bonding Strength	Yes	No	No

IV. CONCLUSIONS

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 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.

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