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Preface

Proper evaluation and modeling of pavements and paving materials are very important for designing and constructing long-lasting pavements. This Geotechnical Special Publication (GSP) contains 13 peer-reviewed technical papers showcasing recent developments in evaluation of pavements and characterization of pavement materials. Three papers in the first category introduce readers to the recent developments in evaluation of aggregate for pavement performance improvement. Papers in the second category describe recent trends in characterization and modeling of asphalt pavements and materials. Four papers listed under this category include performance grade asphalt binder, emulsion, asphalt concrete, and pavement performance modeling. Three papers in the third category highlight topics of pavement management and quality control. Three papers in the fourth category focus on the evaluation and modeling of concrete pavements. Papers included in this GSP were presented at the GeoHubei International Conference on Sustainable Civil Infrastructures: Innovative Technologies and Materials, held in Hubei, China, July 20-22, 2014. It is expected that pavement materials and construction engineers and researchers benefit from these papers received from various countries and presented in this GSP.

The Editors would like to thank the authors and individual reviewers for their dedication and contributions of time and effort to ensure the high technical quality of the papers in this GSP. In particular, the review and re-review work of the following reviewers are appreciated: Dr. Dharamveer Singh, Indian Institute of Technology, India, Dr. Renjuan Sun, Shandong University, China, Dr. Sean Lin, Ecompex, Inc., USA, Ms. Jielin Pan, University of New Mexico, and Dr. Mohammad Imran Hossain, Bradley University.

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Effects of Surface Roughness on Contact Angle Measurements on a Limestone Aggregate

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ABSTRACT: Recent studies have shown that the sessile drop approach is a reliable method to measure contact angles on asphalt pavement materials. The measured contact angles are in turn utilized for computing the surface energy properties of asphalt binders and aggregates. Based on the surface energy and bonding strength characteristics of the materials, appropriate aggregates can be selected to construct pavements that are resistant to moisture damage. In this approach, surface roughness could be an important factor which could affect the contact angle measurements on aggregates. The main objective of the present study is to determine the differences in contact angle measurements on a limestone aggregate at different levels of surface roughness. Initially, contact angle measurements were conducted on selected points on the unpolished surface of the limestone specimen. Later, the same specimen was subjected to different stages of polishing using silicon carbide grits. At each stage, the contact angle measurements were repeated as well as surface roughness was measured using a 2D profilometer. It was observed that there was a change in the contact angle measurements as the roughness of the surface decreased with polishing.

INTRODUCTION

Moisture damage susceptibility has been identified as a major cause of distress in pavements. Moisture attacks the pavement directly or it enhances the deterioration of the pavement indirectly. The amount of money spent for the rehabilitation and maintenance of asphalt pavements from the moisture damage problems has been significant (Ahmed 2011). For better performance of asphalt and aggregate in the field, it is necessary that the asphalt and aggregate must have good adhesive bond strength (Hefer 2004). Recently several studies have been conducted to evaluate the moisture susceptibility of the asphalt materials using surface energy method (Koc and

Bulut 2013; Masad et al. 2006; Little and Bhasin 2006; Hefer et al. 2006). Among the testing equipment used to determine the surface energy properties of asphalt concrete materials, the sessile drop device is found to be relatively accurate, reliable, and practical when compared to other methods like Wilhelmy plate and universal sorption device (Koc and Bulut 2013). The sessile drop device measures the contact angles directly on the aggregate surface. These contact angles can be used to calculate surface energy properties of the different asphalt and aggregates. Contact angle on the surface of a solid with the interfacial forces is defined by Thomas Young (Giese and van Oss 2002) as:

$$\gamma_l \cos\theta = \gamma_s - \gamma_{sl} \tag{1}$$

where, γ_l, γ_s, and γ_{sl} represents the interfacial energies at liquid-air, solid-air, and solid-liquid interfaces, respectively, while θ is the contact angle made by the liquid drop on the solid surface (Figure 1).

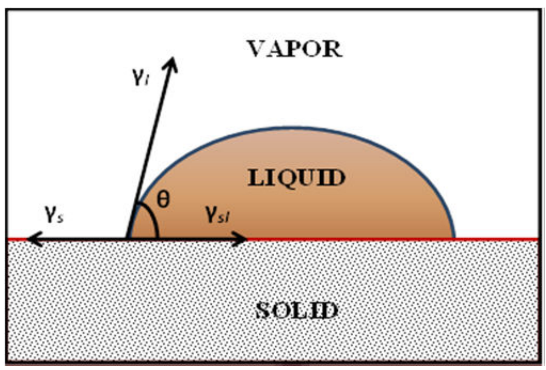

FIG. 1. Schematic representation of a drop on a solid surface.

When a liquid drop is deposited on a solid surface, it could spread or it could preserve a finite area, depending on the interaction of the drop with the solid surface. If the energy required to form a unit area of solid-liquid interface is higher than the energy required to form the liquid-air interface, the drop will continue to spread on the solid surface (Cassie 1948). However, the roughness of the solid surface could affect the interaction of the liquid with the solid surface (He et al. 2004). Therefore, the spread of the liquid drop depends on the surface energy of the liquid and the solid surface as well as the surface roughness. Even though it is practically impossible to obtain an ideal smooth surface for the measurement of contact angle, it is desirable that the roughness is reduced as much as possible, so that the surface is relatively smooth and devoid of irregularities. Once the contact angle values are obtained using the sessile drop device using three probe liquids (e.g., water, ethylene glycol, and diiodomethane), the surface energy components of the aggregate surface can be determined using the approach presented in Giese and van Oss (2002).

The present study was intended to compare the contact angle measurements on a limestone aggregate with different levels of surface roughness. Surface roughness could be an important factor which could affect the contact angle measurements on aggregates. After each polishing stage, the contact angle measurements were conducted using the sessile drop device and surface roughness measurements were taken using a 2D profilometer. The results from the present study imply that if the surface roughness of a solid surface is adjusted to a common platform (e.g., the level of roughness), the sessile drop experiment can bring out the unique properties of the aggregate surface.

EXPERIMENTAL PROGRAM

Sample Preparation

Dolese Hartshorne limestone samples acquired from the respected quarry in Oklahoma were 10 to 20 cm in diameter. The rock samples were sliced using a diamond saw to obtain about 1 to 2 cm in thickness and about 2.5 cm × 3 cm in cross-sectional area specimens. Immediately after the cutting process, specimen was washed with soap and water. The sample was then rubbed with hexane saturated paper towels in order to remove the oil, if any, resulted from the cutting process. After that, the sample was kept in the oven for 12 hours at 105±5°C for drying followed by keeping the specimen in a desiccator for 12 hours to cool down to room temperature. Contact angle measurements were carried out after the drying and cooling processes. Before polishing the samples, contact angle and roughness measurements were taken. As shown in Figure 2, the contact angle measurements were conducted at points 1, 2, 3, 4, and 5. However, roughness measurements were carried out only at points 1, 3, 4 and 5.

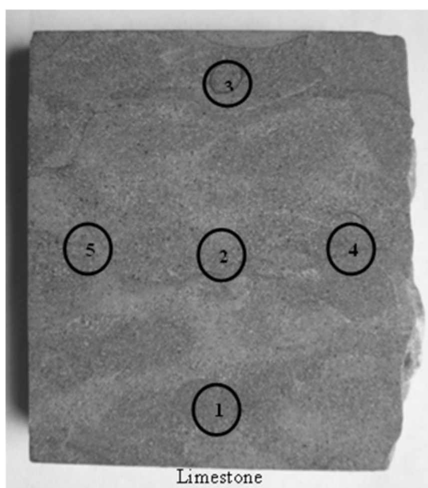

FIG. 2. Photograph of Dolese Hartshorne limestone sample used in this study.

The Dolese Hartshorne limestone specimen was polished on one side with 400 grade silicon carbide grit (400 SiC) after the completion of the initial contact angle measurements and roughness measurements on the unpolished specimen. Contact angle and roughness measurements were repeated after the cleaning and drying processes explained earlier. The specimen was then polished with 600 grade silicon carbide grit (600 SiC) followed by the cleaning and drying processes described above. The contact angle and roughness measurements were conducted after polishing with the 600 SiC grit.

Roughness Measurements

Roughness of the sample was measured using two dimensional (2D) profilometer (Mahr perthometer). The 2D profilometer was equipped with a stylus which travels on a straight line for a specified distance of 5.6 mm to measure the roughness on the line. Arithmetic mean roughness (Ra) was selected to represent the roughness of the sample surface. Arithmetic mean roughness is defined as the average absolute deviation of surface irregularities from the mean line along the assessment length of the profile (Gadelmawla et al. 2002). The Ra is mathematically represented as:

$$Ra = \frac{1}{l}\sum_{0}^{n} yi \qquad (2)$$

where, y_i is the height of peak or valley from the mean line and n is the number of measurements along the assessment length l (Gadelmawla et al. 2002). The Ra gives a general description about the surface height variations (Gadelmawla et al. 2002). Measurements were taken on points 1, 3, 4 and 5 as shown in Figure 2.

Contact Angle Measurements

For measuring contact angles, a sessile drop device (FTA 1000B) is used in this study. The specimen is kept on a horizontal platform on the sessile drop device and an automatic syringe system is used to dispense a probe liquid drop on the specimen. Three probe liquids utilized for the experiment is water, ethylene glycol (EG) and diiodomethane (DIM) (Koc and Bulut 2013). Probe liquids are selected according to Giese and van Oss (2002), from which two polar liquids (water and ethylene glycol) and one apolar liquid (DIM) are used for the study. As soon as a drop is deposited on the surface of the sample, a high resolution camera takes a series of 60 images of the drop making contact with the surface of the specimen. Average contact angle all of these 60 images is reported as contact angle for that location. Later, these images are evaluated by an image analyzing software and the contact angle is determined by fitting a tangent line between the drop and specimen by the software.

A calibration standard, ruby hemisphere of 90 ± 1^{o} is used for the calibration of the sessile drop device preceding the contact angle measurements on the sample. The ruby hemisphere is kept on the platform of the sessile drop device and a series of images are taken. Magnification of the lens is adjusted so that contact angle measured is verified so that it reads within the allowable limit. Contact angle measurements were taken on points 1, 2, 3, 4 and 5 as shown in Figure 2. Five repetitions were made on these five points and overall average of all these readings were considered as the average contact angle of the sample for the particular polishing stage. After each repetition, the sample was washed, dried in the oven for 12 hours and cooled down to room temperature in the desiccator as explained earlier.

RESULTS AND DISCUSSIONS

Two dimensional (2D) surface roughness measurement test results (e.g., Ra values) show that the surface roughness reduces as the specimen is polished progressively from unpolished stage to increasing levels of polishing with finer grits (e.g., 400 SiC and 600 SiC grits). Test results are shown in Figure 3. Previously, Gorgulu and Ceylanoglu (2008) reported a decrease in the Ra value with progressing in polishing stages measured with a 2D profilometer. In their study, the Ra value of limestone sample decreased as the polishing proceeded with different grits of SiC, which is similar to present study. Contact angle values determined in this study using the sessile drop device showed a decreasing pattern when the sample was polished with 400 SiC and 600 SiC grits. The variation of contact angles using probe liquids water, ethylene glycol (EG), and diiodomethane (DIM) are shown in Figure 4. Error bars shows the standard deviation of the contact angle for each polishing stage. As shown in Figure 4, the contact angle with probe liquids EG and DIM reduced after specimen was polished with 400 SiC and 600 SiC grits. However, the contact angle with water showed much lesser variation with polishing when compared to EG and DIM.

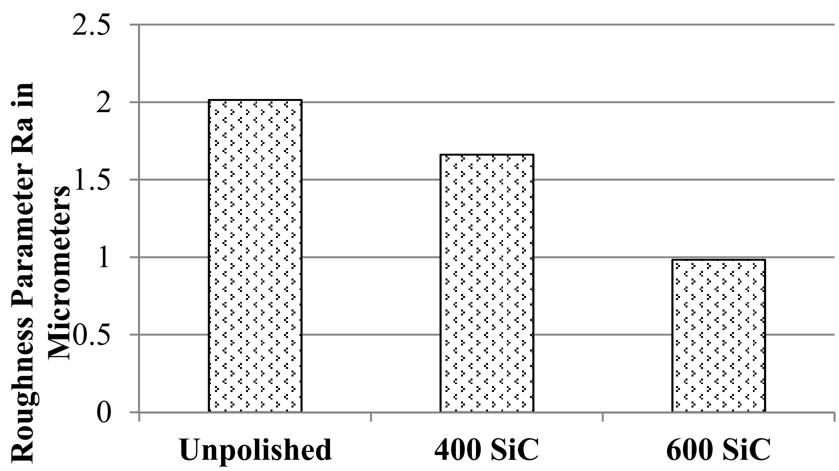

FIG. 3. Variation of surface roughness with different polishing stages.

According to Cassie (1948), it is possible that the surface roughness will cause the liquid to entrap air between the peaks and valleys and therefore the surface will not exhibit the “true” contact angle. Later, when the sample is polished, these peaks and valleys will become less prominent and this could be the reason for obtaining smaller contact angles as the specimen is polished with finer grits.

Even though the contact angle of water has not changed much due to polishing with 400 SiC, there was a reduction in standard deviation. There was a slight reduction in average contact angle for the water when sample was polished with 600 SiC polishing with further reduction in the standard deviation. Also, as shown in Figure 4, there is a reduction in contact angle with EG in 400 SiC polishing stage, but the standard deviation has increased. The calibration technique with ruby hemisphere was introduced after 400 SiC polishing stage and therefore variation in the standard deviation was slightly high. Figures 5, 6 and 7 show the spread of the liquids on the sample in different polishing stages. Spread of the liquid is analyzed by plotting the change in contact angle as soon as it is deposited on the surface of the solid with time elapsed.