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Research on the Evaluation Method of Asphalt Mixture Uniformity Based on Shape-Centre Method

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Abstract. In order to control the quality of the project and reduce the impact of asphalt pavement segregation on the early road service life, this paper investigates the asphalt mix paving uniformity. First of all, based on the theory of form-centered method, the article proposes an evaluation method using weighted form-centered distance coefficient of variation to evaluate the uniformity of asphalt mixture. Then, a series of operations such as preprocessing and image segmentation were performed based on digital image technology on the image data collected from the pavement construction site, and the data calculation results of HT, an evaluation index of asphalt mixture uniformity, were obtained. Finally, the construction depth ratio evaluation index was corrected, and the link between the asphalt mixture paving uniformity evaluation index HT and the construction depth correction value XTD was studied based on the field test and correlation analysis. The results surface, using image processing method and form-centered evaluation theory to obtain the weighted form-centered coefficient of variation HT and the corrected value of constructive depth have a significant correlation, when the coefficient of variation of uniformity HT is in the range of 0.307~2.143, it can be considered that the asphalt mixture in this area does not segregate, and the ranges of mild segregation and moderate segregation are 2.1431~4.026 and 4.026~6.460, respectively. When the weighted form-center distance coefficient of variation HT is greater than 6.460, it can be considered that the asphalt mixture in the detection area has produced heavy segregation; this study is of great significance for ensuring road construction quality and improving pavement construction technology.

Keywords: Asphalt Pavement; Uniformity; Digital Image Technology.

1. Introduction

Asphalt mixture in the preparation, production, transportation and paving and other aspects of the phenomenon of uneven coarse and fine aggregates for the gradation segregation, the quality of road asphalt mixture paving directly affects the safety and performance of the pavement [1-4]. Coarse aggregate concentrated places with large voids, produce water damage fine aggregate concentrated places, easy to produce shear deformation. Therefore, detecting segregation of asphalt mixtures is important to improve the overall service life of roads.

Most of the current quality control of pavements still uses traditional methods such as core drilling and sand laying to test the quality of pavements. The National Transportation Research Board of the United States in the NCHRP 441 report [5], the asphalt pavement segregation is defined as aggregate-asphalt segregation, temperature segregation and gradation segregation of three types, and proposed the use of the sanding method to measure the surface structure depth ratio. Chun, S et al.[6] selected four asphalt pavement sections with different segregation severities, and used the Dominant Aggregate Size Range and DASR porosity (correlated with rutting performance) to analyze the impact of segregation. The findings revealed that: segregation causes deviations in the coarse aggregate portion of the mixture gradation, reduces asphalt content, and leads to air voids exceeding the 10% threshold; it also damages the coarse aggregate interlocking structure and significantly increases DASR porosity. Liu Jiahui et al. [7-10] proposed the particle-area ratio as an

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evaluation index for the distribution state of coarse aggregates on the cross-section, and verified the feasibility of this index for assessing the homogeneity of asphalt mixture specimens. Most of the aforementioned testing methods characterize the overall construction quality based on local detection results, leading to significant lag and limitations in the collected data [11-13]. Therefore, developing a rapid detection method for the uniformity of asphalt pavement construction quality is of great significance for ensuring construction process quality and providing real-time evaluation and feedback for on-site operators.

Based on digital image technology and morphological center theory, this paper establishes the evaluation index and model for the paving surface uniformity of conventional asphalt mixtures. Through the combined strategy of on-site sand paving test and image method, it studies the real-time feasibility of evaluating the paving surface uniformity of asphalt mixtures based on the weighted morphological center method. Finally, it establishes the evaluation standard for asphalt mixture uniformity based on the morphological center method, providing technical support for the control of construction quality uniformity and long-term durability of asphalt pavement structures.

2. Models and Principles

2.1 Theory and Assumptions of Asphalt Mixture Uniformity Evaluation

The asphalt mixture is a multi-component composite material, and under homogeneous conditions, various components will be uniformly distributed inside the asphalt mastic. Figure 1 is a schematic diagram of asphalt and aggregates.If the asphalt mixture is homogeneous, the centroid of each aggregate grade within any cross-section should coincide with the geometric center of that cross-section. In Figure 2 (the aggregate cross-section defined by the shape-center method), the white dots represent aggregates, the black area represents asphalt mortar distribution, and the intersection of the double-arrow axes is the geometric center of the cross-section; ideally, the center of gravity of the mixture specimen should lie at this center. In actual engineering, due to aggregate shape/size and construction conditions, the centroid of a given aggregate grade often deviates from the geometric center. When this deviation exceeds a specified limit, the asphalt mixture can be deemed segregated.

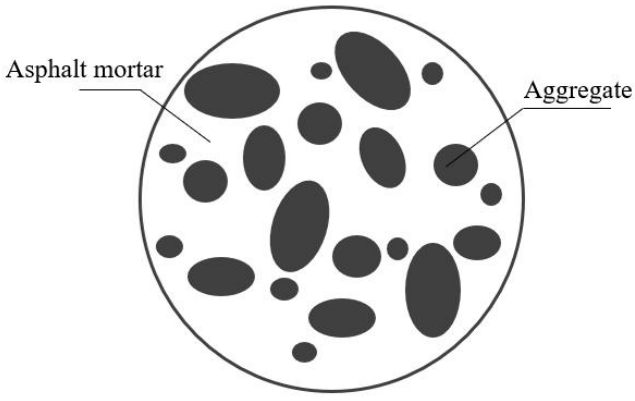
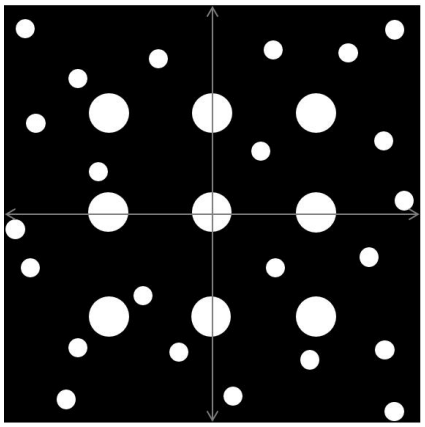


Fig.1 Simplified model of asphalt mixture image


Fig.2 Asphalt mixture image

Considering the significant inhomogeneity of the actual shape and size of aggregates, to improve the statistical efficiency and accuracy of pavement aggregate particles, it is necessary to simplify the experimental research model. This paper puts forward the following assumptions for the asphalt mixture model:

(1) The particle shape of each grade of aggregate is round, and the size of each particle size aggregate is exactly equal in size.

(2) The density of each grade of aggregate is the same.

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2.2 Establishment of Asphalt Mixture Uniformity Evaluation Model

In fact, as a multi-component composite material, the surface characteristics of asphalt mixture are complex and irregular, affected by multiple factors such as aggregate gradation, asphalt mortar distribution, and construction technology. To achieve quantitative characterization of mixture uniformity, this paper introduces the coefficient of variation, a statistical indicator, and establishes a quantitative calculation model. With the ratio of the standard deviation of the weighted centroid of aggregates in each cross-sectional image to the mean value of the weighted centroid of aggregates in the entire set of images under the ideal homogeneous state as the core calculation basis, this model can accurately reflect the uniformity of aggregate distribution during asphalt mixture paving. The specific calculation method is as follows:

The center of gravity of each grade of aggregate in the asphalt mixture cross-section is first calculated from Eq. (1). Where $\overline{x_i}$ and $\overline{y_i}$ are the mean values of the coordinates of the center of gravity of the ith aggregate; N_i is the total number of particles in the image of the i-th aggregate grade; x_{in} and y_{in} are the two-dimensional coordinate of the n-th particle in the image of the i-th aggregate grade.

$$\overline{x_i} = \sum_{n=1}^{N_i} \frac{x_{in}}{N_i},\ \overline{y_i} = \sum_{n=1}^{N_i} \frac{y_{in}}{N_i} \tag{1}$$

The distance between the form center and the geometric center of gravity of each grade of aggregate is obtained by calculating from the distance between two points formula. D_i represents the eccentricity distance between the form center and the center of gravity of the i-th aggregate grade.

$$D_i = \sqrt{(\overline{x_i} - x_0)^2 + (\overline{y_i} - y_0)^2} \tag{2}$$

Given that an asphalt mixture comprises i distinct aggregate grades, a holistic consideration of the distribution pattern of each grade across the full cross-sectional image is essential for evaluating the mixture's cross-sectional uniformity. In this paper, the aggregate area ratio (K_i) is thus adopted as the quantitative index to denote the distribution coefficient of each aggregate grade in the image.

$$K_i = \frac{\sum_{n=1}^{n_i} \mathrm{S_{in}}}{S}, S_i = \sum_{n=1}^{n_i} \mathrm{S_{in}}, S = \sum_{i=1}^{i} S_i \tag{3}$$

Where S_i denotes the pixel area sum of the ith aggregate; S denotes the pixel area sum of all aggregate pixels of each image; and $\mathrm{S_{in}}$ denotes the pixel area of the nth particle in the ith aggregate.

The distribution coefficient K_i is used to weight the form-centered drama and sum up to get the weighted value Ht_i of each aggregate cross-section and the weighted form-centered distance Ht of the whole cross-section, and finally, the evaluation index of each asphalt mixture image — the coefficient of variation of weighted centroid distance(HT)—is obtained, the size of which reflects the current asphalt paving mixture Its value reflects the current homogeneity condition of the paved asphalt mixture.

$$Ht_i = K_i \times D_i \times 100\%,\ Ht = \sum_{i=1}^{i} Ht_i \tag{4}$$

$$HT = \frac{\sqrt{\frac{1}{\mathrm{k}} \sum_{i}^{k} \left(Ht_i - Ht^{\mathrm{ideal}} \right)^2}}{Ht^{\mathrm{ideal}}} \tag{5}$$

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Where: Ht^{ideal} represents the mean value of the weighted centroid distance of the asphalt mixture in the image in the ideal state; Ht_i represents the sum of the weighted centroid distances of the asphalt mixture in the current image.

2.3 Parameter Corrections

It is found that the segregation degree of asphalt mixture does not always show a direct linear correlation with the surface texture depth, and the presence of fine aggregates will interfere with the evaluation results of the actual segregation state of the pavement. When segregation occurs in fine aggregates, the actual gradation of the mixture sampled on site deviates significantly from the designed gradation, and the corresponding coefficient of variation of weighted centroid distance is always greater than 0, which is inconsistent with the evaluation principle of the sand patch method. For this reason, we adopt Formula (6) to revise the original calculation formula of the texture depth ratio.

$$XTD = \frac{\sqrt{(TD - TDD)^2 + TDD}}{TDD} \tag{6}$$

3. Results and Analysis

The study was conducted on the surface of unrolled AC-20 asphalt mixes after paving. Image acquisition parameters: the actual size of the captured image is set to 45.5cmx45.5cm, the height of the camera acquisition is 50cm, The aggregate is divided into three classes, i.e., i value = 3. the shooting time is between 13:00-15:00 pm, the resolution is 3456 x 3456 pixels, and the storage format of the photo is .jpg format. After the image acquisition is completed to mark the acquisition area, using the sand paving method to measure the target area of the construction depth, and subsequently, MATLAB software was utilized to conduct real-time processing on the asphalt mixture paving images collected on site, and a summary table of mixture uniformity evaluation indexes under the specified height was finally obtained (Table 1).

Table 1 Evaluation results of AC-20 asphalt mixture uniformity

NUMBER	XTD	HT	NUMBER	XTD	HT
1	1.108	1.86	10	1.217	2.467
2	1.195	2.347	11	1.357	3.193
3	1.45	3.5	12	1.021	1.507
4	1.141	2.227	13	1.35	3.1
5	1.108	1.953	14	1.108	1.927
6	1.233	2.487	15	1.119	2.067
7	1.228	2.493	16	1.217	2.433
8	1.021	1.553	17	1.032	1.56
9	1.326	2.94	18	1.032	1.673

A linear fit of the asphalt paving surface calculation results HT calculated by image processing to the constructional depth corrections yielded a fitted plot with 95% confidence bands, 95% prediction bands (Fig. 3) and residual results of the data fitting (Fig. 4) as well as a table of the linear fit results (Table 2).

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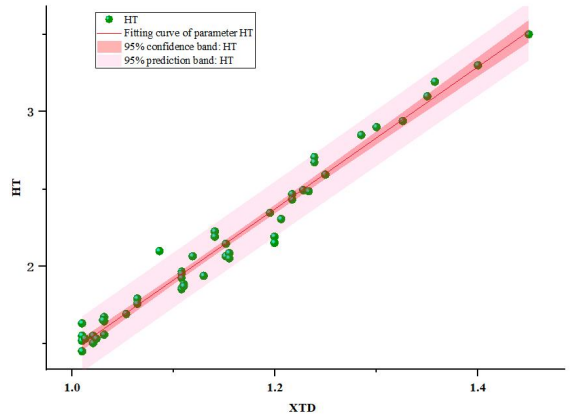


Fig. 3 Plot of HT fitting curves

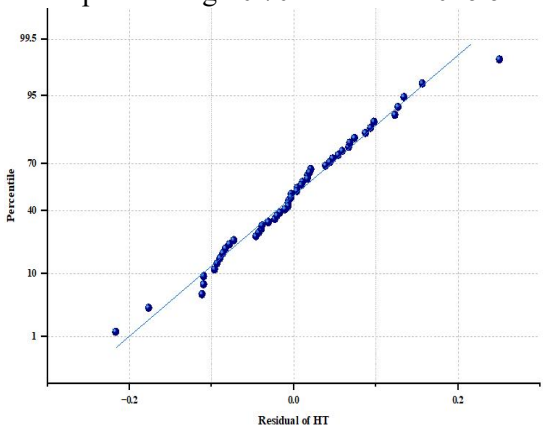


Fig. 4 Plot of residual results

Table 2 Results of linear fitting of HT

Indicator	Parameter	Value	Standard Error	T-value	Prob>|t|	95%lCL	95%UCL	R-Squared
HT	Intercept-B	-3.1373	0.12912	-24.2975	1.26863E-28	-3.39695	-2.87772	0.97228
	Slope-A	4.59163	0.11189	41.03523	4.8989E-39	4.36664	4.8	

Figs. 3 and 4 show that after the correction of texture depth ratio parameters, the asphalt mixture uniformity index HT from the centroid method is significantly positively correlated with the texture depth correction value XTD from the sand patch method and the residual data points of parameter HT are roughly distributed along a straight line and conform to the normal distribution law, a result that verifies the applicability of this image processing method in evaluating the paving quality of asphalt mixtures.

According to Table 1, we can get the fitting equations of the asphalt mixture homogeneity evaluation index HT and the correction value of the construction depth calculated by the sand spreading method as shown in Eq. 7, in which the standard deviation of the slope A is equal to 0.11189, the standard deviation of the intercept B is equal to 0.12912, and the confidence interval is in the ranges of (4.36664,4.8) and (-3.39695,-2.87772), and the correlation coefficient between the two parameters is 0.97228, so it can be seen that there is a significant correlation between the variation factor HT and the actual segregation evaluation index XTD obtained by the shaped-center method. The correlation coefficient between the two parameters is 0.97228, so it can be seen that the correlation between the coefficient of variation HT obtained by the centering method and the actual segregation evaluation index XTD is significant.

$$HT = (4.59162 \pm 0.11189)\text{XTD-}(3.13734 \pm 0.12912) \tag{7}$$

The U.S. NCHRP 441 report on the asphalt surface of the constructive depth ratio of the in-depth study, the establishment of a related prediction model, the test shows that the model can be a better prediction of dense graded asphalt mixture surface constructive depth of the accuracy. Therefore, the article is based on the U.S. NCHRP 441 asphalt mixture uniformity evaluation standards, through fitting and correlation analysis to obtain this paper based on the shape of the heart method to evaluate the uniformity of asphalt mixtures evaluation criteria shown in Table 3.

Table 3 Evaluation Criteria of Asphalt Mixture Paving Uniformity Based on Shape-Centered Approach

Evaluation indicators	No segregation	Slight segregation	Moderate segregation	Severe segregation
NCHRP Report 441	0.75-1.15	1.16-1.56	1.57-2.09	>2.09
HT	0.307-2.143	2.143-4.026	4.026-6.460	>6.460

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4. Summary

Asphalt mixture segregation is one of the core causes inducing early damage to asphalt pavements. If the aggregates in the mixture exhibit the characteristic of uneven distribution, it will not only adversely affect the long-term service performance of the pavement structure but also lay hidden dangers for traffic safety during the road operation phase. In this paper, firstly, based on the image processing algorithm, preprocessing, filtering, image segmentation and other operations are carried out on the acquired image to realize the transformation of the actual size of the aggregate and the pixel size, and then based on the shape-centering theory, the image of the paved surface of asphalt pavement is acquired and analyzed, and the following results are obtained:

(1) The coefficient of determination between the evaluation index of asphalt mixture uniformity HT obtained by processing based on the shape-centered method and the correction value of construction depth XTD calculated by using the sand paving method is equal to 0.97228, which has obvious positive correlation, and the larger the value of HT parameter is, the more serious the segregation of the asphalt mixture surface is.

(2) The residual of HT parameter, roughly falls on a straight line, basically meets the normal distribution, so it can be obtained using image processing method to evaluate the asphalt mixture paving surface uniformity has a certain technical feasibility.

(3) Based on the calculation results of sand paving method and asphalt mixture uniformity evaluation indexes, the evaluation criteria for evaluating asphalt mixture paving surface uniformity using the form-center method are obtained by correcting the evaluation indexes of the constructive depth ratio and fitting analysis. When the weighted center-of-form distance coefficient of variation HT meets the range of 0.307-2.143, there is no segregation; the ranges of mild segregation and moderate segregation are 2.143-4.026 and 4.026-6.460, respectively, and the asphalt mixes in the testing area can be considered to be heavily segregated when the value of the weighted center-of-form distance coefficient of variation HT exceeds 6.460.

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