THE EVALUATION OF SKID RESISTANCE WITH VARIOUS FILM THICKNESS OF MOISTURE IN DENSE-GRADED ASPHALT CONCRETE

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ABSTRACT

The research objective was to evaluate the skid resistance and film thickness of moisture in dense-graded asphalt concrete. The research scope was to produce testing slabs, utilize the polisher to make polishing efforts, and evaluate the skid resistance with various film thickness of moisture. The 450x450x60-mm testing slabs with 19mm DGAC were made and an in-house wheel-tracking polisher device was utilized to polish specimens from 0, 50,000, 100,000, and 150,000-round. Various film thickness of moisture including 0, 1, 3, 5-mm were set up on the top of the testing slabs to mimic the extreme weather event and the frictional properties were evaluated by the British Pendulum Tester and Dynamic Friction Tester jointly. The test results showed that WTPD is capable of providing incremental polishing efforts to the DGAC specimens in the laboratory; BPN and DFT_{20} decreased 22% and 46% when film thickness of moisture increased from 0 to 3 and 5-mm before the testing slab was polished, respectively; after polishing efforts reached more than 50,000-round.

Key words (3): Skid Resistance, Film Thickness of Moisture, Dense-Graded Asphalt Concrete

INTRODUCTION

The surface course is the only layer visible by vehicle drivers and the only layer in contact with vehicle tires. There are three major Hot Mix Asphalt (HMA) pavement types which are routinely selected for surface mixtures, including: Dense-Graded Asphalt Concrete (DGAC), Stone Matrix Asphalt (SMA), and Open-Graded Friction Course (OGFC). The surface layer should provide adequate friction. Friction properties of surfaces mixtures are significantly related to highway safety. A well maintained surface course provides an adequate level of friction to operate vehicles safely. The classic theory of friction force, as Figure 1, is as known “Coulomb Friction”, expressed as (Eq. 1) (Tipler, 1998):

$$F_f = \mu \times N \qquad \text{(Eq. 1)}$$

Where: F_f = the maximum possible force exerted by friction; μ = the coefficient of friction; N = the normal force to the contact surface.

The modern understanding of the friction force between tire and pavement (Kummer, 1966; French, 1989) believed that the rubber materials (or tire) govern the friction force while molecular-kinetic thermal processes were performed and the molecular chains were created against the contact surface which is considered as the pavement. There are two separate mechanisms involved, hysteresis and adhesion, and estimated as (Eq. 2):

$$F_\mu = F_a + F_h \qquad \text{(Eq. 2)}$$

Where: F_μ = friction force; F_a = adhesion force involved by the interface shear strength and contact area; F_h = hysteresis force generated from losses of rubber materials damping.

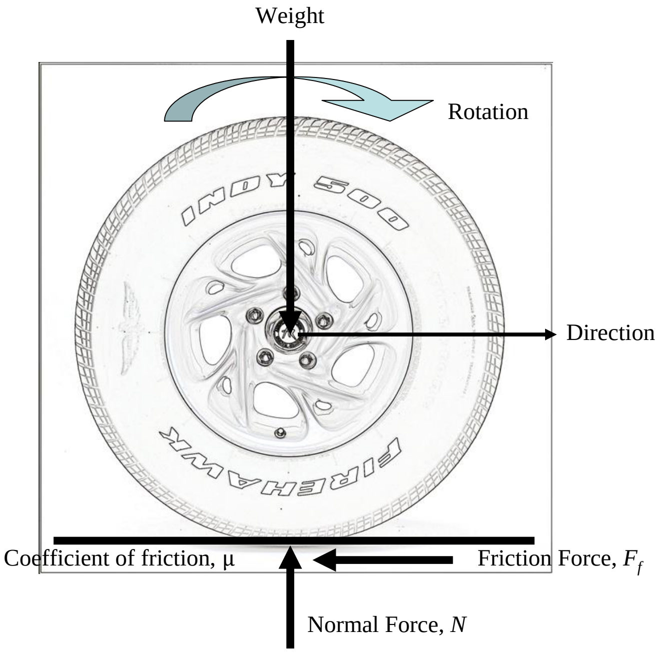


Figure 1: Simple force systems between tire and pavement. (Modified by Dr. Yu-Min Su)

Factors affecting friction

There are a number of factors which influence the frictional properties of HMA pavements. The most important factor is the dry/or wet surface conditions. Pavements under dry conditions will most likely provide appropriate skid resistance. Hence research is mostly focused on the skid resistance under wet conditions or under some severe blizzard weather conditions for which pavements are extremely slippery due to ice and snow. The factors affecting friction are discussed as follows: 1) traffic wearing, 2) water film, 3) tire effect, 4) seasonal variance, 5) aggregate properties, and 6) types of mixture.

To date, it is generally agreed that the pavement friction property depends on both measurements of macro- and micro-texture to estimate the skid resistance. An international standard for terminology in road surface texture has been set by the Technical Committee on Surface Characteristics of the World Road Association's "Permanent International Association of Road Congress" (PIARC, 1997), shown as Figure 2:

a) "Mega-texture": Wavelength= 50 to 500-mm (2 to 20 in.)

b) "Macro-texture": Wavelength= 0.5 to 50-mm (0.02 to 2 in.)

c) "Micro-texture": Wavelength= 1 μm to 0.5 mm (0.0004 to 0.02 in.)

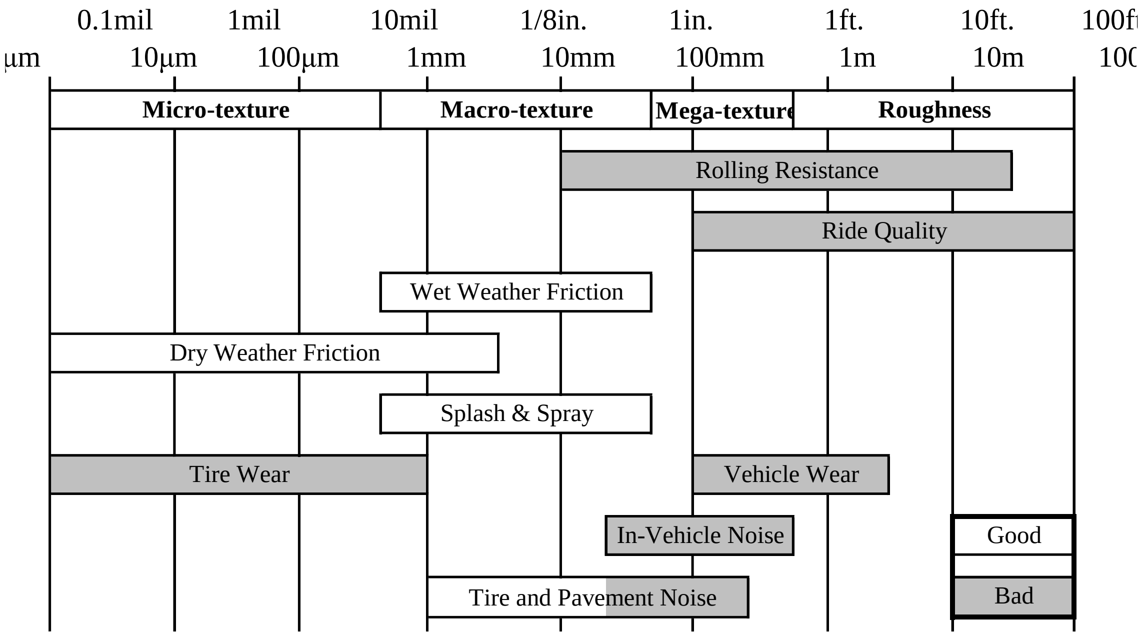


Figure 2: Texture Wavelengths and Pavement-Tire interactions (Modified) (43).

Methods for measuring friction

Locked wheel device: Wet pavement friction measurements could be obtained by using the ASTM E274 towed friction trailer which is practiced in many states. Typically, the towed friction trailer allows two types of tires for friction evaluations including the most often used Standard Rib Tire for Pavement Skid-Resistance Test (ASTM E-501) and Standard Smooth Tire for Pavement Skid-Resistance (ASTM E-524).

Figure 3: ASTM E-274 towed trailer of National Freeway Bureau in Taiwan. (Photo taken by Dr. Yu-Min Su)

National Freeway Bureau (NFB) in Taiwan routinely uses the rib tire on the trailer, shown as Figure 3. A locked tire with 165 kPa (24 psi) of pressure sliding on a wetted surface, under a constant speed and load, could help measure the steady-state friction force. When the towed trailer reaches to 64 km/h (40 mph) of standard test speed, the wheel break is locked after the watering system provided a water film of 0.5mm (0.02 in). The locked wheel should be maintained 100 percent sliding on the testing surface at least 1.0 second to receive frictional data, reported as Skid Number or Friction Number (SN_{40}).

Measurement of macro-texture: The traditional method to have the macro-texture measurement is Sand Patch test (ASTM E965). The method consists of spreading a fixed volume of dry Ottawa sand or glass spheres over the surface and working them into the surface texture in a circular pattern. The sand should be spread until it is flush with the tops of any surface asperities. The area covered by the sand and the known volume of sand allow calculation of the average texture depth, called the Mean Texture Depth (MTD). The method and equipment are simple, but significant variability (poor repeatability) in the measurements has been reported. In addition, only an average texture depth can be obtained. No further analysis of the nature of that texture depth can be accomplished. The Circular Texture/Track Meter (CTM), shown in Figure 4(A), is another advanced way to measure pavement macro-texture. By CTM, the Mean Profile Depth (MPD) of a pavement surface property can be measured in accordance with ASTM E2157.

Measurement of micro-texture: Micro-Texture, on the other hand, can be measured in the field or the laboratory using the device such as British Pendulum Tester (BPT) and the Dynamic Friction Tester (DFT) in accordance with ASTM E303 and ASTM E1911, respectively. The BPT has been used for many years, shown in Figure 4(B). However, like sand patch method for macro-texture, the results of BPT are typically variable than with the advanced DFT. As shown in Figure 4(C), DFT is a portable device that allows direct measurement of the surface friction of a variety of contacting speeds.

EXPERIMENTAL PROGRAM

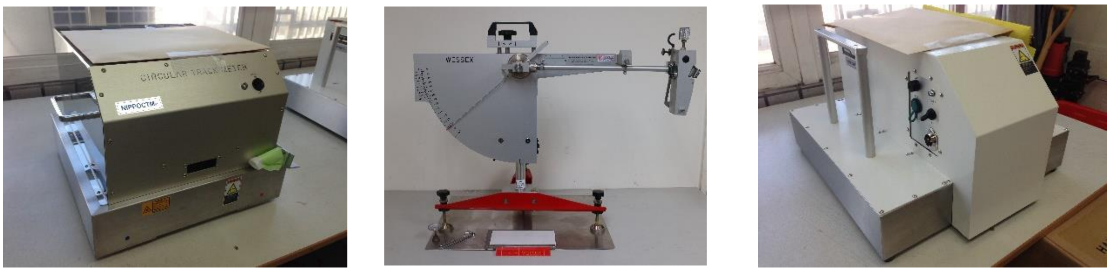
The research objective was to evaluate the skid resistance and film thickness of moisture in dense-graded asphalt concrete. The research scope was to produce testing slabs, utilize the polisher to make polishing efforts, and evaluate the skid resistance with various film thickness of moisture. The 450x450x60-mm testing slabs with 19mm DGAC were made and an in-house wheel-tracking polisher device was utilized to polish specimens from 0, 50,000, 100,000, and 150,000-round. Various film thickness of moisture including 0, 1, 3, 5-mm were set up on the top of the testing slabs to mimic the extreme weather event and the frictional properties were evaluated by the British Pendulum Tester and Dynamic Friction Tester jointly. It is worthy to note that this pilot study was performed and assessed in the Laboratory of Asset management and Pavement engineering with Smart technologies (LAPS) at the Department of Civil Engineering of the National Kaohsiung University of Science and Technology, located in Kaohsiung, Taiwan.

DGAC mixture and preparation of testing slabs

Plant-made DGAC mixes were blended in a local batch-type asphalt plant and utilized to compact into the testing slabs. DGAC mixtures were earlier identified as the 19-mm mixture blended in accordance with ASTM D3515 which has been commonly used asphalt concrete for the surface layer in Taiwan. The mixtures were thereafter transported and compacted into a 450×450×60-mm wooden frame by using a heavy steel-wheel device, shown in Figure 5. The steel-wheel device acquires two persons to operate and there is a vibration function to facilitate compacting efforts over asphalt mixtures.

Utilization of the in-house wheel-tracking polishing device

An in-house wheel-tracking polishing device (WTPD), similar with other polishing devices developed in NCAT and Purdue, was manufactured in a local precision machinery shop and it provides up to 59.8 Kg (131.8 pounds) of overall lording perpendicular to the testing specimen, shown in Figure 6(A). The WTPD consists of three pneumatic tires, shown in Figure 6(B), and three tires run on a circular path with its diameter of 284mm, which is consistent with that of CTM and DFT measure. Hence, WTPD is able to evaluate the polishing efforts over any surfaces in conjunction with the micro- and macro-texture measurements. In this study, three designated polishing efforts, namely 0, 50,000, 100,000, and 150,000 rounds, were achieved with maximum 59.8Kg of loading perpendicular to the DGAC specimen. It has to be noted that the WTPD consists of the water supply system to spread water on the surface of the testing slabs. The temperature of tap water was known around 23°C during the tests were performing.



(A) (B) (C)

Figure 4: (A) Circular Texture/Track Meter, (B) British Pendulum Tester, and (C) Dynamic Friction Tester (Photos taken by Dr. Yu-Min Su).

Figure 5: Compacting DGAC mixture into a wooden frame. (Photos taken by Mr. Siang-Hao Liang)

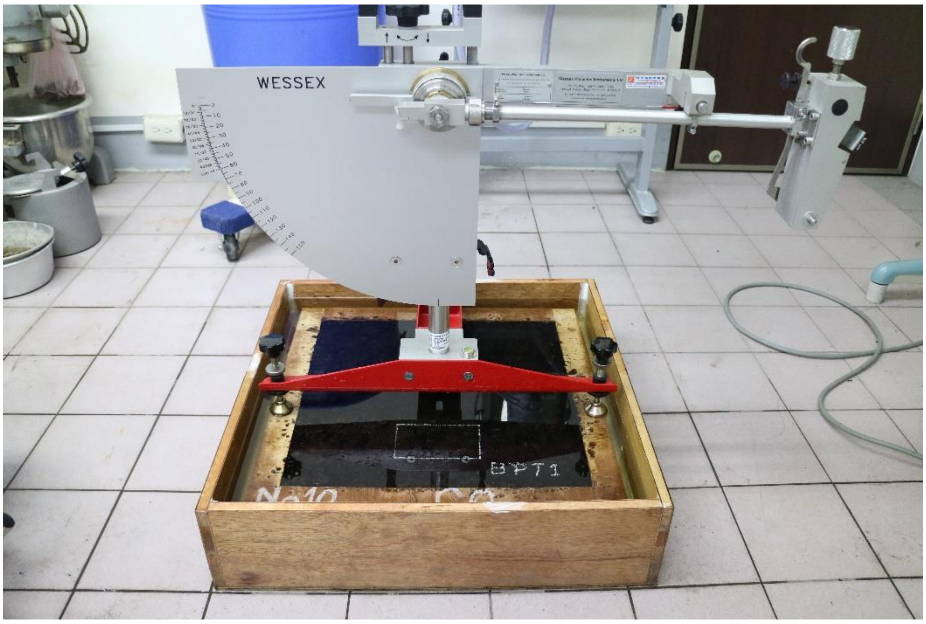
(A) (B)

Figure 6: (A) In-house wheel-tracking polishing device (WTPD); (B) a view of eight-inch pneumatic tires. (Photos taken by Mr. Siang-Hao Liang)

Various film thickness of moisture

In this study, four different conditions in film thickness of moisture were assessed, namely 0, 1, 3, 5-mm. The compacted DGAC specimen was placed in a wooden-made container and designated film thickness of moisture can be prepared for the following frictional testing, shown in Figure 7(A). It has to be noted that the condition of 0-mm film thickness was arranged to submerge the specimen in water for an overnight and later pad drying the surface to reach the saturated surface dry (SSD) condition. It was to utilize various film thickness of moisture to mimic different surface run-off conditions during the extreme weather events and evaluate the skid resistance. The BPT and DFT can set up on the specimen to measure the frictional properties while different film thickness were administrated, shown in Figure 7(B).

(A)



(B)

Figure 7: (A) Preparations of various film thickness of moisture; (B) Setting up BPT to measure the skid resistance of the specimen. (Photos taken by Mr. Siang-Hao Liang)

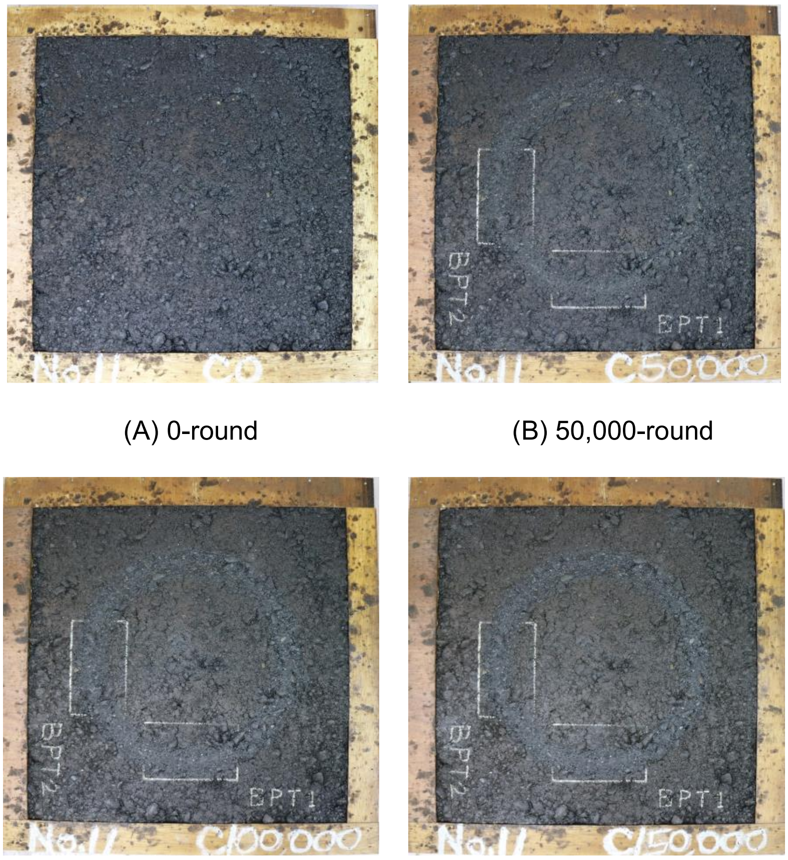
ANALYSIS AND DISCUSSIONS

There are two initial experimental results presented in this paper, including incremental polishing efforts in conjunction with WTPD and frictional properties of BPT and DFT.

Results of polishing effort in conjunction with WTPD

There were 0, 50,000, 100,000, and 150,000-round of polishing efforts in conjunction with WTPD made on the compacted DGAC slabs. Figure 8 (A) (B) (C) (D) show increasing WTPD polishing efforts, namely the incremental rounds of three-wheels traveling over the specimen: before the procedure of polishing initiated, the specimen exhibited an even surface; after the first 50,000-round of polishing, a “ring” or “donut” was shed light on the path of three-wheel being travelled and polished. The more rounds of it rotated, the more noticeably the polished path is shown.

As it was anticipated, WTPD featuring pneumatic wheels contributed adequate efforts to polish the surface. Figure 9 (A) (B) display such aftermath after 150,000-round of polishing efforts. The close-up views revealed certain level of consolidation on the polished path in comparison with surface conditions in the adjacent area. In addition, asphalt binders or mastics originally coated on the coarse aggregates were partially polished from the surface of aggregates. The texture of aggregate was thereafter exposed. However, extensive polishing efforts also stripped off asphalt binders or mastics around the coarser aggregates which might cause a rather rough surface on the polished path. The frictional properties after those polished efforts are of concerns.



(A) 0-round (B) 50,000-round

(C) 100,000-round (D) 150,000-round

Figure 8: Specimen subject to (A) 0-round; (B) 50,000-round; (C) 100,000-round; (D) 150,000-round of polishing efforts. (Photos taken by Mr. Siang-Hao Liang)

(A)

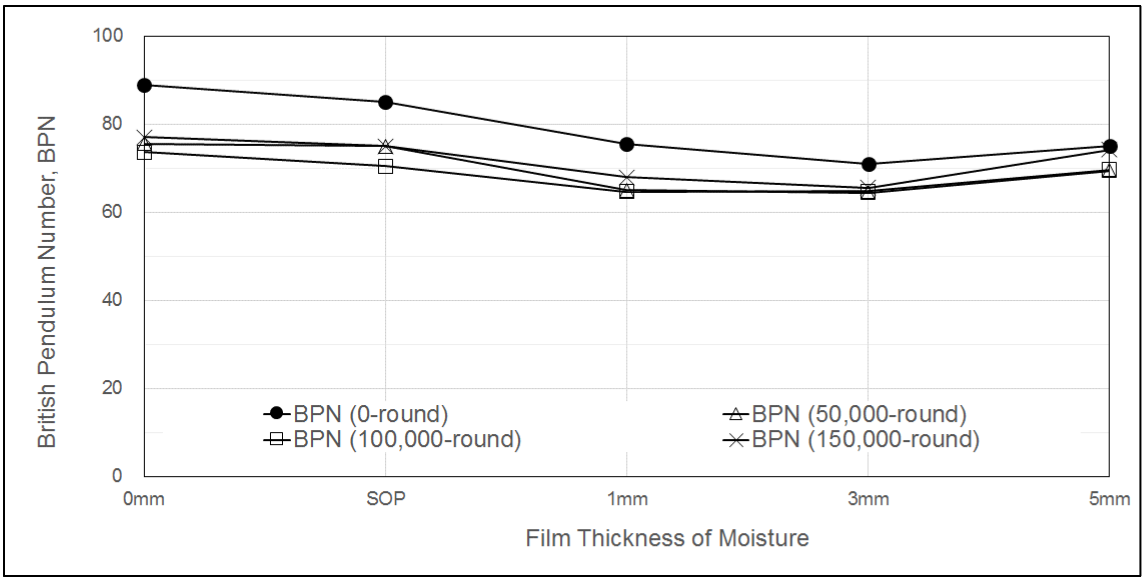
(B)

Figure 9: (A) (B) Close-up views of the DGAC specimen after 150,000-round of WTPD polishing efforts. (Photos taken by Mr. Siang-Hao Liang)

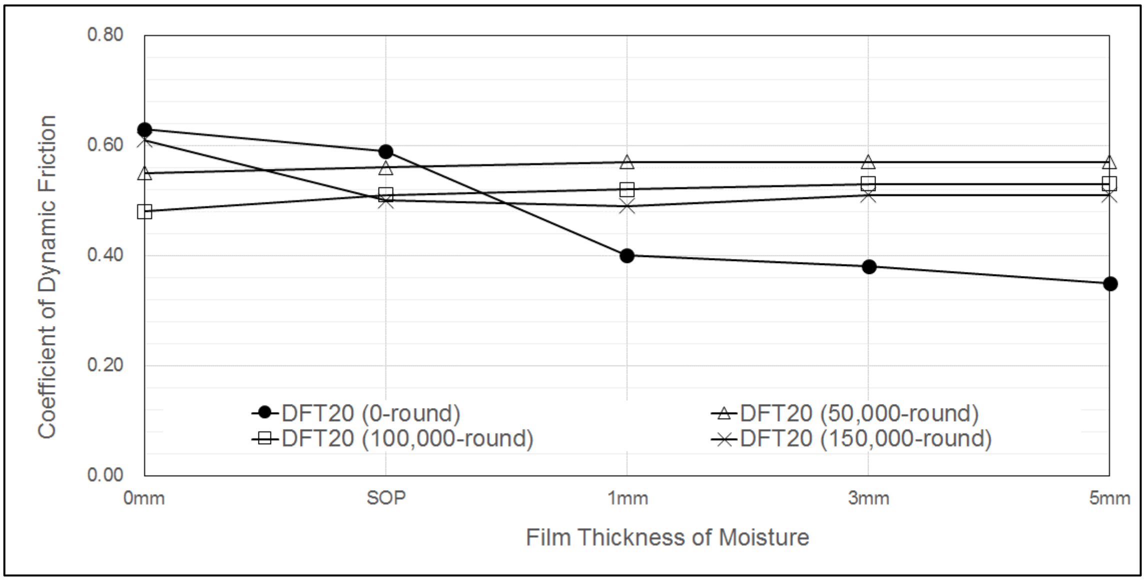
Results of frictional properties of BPT and DFT

In this study, BPN and DFT_{20} were utilized to analyze the frictional properties along with different polishing efforts and film thickness of moisture. Figure 10 (A) and (B) demonstrate experimental results in BPN and coefficient of dynamic friction, respectively.

In terms of BPN, the thicker film of moisture it was, the BPN decreased. The major reduction can be found for the unpolished surface condition. BPN dropped from nearly 90 (0-mm) to 70 (3-mm), which was about 22%; the reductions in BPN for surface conditions subject to different polished efforts, namely 50,000, 100,000, and 150,000-round, were seemingly similar to each other and BPN dropped from nearly 75 (0-mm) to 65 (3-mm). However, both BPN of unpolished and polished surface conditions slightly increased, when film thickness reached to 5-mm. More future tests and data interpretations are needed to collect and validate.



(A) BPN



(B) DFT

Figure 10: (A) (B) Frictional properties of BPN and dynamic friction featuring different film thickness of moisture. (Figures organized by Dr. Yu-Min Su)

In terms of DFT_{20}, it generally agrees with that the thicker film of moisture it was, the DFT_{20} also decreased for the unpolished surface condition. The DFT_{20} dropped from nearly 0.65 (0-mm) to 0.40 (1-mm), 0.38(3-mm), and 0.35 (5-mm), which was about 46%; for polished surface conditions, DFT_{20} reading were generally steady among 0.50 to 0.55, no matter what levels of polishing efforts were achieved. The best rationale can be conceptually presumed when the asphalt binders or mastics are coated on the coarse aggregates, the dynamic friction reduces dramatically when film thickness of moisture reaches to 1-mm or more; however, when asphalt binders or mastics are removed from the aggregates by the WTPD polishing efforts, the exposed aggregates are able to offer distinct yet uniform contributions to the overall skid resistance. It also has to be noted that SOP conditions for both BPN and DFT tests refer to the testing condition in accordance with ASTM standards aside from planned film thickness of moisture.

CONCLUSIONS AND RECOMMENDATIONS

The main findings of utilizing BPT and DFT to evaluate frictional properties along with different WTPD polishing efforts and various film thickness of moisture are as follows:

- The in-house made WTPD is capable of provide incremental polishing efforts to a laboratory-prepared testing slab. The frictional properties due to incremental polishing efforts can be assessed by CTM, DFT, and BPT in the laboratory and it also causes removal of asphalt binders or mastics from the asphalt mixture.

- BPT and DFT can serve as good assets to evaluate frictional properties. Both BPN and DFT_{20} reduced up to 22% and 46% for the unpolished surface, when film thickness of moisture increased from 0 to 3 or 5-mm, respectively. After 50,000-round or more efforts were polished, both BPN and DFT_{20} show stable frictional properties, which can be attributed to the exposed aggregates texture.

- More similar tests to DGAC specimens are required to collect, test, and validate in the future. Micro- and macro-texture evaluations are also suggested and performed in conjunction with CTM. The analysis can later utilize data of MPD measured by CTM and coefficient of dynamic friction measured by DFT and International Friction Index or IFI can be calculated and studied.

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Mr. Sian-Hao Liang is a graduate research assistance who works in the Department of Civil Engineering at the National Kaohsiung University of Science and Technology. Mr. Liang's current research work is to investigate the skid resistance of the plant-mix asphalt concrete in Taiwan;

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