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AIR VOIDS CHARACTERISATION AND PERMEABILITY OF POROUS ASPHALT GRADATIONS USED IN DIFFERENT COUNTRIES

Norhidayah Abdul Hassan, Mohd Zul Hanif Mahmud, Kabiru Abdullahi Ahmad, Mohd Rosli Hainin, Ramadhansyah Putra Jaya and Nordiana Mashros
Faculty of Civil Engineering and Transportation Research Alliance, Universiti Teknologi Malaysia, Skudai, Malaysia
E-Mail: hnorhidayah@utm.my

ABSTRACT

This paper presents the evaluation made on the properties of porous asphalt mixtures practiced in different countries. In order to fully understand the properties of porous asphalt mixtures, investigation should be conducted from different perspectives. Therefore this study was carried out to investigate the air voids properties and functional performance of porous asphalt simultaneously. An image analysis technique was conducted to analyse the air void properties within the gyratory compacted samples captured using a non-destructive scanning technique of X-ray Computed Tomography (CT). The results were then compared to the functional performance in terms of permeability. Four aggregate gradations of porous asphalt used in different countries i.e. Malaysia, Australia, Singapore and the United States were adopted for comparison. From the analysis, Australian mixture was found with the most homogeneous air voids distribution throughout the sample compared to other mixtures. The air void properties investigated have successfully described the air voids formation within the mixtures which reflects the result of permeability. This shows that air voids distribution within the sample plays an important role in determining the effectiveness of water transmission.

Keywords: porous asphalt, durability, permeability, image processing, image analysis, X-ray CT.

INTRODUCTION

Porous asphalt mixture is an open graded gradation that consists of low composition of fine aggregates to allow the mixture to have large quantity of interconnected air voids. These interconnected voids forms capillary channels for the water to flow through and reduce the water runoff from the pavement surface. This shows that the presence of air voids (interconnected and isolated voids) within the mixture is the most significant factor that influences its permeability [1-4]. Moreover, an aggregate gradation is one of the factors that determine the characteristics of the voids formed within the mixture [2]. For porous asphalt mixture, there are various aggregate compositions have been designed by the department of transportation in various countries to fulfil its specific functions [3]. Therefore, this laboratory investigation is an attempt to evaluate different porous asphalt mixtures used in different countries by examining the mixtures' air void properties using imaging technique and correlates with their permeability performance. However, it should be noted that, this study focuses on correlating the air voids characteristics and the permeability rate and no rating was assigned for the mixtures as it is subjected to major performances evaluation.

MATERIALS AND METHODS

Mixture design

In this study, four types of open graded mixtures for porous asphalt mixtures were adopted from various countries i.e. Australia (Australian Asphalt Pavement Association, 2004), Malaysia (Public Works Department, 2008), the United States (ASTM D 7064, 2013) and Singapore specification (Land Transport Authority, 2010) [5-8]. The aggregate gradations and their compositions used are presented in Figure-1 and Table-1.

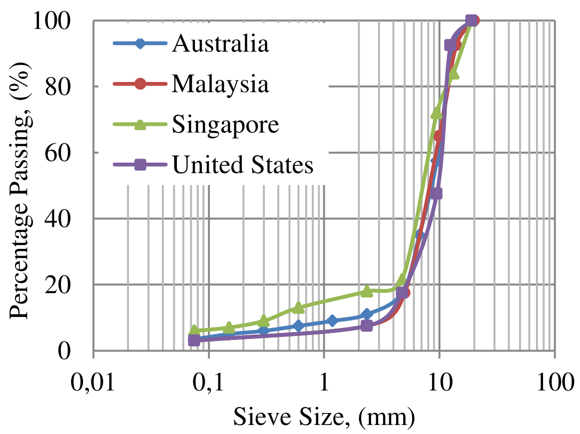

Figure-1. Aggregate gradations for porous asphalt mixtures.

Crushed granite aggregate and performance grade bitumen (PG 76) were used for laboratory sample preparation. A total of 12 specimens were prepared for the evaluation. Details of the sample prepared for each gradation are presented in Table-2. The mixtures were mixed and compacted at 180 °C and 170 °C respectively. The specimen was compacted using Superpave Gyratory Compactor at vertical pressure of 600 kPa with angle of gyration 1.25° and rate of gyration 30 rpm. The samples were compacted to achieve the target dimensions (diameter, 100 mm and target height, 50 mm) with the desired air voids content between 18 to 20%.

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Table-1. Aggregate compositions for different porous asphalt mixtures.

Criteria	**Mixture type**			
	Malaysia	**United States**	**Singapore**	**Australia**
Coarse Aggregates, % (retained 4.75 mm)	83.5	82.5	78.5	82.5
Fine Aggregates, % (passing 4.75 mm)	13.5	14.5	15.5	14.0
Filler, % (passing 75μm)	3.0	3.0	6.0	3.5

Table-2. Porous asphalt mixture design properties.

Mixture type	**NMAS** (mm)	**OBC** (%)	$\mathbf{G_{mb}}$ (g/cm^3)	$\mathbf{G_{mm}}$ (g/cm^3)	**Air voids** (%)
Australia	13.2	5.25	1.971	2.455	19.71
Malaysia	14.0	5.00	1.960	2.447	19.98
Singapore	13.2	4.75	1.965	2.405	18.29
United States	12.5	5.25	1.933	2.412	19.84

Permeability test

The permeability of the porous asphalt mixture was measured using Flexible Wall Permeameter (falling head method) in accordance to ASTM PS 129 at an ambient temperature of 25 °C. Permeability test was used to determine the rate of permeability that represents the effectiveness of water transmission within the pavement layer. The coefficient of permeability, *k* was calculated using Equation. (1) as stated in ASTM PS 129. The parameters used in Equation. (1) are *k* (coefficient of permeability, cm/s), *A* (cross section area of sample, cm^2), *a* (cross section area of standpipe, cm^2), *l* (height of sample, cm), h_1 (initial height of water above the sample, cm), h_2 (height of the water after time, cm), and *t* (time taken for the water to fall from h_1 to h_2, second).

$$k = \frac{al}{At} \ln\left(\frac{h_1}{h_2}\right) \tag{1}$$

Image analysis technique

The air voids properties were analysed using imaging technique where the samples were scanned using X-ray CT (inspeXio smx-225CT).The X-ray CT generates multiple two-dimensional (2D) image slices with the resolutions of approximately 0.106 mm/pixel. The 2D images were rendered to produce 3D image as shown in Figure-2a. The images were captured at the interval of 0.1 mm and processed using imaging software of Image J. Detailed procedures for image processing can be found in Abdul Hassan *et al.* [4, 9]. In this study, the air voids distribution was analysed in horizontal and vertical of the virtual cut sections (refer Figure-2b-c). For horizontal section, the images were analysed for multiple stacks at the interval of 0.1 mm while for vertical section, the images were analysed for eight different orientations with the interval degree of orientation of 22.5°(from 360°).The air voids were analysed in terms of the voids content, number of voids and voids size (area). These basic parameters can be used to describe the air voids connectivity which determines the permeability rate of the water within the sample. Samples with the same air voids content show higher air voids connectivity with less number of air voids counted and large voids size compared to those with high number of voids and small voids size. It is expected that samples with greater air voids connectivity have greater ability to transmit water from the pavement surface.

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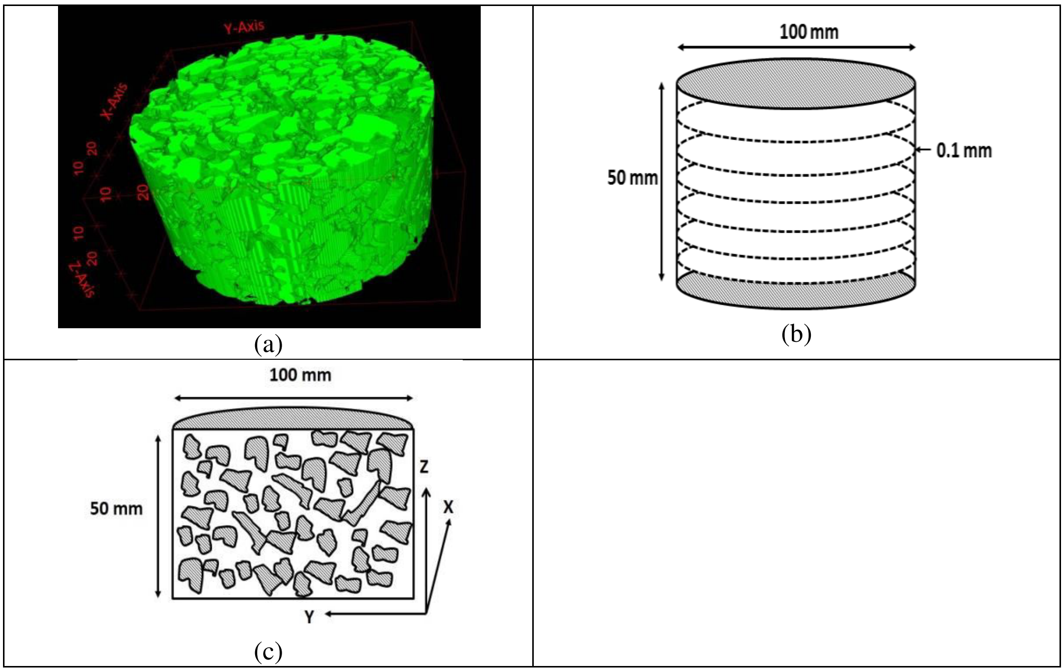

Figure-2. Image processing (a) 3D image (b) Horizontal section (c) Vertical section.

RESULTS AND DISCUSSIONS

Permeability

Figure-3 shows the permeability rate for the different porous asphalt gradation. The result shows that the Australian gradation has the highest rate of permeability followed by the United States, Malaysia and Singapore. This proves that even though the mixtures were designed to achieve almost similar air voids content but the result of permeability seems inconsistent among the mixtures. Based on this result, it is expected that different aggregate composition which refer to the fine and coarse aggregates used has led to the different formation of aggregate structure thus influence the characteristics of the air voids within the compacted mixture. Basically, coarse aggregate mixtures produce better rate of permeability. Singapore mixture with finer aggregate compositions gives the lowest permeability compared to other mixtures. This is due to the fines that fill up the gap and reduce the interconnected voids within the mixture. Besides, it could be also attributed to the low air voids content as a result of the difficulty in achieving higher voids content during compaction.

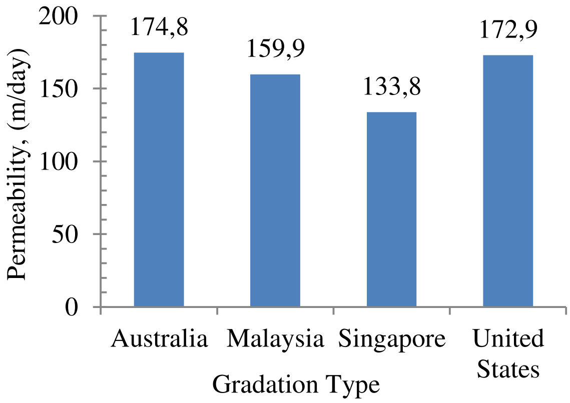

Figure-3. Permeability of porous asphalt with different gradations.

Air voids properties distribution

Figure-3 shows the detailed air voids properties distribution analysed for horizontal cross section. Table-3 presents the mean and standard deviation of the void content and void number analysed for horizontal and vertical sections. A few image slices at the top and bottom of the sample were excluded from the analysis to avoid the effect of material dislodging at the edge of the sample which could cause high variation in the air voids content. High air voids content at the first few slices on the top and bottom of the sample suggests that these sections were not significantly impacted by the compaction process. Height ratio was taken as a ratio of the referred height of the image slices to the total sample height where 0 and 1 represent the top and bottom sections of the sample respectively. Overall, based on Figure-3, it can be seen that, higher air void content were measured at the bottom section compared to the top section particularly for Australian, Malaysian and the United States mixtures.

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While for Singaporean mixture, less air voids was observed at the bottom section which could be due to the settlement of fine particles during compaction and thoroughly fill the void spaces. For vertical section analysis, mixtures for the United States, Malaysia and Australia consist of higher air voids content compared to Singapore (Table-3). However among the three mixtures (United States, Malaysia and Australia), the Malaysian mixture has the highest number of voids which describe the mixture contain less interconnected void spaces for the water to flow through. This in line with the aforementioned result where both Australia and the United States have high permeability rate as a result of greater interconnected voids presence in the mixture in comparison to other mixtures. This suggests that the porous asphalt mixture should be designed not only to have high air void content but to promote the voids connectivity to a large extent.

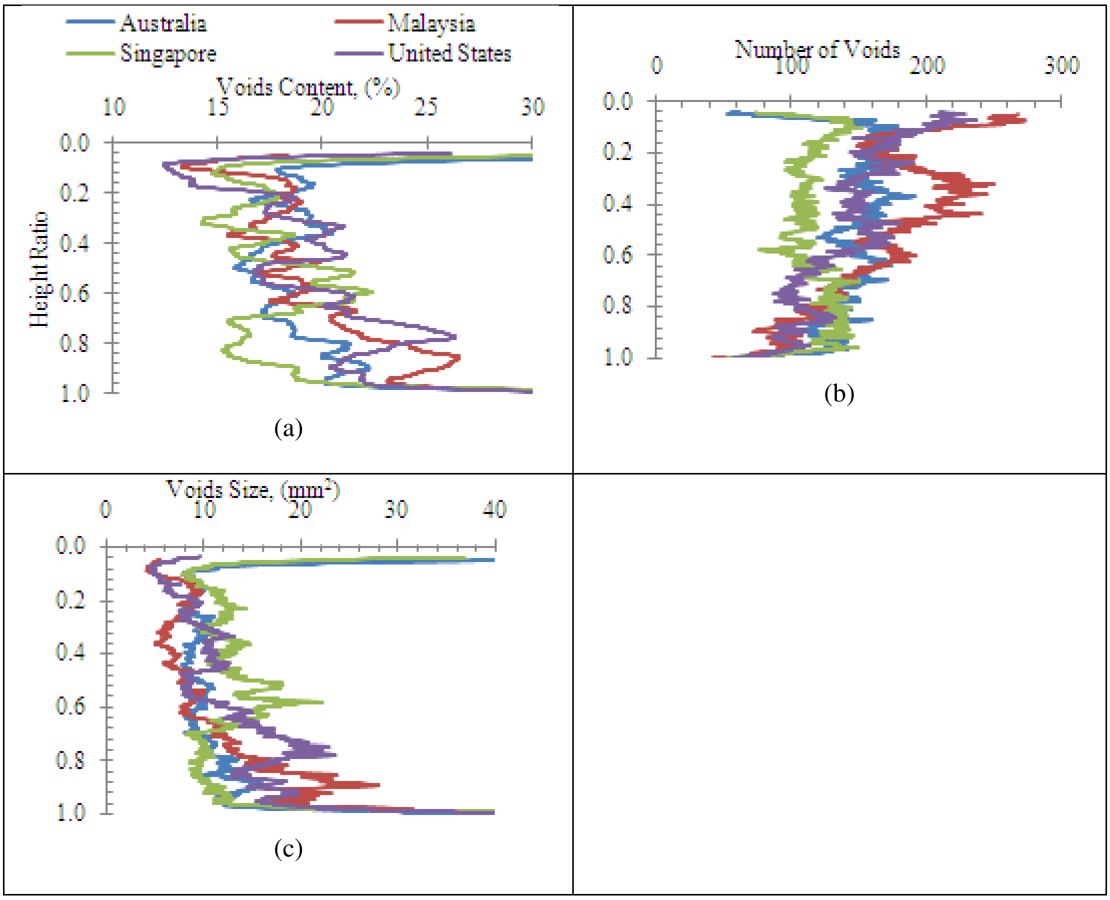

Figure-4. (a) Voids content (b) Number of voids (c) Voids size for horizontal section.

Table-3. Mean and standard deviation voids properties analysed for horizontal and vertical sections

Section of analysis	Air voids properties	Mixture types			
		Australia	Malaysia	Singapore	United States
Horizontal	Mean Voids Content (%)	19.71	19.98	18.29	19.84
	SD Voids Content	4.28	3.64	4.03	5.63
	Mean Number of Voids	145	164	117	139
	SD Number of Voids	22	48	16	35
Vertical	Mean Voids Content (%)	18.71	22.35	15.70	22.58
	SD Voids Content	1.39	1.49	1.21	2.23
	Mean Number of Voids	118	140	92	124
	SD Number of Voids	68	72	60	110

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CONCLUSIONS

From the result, it can be concluded that samples for Singaporean gradation are less permeable compared to other gradation types. An excessive amount of fines in the Singaporean gradation has created large mastic regions to fill up the voids spaces which reduce the voids size and voids connectivity. This suggests that the fines content should be low enough to avoid the closure of void spaces. Coarser aggregate gradations i.e. Australian, Malaysian and the United States have high permeability rate as a result of high interconnected voids within the mixtures. Even though the Malaysian gradation contains high composition of coarse aggregate, but due to low voids content and less interconnected voids formed at the bottom section and the surface of the sample respectively, have increased the duration of drainability compared to Australian and the United States gradations. This indicates that the combined amounts of coarse and fine aggregates should be optimised to promote interconnectivity within the air voids system. In addition, the air voids characteristics analysed in vertical and horizontal cut sections are able to describe the influence of air voids formation within the mixture on the permeability rate of porous asphalt.

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