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Microstructural investigation on air void properties of porous asphalt using virtual cut section

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HIGHLIGHTS

- A research framework for virtual cut section analysis on porous asphalt mixture.
- Polar diagram is used to complement the conventional cross-section analysis.
- Air voids shape in porous asphalt are predominantly elongated.
- Recommend F_{max} parameter in determining air void size of porous asphalt.

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ABSTRACT

The microstructure properties of asphalt mixtures reflect the structural and functional performance of asphalt mixtures. Thus, numerous imaging methods are developed including destructive and non-destructive methods to uncover the internal structure properties of asphalt mixtures. However, accurate analysis of internal microstructure properties is challenging. This study used a non-destructive method employing virtual cut section (imaging technique) to analyze the air void properties of laboratory-fabricated porous asphalt. Conventionally, the investigation of internal structure properties particularly on vertical section requires the sample to be cut (destructive method) into several sections. This method causes defects to the sample and limits the amount of data that can be extracted from the image. The imaging technique designed in this study provides comprehensive understanding of the distribution and properties of air voids from different angles within the compacted sample of porous asphalt. The void properties in porous asphalt should be assessed accurately to ensure effectiveness of water permutation through the porous structure and acoustic function of the mixture. The compacted samples were X-rayed and virtually analyzed into various cut sections. The void properties were characterized in terms of the content, number, shape, and size of voids. Results indicate that air voids within the porous asphalt are homogeneously distributed with an elongated shape; this characteristic indicates high void connectivity. The vertical cross-section analysis justifies the characteristics of air voids in the conventional analysis of horizontal cross section.

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1. Introduction

Porous asphalt is typically used as a wearing course that allows water to permeate into the porous surface. The process is possible because porous asphalt is designed on the basis of open graded gradation [1–3]. Open graded gradation consists of a large quantity of coarse aggregates and a small quantity of fine aggregates [4–6]. This method allows for the mobility of aggregates during compaction, thereby resulting in high formation of interconnected voids within the layer. Air void content (interconnected voids) in porous asphalt mixture is the main parameter that influences the structural and functional performance as well as service life [7–10]. The common parameters used to describe the connectivity of air voids are the content, number, shape, and size of voids [1,11–15]. This pavement type needs to maintain sufficient amount of air void content to ensure effective permutation of the pavement and prolong the benefits of the structure to the road users. Therefore, a detailed analysis on the air void formation within the porous asphalt is significant to enhance understanding of its functional performance.

The content or properties of air voids can be quantified using various methods, including vacuum method, dimensional analysis, water displacement concept, and imaging technique [16–23].

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Numerous efforts have been made in the recent years to investigate the microstructure properties (particularly air voids) of asphalt mixture using imaging techniques [9,24–27]. Using these techniques, air voids can be characterized either in a destructive or a non-destructive manner. Current non-destructive imaging technique, i.e., X-ray computed tomography (CT) scanning, is preferred as the sample can be used for subsequent testing after the scanning process. Another option to investigate air void properties is through destructive methods. A destructive method for imaging the internal structure properties of asphalt mixture was developed in early 1990s [28]. Although destructive imaging techniques are cost effective and do not require sophisticated equipment (digital camera) to obtain the cross-sectional view of the sample, the process of cutting requires the use of a special cutter, thereby limiting the number of permissible cross sections or image slices to be obtained. Furthermore, these techniques cause misleading analysis on the properties and distributions of air voids. The cutting process triggers air void distortion in addition to causing severe aggregate loss especially at the edge of the slices. As porous asphalt is designed to possess low structural strength and limited amount of fine aggregates, the cutting process will result in deformed samples and excessive aggregate loss. Thus, void properties captured using destructive methods in terms of quantity, size, and shape may differ from those obtained using non-destructive methods.

Non-destructive techniques allow the internal structures of the asphalt samples to be analyzed without cutting or disrupting the sample [5,29,30]. Such techniques provide detail overview of the internal structure as the images can be captured throughout the samples and analyzed from various angles [13,31,32]. However, considering only the horizontal cross section of the X-ray CT images for the analysis of air void distribution cannot fully describe the exact void connectivity as the water flows from the top to the bottom section of the porous asphalt. Voids within the porous asphalt layer act as a series of micropipes that connect to one another to channel the water away from the surface [5,14]. Therefore, the horizontal cut section of the captured images will only provide the transverse section of the pipes. Compared with the vertical cross section, the horizontal one will provide the longitudinal section of the pipes to reflect the void connectivity. Accordingly, better views of the hydraulic conductivity from top to bottom within the porous asphalt layer can be provided.

In this study, air void properties of porous asphalt were non-destructively characterized using the virtual cut section (vertical cross-sectional image) of X-ray CT images. A complete procedure of the image analysis technique was introduced including image acquisition, image processing, and image analysis. Although this study applies the procedure on porous asphalt, the concept is relevant to any potential materials. The void analysis covers a few basic parameters (i.e., content, number, size, and shape) measured from the images in horizontal and vertical cut sections and relates to the air void connectivity.

2. Material and methods

2.1. Materials and sample preparation

Laboratory-fabricated samples of porous asphalt mixture were prepared for X-ray CT scanning. The samples were prepared in accordance to Malaysian road specifications [33]. The samples were compacted using Superpave gyratory compactor with 50 gyrations in accordance with ASTM D 7064 specification [34]. Superpave gyratory compactor is able to simulate the actual field conditions [35]. Furthermore, the Superpave gyratory compactor method can produce lower coarse aggregate breakdown [36]. Each of these samples was compacted at the vertical pressure of 600 kPa and gyration rate of 30 rpm to achieve the desired air void content of approximately 20%. Due to the limitations of the X-ray scanner (inspeXio smx-225 CT) in capturing the microstructure properties of the asphalt mixture at large scale, the samples were prepared in a 100 mm diameter mold with thickness of 50 mm. The granite type aggregates were sieved to obtain an Australian open graded gradation enveloped with the nominal maximum aggregate size of 13.2 mm as shown in Fig. 1 [37]. Polymer modified bitumen (PG 76) was added to the sample as a binder at designed bitumen content of 5.25% (obtained from mixture design). The samples were mixed at 195 °C first and then compacted at 175 °C. The properties of the materials used are provided in Table 1.

2.2. Microstructure investigation

This section emphasizes on the characterization of air void properties of porous asphalt. Air voids play an important role in influencing the permeability, acoustic characteristics, and frictional properties of porous asphalt. Thus, accurate data of air void properties should be obtained because they reflect the performance of porous asphalt. The porous asphalt samples were scanned using X-ray CT scanner to capture the horizontal images. The horizontal images were then processed and analyzed using the ImageJ software. Fig. 2 shows the detailed framework of the study. The framework was divided into two main stages. Stage I focuses on image processing wherein several imaging procedures were performed on the images, such as cropping, image scaling, and quality enhancement. Stage II involves the development of three-dimensional (3D) images from horizontal images using Volume Viewer. The vertical cut sections were obtained from the 3D images and then stacked for subsequent analysis. The air voids were then thresholded, analyzed, and verified to the experimental value. Details on the image acquisition and processing methods are provided in the following sections.

2.2.1. X-ray CT scan and image acquisitions

This study used a non-destructive image acquisition technique to capture the cross-sectional view of porous asphalt. The samples were scanned using X-ray CT scanner (inspeXio smx-225 CT) with the maximum output voltage of 225 kV. This scanner used the cone beam method to reconstruct 3D images as shown in Fig. 3a. During the scanning process, the sample was rotated 360° at an image slice of 0.1 mm thickness. The scanning parameter of the X-ray CT scanner was set to capture 1200 views with the average count of 15 times at each angle of rotation. By increasing the number of views and average count, the data obtained from the scanning procedure would be accurate (detailed information) but would increase the scanning duration. These image slices were combined into a stack at the interval of approximately 0.1 mm as illustrated in Fig. 3b. The output voltage used to scan the sample was selected to be 190 kV with the ampere of 100 μA for good-quality images. The resolution obtained from the X-ray CT scan was 0.106 mm/pixel. These images were saved in Tagged Image File Format (TIFF) as 16 bits. TIFF digital file format was selected to avoid data compression and degraded image quality during image conversion and processing.

2.2.2. Image enhancement

Considerable imaging software is available for image processing and image analysis. In this study, the images were processed using ImageJ. ImageJ is an open source imaging software initially designed for medical purposes. TIFF images were converted into 8 bits for further analysis. Notably, 8-bit image comprises of 256 gray levels of the dark regions (low-density material, i.e., air voids) and the brightest regions (high-density material, i.e., aggregate). Images obtained from the X-ray scanning were analyzed as stack formation. A few image slices at the top and bottom sections were excluded from the analysis due to image distortion during the scanning process. These images were cropped in accordance with the exact dimension of the sample (100 mm diameter and 50 mm thickness). Images obtained from X-ray CT scanning are often not in perfect conditions and thus require image enhancement and correction owing to excessive noise, poor contrast, imbalance color representation, and disproportional illumination [13,38,39]. Thus, image treatments using several mathematical functions, such as contrast enhancement and noise elimination (Gaussian filter or Median filter), were conducted to improve the appearance of the image as shown in Fig. 4. This procedure was conducted to visualize the region of interest for accurate image analysis.

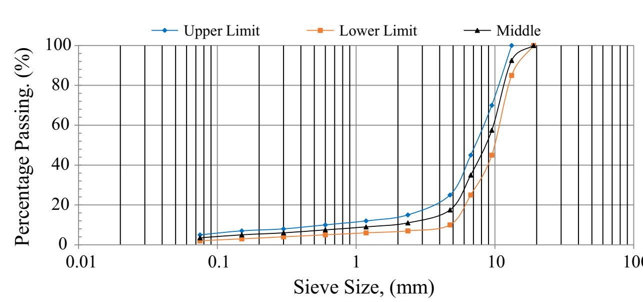

Fig. 1. Australian open graded gradation for porous asphalt mixture, (AAPA, 2004).

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