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Estimation of Asphalt Pavement Surfaces Using Image Analysis Technique

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***Abstract*—**Asphalt concrete pavements gradually lose their skid resistance causing safety problems especially under wet conditions and high driving speeds. In order to enact the actual field polishing and wearing process of asphalt pavement surfaces in a laboratory setting, several laboratory-scale accelerated polishing devices were developed by different agencies. To mimic the actual process, friction and texture measuring devices are needed to quantify surface deterioration at different polishing intervals that reflect different stages of the pavement life. The test could still be considered lengthy and to some extent labor-intensive. Therefore, there is a need to come up with another method that can assist in investigating the bituminous pavement surface characteristics in a practical and time-efficient test procedure.

The purpose of this paper is to utilize a well-developed image analysis technique to characterize asphalt pavement surfaces without the need to use conventional friction and texture measuring devices in an attempt to shorten and simplify the polishing procedure in the lab.

Promising findings showed the possibility of using image analysis in lieu of the labor-sensitive-variable-in-nature friction and texture measurements. It was found that the exposed aggregate surface area of asphalt specimens made from limestone and gravel aggregates produced solid evidence of the validity of this method in describing asphalt pavement surfaces. Image analysis results correlated well with the British Pendulum Numbers (BPN), Polish Values (PV) and Mean Texture Depth (MTD) values.

***Keywords*—**Friction, Image Analysis, Polishing, Statistical Analysis, Texture.

I. INTRODUCTION

PAVEMENT surfaces require frequent measurement of friction as part of safety monitoring program. Skid resistance and texture of pavement surface are two important parameters often measured during the service life of the pavement to ensure that they meet the minimum required criteria for safety reason. Pavement skid resistance is defined as the ability of the traveled pavement surface to prevent the loss of traction. It has been proven that pavement skid resistance is controlled by many factors, among which aggregate and mixture properties are the most important. The main texture parameters that influence pavement surface friction are microtexture and macrotexture, as can be seen in a vast number of recent studies, for example, by [1]-[9]. Some of known facts about microtexture and macrotexture are summarized in Table I.

To lab-study the asphalt pavement wearing characteristics over its life span it is necessary to simulate the wearing and polishing action in a laboratory setting. This can be carried out by different lab-scale polishing devices. To complete the cycle, it is also required to use friction and texture measuring devices to quantify the exposed surfaces' frictional characteristics. These pavement surface friction and texture characteristics have been measured using different equipment over the years. Details about these polishing, friction and texture measuring devices are shown elsewhere [10]. The application of polishing action, followed by friction and texture measurements at predetermined times during the test is usually lengthy and labor-intensive, which makes the process difficult to be accepted by agencies in the asphalt industry. Therefore, there is a need to improve the process to make shorter and less labor-sensitive through utilizing state-of-art technology and analysis procedures.

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TABLE I
THE DISTINCTION BETWEEN MICROTEXTURE AND MACROTEXTURE

Feature No.	Microtexture	Macrotexture
1	Results from aggregate surface asperities.	Results from the large aggregate particles in the mixtures.
2	Estimated using low speed friction measurement devices.	Estimated using volumetric or laser-based devices.
3	Important at low and high speeds.	Important at high speeds.
4	Function of aggregate shape and mineralogy.	Function of mix properties, compaction method, and aggregate gradation.
5	Provides a gritty surface to penetrate thin water films and produce good frictional resistance between the tire and the pavement.	Provides drainage channels for water expulsion between the tire and the pavement thus allowing better frictional resistance and prevent hydroplaning.
6	0.001-0.5 mm height 0.1-0.5 mm wavelength	0.1-20 mm height 0.5-50 mm wavelength

The main objective of this paper is to utilize a well-developed image analysis technique to characterize asphalt pavement surfaces without the need to use conventional friction and texture measuring devices in an attempt to shorten and simplify the polishing procedure in the lab.

As thoroughly presented in the literature, image analysis techniques have been utilized in many pavement and materials engineering applications. This method has proven to be a valuable way to serve the highway materials industry as will be discussed in the following paragraphs.

Crack sealing is a routine and necessary operation of pavement maintenance. Manual observation of road surfaces has been the most common method for evaluating road surface cracks around the world. However, it is difficult to objectively and accurately assess the road cracks based on human visual perception. The ultimate objective of a study [11] by Kim et al. is to evaluate crack sealing performance on highways, in order to choose the best crack sealing practice in an automated manner. This study proposes a research methodology to quantify the level of road surface distress using video image processing. Although the proposed method is in its conceptual stage yet, when the method is coupled with high-resolution image capturing devices installed on a vehicle, it has the potential for accurate and quantitative assessment of crack sealing performance.

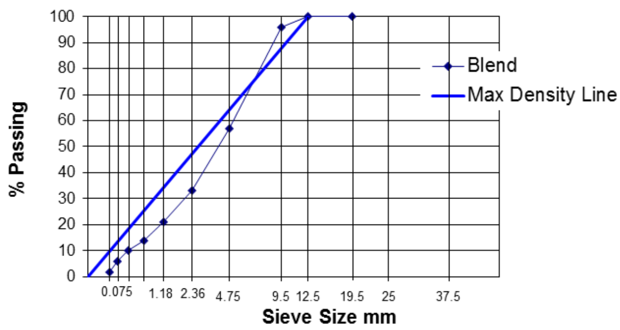
Another study by Tutumluer et al. [12] focused on evaluating performances of different video imaging systems for automating the determination of coarse aggregate size and shape properties, i.e., flat and elongated ratio, gradation angularity. Based on the evaluation results, not all the properties could possibly be determined from one system. The newly developed University of Illinois (UI) Aggregate Image Analyzer can provide one system for all properties, based on the use of three cameras for accurately reconstructing three-dimensional shape, i.e., computing volume of an aggregate particle, and automating the determination of all the aforementioned properties. The computed flat and elongated ratios in percentage by weight were in very good agreement with the results obtained by the manual caliper method. The repeatability of the UI Image Analyzer results was also very good. The imaging based gradation curves were found to match very closely with the mechanical sieve analysis results. In addition, a new Angularity Index was developed to numerically quantify the shape of coarse aggregates analyzed using the UI Aggregate Image Analyzer.

According to a study by Al-Rousan et al. [13], imaging techniques have provided a good means to quantify aggregate shape properties rapidly in spite of the fact that they might differ in the mathematical procedure and the instrumental setup they utilize. The validity of the mathematical procedure is essential for the results to be useful in quantifying aggregate shape. Some of the most widely used aggregate shape analysis techniques were evaluated in their work. The analysis results revealed that some of the available analysis methods are influenced by both angularity and form changes and, consequently, are not suitable to distinguish between these two characteristics. Also, some of the analysis methods are quite adequate to measure both texture and angularity when changes are made to the image resolution and magnification level. They recommended several methods such as wavelet analysis of gray images for texture; both the gradient method and tracing the change in slope of a particle outline method for angularity; aspect ratio for 2-dimensional form; and sphericity or the proportions of the three particle dimensions for 3-dimensional form.

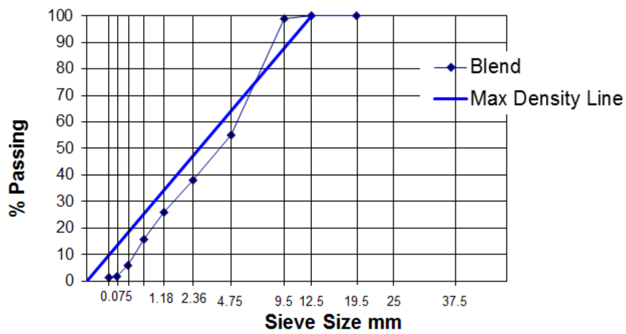
In a research by Janaka et al. [14], an image analysis technique using ImageJ was proposed to evaluate particle size distribution of gravels. This method gave same gradation curves as that by sieve analysis test, the image analysis technique used can be considered as simple and less time consuming process than sieve analysis test. This method can also be applied as an in-situ method since the method needs only a computer and a camera.

II. Materials

The aggregate used was Columbus limestone brought from Akron Crushed Limestone Company in Akron, Ohio and Stocker sand and gravel brought from Stocker Sand and Gravel Co in Gnadenhutten, Ohio. The gradation curve of the aggregate in mixing HMA is shown in Figs. 1 (a) and (b) for limestone and gravel aggregates, respectively. The binder used was Performance Grade 64-22 (PG 64-22) and brought from Marathon Petroleum Company, LLC in Cleveland, Ohio. An optimum binder content of 6.1% and 6.3% were used for limestone and gravel aggregates, respectively. This was used based on SuperPave Specifications adopted by Ohio Department of Transportation (ODOT). The preparation of SuperPave gyratory compacted HMA specimens follows typical procedure.



(a) Columbus limestone aggregates gradation curve



(b) Sand and gravel gradation curve

Fig. 1 Aggregate gradation curves

III. Methods

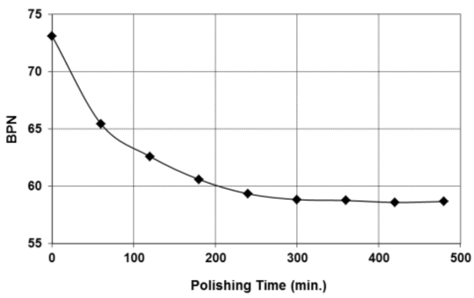
A. Polishing of HMA Surfaces

To produce different friction and texture properties on the surface of gyratory compacted Hot Mix Asphalt (HMA) specimens, a laboratory-scale accelerated polishing machine was used. A detailed description of the accelerated polishing machine is given in [15]. In essence, the accelerated polishing machine uses the rubber pad to brush against the HMA specimen surface at constant rotational speed and constant normal pressure. Different surface texture and friction properties can be produced by polishing the original HMA specimens to different duration of polishing. A picture showing the accelerated polishing machine is presented in Fig. 2. Also, a time history of the friction measurement and texture measurement of a typical HMA specimen is shown in Figs. 3 (a) and (b), respectively. As can be seen, the accelerated machine is capable of producing HMA surface with different friction and texture properties.

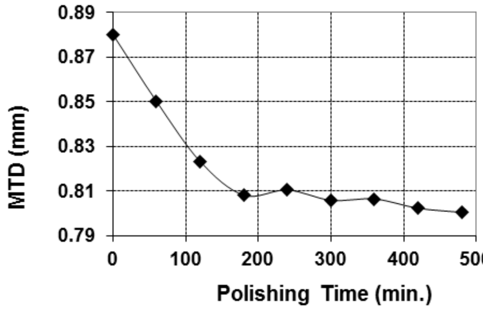
(a) General view of the accelerated polishing machine

(b) Close-up of the rubber shoe-specimen interface

Fig. 2 Accelerated polishing machine using rubber shoes for testing HMA specimens



(a) Time history of the friction measurement of a typical HMA specimen



(b) Time history of the texture measurement of a typical HMA specimen

Fig. 3 Time history of the friction and texture measurement of a typical HMA specimen

B. British Pendulum Tester

There are many different methods and equipment that can be used to measure friction in a laboratory setting. The measurement of surface friction is usually carried out using the British Pendulum Tester (BPT). The BPT [16] is the most widely used device; it can be used on curved coupons from the polishing wheel, on flat specimens from circular polishing track or reciprocating polisher, or on actual roadway surfaces. The BPT consists of a rubber slider attached to the end of a pendulum arm. As the pendulum swings, it is propelled over the surface of the specimen. As the rubber slider contacts the surface of the specimen, the kinetic energy of the pendulum decreases due to friction. This energy loss is measured and reported as the polish value; PV on curved coupons or British Pendulum Number; BPN on flat surfaces. The slider travels at roughly 6 mph (10 km/h). Fig. 4 shows the BPT setup for friction measurement. Five measurements are made for each specimen, from which an average of the last four readings is recorded as the PV or BPN.

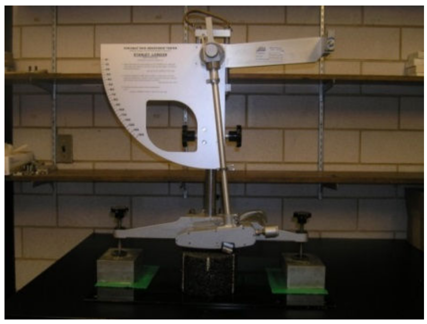


Fig. 4 Friction measurement setup using the BPT

C. Sand Patch Method

The sand patch method [17] is a technique to measure macrotexture of the HMA surface. As schematically depicted in Fig. 5, this method involves taking a known volume of a spreadable material and spreading it out in a circle on the surface of the specimen. The Mean Texture Depth (MTD) is determined by dividing the volume of the spread material by the surface area covered by the spread material. This technique is used for the 6 inch gyratory compacted specimen due to the ease associated with a small area to cover.

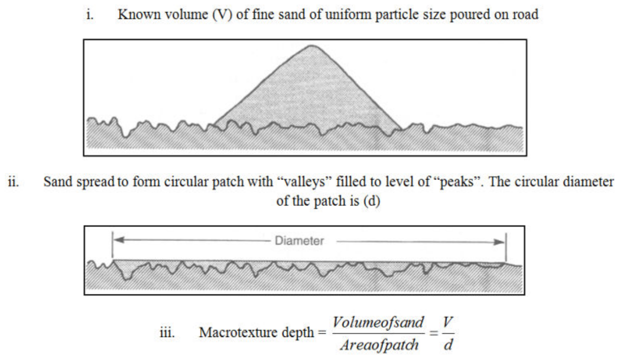


Fig. 5 Illustration of the sand patch method

D.Supplemental Image Analysis Techniques

Digital image analysis techniques are used to quantify the percentage of the exposed aggregate area of the specimen surface after being subjected to polishing by the accelerated polishing device. The percent of exposed aggregate area is defined as the area of the exposed aggregate surface divided by the total area of the HMA specimen surface that is being polished by the device. The typical image analysis procedure involves first taking the digital images of the specimen surface using the Olympus C-5060 Wide Zoom high-performance 5.1-megapixel digital camera. The digital images are then opened in the software (Scion image provided by National Institutes of Health) and converted into binary images for the subsequent calculation of exposed aggregate area.

IV. Results and Discussion

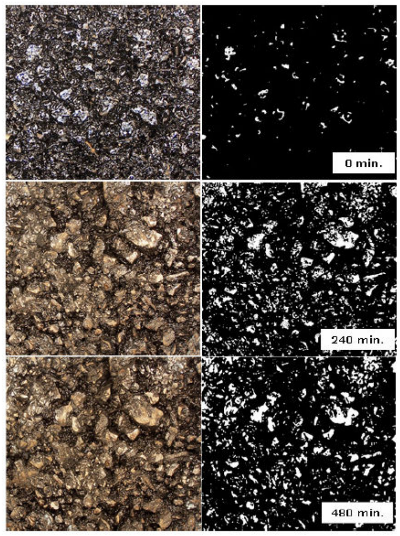
A. Repeatability of the Accelerated Polishing Equipment

The repeatability of the polishing results using the developed accelerated polishing device was examined. For each set of specimens made of the same mix formula (aggregate source, aggregate gradation, optimum binder content, binder type, and compaction method and effort), three replicate specimens were tested. The image analysis results (Agg. %) from the three replicates are statistically analyzed using Homogeneity of Variance (Levene statistic), one-way Analysis of Variance (ANOVA), and Multiple Comparisons to check for the repeatability of test results. Homogeneity of Variance and one-way ANOVA are used to check if there is any significant difference between the variances and the means of at least two specimens for each set of specimens (three specimens) made of the same JMF. Multiple Comparisons, on the other hand, is used to check if there is any significant difference between the means of different two-specimen combinations of the three specimens made of the same JMF. The software Statistical Package for the Social Sciences (SPSS) was employed for obtaining the statistical analysis results. Table II summarizes the statistical analysis results. It can be seen that the difference between the variances and the means of the results (in terms of Agg. %) for the three replicate specimens is insignificant for all cases when considering the aggregate exposure area (Agg. %), thus supporting the repeatability of the polishing action provided by the accelerated polishing device.

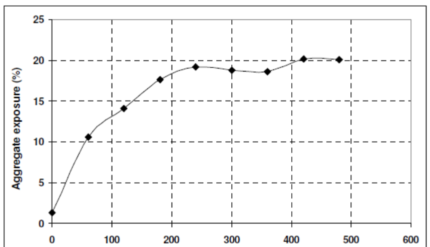
B. Comparing the Polishing Trend with the Aggregate Exposure Area

Image analysis is carried out to quantify the area of exposed aggregate (Agg. %) of the gyratory compacted HMA specimen surface during different stages of the polishing test.

The percent of aggregate exposure area of Limestone specimens is measured from the digitized images shown in Fig. 6 (a) and then plotted against the polishing duration in Fig. 6 (b). Similarly, the digitized images of the Sand and Gravel specimens shown in Fig. 7 (a) are used to plot the percent of aggregate exposure area versus the polishing duration in Fig. 7 (b). From Figs. 6 (b) and 7 (b), one can see that the more polishing the specimen is subjected to, the more aggregate area is exposed until reaching the maximum percentage at which curve stabilizes.



(a) The captured images on left and the digitized images on right at different polishing stages



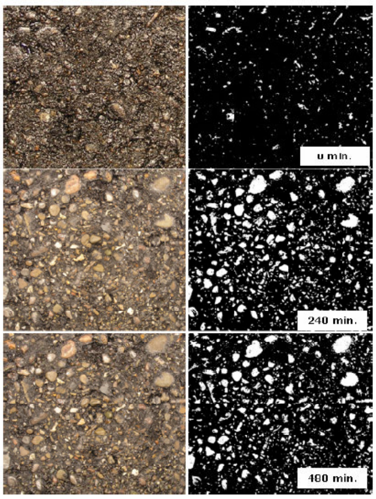
(b) Aggregate exposure area vs. polishing time

Fig. 6 Image analysis results of tests conducted on gyratory compacted specimens made from Limestone aggregate

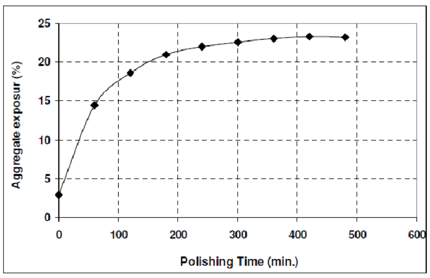
TABLE II
HOMOGENEITY OF VARIANCE, ONE-WAY ANOVA, AND MULTIPLE COMPARISONS RESULTS

	Factor	Homogeneity of Variances		1-way ANOVA Table		Multiple Comparisons	
		Levene Statistic	Significance [a]	F	Significance [a]	Group	Significance [a]
Possible Medium Polish (Columbus Limestone)	BPN	0.167	0.847	0.280	0.758	1 2	0.982
						1 3	0.853
						2 1	0.982
						2 3	0.755
						3 1	0.853
						3 2	0.755
	MTD	0.384	0.685	5.705	0.009	1 2	0.964
						1 3	0.027
						2 1	0.964
						2 3	0.015
						3 1	0.027
						3 2	0.015
	Agg. %	0.391	0.680	1.501	0.243	1 2	0.312
						1 3	1.000
						2 1	0.312
						2 3	0.305
						3 1	1.000
						3 2	0.305
Possible Low Polish (Stocker Sand and Gravel)	BPN	0.484	0.622	1.068	0.359	1 2	0.854
						1 3	0.334
						2 1	0.854
						2 3	0.640
						3 1	0.334
						3 2	0.640
	MTD	0.884	0.426	93.006	0.000	1 2	0.304
						1 3	0.000
						2 1	0.304
						2 3	0.000
						3 1	0.000
						3 2	0.000
	Agg. %	0.121	0.887	0.340	0.715	1 2	0.957
						1 3	0.858
						2 1	0.957
						2 3	0.699
						3 1	0.858
						3 2	0.699

a. **Significant at the p-value smaller than 0.05**



(a) The captured images on left and the digitized images on right at different polishing stages



(b) Aggregate exposure area vs. polishing time

Fig. 7 Image analysis results of tests conducted on gyratory compacted specimens made from Sand and Gravel aggregate

C. Simple Linear Regression Analysis

A statistical analysis is conducted to examine the correlations between the friction values of aggregate (PV) and HMA (BPN) and the percent of exposed aggregate area (Agg. %) at different stages of polishing. The friction values of aggregate are obtained from a previous study conducted by Liang and Chyi in 2000 [18]. On the other hand, the HMA surface friction values are taken from another study by Khasawneh in 2008 [10]. The regression models and the coefficient of determination (R2) for each model are presented in Table III together with the ANOVA analysis results. It can be seen that PV and BPN correlates well with the percent of exposed aggregate area at different stages of polishing.

TABLE III
SIMPLE LINEAR REGRESSION BETWEEN AGGREGATE AND HMA FRICTION VALUES AND AGGREGATE EXPOSURE AREA

Correlation Variables	Model Equation	R^2	ANOVA Table	
			F-value	p-value
PV vs. Agg.% (Limestone)	PV = 45.245 – 0.543 Agg. %	90.7	68.45	<0.0001
BPN vs. Agg.% (Limestone)	BPN = 78.755 – 1.103 Agg. %	87.1	47.10	<0.0001
PV vs. Agg.% (Sand and Gravel)	PV = 44.527 – 0.657 Agg. %	99.8	1751.75	<0.0001
BPN vs. Agg.% (Sand and Gravel)	BPN = 76.022 – 0.742 Agg. %	99.3	537.304	<0.0001

V. CONCLUSION

The conclusions presented in this section were the main outcomes obtained from this study.

The polishing machine was repeatable in producing surfaces with different polishing states as shown by results from conventional friction and texture measuring devices (BPN and MTD) and the newly developed technique based on image analysis methods (Agg. %).

PV and BPN correlates well with the percent of exposed aggregate area at different stages of polishing. This shows that the developed image analysis technique can be used as part of the polishing and wearing characterization process of different types of aggregates and thus shortens the polishing time to acceptable levels.

It is recommended that more aggregate types and HMA mixes be tested using this method before we can generalize the results obtained.

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