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Accurate detection and evaluation method for aggregate distribution uniformity of asphalt pavement

Ke Zhang [a,*], Zhengqi Zhang [b], Yaofei Luo [b], Siyuan Huang [a]

[a] College of Information Engineering, Fuyang Normal University, Anhui, Fuyang 236041, China
[b] Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang'an University, Xi'an, Shaanxi 710064, China

HIGHLIGHTS

- The pavement surface image acquisition device (PSIAD) is developed.
- The macro-structure width of pavement surface is calculated.
- An adaptive threshold segmentation algorithm is proposed for CT image of sample.
- The horizontal and vertical uniformity coefficients are proposed.

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ABSTRACT

The construction uniformity of asphalt mixture has been widely evaluated, but rarely focused on the surface and internal structure of asphalt pavement simultaneously. To evaluate the aggregate distribution uniformity of asphalt pavement effectively, firstly, the pavement surface image acquisition device (PSIAD) was developed to collect the texture image on the surface of asphalt pavement. Then the sectional images of pavement core samples were acquired by industrial computed tomography (ICT) equipment. Finally, the aggregate distribution uniformity of asphalt pavement was evaluated from pavement surface and internal structure by MATLAB image processing technology. According to the results, the PSIAD based on the camera with charge coupled device (CCD) and shading black-box can avoid the information error of original pavement surface texture image, which is caused by the change of light conditions. The macro-texture width index K can substitute the texture depth to evaluate the aggregate distribution uniformity on the surface of asphalt pavement, and the aggregate distribution uniformity evaluation criterion of pavement surface based on K value was established. The improved iterative threshold segmentation algorithm based on ring-shaped partition can segment coarse aggregate particles on CT image effectively. D_H is the variation coefficient of coarse aggregate area ratio in four regions on the same sectional image. D_{V1} is the variation coefficient of average coarse aggregate area ratio on different sectional images in one core sample. D_{V2} is the variation coefficient of the ratio of aggregate area with different equivalent diameter on different sectional images in one core sample. The coarse aggregate distribution evaluation indexes of D_H, D_{V1} and D_{V2} can reflect the distribution uniformity of aggregate inside the asphalt pavement.

1. Introduction

The construction uniformity significantly affects the performance of asphalt pavement [1,2]. Li et al. [3] found that the water stability of asphalt mixture reduces significantly with the increasing of coarse aggregate segregation degree. Fine aggregate segregation is adverse to high temperature stability and anti-skid performance of asphalt pavement. Khedaywi et al. [4,5] found that the indirect tensile strength, rutting resistance and water sensitivity of asphalt mixture decline obviously because of the gradation segregation. Peng and Zheng et al. [6,7] studied the effect of homogeneity on mechanical and fatigue properties of asphalt mixture. It was found that the mixture with good homogeneity has a small variation in mechanical properties and the fatigue life of inhomogeneous mixture is greatly reduced. Azari et al. [8,9] studied the influence of homogeneity on the performance of asphalt mixtures.

* Corresponding author.
E-mail addresses: zhangke_365@126.com (K. Zhang), z_zhengqi@126.com (Z. Zhang), hpulyf@163.com (Y. Luo), huanghh1025@126.com (S. Huang).

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It was found that the shear modulus of inhomogeneous asphalt mixture increase and the rutting resistance and fatigue resistance decrease significantly. Thyagarajan et al. [10] investigated the influence of compaction factors on the air void distribution and its manifestation on the mechanical response. Airey et al. [11] studied the influence of laboratory (gyratory, vibratory and slab-roller) and field compaction on internal structure and mechanical properties, and found that slab-compacted specimens tend to mimic field compaction better than gyratory and vibratory compaction. Hassan et al. [12] studied the effect of different compaction methods on the orientation and distribution of aggregates in asphalt mixtures, and fund that aggregates near the edge of a specimen tend to form circumferential alignment while the aggregates near the center of the specimen are randomly oriented.

Aggregate distribution uniformity is an important aspect of construction uniformity for asphalt pavement. The aggregate distribution reflects the quantity and location of various aggregates in asphalt mixture or cement concrete [13]. So the distribution uniformity of aggregates is an important factor influencing the mechanical properties of asphalt pavement. Aggregate gradation reflects the gradation composition and gradation difference of various aggregates in asphalt mixture, but cannot reflect the spatial arrangement of aggregates inside the asphalt pavement. Compared with the traditional proportion of aggregate composition, the distribution characteristics of aggregate particles in core sample can be used to characterize the distribution uniformity of asphalt mixture more specifically after the completion of construction.

The effective segmentation of aggregate on the two-dimensional image of asphalt mixture can be realized by using the digital image processing technology [14]. Many scholars at home and abroad have attempted to adopt aggregate distribution based on digital image processing technology to evaluate the construction uniformity of asphalt mixture. Pan et al. [15] selected the static moment of various specifications of aggregates on X axis and Y axis to evaluate the segregation degree of asphalt mixture quantitatively. Wu et al. [16] found that the variation coefficient of aggregate area ratio (uniformity index) can be used to evaluate the segregation of asphalt mixture. Chen et al. [17] quantitatively evaluated the segregation of aggregate particles by using the moment of inertia of aggregate on cross-section of asphalt mixture. Peng et al. [18] studied from the distribution quantity and distribution location of aggregate, and proposed the area ratio coefficient k and uniformity index D to evaluate the segregation of asphalt mixture. Meanwhile, Peng et al. [19] found that the fractal dimension of aggregate gradation based on the fractal theory can be used to evaluate the segregation degree of asphalt mixture quantitatively. Li et al. [20] evaluated the vertical segregation of aggregate in asphalt mixture by using the indexes of non-uniformity coefficient and vertical variation coefficient. Peng et al. [21,22] proposed the distribution quantity and distribution location of aggregate which were calculated by statistical analysis method to evaluate the segregation of asphalt mixture, and analyzed the influence factors such as aggregate gradation, asphalt content, compaction work and test temperatures. Bessa et al. [23] analyzed the contacting point, particle orientation and aggregate segregation in asphalt mixtures by digital image processing technique. Bruno et al. [24] obtained the gradation information of asphalt mixture by using a variety of digital image segmentation techniques, and proposed the method to evaluate the aggregate gradation of mixture. Wu et al. [25] used digital image technology to analyze aggregate distribution on the slice of asphalt mixture specimens. The variation coefficient of aggregate area ratio was also proposed as an index to evaluate the uniformity of asphalt mixture. Liu et al. [26] used the improved OTSU to process the X-ray computed tomography images, and evaluated the homogeneity of asphalt concrete with the fractal theory. Hu et al. [27] analyzed the computed tomography (CT) images of the specimen by image processing technology to evaluate the homogeneity of asphalt mixture during lab compaction. Hunter et al. [28] selected image analysis techniques to quantitatively analyze the orientation and distribution information of aggregates on horizontal planes within asphalt mixture specimens. Mora et al. [29] attempted to apply to analyze the particle size distribution of coarse aggregate using the digital image processing (DIP) technique. Erdem [30] selected fractal analysis and 3D X-ray computed tomography accompanied by digital image analysis technique to quantitatively evaluate the segregation resistance in normal self-compacting concrete and self-compacting lightweight concrete. The above studies have promoted the application of digital image processing technology in the quality control of asphalt pavement construction.

At present, lots of indexes of aggregate distribution based on digital image processing technology were put forward. But there are not reliable grading standards in these evaluation indexes, and the difference of asphalt pavement segregation cannot be distinguished clearly. Meanwhile, because of the complexity of aggregate segregation problem, how to evaluate the segregation degree of asphalt pavement quickly, objectively and effectively is still a hotspot. In addition, the core samples were drilled in surface segregation areas, and found that the aggregate segregation inside the pavement does not occur. The aggregate segregation of pavement surface is not consistent with internal structure [31]. In past studies, the aggregate segregation of asphalt pavement has been widely evaluated by the index such as texture depth of pavement surface [32–34]. Pavement surface and internal structure are both organic parts of asphalt pavement. According to the aggregate distribution of pavement surface and internal structure, the construction uniformity of asphalt pavement can be evaluated more rationally.

Considering of the surface and internal structure of asphalt pavement in this paper, the aggregate distribution was analyzed based on digital image processing technology. Firstly, the pavement surface image acquisition device (PSIAD) was developed to ensure good imaging results of pavement texture and the consistency of image collection. Then, the texture image of asphalt pavement surface was captured by PSIAD, and the internal image of pavement core sample was obtained by the industrial computed tomography (ICT). Next, the images of pavement surface and core sample were processed and analyzed by MATLAB software. The evaluation indexes of aggregate distribution uniformity of asphalt pavement surface and internal structure were put forward. Finally, relying on the middle layer of Tong-Xun expressway, the aggregate distribution uniformity of asphalt pavement was evaluated from pavement surface and internal structure. The research results can provide some references for the detection and evaluation of aggregate distribution uniformity for asphalt pavement.

2. Image acquisitions of pavement surface and internal structure

2.1. Image acquisition of asphalt pavement surface

The homogeneity of the image is critical to digital image acquisition. All the images of different regions on asphalt pavement that need to be contrasted should ensure the same resolution and the uniformity of illumination. Obviously, it is difficult to ensure the same light condition when the image collected by ordinary photographic method directly on asphalt pavement. Therefore, in order to avoid or reduce the error of original images caused by the light conditions on asphalt pavement, it is necessary to standardize the light condition and operation process of image acquisition. In this