Segregation Evaluation in Hot-Mix Asphalt Pavements Using Digital Image Technique

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ABSTRACT: The segregation shortens the pavement service life seriously, and the influences of segregation in hot-mix asphalt pavements have been analyzed in many literatures. However, there is no appropriate method available for segregation level evaluation in hot-mix asphalt pavements during contractor's quality control (QC) operations and agency's quality assurance (QA) activities. Based on the digital image technique, the method of characterizing and evaluating surface segregation was developed in this study. The method includes segregation characterization in hot-mix asphalt pavements, the rules of non-segregation and evaluation of various segregation levels. The parallel testing results indicate the precision of new method is satisfied for QC/QA in pavement engineering.

KEY WORDS: Asphalt Pavement, Surface Segregation, Digital Image Technique.

1 INTRODUCTION

"Segregation" is a term often used in the Hot Mix Asphalt (HMA) industry to describe a number of different phenomena. Its most general definition came from Stroup-Gardiner and Brown (1): "Segregation is a lack of homogeneity in the hot mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress (es)." "Constituents" should be interpreted as asphalt binder, aggregates, additives and air voids.

Generally there are two types of segregation identified in the HMA pavement layer: gradation segregation and temperature segregation (i.e., temperature differential). Gradation segregation is the most common type and can occur as the result of aggregate stockpiling and handling, production, storage, truck loading practices, construction practices or equipment adjustments. Temperature segregation was identified in the literature as occurring as the result of differential cooling of portions in the mix on the surface of the mix in the haul truck, along the sides of the truck box, or in the wings of the paver. Aggregate segregation and construction-related temperature segregation display the same symptoms and result in the same type of damage, which can cause them to be confused with one another. The ultimate damage mechanism, excessive air voids (often expressed as "inadequate density"), is the same in both cases.

Based on the reference (2), the qualitative definition of aggregate segregation is “the non-uniform distribution of coarse and fine aggregate components within the asphalt mixture.” There are two basic types of aggregate segregation:

(1). Coarse segregation. It occurs when gradation is shifted to include too many coarse aggregates and inadequate fine aggregates. Coarse segregation is caused by low asphalt content, low density, high air voids, rough surface texture, accelerated rutting or fatigue failure. Typically, coarse segregation is considered the most prevalent and serious type of segregation; thus segregation research has focused on coarse segregation. The term “segregation” by itself usually means “coarse segregation.”

(2). Fine segregation. It occurs when gradation is shifted to include too many fine aggregates and inadequate coarse aggregates. High asphalt content, low density, smooth surface texture, accelerated rutting or better fatigue performance leads to fine segregation (3).

The influences of segregation on mixture properties were summarized by Stroup-Gardiner and Brown (1) in table 1. In addition to these percent changes in properties, air voids were also found to increase with increasing levels of segregation. Air void content was between 0 and 4 percent higher than non-segregated areas at low levels of segregation, 2 to 6 percent at medium levels, and greater than 4 percent at high levels.

Table 1 Influences of segregation on mixture properties

Mixture Property	Percent of Non-Segregated Mix Property by Level of Segregation			
	Fine	Low	Medium	High
Permeability	Increased slightly	Increasing with level of coarse segregation		
Resilient Modulus	Little or slight increasing stiffness	80～90%	70～80%	50～70%
Dynamic Modulus	Little or slight increasing stiffness	80～90%	70～80%	50～70%
Dry Tensile Strength	110%	90～100%	50～80%	30～50%
Wet Tensile Strength	80～90%	75%	50%	30%
Low-Temperature Tensile Stress	No conclusions due to test method difficulties			
Loss of Service Life for Segregation in Upper Lifts	Not Estimated	38%	80%	99%
Rutting Potential	Not influenced by gradation segregation obviously			Mixed results

Traditionally, visually identified areas of non-uniform surface texture have been classified as segregated mix. Because such evaluation is subjective, inspectors and contractors have difficulty negotiating on what is and is not segregation. Testing results of these suspect areas show gradation and density changes.

Both segregation and low density can significantly increase the possibility of localized pavement distresses. Therefore, a non-uniform surface texture or non-uniform density may be indicative of compositional or volumetric non-uniformities of both, which can lead to accelerated pavement distresses. A methodology for measuring segregation needs to be developed so that the total percent of non-uniformity in the mat can be estimated. The effect of non-uniformity on pavement performance and pavement life is needed so that the loss of segregation for agencies can be estimated. Only then a reliable, statistically viable specification for characterizing and measuring segregation can be developed. But few have offered a feasible alternative to the initial visual inspection.

The study presented in reference (1) investigated a variety of regular technologies for characterizing segregation (visual inspection, “sand patch” texture measurement, and nuclear density gauges) and measuring segregation (permeability, nuclear density/moisture content gauges, and destructive testing). Many developing technologies, such as infrared thermography, ground penetration radar, thin-lift nuclear asphalt content/density gauges, dynamic (laser-based) surface texture measurement devices, and seismic pavement analyzers, were also evaluated. The criteria to evaluate the methods and technologies included (1) the ability to measure and detect mixture properties that would change because of segregation and (2) the availability of equipment that could be used in a rapid, repeatable, and nondestructive manner, preferably at normal highway speed. The researchers recommended infrared thermography and dynamic texture measurements as the most promising technologies. Reference (1) further suggested that infrared thermography has a good potential for quality control because it can be used during paving operations. On the other hand, dynamic texture measurement device appears to be the most practical means for characterizing and quantifying segregation for quality assurance purposes.

There are two systems to measure texture and detect segregation of asphalt pavement currently. The first one is marketed as MGPS Surface profiler. It is using a high-frequency laser sensor with a “footprint” selected specifically for delivering high-definition surface profiles. The second one (ICC) is using relatively slower sensors with a larger footprint (“profile-grade” lasers) and producing an estimate of texture using a root mean square (RMS) calculation on the filtered high-definition surface profile. The measured mix properties with two systems above were compared with corresponding average sand patch (MTD) measurements in Figure 1. The data in Figure 1 suggests that the systems yield a good estimate of the macro-texture for the finer mixes but cannot appropriately predict the macro-texture for the coarser SMA or OGFC mixes and no visual segregation was observed in any mix (4).

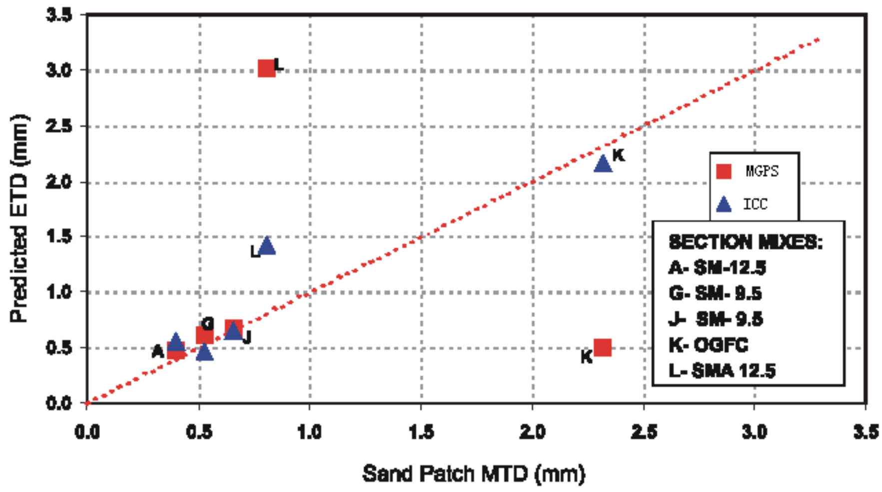

Figure 1: the comparison of ETDs vs. MTD (Kevin, 2003)

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2 MEASURING TEXTURE OF ASPHALT PAVEMENT USING DIGITAL IMAGE TECHNIQUE

Because the laser-based equipments cost too much for both contractors performing quality control and agencies performing quality assurance, together with other disadvantages mentioned above of these equipments, a digital image technique was developed for measuring the texture of asphalt pavement with (5).

2.1 Mechanism of Digital Image Method

When light shines on a rough surface, a phenomenon can be observed that the raised parts on the rough surface are light and the hollow parts of the rough surface are dark. Recording this light and dark difference with digital (vedio) camera for a large area and then processing this visual difference into the numeral using digital image processing technique, the digital surface model (DSM) of the rough surface can be obtained. Based on the DSM, an evaluation of pavement texture can be implemented.

For example, the sand patch method (ASTM E-965 [ASTM, 2002]) is a regular method for measuring pavement texture. It defines a mean texture depth (MTD) with volumetric techniques. This procedure can be accomplished with an integral equation to DSM (equation 1 and 2) and the simulation is illustrated in fig. 2.

$$V = \iint_D [F_0 - F(x, y)]dxdy \tag{1}$$

Where:
F_0— a referenced plane covering on the pavement surface;
D— an analyzing area corresponding with sand patch area (ASTM E-965);
V— volume between F_0 and DSM corresponding with sand volume (ASTM E-965).

$$H = \frac{V}{A} \tag{2}$$

Where:
H— mean texture depth (MTD);
A— area of D (known).

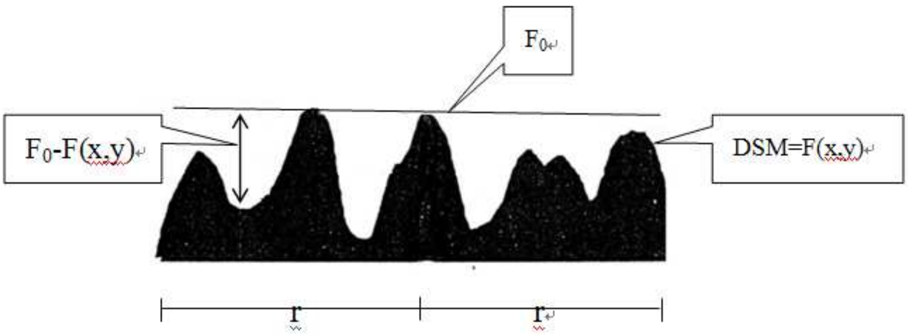

Figure 2: Illustration of simulating sand patch method

2.2 Precision Evaluation of Digital Image Method

Digital image method requires only a digital photo of pavement surface, which makes it very simple and convenient. When a digital photo of pavement surface is taken, a pad made of rubber with grain on its surface used as calibration is put on the pavement and then a photo containing the calibration pad and pavement is taken. This procedure is illustrated in fig. 3. Because the grain height is known, the pixel value of the digital image can be transferred into elevation of surface and then DSM can be obtained. With this method, some data of DMTD (Digital Image Mean Texture Depth) and MTD at the same place were collected from five different projects and different kinds of HMA (the typical asphalt mixes in China, such as DAC, SMA and so on). The comparison shown in fig. 4 indicates that DMTD and MTD have a very good correlation and DMTD has enough precision for assessing pavement surface texture.

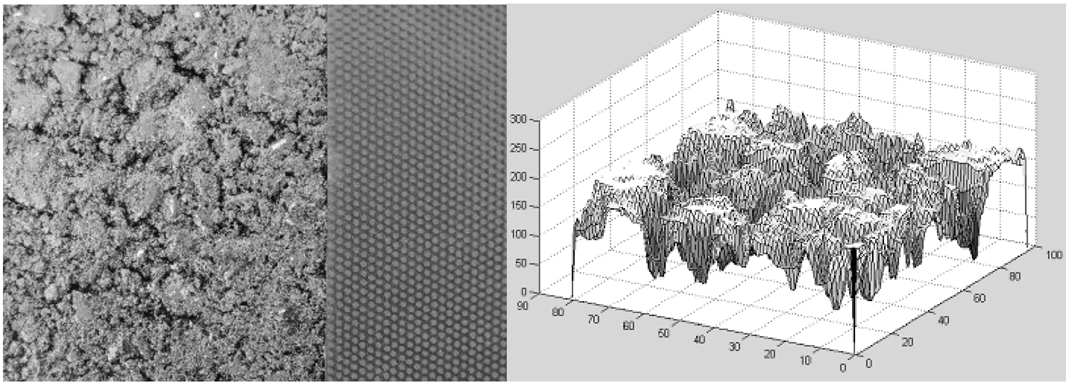

Figure 3: Illustrations of recording pavement surface characteristic

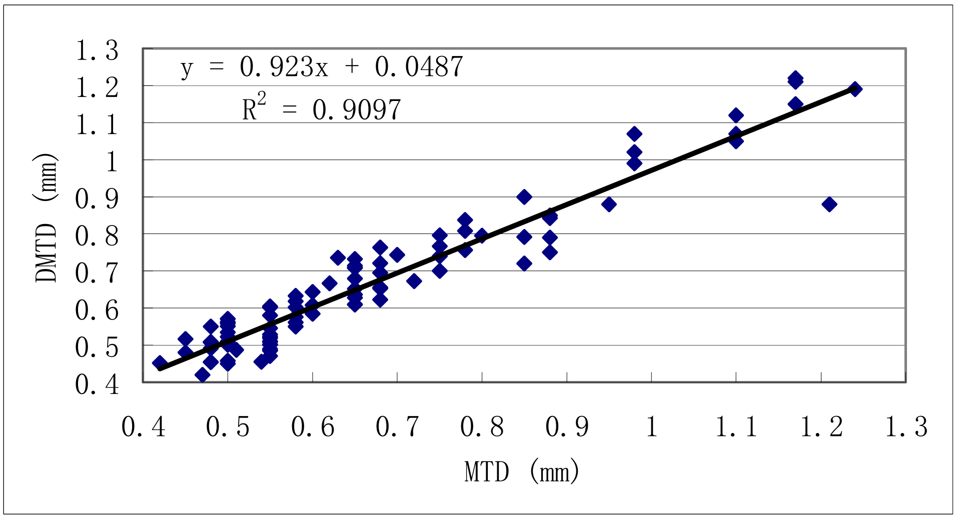

Figure 4: Comparison of DMTD and MTD

3 CHARACTERIZING PAVEMENT SEGREGATION AND EVALUATION

Recently, more and more projects adopted dense-gap graded HMA to enhance the rutting resistance. Compared with continuously graded HMA, dense-gap graded HMA has higher segregation possibility, which has been observed in several recently constructed projects. Therefore, characterizing pavement segregation and evaluating its level are critical for quality control and assurance during asphalt pavement construction.

3.1 The Rules of Characterizing Pavement Segregation and Evaluating

So far, there is no specification for characterizing and evaluating pavement segregation in construction activities. The stipulated rules are essential. Three rules used are:

(1) A statistical average of DMTD is considered as non-segregation. All parts whose DMTDs are greater than average are classified as “coarse segregation” and all

parts whose DMTDs are smaller than average are classified as “fine-segregation”. It is an impersonal rule. While sometimes the non-segregation defined based on average is not desirable.

(2) It is a subjective rule. The non-segregation is defined by inspectors.

(3) The non-segregation is determined in the lab. A rut specimen (shown in fig. 5) is prepared in the laboratory. The gradation and asphalt content of the specimen are conformance with the Job Mix Formula (JMF) designed for special projects. After taking and saving the digital image, the DMTD of the specimen surface can be educed and it will be the criteria of the mixture with “non-segregation”.

Figure 5: A rut specimen fabricated in laboratory

3.2 Evaluation of Segregation Level

Theoretically, digital (vedio) cameras are alternatives to quomodo of recording pavement surface characteristics. However, high speed digital video camera is not popular and costs too much nowadays, for which an ordinary digital camera (with 1.3 million pixel resolution) is selected in the study.

Based on the reference (1), sampling (taking digital image) method used is shown in fig. 6.

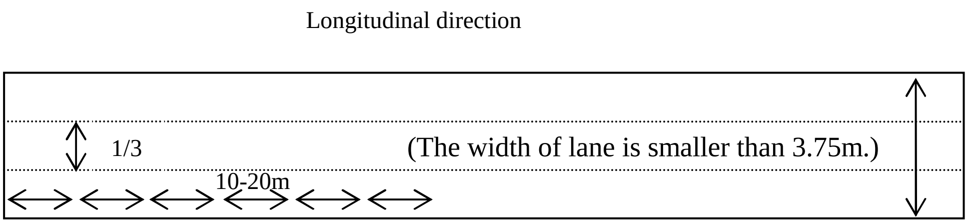

Figure 6: Illustration of sampling method

In this study, the term of the Expected Texture Depth (ETD) is also defined. If the texture depth of the part of pavement surface equal to ETD, it indicates non-segregation occurs in this part. The factors are used for measuring and evaluating various levels of segregation (shown in Table 2). For example, if the value of ETD equals to 1.0 mm, all data of DMTD that is greater than 0.8 mm and smaller than 1.1 mm will be classified as non-segregation.

Table 2 Factors for measuring and evaluating various levels of segregation

Limit	Fine Level Segregation	Non Segregation	Low Level Segregation	Medium Level Segregation	High Level Segregation
Lower	< 0.80	0.80	1.10	1.40	1.70
upper	None	1.10	1.40	1.70	None

3.3An Engineering Example

As for a new constructed freeway project with DAC (Dense Grade Asphalt Concrete) as the surface layer, the value of ETD is defined as 0.5 mm. The evaluation results of a paving lot of this project are listed in Table 3.

Table 3 Segregation Evaluation results of a paving lot

Limit	Fine Level Segregation	Non Segregation	Low Level Segregation	Medium Level Segregation	High Level Segregation
Lower		0. 40	0. 55	0. 70	0. 85
upper	0. 392	0. 55	0. 70	0. 85	
Samples	0	32	4	0	0
(%)	0	89%	11%	0	0

4 CONCLUSIONS

As an innovative approach for characterizing and measuring segregation, the digital imaging method was developed and recommended in this study. The data collected shows there is a good possibility that segregated areas can be identified using image recognition techniques pre-calibrated for typical mixes and its level can be evaluated. These techniques may include processing of high quality digital images of the completed HMA layers. The size of image file used could be adjusted by choosing a camera with various resolutions according to the sample frequency. This approach would have the advantage of providing a better coverage of the paving area and a permanent record (image) of the originally constructed layer. Among other things, these images could help resolve disputes between agencies and contractors. Numbers of practices have indicated that the precision of characterizing and evaluating results are satisfied. The digital image method developed may make characterization and evaluation of pavement surface segregation more simple and easy to operate.

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