Internal Structure Parameters of Asphalt Mixture Made by Different Compaction Methods

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ABSTRACT: In this study, an attempt was made to estimate the internal structure parameters of asphalt mixture. This was done by studying the aggregate orientation, aggregate distribution and internal anti-shear parameters: the internal friction angle φ and the cohesive force C. Four gradations and two types of compaction: vibratory compactor and Superpave gyratory compaction (SGC) were analyzed.

The results indicated that the particles in specimens which compacted using SGC were found to be more horizontal and uniform distribution, but exist larger space between coarse particles(>2.36mm) and smaller C compared with samples compacted using vibratory compactor. For coarse gradations, the coarse particles were arranged more closer, and decreasing the contents of 2.36mm aggregate could help the coarse aggregates be compacted more tightly.

KEYWORDS: Image analysis, internal structure, asphalt mixture, compaction

1 INTRODUCTION

Asphalt mixture is one type of heterogeneous material that consist of aggregates, aid voids, and asphalt binder. The internal structure of asphalt mixture is influenced by many factors, including aggregate gradation, aggregate distribution, aggregate shape, asphalt content and as important as the compaction type. The internal structure plays a significant role in the asphalt mixture performance including rutting, fatigue and cracking.

In the past decades, many studies have recognized that the internal structure is the true factor to influence the performance, but limited by research methods at that time, these findings are based on macro-volumetric parameters analysis such as bulk specific gravity, air voids, VMA of asphalt mixture.

In recent years, some studies use the digital image technique analyzing the internal structure of engineering materials. (Yue and Morin 1995) are some of earlier researchers to study the internal structure of asphalt mixture using image analysis. They presented a digital image processing based finite element method for the two-dimensional mechanical analysis of geo-materials by taking into account their material heterogeneous and microstructures. (E.Masad etal.1998) and (L.B.Wang etal.2001) are some of researchers to use CT and image processing technique to analyze the air voids and internal structure. Their findings illustrated asphalt mixture will be different internal structure when compacted by different compaction.

On the other hand, Based on Mohr-Coulomb theory, the anti-shear intensity of asphalt mixture is consist of φ and C, these two are internal mechanics parameters of asphalt mixture that depended on the gradation of aggregate, asphalt content, asphalt performance, and compaction. Generally, measure these two parameters should use triaxial compression test, many researchers have studied for these two parameters since 1930's, because of the complexity, the method is only used for research.

2 OBJECTIVES

(1) Develop internal structure parameters of asphalt mixture based on digital image processing
(2) Evaluate the difference of asphalt mixture internal structure parameters when the specimens have different gradations or made by different compactions
(3) Analyze the correlations between internal structure parameters and anti-shear intensity of asphalt mixture.

3 PROJECTS

3.1 Image capture

After samples for studied are selected, the section images are captured using high resolution camera. As the accuracy of information extracted from an image depended on is imaging quality, great care must be taken during the image capture. In this paper, for imaging process and analysis, one processing program was developed base on Matlab image processing toolbox （R.C.Gonzalez etal.1999）.

3.2 Image process and analysis

The first step in any image processing technique is calibrating the image in terms of physical measurement unit. This step helps ensure clear representation. Next step is to segment the image to background and the features of interest. One of the difficulties in process digital image is in clearly identifying the boundaries of aggregate from asphalt mastic. For example, two or three aggregates touch each other perhaps erroneously be assumed to one large aggregate. In this study, the interest feature is coarse aggregates (aggregates sizes>2.36mm), so the asphalt mastic together with fine aggregates form background. Thus, the image after thresholding is converted into binary image, in which the coarse aggregates are set to white, and the background is set to black.

3.3 Image parameters illustration

After processing image, the coarse aggregates are targets for analysis of asphalt mixture internal structure. For this study, analyzing the distribution of coarse aggregates, the proportion between coarse aggregate and asphalt mastic are our target. The centroids of aggregates define the location of the particles in x-y coordinates (Kasthurirangan Gopalakrishnan 2005). The centroids are joined according to the Delaunay triangulations principle. Delaunay triangulation can be considered to be a mathematically rigorous method to define nearest neighbors. These triangle define the distance between the neighboring particles. For illustration, the Figure 1 shows the particles analyzing according to the Delaunay triangulations.

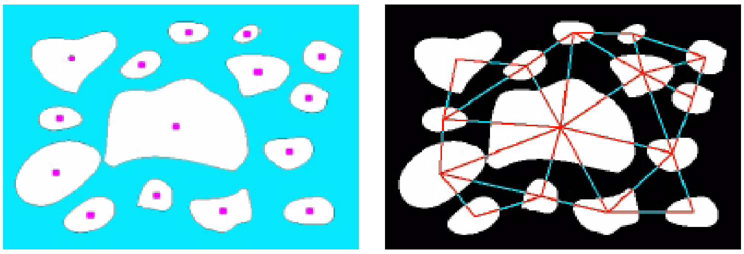


Figure 1：Centroids connected by Delaunay triangles to measure inter-particle distance

The edges of these triangles give the edges between the centroids of the particles. we refer to this distance as D_1. Part of D_1 lie in the aggregates themselves and part of it lies in the mastic. This distance that lie in the asphalt mastic also can be measured and we call them D_2. The area enclosed by the triangle A_1 can be measured. As same as D_2 the area within the triangle that lies in the mastic A_2 can also be measured. These parameters were illustrated in Figure 2.

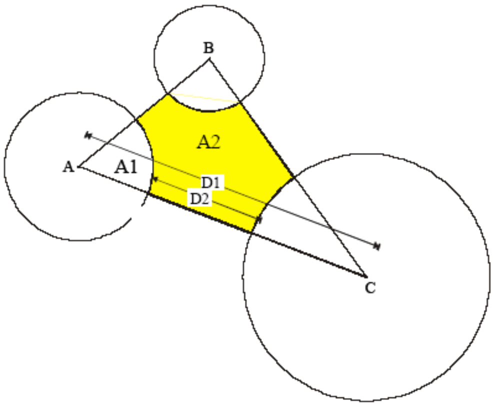


Figure 2: Internal particle distance and area parameters

In summary, the following parameters are used in this study:

(1) D_1- centroid-to-centroid inter-particle distances.
(2) D_2- edge-to-edge inter- particle distances
(3) A_1- area of triangles(whole)
(4) A_2- area of triangles in asphalt mastic

3.4 Anti-shear intensity test

Whereas the internal mechanics parameters φ and C are important for asphalt mixture performance and the triaxial compression test is complicated, we develop a new way to measure the two parameters.

Based on elasticity hypothesis, the internal force of penetration test model is not influenced by materials elastic modulus and poisson's ratio. So modeling a penetration sample by universal finite-element software, compute the principal stress of location that is largest shear stress, this value defined anti-shear parameter, then multiply the strength measured by penetration test with the parameter, this result was the anti-shear stress of the sample. The nest step, under Mohr-Coulomb theory, combine uniaxial compression and penetration test result, give out the material internal parameters: φ and C.

4 MATERIALS AND GRADATIONS

The aggregate used in this study were provided by Liaoning highway administration. The properties of aggregate used in test are listed in Table 1. And the gradations used are depicted in Table 2. The gradations including four types: coarse (1,3) and fine (2,4) gradation, the passing of 4.75 are 32% and 45% respectively. And the difference between 1 and 3 is the passing rate of 2.36mm, the same as 2 and 4.

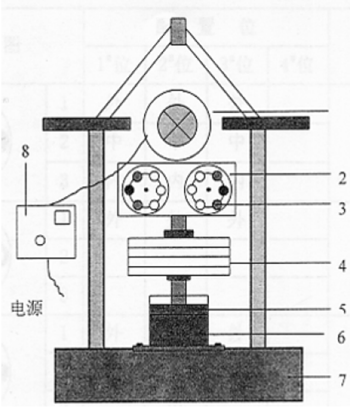
Table 1: Density of aggregate used in this study

Sieve size (mm)	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	<0.075
Apparent specific gravity (g/cm^3)	2.735	2.741	2.742	2.739	2.726	2.716	2.733	2.723	2.718	2.724	2.723
Bulk specific gravity (g/cm^3)	2.707	2.709	2.701	2.678							

The samples are compacted according to ASSHTO TP4-93 procedure using SGC and vibratory compactor designed by Harbin institute of technology, the parameters are shown in Figure 3. The values of average air voids of samples are measured according to requirement of JTG 052-2000 specification.

Table 2: Aggregate gradation used in this study

		Passing / %										
Sieve size/mm		19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
gradations	1	100	89.7	74.2	43.3	32	22.9	16.5	12.1	8.9	6.6	5
	2	100	91.7	79.2	54.2	45	29.4	19.4	13.3	9.2	6.7	5
	3	100	89.7	74.2	43.3	32	30	16.5	12.1	8.9	6.6	5
	4	100	91.7	79.2	54.2	45	40	19.4	13.3	9.2	6.7	5



1.power
2.eccentric cover
3.eccentric mass
4.load
5.compactor
6.sample mold
7. base

Figure 3: Vibratory compactor

After forming the specimens, drill cores whose diameter is 100mm out of compacted ones. The procedure was shown in Figure 4. So we can capture the internal structure imaging around the specimen.

a. D=150mm samples compacted by SGC and VC
b. Drill and clamp for asphalt mixture specimens in lab
c. Specimens（d=100mm）cored out of original samples whose D=150mm

Figure 4: The procedures for preparing the samples

5 RESULTS AND DISCUSSIONS

5.1 Aggregate orientation

The particle orientation is measured as the angle between the major axis of the particle and a horizontal line on the image. The major axis is defined as the longest distance between two pixels in the particle. Refer to the findings of E. Masad (1998), and the orientation is measured by a vector magnitude △, the value of △ varies from 0%~100%. Complete random distribution of the orientation will give a vector magnitude of 0%. On the other hand, 100% vector magnitude value means all observed orientation have the same direction. and the average major angle of θ. Defined by the following equations (1) and (2):

$$\Delta = \frac{100}{N}\sqrt{(\sum \sin 2\theta_k)^2 + (\sum \cos 2\theta_k)^2} \qquad (1)$$

$$\theta = \frac{\sum |\theta_k|}{N} \qquad (2)$$

Where:

N: the number of particles in image

θ_k: the major axis angle of each particle.

The vector magnitude △ and average angle θ are shown in Figure 5. For all four gradations, the average angle is found to be smaller for specimens compacted using the SGC compared with samples compacted using vibratory compactor. The vector magnitude is consistently smaller for vibratory compactor samples compared to the SGC samples. These results indicate that particles have preferred orientation towards the horizontal direction in SGC samples while they appear to have more of a random distribution in vibratory compactor samples.

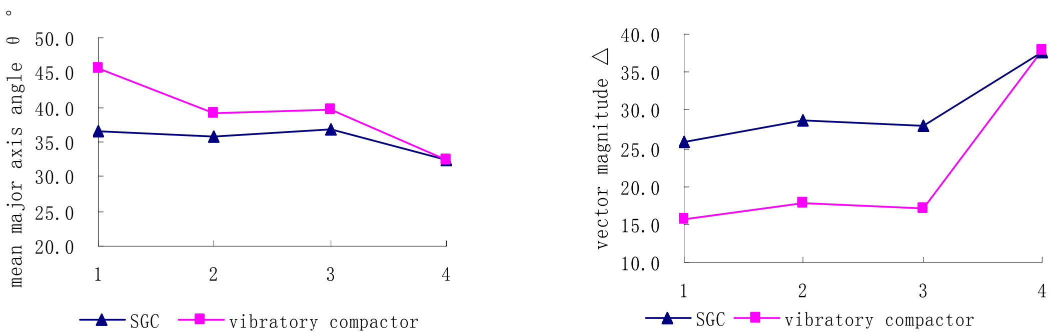


Figure 5: Values of average major axis angle (θ), vector magnitude (△) using different compactors

5.2 Aggregate distribution

Under Delaunay triangulation principle we compute the internal structure of samples compacted under different compaction, the result illustrate that the A_2 of coarse gradation samples (1,3) are obviously smaller than fine gradation samples(2,4), and also the D_2, D_1 are same trend. It is reasonable, the distance of particles are smaller in coarse gradation than in fine gradation. On the other hand, when the content of coarse aggregate(larger than 2.36mm) is same(for example 1 and 3) ,the A_2 of 3# is smaller than 1# ,because the content of 2.36mm for 3# is little than 1#, the coarse aggregate can be compacted more easy. The skeleton of coarse aggregates are more closer. For D_1 and D_2, the D_2 is more sensitive for internal structure change. This is understandable since it is the asphalt mastic that shrinks and not the aggregates. By considering asphalt mastic alone(D_2) the changes in lengths are more obvious. The data are shown in table 3.

Table 3: Internal structure parameters under Delaunay triangulation principle

Specimens		A_2 mm^2	D_1 mm	D_2 mm
Vibratory compactor	1	46.85	16.64	7.78
	2	50.19	16.72	8.20
	3	42.63	16.72	7.96
	4	48.26	17.03	8.75
SGC	1	48.45	20.28	7.95
	2	57.46	21.96	9.34
	3	46.61	21.22	7.74
	4	55.60	22.41	9.14

5.3 Internal mechanics parameters φ and C

The internal mechanics parameters φ and C are influenced by gradation, asphalt content and compaction type as illustrated in the above chapter, and it should be measured by the method introduced above. The results are shown in table 4. For φ, the trend obviously shows that it is smaller in fine gradations 2 and 4 than corresponding coarse gradations 1 and 3 under all compaction type, on the other hand the C is larger than coarse gradations. For anti-shear intensity, it is influenced by φ and C, the samples compacted by vibratory compactor are larger than samples compacted by SGC, and the gradation 3 is the largest one in all gradations, its φ and C is not always largest in all the gradation but the combination of the two parameters is largest under Mohr-Coulomb theory so the anti-shear intensity is the largest.

Table 4: Internal mechanics parameters of samples

Specimens		Anti-compression MPa	Anti-penetrating MPa	φ / °	C / MPa	Anti-shear MPa
Vibratory compactor	1	1.038	4.018	44.9	0.215	1.362
	2	1.589	4.698	41.4	0.359	1.593
	3	1.474	6.228	45.8	0.299	2.111
	4	1.477	5.157	43.8	0.315	1.748
SGC	1	0.884	3.417	44.9	0.183	1.158
	2	1.278	4.154	42.8	0.279	1.408
	3	1.080	4.217	45.0	0.224	1.429
	4	1.334	3.778	40.6	0.307	1.281

6 CONCLUSIONS

Computer automated procedures that integrated aspects of digital image analysis are developed to quantify the internal structure of asphalt mixture. The internal structure is described in terms of aggregate orientation, aggregate distribution, and internal mechanics parameters φ and C.

(1) The internal structure of asphalt mixture are different. And the difference can be measured by two-dimensional image analysis of core samples.

(2) Results indicate that particles have preferred orientation towards the horizontal direction in SGC samples while they appear to have more of a random distribution in vibratory compactor samples.

(3) For aggregate distribution, the A_2 and D_2 are more sensitive, and they have same trend that the two parameters are all larger when the gradation is fine gradation compared with coarse gradation. And the two parameters are larger when compacted using SGC compared with vibratory compactor.

(4) For internal mechanics parameter φ and C, the φ of coarse gradations are larger, and the C has opposite trend compared with φ. For different compactions, the φ dose not appear systematic trend, the C of samples compacted using vibratory compactor are all larger than corresponding gradation samples compacted using SGC.

(5) In summary, the aggregate orientation, aggregate distribution and internal mechanics parameter φ and C are obviously different under different gradations and compactions, and they indeed plays a significant role in the asphalt mixture performance, in this study the anti-shear intensity is influenced by all of these parameters.

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