

PAPER • OPEN ACCESS

Mix design and application of porous asphalt pavement using Japanese technology

To cite this article: H Nakanishi *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **512** 012026

View the [article online](#) for updates and enhancements.

Mix design and application of porous asphalt pavement using Japanese technology

H Nakanishi¹, M O Hamzah², M RMohd Hasan², P Karthigeyan³ and O SHaur³

¹TAIYU Kensetsu Co., Ltd. 5-14-2 Kanayama, Naka-ku, Nagoya, Japan

²School of Civil Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia

³Kamunting Premix Asphalt Plant Sdn Bhd, Lot 4188, Jalan Perusahaan 3, Kamunting Industrial Estate, 34600 Kamunting, Perak, Malaysia

E-mail: nakanishi@taiyu.co.jp

Abstract. Early applications of porous asphalt in Malaysia took place in the 1990's on the JKR roads. However, the performance of the material has not been encouraging, primarily due to ravelling and clogging. Initial porous asphalt experience in Japan was imported from Europe in 1987 and encountered similar problems. However, these problems have been successfully resolved by using a high viscosity modified asphalt developed in Japan. Now, porous asphalt has been popular in Japan. This paper presents the design concepts of the technology. The aggregate design incorporates a gap between 2.36mm and 4.75mm to increase the percentage of connected air voids; hence improved permeability and better resistance to clogging. Bonding between aggregate particles is significantly enhanced using TPS modifier that results in approximately binder grade comparable to PG82. The modified binder is characterized by its high mechanical properties, good anti-stripping and anti-aging properties. The results of the tri-axial compression test are introduced to explain the durability of the porous asphalt. In view of the superior laboratory mixture properties, a field trial was conducted on the North-South Expressway. The monitoring results after six months in service demonstrate excellent condition. This paper also deliberates on the successful applications of Japanese technology in Asia.

1. Introduction

For several years, the Universiti Sains Malaysia and TAIYU Kensetsu Company Limited have worked together to adapt Japanese porous asphalt pavement technology to improve the performance of porous asphalt pavements in Malaysia. The research venture culminated into a field trial on kilometre 188.6 to 189 on the North-South Expressway. Earlier porous asphalt application in Malaysia in the 1990's was biased to European porous asphalt technologies. However, there are many complaints on its lack of durability and short service life primary due to clogging and ravelling. In the Japanese context, porous asphalt technology was imported from Europe in 1987, but various improvements in modified asphalt and mix proportion of aggregates have been successfully performed to fit climate and traffic conditions in Japan. The improved modified asphalt and porous mixture have been successfully implemented and tried in China [1], Korea [2], Taiwan [3, 4], and others after year 2000.

Laboratory tests at the USM Highway Engineering laboratory affirmed the need for high viscosity modified asphalt and mix design technologies to ensure durability and sustainability of porous asphalt



in Malaysia. The research findings have been presented to international [5] and domestic [6] conferences.

This paper presents the fundamentals and characteristics of Japanese porous asphalt pavement technology. The paper also dwells on the porous asphalt mixture shear strength via tri-axial compression test and the mechanism of strength generation and sustainability of the pavement [7], which have been published by the main author and his team. The monitoring test results from a field trial carried out on the South-North expressway based on Japanese technology will be deliberated.

2. Porous asphalt mixture

Porous asphalt mix design implicates selection of an appropriate aggregate grading and blending it with a target binder content. The stability of its aggregate gradation relies on maximising the stone-to-stone contact of the coarse aggregate matrix. The asphalt mortar comprising of asphalt, fine aggregates, and mineral filler; binds the coarse aggregates together. Therefore, asphalt binder, aggregates, and mineral filler are essential components that must be considered.

2.1. Properties of TPS modified asphalt

The Japanese porous asphalt emphasises on the asphalt binder performance. Accordingly, the asphalt binder used must exhibit higher strength or higher viscosity even when subjected to high temperatures. The Japanese standard on asphalt properties for porous mixtures was not initially influenced by the Strategic Highway Research Program (SHRP) requirements. However, the modified binder used that meets the Japanese standard is equivalent to PG82.

The modifier used to strengthen conventional binder penetration grade 60/70 properties is TPS. TPS is a bitumen modifier that can be manually added into the pugmill of the asphalt batch mix plant and let to homogeneously mix with the porous asphalt mixture within one minute. The TPS modified asphalt meets the Japanese standard, and it exhibits better performance in terms of softening point, viscosity at 60 °C, besides other excellent properties. TPS is being employed widely in Asian countries. A detailed explanation on the properties of TPS modified asphalt was presented at an international conference held in Singapore [5] based on extensive laboratory tests conducted at USM.

2.2. Influence of asphalt property to the sustainability of porous pavement

The durability and sustainability of porous asphalt pavement based on Japanese technology is evident from field trials monitoring results conducted on a motorway in Bangkok, Thailand in December 2015. The site was paved with Thai and Japanese porous asphalt technologies using identical asphalt mixing plant, mix proportion, site location, paving period, paving company and paving machinery but different binders. The Thai porous asphalt used PG 76 binder prepared in Thailand, while the Japanese porous asphalt used TPS modified asphalt equivalent to PG 82.



Plate 1. Ravelling & Pothole on PG76

Plate 2. Soundness on PG82

As shown in Plates 1 and 2, after two years in service, the differences in performance is obvious. A lot of ravelling and pothole have occurred on the track area where PG76 was used, while the porous

asphalt pavement using TPS modified asphalt remains in good condition. This takes place despite the TPS porous pavement being placed on the slowest lane where traffic loading and time of loading were much more severe. The positive results indicate the positive role of the TPS modified binder since all construction variables and weather conditions are identical.

Figure 1 shows the difference in shearing strength of PG 76 and PG 82 binders. The PG76 results represent typical values since no test data on DSR of TPS modified asphalt used at Bangkok and Thai PG 76 is available. The data shown in Figure 1 is the DSR test result carried out for PG 82 at USM. Regarding PG 76 produced in Thailand, the lower limit values for PG 76 is used, which was supposed to be from the DSR data of PG82. If the temperature of the pavement is assumed to be 65 °C, the elastic component of the complex shear modulus ($G^*/\sin \delta$) at 65°C of PG 76 is approximately 2.8 kPa, while that of PG 82 is estimated to be 7.5 kPa. The difference in DSR is remarkable, and this explains the differences in the performance of the porous pavement.

The $G^*/\sin \delta$ derived from the DSR test result can be related with the rutting property of the mixture. However, according to the research carried out through tri-axial compression test, there is a close relationship between the shearing strength and the Cantabro loss that could be used to evaluate the ravelling property. Though it will be explained in Section 3, the results of the field trial in Bangkok corroborate this idea.

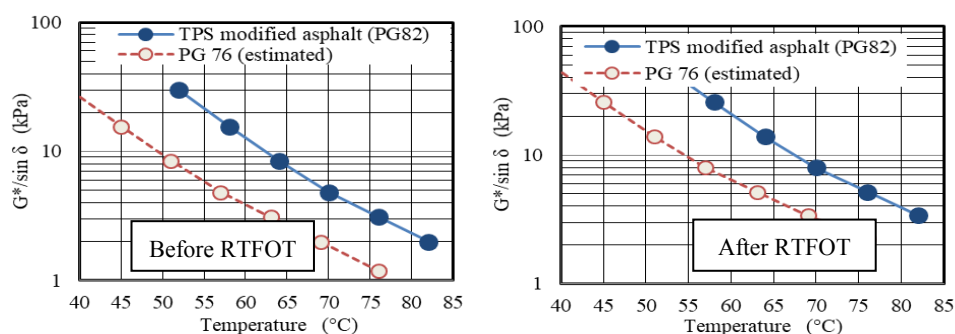


Figure 1. Comparison of DSR between PG 76 and PG 82

2.3. Mix proportion and gradation of porous asphalt mixture

Ensuring proper air voids is essential for a durable porous asphalt mixture. More importantly, these air voids must be interconnected to sustain the drainage function. The ranges of synthetic gradation of the porous asphalt mixture in Asian countries are almost the same.

Aggregate gradation envelope for porous asphalts is typically expressed in terms of an upper and lower limits. It is not right to assume that any gradation that lies within this envelope would result in a durable porous mixture. To the layman, these gradations are categorized as open-graded. However, more correctly, it should be categorized as not open-continuous but rather an Open-Gap gradation.

This is because of the need to incorporate a gap between 2.36 mm and 4.75 mm to increase the connected air voids percentage and to enhance the mechanical strength of the mixture. By gap gradation means reducing the amount of medium-sized aggregate from 2.36 mm to 4.75 mm. This is because the existence of the medium-sized aggregate sometimes disturbs the formation of the stone-to-stone contact and the source of mix strength and stability; hence decreasing the connected air voids. From experience, the difference between the passing weight percentage at 4.75mm and 2.36mm should preferably be less than 6%.

2.4. Properties of porous asphalt mixture

The porous asphalt mixtures have been designed to conform to specifications used in each country namely; Malaysia, Vietnam, and Thailand. Different aggregate types have been used according to the country as shown in Table 1. However, in all countries, between 4 to 5 % calcium carbonate was used

as a mineral filler. Asphalt binder used for these mixtures was TPS modified asphalt, which consists of 88% pen grade 60/70 base bitumen and 12% TPS modifier. In addition, anti-stripping agent, Tough Fix, was used for granite aggregate in Malaysia in weight percentage of 0.3 % to binder content.

The mix design follows several distinct steps beginning with determining the proportion of aggregates to attain 20 % air voids, followed by the determination of the design asphalt content based on the asphalt flow down test. The detail of this procedure has been presented elsewhere [5]. Table 1 shows, the synthetic gradation, asphalt content, air voids and connected air voids, and mechanical properties used according to country.

Table 1. Properties of porous asphalt mixture (in Asian countries)

Item	Unit	Malaysia (In-house @USM)	Vietnam (In-house test)	Thailand (QC on Dec. 2015)	Standards In Japan
Types of aggregate used	Coarse Aggregate	Granite	Basalt	Limestone	
	Fine aggregate	Crushed granite dust	River sand	limestone dust	
Synthetic Gradation	19mm	%	100 (20) ^a	100	100
	13.2mm	%	91.6 (14) ^a	100	90-100
	9.5mm	%	61.5 (10) ^a	64.2	
	4.75mm	%	18.9 (5) ^a	15.6	11-35
	2.36mm	%	16.4	15.0	10-20
	0.075mm	%	5.7	5.1	3-7
Asphalt Content (TPS content)	%	4.7 (12%)	4.9 (12%)	4.5 (12%)	4 ~ 6
Max. Theoretical Density	g/cm ³	2.457	2.614	2.552	-
Density	g/cm ³	1.959	2.082	2.043	-
Air Void	%	20.3	20.4	19.9	Around 20
Connected Air Void	%	18.5	18.5	16.9	(Min. 13) ^b
Marshall Stability	kN	8.89	4.17	5.16	Min. 3.43
Flow Value	1/10mm	34.9	22.0	18.0	-
Permeability Coefficient	cm/sec	0.495	0.383	-	Min. 0.01-
Cantabro Loss at 20 ° C	%	9.1	12.1	7.6	Max. 20
Dynamic Stability	pass/mm	21,094	10,500	7,000	Min. 3,000
ITSR by DASM ^c		0.84			

Note: ^a Figure in parentheses shows the size of sieve used in Malaysia.

^b Recommended value.

^c DASM stands for Dynamic Asphalt Stripping Machine developed at USM.

As shown in Table 1, proper open-gap gradations have been designed for all mixtures. It can be seen that the percentage of medium-sized aggregate from 2.36mm to 4.75mm is very small (less than 3%). The connected air voids exceed much more than the 13% recommendation value. These porous asphalt mixtures also meet all other specified values.

3. Shearing strength of porous asphalt mixture

From our experiences, deteriorations of the porous asphalt mixture occur easily when subjected to high temperature. In practice, the mechanical strengths of porous asphalt mixture, especially shear strength, reduces as temperature increases despite pavements being exposed to no changes in traffic loading. This strength generation mechanism can be explained from the experimental research results on shearing strength by tri-axial compression test [7].

In this section, the results and knowledge derived from the tri-axial compression test are drawn. This research was published in the Japanese Pavement Industry magazine. Nevertheless, the results and knowledge are again presented in this paper since it did not make freely accessible to the public internationally.

3.1. Tri-axial compression test for porous asphalt mixture

This test has been carried out at Research Laboratory of TAIYU Kensetsu Co., Ltd. The photo of the equipment setup, test parameters and typical results are shown in Plate 3, Table 2 and Figure 2, respectively.



Plate 3. Test situation of Tri-axial test

Table 2. Test conditions of Tri-axial test

Item	Test conditions
Size of specimen	$\phi 5 \times 10 \text{ cm}$
Casting method	By compaction
Density	Standard density $\pm 1\%$
Test temperature	60°C
Curing temperature	60°C , 30 minutes
Loading rate	2 mm/min
Side pressure (kgf/cm^2)	0, 0.5, 1.0, 1.5, 2.0

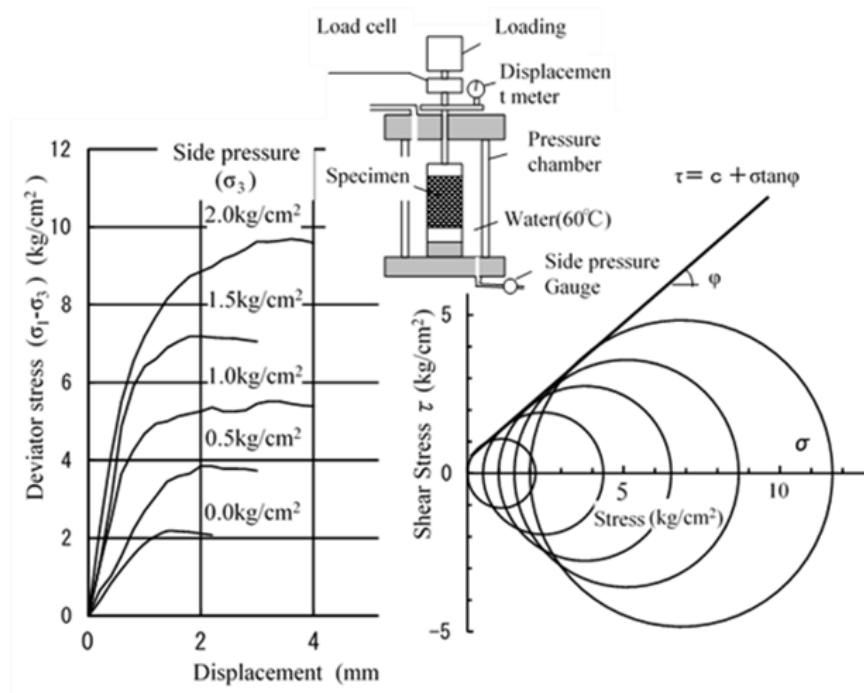


Figure 2. An example of the tri-axial compression test results

Four porous asphalt mixtures prepared with different mix proportions and air voids at approximately 16 %, 22 %, 26 %, and 30 %; were tested. The binder viscosities at 60°C used ranged from 58,500 poise ($5,850 \text{ Pa}\cdot\text{s}$) to 60,000,000 poise ($6,000,000 \text{ Pa}\cdot\text{s}$). The tri-axial tests were carried out in the temperature-controlled chamber at 60°C using the tri-axial compression machine used for testing soils. Specimens with the same mix proportion were subjected to five levels of side stress (σ_3). A linear relationship was found between the side stress and deviator stress, $\sigma_1 - \sigma_3$, and the results are similar to those obtained from the soil test. The internal friction angle (ϕ) was obtained from the gradient of the straight line, and cohesion (C) is obtained from the intercept of the straight line.

In the study, the unit for stress is kg/cm². Tri-axial compression tests have been carried out for all mixtures in which the combinations of the mix proportion of aggregates and the viscosity at 60 °C of asphalt used are respectively different, cohesion "C" and internal friction angle "φ" for each mixture have been experimentally obtained. All tests were carried out at 60 °C.

3.2. Shearing strength of porous asphalt mixture

The shear strength "τ" is expressed in terms of cohesion "C" internal friction angle "φ" and vertical stress "σ" in the form of $\tau = \sigma \tan(\phi) + C$. Porous asphalt mixture with higher shear strength will be more stable and can better resist external forces. Table 3 shows the test results of the tri-axial compression test and other mechanical properties on each mixture condition. Figure 3 and Figure 4 show the cohesion and internal friction angle, respectively. The results imply that the deterioration of the porous asphalt mixture follows the "Coulomb's Failure Criterion" too as in soil mechanics. Therefore, porous asphalt mixture with higher cohesion and higher internal friction angle should be more sustainable and durable.

Table 3. Test results of tri-axial compression test (at 60°C, $\sigma_1=6.4$ kg/cm²)

Mix proportion	Air void (%)	Viscosity at 60°C (poise)	Test results of Tri-axial compression test			Dynamic stability (pass/mm)	Cantabroloss (%)
			Cohesion (C:kgf/cm ²)	Internal friction angle (φ: degree)	Shearing strength (τ: kgf/cm ²)		
A	16.9	58,500	0.74	40.0	6.10	3736	9.4
	16.6	1,170,000	0.78	40.7	6.28	5907	7.8
	15.8	9,230,000	0.85	41.8	6.58	7000	4.3
	15.2	60,000,000	0.91	43.0	6.87	10800	3.1
B	22.0	58,500	0.43	40.9	5.97	2167	14
	21.7	1,170,000	0.57	41.8	6.28	4875	9.4
	21.6	9,230,000	0.64	42.0	6.41	5250	6.6
	22.2	60,000,000	0.65	42.8	6.58	7875	6.1
C	26.9	58,500	0.34	40.8	5.86	1768	26.2
	26.4	1,170,000	0.39	40.9	5.93	3627	19.3
	25.9	9,230,000	0.41	41.2	6.01	4717	11.4
	25.9	60,000,000	0.47	41.9	6.21	5727	8.7
D	29.7	9,230,000	0.27	39.4	5.53	2245	33.2
	29.8	60,000,000	0.29	40.2	5.69	3150	27.6

It is essential to know the factors influencing cohesion "C". A linear relationship can be identified between the cohesion and change in viscosity at 60°C when plotted on a semi-logarithmic graph, and it can be demonstrated by a multivariate formula using viscosity at 60°C and airvoids. The formula is shown in Equation (1).

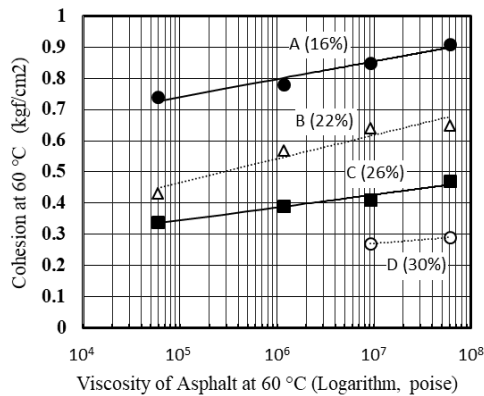
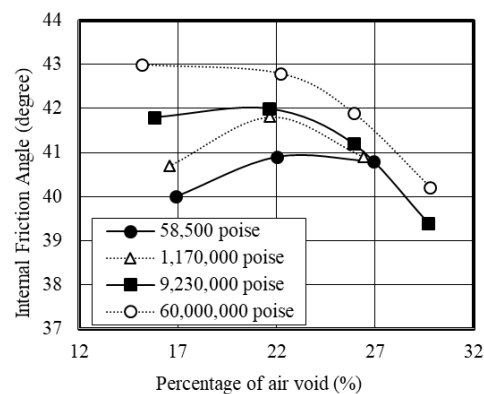
$$C = 1.459 - 0.0413V_o + 1.465 \times 10^{-9}V_i \quad (r: 0.979) \quad \dots\dots\dots (1)$$

where: C: Cohesion (kgf/cm²), V_o: Air voids (%), V_i: Viscosity at 60°C (poise).

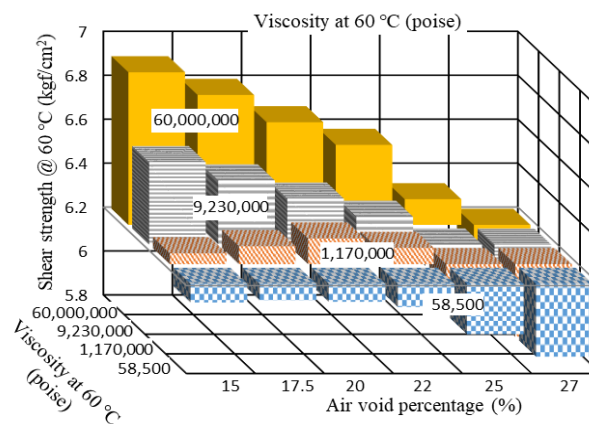
Equation (1) implies that cohesion increases as air voids decrease and increase in viscosity at 60 °C.

On the other hand, as shown in Figure 4, there is no linear relationship between the internal friction angle and air voids. However, the internal friction angle seems to attain a maximum value when at air voids ranging from 20% to 23%.

Figure 5 shows the relationship between asphalt viscosity at 60 °C, air voids percentage, and shear strength at 60 °C.

**Figure 3.** Cohesion**Figure 4.** Internal friction angle

In this assessment, vertical stress by tire contact pressure is approximately 6.4 kg/cm^2 which is equivalent to 8 tons wheel load, was adopted. The shear strength is obtained from the cohesion and internal friction angle in regards with the “Coulomb’s Failure Criterion” that is considered to be true even for the porous asphalt mixture. The shearing strengths for each combination of mixtures were then calculated and shown in Table 3. It indicates that if the shearing strength of the porous asphalt mixture is greater than the shearing stress generated on the pavement surface by the wheel loading, deteriorations of the porous pavement, like ravelling, rutting, and potholes, would not be arising.

**Figure 5.** The relationship between asphalt viscosity at 60°C, air void percentage and shear strength

The relationships between shearing strength and other mechanical properties of the porous asphalt mixture, like Dynamic stability and Cantabro loss, are shown in Figure 6 and Figure 7.

The above data demonstrate that porous asphalt mixture which has a higher shear strength will exhibit greater mechanical property. The shear strength was derived based on the cohesion and angle of internal friction. In addition, higher cohesion and angle of internal friction can be obtained by using highly modified asphalt binder and proper mix proportions.

The results indicate that the shear strength of the porous asphalt increases along with the increase in $G^*/\sin \delta$. Figure 6 and Figure 7 show that both rutting and ravelling resistance is dramatically improved along with the increase in the shearing strength.

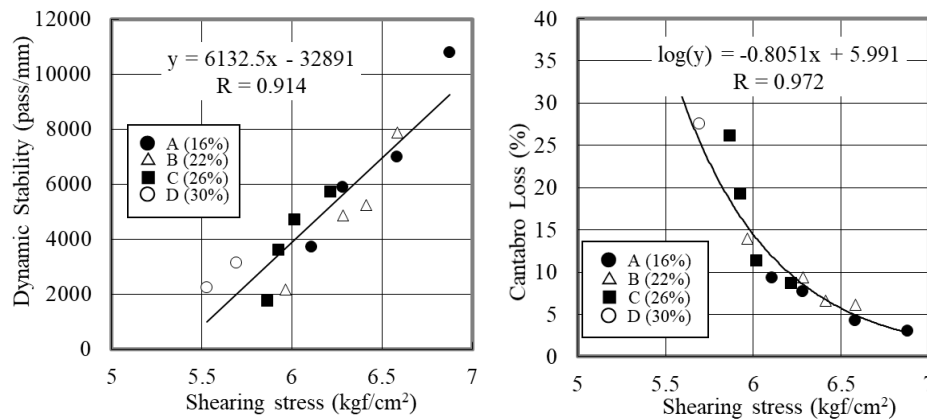


Figure 6. Shearing strength vs Dynamic stability **Figure7.** Shearing strength vs Cantabro

4. Field trial and monitoring results of porous asphalt mixture

4.1. Porous asphalt mixture used for field trial

Porous asphalt pavement based on Japanese technology has been paved on km 188.6 to km 189 on the southbound of North-South Expressway. The 400m stretch was allocated for the trial section in conjunction with the required maintenance by PLUS. Table 4 shows the porous asphalt used for 1st field trial and 2nd field trial. Japanese anti-stripping agent has been employed for these field trials, too.

Table 4. Mix proportion and synthetic gradation of porous asphalt mixture for field trial

		1 st Field trial	2 nd field trial	PLUS standard
Aggregate Mix proportion(%)	10-14 mm	68.8	74.0	
	5-10mm	17.2	10.5	
	0-5 mm	10.0	11.3	
	Mineral Filler	4.0	4.2	
Synthetic gradation(%)	20mm	100	100	100
	14	96.5	95.6	80-100
	10	56.3	50.2	
	5	18.7	17.6	11-31
	2.36	10.5	14.2	10-21
	0.425	5.6	7.7	
	0.3	5.3	7.0	
	0.15	4.9	6.0	
	0.075	4.3	4.9	2-7
Asphalt content (TPS content)		4.7 (12%)	4.7 (12%)	

The gradation for the 1st field trial does not incorporate a gap in the fine aggregate gradation. Rather, the gradation type is continuous. However, the porous asphalt mixture for the 2nd field trial has been improved to include a gap in the aggregate gradation. The properties of the mixture are shown in Table 5. Photographs of construction of field trial are shown in Plate 3, Plate 4 and Plate 5. The paving method is similar to that used in the conventional mixture.

Table 5. Mixture properties just after paving for field trial

Item		1 st field trial	2 nd field trial	PLUS standard (Japanese standard)
Marshall test results	Density (g/cm ³)	1.944	1.963	-
	Air void %	22.2	21.3	20-22
	Connected air void %	18.8	17.2	≥ 13 % ^a
	Marshall stability (kN)	10.31	9.22	-(≥ 3.43) ^b
	Flow value (mm)	2.32	2.34	-
Cantabro loss ratio (%)		20.6	15.5	Max. 20
Permeability coefficient (cm/sec)		0.286	0.237	-(≥ 0.01) ^b
Dynamic stability (pass/mm)		10,138	11,307	-(≥ 3,000) ^b
In-situ permeability (Japan way) (ml/15sec)		1536.1	1521.4	-(≥ 1,000) ^b

Note: ^a Recommendation value, ^b Japanese standard

**Plate 3** Lifting**Plate 4** Rolling**Plate 5** The surface of porous asphalt

4.2. Monitoring results after six months passed

Due to constraints on road occupancy, monitoring was carried out only on the fast lane, and the results are shown in Table 6. Visual observations were performed on the whole area of the field trial. The monitoring of the slow lane will be carried out roughly one year from the construction date. The monitoring situations are shown in Plates 6 to 9.

Table 6 Monitoring results after six months on the fast lane.

Test item		Monitoring results								Standard
Rutting		Rutting is not seen on the whole area of field trial								
Skid resistance	KM	188.65	188.7	188.75	188.8	188.85	188.9	188.95	Average	≧ 55.0 (BPN)
	Value	RHS	LHS	RHS	LHS	RHS	LHS	RHS		
Permeability at site	KM	188.65	188.7	-	188.8	-	188.9	188.95	Average	≧ 1000 /15 sec
	RHS	1503.8	1510.1	-	1547.7	-	1534.5	1493.8		
	LHS	1550.4	1542.4	-	1513.9	-	1502.5	1522.8		
Visual Observation	Cracking	It is not visible in the whole area of the field trial.								
	Ravelling	It is not seen in the whole area of the field trial.								
	Stripping	Surface remains black in colour.								
	Clogging	It is not visible on travelled lane and road shoulder.								

Note: Japanese style on-site permeability tester was used. Measuring time to flow down 400cc water and calculating water volume flowing down for 15 seconds.

**Plate 6** Rutting**Plate 7** Permeability**Plate 8** Full view**Plate 9** Black surface

The porous asphalt mixture used for the field trial remained in excellent condition as expected. The monitoring results after six months proved that the performance of TPS porous asphalt pavement was almost similar to the time when it was first paved six months earlier, while the top surfacings remained black in colour.

5. Conclusion

The porous asphalt pavement tends to deteriorate when subjected to high temperature. That is because the mechanical properties come down along with the increase in temperature. Therefore, the porous asphalt mixture which would be able to endure even in the hot temperature is needed in tropical countries like Malaysia. The key elements which influence the durability and sustainability of the porous asphalt pavement are the asphalt used and the mix proportion of aggregates.

The adequacy of the asphalt used for the porous asphalt can be expressed by the various mechanical properties, like Performance Grade, softening point, viscosity at 60 °C, and others. The PG 82 of performance grade asphalt binder or bitumen with the softening point more than 80 degrees C are preferable. Particularly, the ravelling problem that is a concern in Malaysia could be diminished by using asphalt with the high mechanical property. Furthermore, the selection and adoption of an anti-stripping agent should be deliberated.

The other key element for the porous asphalt pavement is to introduce a gap within the aggregate gradation between 2.36mm and 4.75mmsieve sizes. Whereby, the Open-Gap gradation provides a steady state of stone-to-stone contact and improve the mechanical property of a porous asphalt pavement. Furthermore, it improves the size of pores and the connectivity between the airvoids, which is preferable for the self-cleaning and the sustainability of its function.

6. References

- [1] Nakanishi H 2002 China Study on improvement in durability of function for porous asphalt pavement *Journal of Guangxi Communication Science & Technology* **27** 7-12
- [2] Nakanishi H 2002 Korea Application and experience of special asphalt mixture in Japan *Proc. of the Korea Society of Pavement Engineers Conference* pp 5-57
- [3] Nakanishi H et al 2001 Taiwan Study on improvement in durability of porous asphalt mixture, *Proc. The 11th Conference on Pavement Engineering* pp 634-42
- [4] Nakanishi H Takei S Goto K 2001 Strength generation mechanism for porous asphalt pavement *Proc. The 11th Conference on Pavement Engineering* pp 646-57
- [5] Hamzah M Nakanishi H Mohd Hasan M 2016 Proposed Japanese mix design methodology for porous asphalt using modified binder *Int. Conf. Mairepav 8*
- [6] Hamzah M Nakanishi H 2016 KL Presentation to PLUS in-house seminar on Japanese porous asphalt technology - Lessons from porous asphalt field trial *Int. Conf. GEOTROPIKA Bangkok*
- [7] Nakanishi H Takei S Goto K 1995 Japan Proposal on improvement in functional sustainability of porous asphalt pavement *Road construction* **571** pp 40-53

Acknowledgement

A series of research and trials were attempted for the porous asphalt pavement, and we express our heartfelt gratitude to many individuals and organisations for their understanding and support. We thank PLUS and OPUS for the understanding and appreciating the challenges that we faced and gave us a suitable site and opportunity to carry out the field trial. UEM EDGENTA Berhad through the Infrastructure sector cooperatively supported our activities to develop new porous asphalt pavement in Malaysia. We highly appreciated the cooperation and support for the evaluation tests at the site.