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Evaluation of LADOTD Aggregate Friction Rating Table by Field Measurements

by

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16. Abstract

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The collected data and measurements were used to perform comprehensive statistical analyses of the influence of aggregate properties and mixture design on skid resistance value and its variability. Statistical correlation models were developed among different measurement devices as well as various surface texture and frictional properties. Consequently, the analysis results led to the development of a procedure for predicting pavement end-of-life skid resistance based on the design traffic, aggregate blend polish stone value and gradation parameters. The developed friction prediction procedure can be used to update the current DOTD coarse aggregate friction table by specifying the pavement friction requirements under different traffic levels through selection of different mixture and aggregate types. Moreover, the DFT and CTM measurements observed on field pavement surfaces of this study were compared with those measured on laboratory-prepared slab surfaces obtained in the LTRC Project 09-2B. Finally, a benchmark DFT rating table based on the traffic level and mixture type was proposed for the DFT20 value after 100,000 polishing cycles, which can be used to evaluate the friction resistance of the new aggregate sources to be certified by DOTD.

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IMPLEMENTATION STATEMENT

The developed skid resistance prediction procedure based on the design traffic, aggregate blend polish stone value, and gradation parameters should be considered for implementation in routine wearing course mix design of DOTD.

The PSV-based friction rating table should be replaced by a new wearing course coarse aggregate friction requirement table based on blend PSV, mixture type, and traffic recommended in this report.

The speed gradient equations for both ribbed- and smooth- tire skid numbers should be implemented by the Pavement Management Section in converting the skid number measurements of different speeds into single-speed based skid number measurement values.

This study also demonstrated that the friction requirement of new aggregate sources should be certified by the laboratory polishing slab test using a Three Wheel Polishing Device (TWPD). Further TWPD testing are recommended on one mix type (such as 12.5-mm Superpave or SMA) using both one very good and one very poor coarse aggregate sources.

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INTRODUCTION

According to the National Highway Traffic Safety Administration, 32,999 traffic crashes were fatal, 3.9 million citizens were injured, and 24 million vehicles were damaged during the year of 2010 *[1]*. In addition to human loss, crashes also have an effect on the nation's economy. In the same report by Blincoe et al., the economic costs of crashes were reported as $277 billion and if quality of life valuations were considered, the total societal and economic cost was $871 billion *[1]*. Crashes are always complex in nature; however, there are mainly three factors causing highway crashes: driver related, vehicle related, and highway condition related *[2]*. Among them, transportation agencies can only control highway conditions to reduce crashes. Within highway condition, low friction of the pavement especially at wet conditions is a principal factor in crashes *[3]*. In order to ensure a satisfactory surface friction condition throughout the service life of a pavement, many state highway agencies have developed specifications and friction design guidelines.

In NCHRP report 1-43, Hall et al. conducted a survey to identify the current status of the evaluation and design practices on pavement friction by different states *[4]*. According to the survey, most of states are using skid trailer for surface friction measurements and polish stone value (PSV) as the material selection criteria to fulfill the friction requirements. Illinois DOT considers different mixture types to fulfill friction requirements based on ADT. With an increase in ADT the use of higher friction performing mixture are suggested. Maryland State Highway Administration uses aggregate PSV value to fulfill friction demand at different friction requiring road section such as approaching railroad crossing, traffic lights, pedestrian crossing, roundabouts and intersections *[5]*. Michigan DOT uses aggregate wear index value as friction guidelines considering ADT *[6]*. Pennsylvania DOT has categorized surface aggregate sources based on skid resistance level as low, medium, good, high grade and excellent and recommends the use of higher quality aggregates as ADT increases *[6]*.

To ensure sufficient pavement skid resistance, DOTD currently uses the aggregate friction rating table, which is based on the PSV, as the only guideline to select the coarse aggregate in the wearing course mixture design. But the PSV of the coarse aggregate is only one of the many factors that affect pavement surface friction. The previous LTRC research project 09-2B indicated that low skid-resistant aggregates could be used in a wearing course mix design by blending with high skid-resistant aggregates to produce a satisfactory level of surface friction as required. Therefore, there is a need to modify the current aggregate friction rating table by using the indices that can reflect the real field friction performance with proper threshold values. In this way, the Department will have the flexibility to specify aggregates for asphalt mixtures with various qualities to achieve better cost-benefit ratios.

Summary of Literature

Introduction of Pavement Surface Friction and Texture

Pavement friction is defined as the ratio of vertical and horizontal force developed as a tire slides along a pavement surface. It is a resistive force at the contact surface acting opposite to the direction of movement. The friction between the tire and pavement is the most important factor in reducing crashes *[3, 4]*. Pavement surface friction is also known as the skid resistance. Noyce et al. defined skid resistance as the friction force developed at the contact area of tire and pavement *[2]*. One of the common field friction resistance measuring devices is a locked wheel skid trailer (LWST), which measures the friction resistance termed as skid number (SN). DOTD uses the LWST to measure the in-situ friction of the pavements.

When a pavement surface gets wet, it loses significant amount of friction. A study from Kentucky showed that crashes at wet weather condition increases as surface friction decreases *[7]*. The study from Texas also found a higher percentage of crashes at lower friction surface and vice versa *[4]*. Recently, Najafi et al. concluded that friction has significant impact on rate of car crashes not only when the pavement is wet but also when it is dry *[8]*.

Tire pavement friction is composed of two components, adhesion and hysteresis. The bonding and interlocking between rubber and pavement aggregates results in the adhesion mechanism. On the other hand, hysteresis is heat energy developed during tire pavement interaction. The tire will be deformed when it comes in contact with gap between pavement surface aggregates. Once a deformed tire comes into relaxation, part of the stored energy will be recovered and part of it will be lost in the form of heat energy. This loss of energy in the form of heat inducing friction is known as hysteresis *[9]*. Both components are related to surface characteristics and tire properties. Adhesion is more related with micro texture, whereas hysteresis is more related with macro texture *[4]*. Figure 1 illustrates the tire surface friction mechanisms.

Pavement surface friction is affected by four major factors: pavement surface characteristics, vehicle operating parameters, tire properties, and environmental factors (Table 1) *[4]*. Among the four types listed in Table 1, highway agencies can only control the pavement surface characteristics. This research also focuses on the friction from pavement surface characteristics.

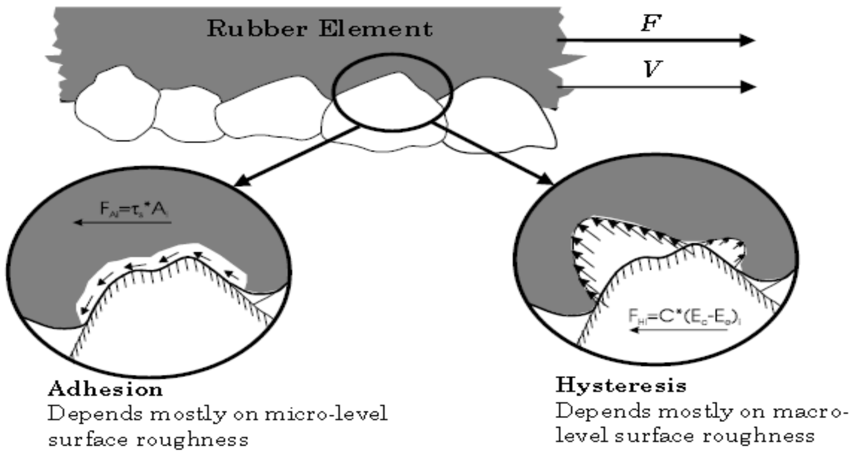


Figure 1
Mechanism of pavement tire friction

Table 1
Factors affecting pavement friction *[4]*

Pavement Surface Characteristics	**Vehicle Operating Parameters**	**Tire Properties**	**Environment**
Micro-Texture Macro-Texture Mega-Texture/ Unevenness Material Properties Temperature	Slip Speed -Vehicle Speed -Braking Action Driving Maneuver -Turning -Overtaking	Foot Print Tread Design and condition Rubber composition and hardness Inflation Pressure Load Temperature	Climate Wind Temperature Water (rainfall, condensation) Snow and Ice Contamination (Fluid) -Anti-skid material (salt, sand) -Dirt, mud , debris

The American Association of State Highway and Transportation Officials (AASHTO) guide for pavement friction defines texture as the deviation of the pavement surface from a true planar surface. The friction related texture properties are known as macro-texture and micro-texture *[10]*. The criteria to distinguish different texture based on wavelength ( ) and amplitude (A) established by Permanent International Association of Road Congress (PIARC) in 1987, are as follows:

- Micro- texture (< 0.02 in, A= 0.04 to 20 mils) – Surface roughness quality at the sub – visible or microscopic level. It is a function of the surface properties of the aggregate particles contained in the asphalt mixture.

- Macro – texture (= 0.02 to 2 in, A= 0.005 to 0.8 in) – Surface roughness quality defined by the mixture properties (shape, size and gradation of aggregate) of asphalt mixture.
- Mega – texture (= 2 to 20 in, A= 0.005 to 2 in) –Texture with wavelengths in the same order of size as the pavement – tire interface. It is largely defined by the distress, defects, or "waviness" on the pavement surface.

Among the pavement surface textures mentioned above, micro-and macro-textures are the major features as shown in Figure 2 for the pavement surface friction *[11]*. In addition, there are a vast number of studies in literature which describes the effect of micro-and macro-texture in pavement surface friction *[12-17].*

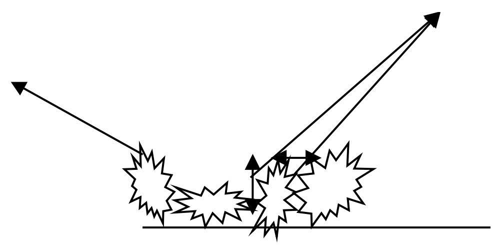


Figure 2
Microscopic view of pavement surface showing micro and macro texture

Texture and Friction Measurements

It is well known that the pavement surface friction is affected by both micro- and macro-texture. Micro-texture mainly influences the magnitude of the pavement friction, while macro-texture mainly impacts the friction-speed gradient (changing rate of measured friction with slip speeds) *[4]*. For flexible pavements, the micro-texture is mainly affected by the surface texture of the coarse aggregate, and the macro-texture is mainly affected by the gradation and volumetric properties of the HMA mixture. The macro-texture of the pavement is often characterized by mean texture depth (MTD) and mean profile depth (MPD). Many different devices are available for characterizing pavement friction and texture. Some of the devices can only be used in the field; other devices can be used in both the laboratory and the field. In this report, four of the most commonly used friction and texture measuring devices are described, namely the Locked Wheel Skid Trailer (LWST), British Pendulum Tester (BPT), Dynamic Friction Tester (DFT), and Circular Track Meter (CTM). More comprehensive reviews of the friction and texture testing devices have been provided by other researchers *[3, 4, 18, 19].*

Relationships between Different Friction Test Devices

The friction between the rubber and road surface is a complicated phenomenon and is affected by many factors, such as slip speed, the texture of the pavement, contaminants on the road surface (water, snow, dust, etc.), and rubber properties (which are dependent on temperature and slip speed) *[20]*. Therefore, even at the same location on the same pavement, different test devices often show different measured frictions.

Previous studies have investigated the correlation between the friction measurements from different test devices. In this section, two correlations are reviewed: (1) the correlation between the LWST skid numbers measured from smooth and ribbed tires and (2) the correlation between the LWST skid number and the friction number measured from portable friction devices.

The original LWST is equipped with two ribbed test tires, one on each side of the trailer. Ribbed test tire is less sensitive to the flow rate of the water delivery system, thus the measured skid number is more reproducible among different devices *[21]*. However, the ribbed test tire is not sensitive to the pavement surface macro-texture (texture at the magnitude of 0.02 to 2 in.). Because the grooves on the ribbed tire are able to provide adequate water drainage capacity regardless of the macro-texture of the pavement. This limitation was noticed by early researchers when evaluating effect of surface grooving on the skid resistance of the pavement using LWST *[22]*. It was found that the benefit of surface grooving on the wet pavement friction can only be justified using LWST with smooth test tires. Smooth test tire relies on the macro-texture of the pavement to reduce the water-film thickness between the tire and the pavement, thus the skid number measured with smooth tire is sensitive to both micro- and macro-texture of the pavement. The quantitative relationship between the smooth and ribbed test tire was investigated by many researchers. Henry and Saito compared the LWST test data using both tires in 22 field sections with various aggregate and mix types in Pennsylvania *[23]*. It was found that the ratio of the measured skid numbers from ribbed and the smooth test tires correlated well with the macro-texture of the pavement [as shown in equation (1)].

$$(\quad) \tag{1}$$

where,
SN40R= Skid number measured by LWST with a ribbed tire at the speed of 40 mph;
SN40S= Skid number measured by LWST with a smooth tire at the speed of 40 mph;
MTD= Mean texture depth.

Before DFT became available, LWST skid number of the pavement were often correlated to British Pendulum Number (BPN) or polished stone value (PSV), which is the BPN on the polished aggregate surface. Since BPT can be run in both laboratory and field, this type of correlation will facilitate the prediction of field skid number in the laboratory. Parcell et al.

observed linear correlations between BPN and LWST skid number at various speeds based on field test data from 25 pavement sections with two types of dense graded wearing course mixes in Kansas *[24]*. Diringer and Barros developed a non-linear correlation between the terminal skid number and the PSV of the aggregate by comparing the field and laboratory test data for 26 sites in New Jersey *[25]*:

( ) (2)

where,

$SN40R_{terminal}$ = Terminal skid number measured by LWST with a ribbed tire at the speed 40 mph;

PSV= polished stone value.

As explained previously, BPN and PSV are both indicators of the micro-texture of the pavement. Therefore, in the above-mentioned correlations, the effect of macro-texture is ignored. In fact, pavement friction is a combined effect of both micro- and macro-texture *[10]*. Thus more researchers believed that a better correlation with LWST skid number can be achieved by considering both micro- and macro-texture of the pavement *[1, 26, 27, 28]*.

Leu and Henry analyzed the skid resistance data collected from 20 test sections in West Virginia and developed a prediction model for ribbed-tire skid number considering both micro- and macro-texture *[27]*. In this model, the micro-texture of the pavement (measured by BPN) affects the intercept skid number at zero speed SN_0 whereas the macro-texture (measured by sand-patch MTD) of the pavement affects the speed gradient of the measured LWST skid number. The developed model is shown in equation (3). An approximation equation [equation (4)] for calculating SN40R was further proposed by Balmer and Hegmon.

( ) ( ) (3)

( ) √ (4)

where,

SN(S)R= Ribbed-tire LWST skid number at test speed ;

BPN = British Pendulum friction number; and

MTD = Sand-patch mean texture depth (mm).

Henry later proposed a simple linear regression model between the skid number, BPN, and sand-patch MTD as shown in equations (5) and (6) *[28]*. He determined the regression constants based on test data collected from 22 test sections in Pennsylvania. These test sections involved different types of pavement surface including conventional mix, open-graded mix, and special surface treatments. Henry also noticed a seasonal variation in the regression constants by comparing the test data collected in fall 1978 and spring 1979 *[28]*.

(5)

(6)

where,

SN40R, SN40S = skid number measured by LWST at 40 mph with the ribbed tire and the smooth tire respectively;

BPN = British Pendulum friction number;

MTD = Sand-patch mean texture depth (mm); and

a_0, a_1, a_2, b_0, b_1, b_2= Regression constants.

One of the most popular harmonization models is the international friction index (IFI) model developed by PIARC *[29]*. A total of 41 different devices (27 friction devices and 14 texture devices) from 16 countries were involved in the PIARC study. In order to harmonize the test results from different devices, the average friction number was used. It was measured by all the smooth tire testers at 60 km/hr as the golden (or the reference) friction number F (60). The speed of 60 km/hr was considered as the average stopping speed of vehicles on the road. The smooth tire testers were chosen based on the consideration that pavement friction is more affected by macro-texture at higher sliding speeds and smooth test tires are known to be sensitive to both micro- and macro-texture of the pavement.

F (60) can be calculated from the friction number and texture (MPD or MTD) measured by any device at any slip speed in two steps. First, convert friction number FRS measured at slip speed S to the friction number FR60 measured by the same device at 60 km/hr using equations (7) and (8). Secondly, convert FR60 to the IFI reference friction number F (60) using equation (9).

(7)

(8)

( ) (9)

where,

S_p= IFI speed number;

a, b, A,B and C= Calibration constants, C = 0 for smooth-tire devices;

TX= Pavement macro-texture in either MPD or MTD;

FRS= Friction number measured at slip speed S by any device;

FR60= Friction number measured at slip speed 60 km/hr; and

F60=IFI reference friction number.

The PIARC model has been accepted by American Society of Testing and Materials (ASTM) in the standard ASTM E 1960. The current version of this standard is ASTM E 1960-07. ASTM E 1960 suggests using DFT20 (ASTM E 1911) as a measure of micro-texture and MPD (ASTM E 1845) as a measure of macro-texture to calculate F(60), which can then be used to calibrate the calibration constants (A, B and C) for other devices. A single pair of calibration constants (a=14.2 and b=89.7) is adopted in ASTM E 1960 to calculate the speed number from MPD. Since the skid number measured by LWST and the friction number measured by DFT or BPT can both be converted to F60 using the IFI model, correlations between these friction measurements can be established. However, a continued study in Europe on the harmonization model suggested that the correlation between the speed number and pavement texture does not match for different devices *[30]*. Other researchers found that the re-calibration of the factors (a, b, A, B, and C) in the PIARC model is required *[9, 31]*.

Flintsch et al. reported a collaborated field test study by six state DOTs to re-evaluate the IFI model *[9]*. The field test was carried out with 5 different friction testers on 24 test sections on Virginia Smart Road with different mixture types. The researchers of this study compared the IFI friction number F (60) calculated from the DFT20 and MPD with F (60) obtained by other high-speed friction testers. It was found that the IFI model does not produce harmonious results among the devices used by the consortium members in the Virginia Smart Road Rodeo for the surfaces tested. Meanwhile the speed number (S_p) measured from all of the five friction testers showed poor correlation with the MPD, no matter whether a linear or a power model was used, although the power model did fit the test data slightly better. The research team finally re-calibrated the calibration constants (a, b, A, B, and C) in the IFI model for different devices investigated.

Fuentes and Gunaratne analyzed the 2007-2008 Wallops Runway Friction Workshop data collected from 14 different pavement surfaces using different test devices *[32]*. These researchers confirmed that the IFI speed number S_p depends on not only the macro-texture of the pavement but also the test device. A modified procedure was proposed to calibrate the calibration constants of the IFI model *[32, 33]*.

Jackson conducted a field test study for comparing different friction and texture test devices *[31]*. Field tests (LWST, DFT, and CTM) were first conducted on 10 road test sections at the national center of asphalt technology (NCAT). Each of the NCAT test section is 200 ft. long. The friction of each section was measured with LWST at 40 mph with both ribbed and smooth test tires. CTM and DFT were run at 5 different locations in each section. The researchers of this study re-calibrated constants (A and B) for the LWST based on the IFI model (equation (9)). Similar field friction and texture tests were then conducted on 10 Florida DOT road sections (3 open graded, five dense graded, and two concrete pavement sections) in order to validate the calibrated IFI speed number model. The research team found that the calibration factors obtained from the Florida test sections were quite different from those obtained from the NCAT sections.

Liang collected a series of pavement friction (from DFT and LWST) and texture (MPD from CTM) data from 8 road sections in Ohio *[6]*. The purpose of collecting the field data was to develop correlations between the skid resistance of field pavements and the laboratory test results from an accelerated polishing machine developed by the researcher. The 8 test sections were selected to include low, medium, and high friction aggregates. Each test section was about 500 ft. long. All the tests were conducted in the left wheel path. Instead of using the IFI model, single- and multi-variable regressions were performed to analyze the test data and a number of correlations were built between the skid number SN40R and the friction and texture measurements (MPD, DFT20, and DFT64) of the pavement. For example, the multi-variable regression correlations were shown in equations 10 to 12. Laboratory polishing tests were performed on the HMA samples prepared based the same job mix formula (JMF) of the road sections.

(10)

(11)

(12)

where,
SN40R= Skid number measured by LWST with a ribbed tire at the speed of 40 mph;
DFT20= Friction number measured by DFT at the speed of 20 km/hr;
DFT64= Friction number measured by DFT at the speed of 64 km/hr;
MPD= Mean profile depth in mm.

The National Center for Asphalt Technology (NCAT) performed a study to investigate the relationship between the frictional characteristics of the laboratory polished HMA samples and the skid number measured in the field *[34]*. In Phase I of the study, the optimized laboratory test procedure was developed using an NCAT three-wheel polishing device (TWPD) *[35]*. In Phase II of the study, DFT was run on four different wearing courses mixes (two stone matrix asphalt mixes and two dense graded asphalt mixes) after different number of TWPD polishing passes. These wearing course mixes were prepared using the same aggregate source and mix design as the corresponding NCAT test sections. The skid number after certain numbers of ESALs was measured on the test section by LWST with a ribbed tire at 40 mph. In this study, the number of laboratory polishing passes was related to the number of ESAL in the field by a linear relationship. It was observed the friction characteristics measured in the laboratory and the field both showed an initial increase with the polishing cycles probably due to the loss of the binder and the subsequent exposure of the aggregate in the initial polishing state. The friction usually reaches the maximum at around 16,000 polishing passes in the laboratory and around 1.2 million ESALs in the field. Therefore, it was assumed that 32,000 polishing passes in the laboratory should also have the same effect as about 2.4 million ESALs in the field, and so on. After paring the laboratory polishing passes with the number of ESALs in the field, the DFT60 measured from the laboratory samples was correlated to the corresponding SN40R measured in the field by linear regression [equation (13)]. It was found that SN40R correlates very well with the DFT60 by the linear equation with an R^2 of 0.935.

(13)

where,
SN40R = Skid number measured by LWST with a ribbed tire at the speed of 40 mph;
DFT60 = Friction number measured by DFT at the speed of 60 km/hr;

Friction Mixture Design Guidelines

Losuiana DOTD currently uses a aggregate friction rating table (Table 2) to ensure the suffucient pavement skid resistance based on the PSV of coarse aggregate.There have been different methods among state DOTDs for friction design and selection of surface aggregates. DOTD conducted a survey in 2006 to record specific methods used by different states to control field skid resistance *[36]*. The survey includes friction practices of 27 different states and Washington D.C as given in Table 3.

Table 2
Aggregate friction rating table
(Louisiana Standard Specifications for Roads and Bridges (2006), Table 502-3)

Friction Rating	Allowable Usage
I [a]	All mixtures
II [b]	All mixtures
III [c]	All mixtures, except travel lane wearing courses with plan ADT greater than 7000
IV [d]	All mixtures, except travel lane wearing courses

Note: (a) PSV > 37; (b) 35⩽PSV⩽ 37; (c) 30 ⩽ PSV ⩽ 34; (d) 20 ⩽ PSV ⩽ 29

Table 3
Methods used to evaluate skid resistance properties

Method	Agencies
British Pendulum	New Jersey, Alabama
Acid Insoluble Residue (AIR)	Arkansas, Oklahoma, Wyoming, Washington D.C.
Other Chemical Tests	Indiana (Soundness)
Skid Trailer	California, Florida, Georgia, Iowa, Mississippi, Montana, Nevada
Multiple Methods	Tennessee (BPN, AIR, Percent Lime, Soundness, Skid Trailer)
	New York (AIR, Skid Trailer)
	Pennsylvania (Petrographic, BPN, AIR)
	Virginia (Geology, Skid trailer, Local Experience)
	West Virginia (AIR, Skid Trailer)
Other	Maryland (Test Track)
No Method - Restrictions	Delaware (Use only Maryland approved quarries)
	Kansas (Based on historical performance)
	Minnesota (No carbonate aggregate in wearing course)
No Method	Connecticut, Maine, New Hampshire, North Carolina, Oregon

Most of the states, including Louisiana, have friction specifications that limit the use of low quality aggregates from frictional point of view in wearing course mix. This controls the use of locally available aggregates and equally causes the depletion of quality aggregates increasing the cost of pavement construction. So, there is a need to evaluate the current friction design practices and modify them accordingly. Recent projects taking the lead in developing improved friction design procedure are discussed below.

Kowalsaki et al. conducted a study on the friction of flexible pavements *[37]*. The objectives of the study were to (1) investigate the way to improve pavement skid resistance by blending different aggregates and by using high-friction mix types, (2) identify a laboratory accelerated polishing method for the HMA samples, (3) develop a preliminary procedure for determining IFI-based flag value as a baseline indicator for laboratory friction measurements, and (4) investigate the relationship between traffic volume and the change of skid resistance in the pavement. Both laboratory and field tests were conducted. In the laboratory tests, 50 laboratory prepared HMA slabs (46 Superpave slabs, 2 stone matrix asphalt [SMA] slabs, and 2 porous friction course [PFC] slabs) were tested under DFT and CTM. A partial factorial test design was adopted in the preparation of the superpave samples so that the following effects could be investigated: (1) aggregate type, (2) aggregate size, (3) aggregate gradation, and (4) high-friction aggregate content. A special compaction procedure was developed to simulate the field compaction of the HMA. A special circular track polishing machine (CTPM) was developed based on the NCAT TWPD. Based on the laboratory test results from the 46 superpave slabs, a predictive model was developed for the terminal F60 based on the aggregate type, size, and gradation. In the field tests, 22 existing sections on the public roads were tested. Historical test data from 3 test track sections in Indiana were also analyzed. The field test program involved DFT, CTM, LWST, and a limited number of BPT. From the field test data, the researchers found that the F60 calculated from the DFT data were lower than the F60 calculated from the LWST data, no matter which type of test tire was used. However, the researcher did not further re-calibrate the IFI model. The objectives of this study were not fully accomplished, and there are several aspects of this study that are not ideal. First, the laboratory-developed terminal F60 prediction model was developed based only on Superpave slabs. Second, field data were collected from different states, of which the mix designs were different from the laboratory slabs. Besides, four LWSTs and multiple operators were involved in the field test data collection. Therefore the field test data were insufficient to verify the laboratory-developed polishing model.

Masad et al. conducted a comprehensive study on the skid resistance of flexible pavement for the Texas Department of Transportation *[38, 39, 40]*. The objectives of this study were to (1) study the influence of the aggregate properties and mix types on asphalt pavement skid resistance and (2) develop a system for predicting asphalt pavement skid resistance during its service life. In Phase I of the study, a prediction model was developed for predicting the laboratory measured friction as a function of material properties and mix gradation. To develop the model, laboratory tests were conducted on three typical mix types and five typical source aggregates in Texas. In the proposed model, the aggregate texture parameters (a_{agg}, $b_{agg,}$ and c_{agg}) are determined using the Aggregate Imaging System and the Micro-Deval device. Aggregate gradation parameters (K and λ) are determined from the gradation curve, which serves as a measure of the macro-texture of the mixture. The aggregate texture parameters and the gradation parameters can then be used to determine the mixture friction parameters (a_{mix}, b_{mix}, and c_{mix}), which are used predict F60 value of the laboratory prepared mixture at different laboratory polishing passes under NCAT TWPD [equation (14)].

$$(\qquad) \tag{14}$$

where,
F60= IFI reference friction number;
a_{mix}, b_{mix}, and c_{mix}= friction parameters of the wearing course mixture; and
N= number of polishing cycles under NCAT TWPD.

In Phase II of the study, the correlation was established between the F60 of laboratory mixture at specific polishing cycle N and the field skid number (SN50S) at a specific number of traffic passes. To develop the model, field friction (DFT20 and SN50R) and texture (MPD) data were collected from 64 test sections across Texas. The test data from the shoulder were assumed to represent the initial friction and texture of the pavement. All tests were conducted on cloudy and sunny days at air temperatures between 50°F to 98°F. It was found that the calculated SN50S from the DFT20 and MPD based on the PIARC model is higher than the measured SN50S using the LWST. Therefore, a modified relationship between SN50S and the F60 was developed as shown in equation (15).

(15)

where,
SN50S= skid number measured by LWST with a smooth tire at the speed of 50 mph;
F60= IFI reference friction number; and
S_p= IFI speed number.

To establish the relationship between the laboratory polishing cycle and the field traffic, a new parameter, traffic multiplication factor (TMF) was introduced. TMF is the estimated total number of vehicles passed on the road during the service life divided by 1000 [see equation (16)]. The proposed relationship between TMF and the laboratory polishing cycle N is shown in equation (17).

(16)

(17)

where,
N= Polishing cycle of the NCAT TWPD;
AADT= Annual average daily traffic; and
A, B, and C= regression coefficients, A= -0.452, B= 58.95, and C= 5.834×10^{-6}.

Combining equations (14) to (17), the skid number of a pavement after a specific number traffic passes can be calculated based on basic aggregate parameters (a_{agg}, b_{agg}, c_{agg} , K, and λ). Unlike the NCAT study, the prediction model proposed by Masad et al. does not require running DFT and CTM on the polished HMA samples at different polishing cycles.

Wu and King developed a laboratory based friction mix design guidelines for Louisiana (Figure 3) *[11]*.Thirty-six laboratory slabs were prepared using three different aggregates (Limestone, Sandstone, and Limestone(70%) + Sandstone (30%)) and four mix type (12.5-mm Superpave, 19-mm Superpave ,Stone Matrix Asphalt (SMA) and Open Graded Friction Course (OGFC)). All slabs were then polished up to 100,000 polishing cycle by NCAT developed Three Wheel Polishing Device (TWPD) and friction value were measured by CTM and DFT. The developed friction design method has incorporated both the aggregate and mixture properties. The report also suggested that there is a possibility of blending of low friction aggregate with high friction performing aggregate without compromising the final friction value of mixture.

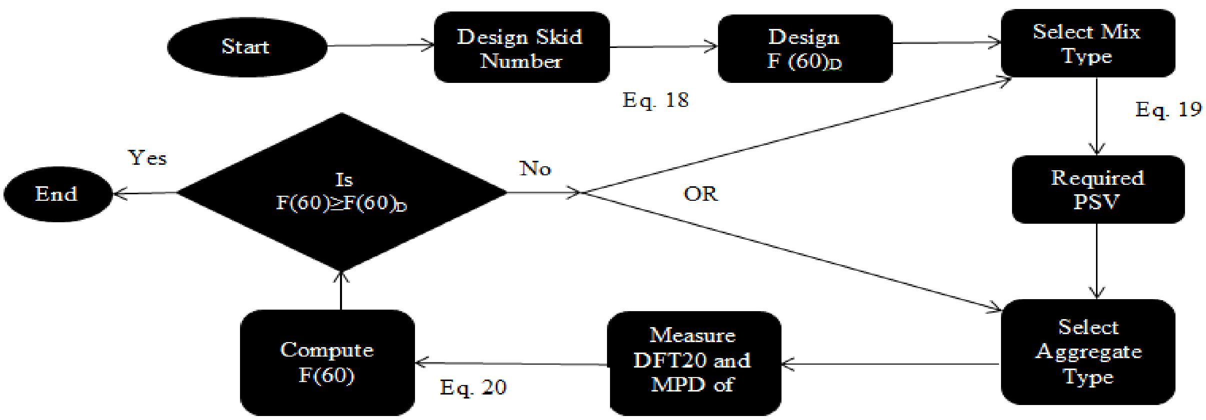


Figure 3
Friction mix design flow chart

$$F(60) = 0.649\ SN(50R) + 0.0572 \quad (18)$$

$$\left.\begin{array}{ll} F(60) = 0.067(PSV)^2 - 3.84PSV + 74.46 & \text{for 19-mm Superpave} \\ F(60) = 0.106(PSV)^2 - 6.19PSV + 108.75 & \text{for 12.5-mm Superpave} \\ F(60) = -0.121(PSV)^2 + 9.41PSV - 153.52 & \text{for SMA} \\ F(60) = -0.066(PSV)^2 + 5.99PSV - 101.65 & \text{for OGFC} \end{array}\right\} \quad (19)$$

$$F\ (60) = (2.18+13.5 \times MPD + 0.38 \times DFT20) \times \quad (\qquad)D \quad (20)$$

Threshold Friction Values

There is no universally adopted minimum skid number that will ensure safe pavement. Establishing minimum friction requirements are not only technical issues but also safety, cost, and judgment issues *[41]*. The Guide for Pavement Friction suggests three different methods to establish a friction number for investigation and intervention based on accident data *[4]*. Henry conducted a survey in 2000 to find out the minimum friction values adopted by different states for design/rehabilitation as shown in Table 4. It can be seen from Table 4 that most of the states use skid trailer for friction measurements except Arizona which uses the MuMeter.

In addition to above surveyed states, the Indiana Department of Transportation (INDOT) has established a friction requirement as 20 measured by smooth tire at speed 40 mph and Oklahoma department of transportation requires minimum SN40R equals to 35.

Table 4

Friction requirements for different states *[3]*

Agency	Friction requirements
Arizona	34(MuMeter)*
Idaho	SN40S>30
Illinois	SN40R>30
Kentucky	SN40R>28
New York	SN40R>32
South Carolina	SN40R>41
Texas	SN40R>30
Utah	SN40R >30-35
Washington	SN40R>30
Wyoming	SN40R>35
Maine	SN40R>35
Minnesota	SN40R>45; SN40S>37
Wisconsin	SN40R>38

*MuMeter refers to friction measurement from side force device at speed 40mph.

OBJECTIVES

The objective of this research is to evaluate the current DOTD coarse aggregate friction rating table and provide recommendation /revision of frictional mix design guidelines based on:

- Field measured skid numbers, and
- Laboratory and field measured DFT and CTM values.

SCOPE

The surface friction characteristics of asphalt pavement in Louisiana were evaluated using friction and texture measuring devices: DFT, CTM, and LWST. The Pavement Management System's (PMS) skid measurement data were also used to assist analysis. A comprehensive statistical analysis was performed on the collected data. The degradation of the pavement friction with traffic polishing was evaluated for different types of mix and aggregate. The results were compared with the PSV of the coarse aggregate to evaluate the current DOTD friction rating table. Numbers of necessary correlations were developed to assist analyzing field test data. Finally, a system for friction design guideline was developed based on aggregate and mixture properties in order to achieve desired skid number for given traffic level.

METHODOLOGY

Field tests were carried out to collect pavement surface friction and texture data from a number of selected pavement sections with typical wearing course mix types currently used in Louisiana, such as Superpave, SMA, and OGFC. Coarse aggregate type, traffic volume, and geographic location were also considered in the selection of test sections. In such a way, data was collected from twenty -two different pavement sections using LWST, DFT, CTM, and Laser Profiler (LP). Description of field experiment design, field testing, and analysis procedure are presented below.

Field Testing Program

Test Sections

A total of 22 different Louisiana asphalt pavement field sections were selected for testing. Each selected road section was at least 0.5 mile long without sharp curve, steep grade, or intersection. Test sections include four common mix types; namely 19-mm Superpave, 12.5-mm Superpave, SMA, and OGFC. Eight different typical surface coarse aggregates were covered. The same aggregate type from different sources may behave differently because of different physical and chemical properties. Hence, aggregates were categorized by their source code. The test sections were distributed across fifteen parishes of Louisiana and categorized by Interstates, U.S. highways, and LA highways. This study did not consider the seasonal variation. However, to overcome the possible effect of seasonal variation, most of the tests were performed during the summer and start of the winter at which surface skid resistance is expected at its lowest. The test sections cover very recently constructed SMA projects to 16-year-old Superpave projects. General information of the test sections are provided in Table 5. The location of the selected test sections are distributed statewide in order to cancel out the possible climate effects on the pavement frictional characteristics. Figure 4 shows the distribution of selected test sites across Louisiana.

Table 5
General information of test sections

Mixture Type	Project No.	Route	Test Date	Const. Date	ADT	Coarse Aggregates
12.5-mm Superpave	261-03-0017	LA 22	7/26/2012	8/2/2006	8600	AA50+AB13+AX65+RP10
	231-01-0006	LA 405	8/1/2012	5/27/2005	440	AA50+RP21
	845-21-0003	LA 3160	9/27/2012	8/4/2005	2800	AA50+AX65+RP09
	056-07-0016	LA 31	7/24/2012	9/27/2007	3200	AA50
	033-01-0032	LA 29	7/24/2012	9/6/2005	4700	AA50+AB13
	272-02-0012	LA 63	7/26/2012	6/14/2006	8400	AA50+AB13+AX65+RP10
	823-02-0027	LA 675	8/7/2012	2/2/2009	9500	AA50+AB13
	414-03-0024	LA 30	8/1/2012	5/31/2006	10400	AA50+AB13+AX72+RP09
	005-09-0033	US 90[a]	9/26/2013	5/17/2001	23837	AA50
	803-08-0015	LA 621	10/9/2013	4/24/1997	18125	AA50
	025-08-0060	US 171[a]	10/9/2012	2/1/2010	32105	AA44+AL22
19-mm Superpave	008-04-0057	US 190	7/24/2012	9/20/2004	10100	AA50
	207-03-0014	LA 35	8/7/2012	3/3/2009	5400	AA50
	260-02-0034	LA 14	7/17/2012	11/5/2004	11600	AA50+RP05
	059-04-0018	LA 25	8/8/2012	3/10/2006	5000	AA50+AB13+AX65+RP09
SMA	451-08-0078	I-20[a]	10/10/2012	9/10/2012	24100	AA39+ABBQ
	424-02-0088	US 90[b]	11/28/2012	5/29/2012	62000	AA39 +AB29
OGFC	025-01-0019	US 171[b]	10/9/2012	5/1/2009	19900	AA44
	451-06-0127	I-20b	10/10/2012	7/27/2005	36200	AA50+AB13
	007-07-0049(1)	US 61[a]	11/07/2012	9/20/2007	26100	AA50+AB13
	007-07-0049(2)	US 61[b]	11/29/2012	9/20/2007	26100	AA50+AB13
	009-02-0018	US 71	2/26/2014	6/14/2003	1590	AA50+AB13

[a,b] Same route with different projects.

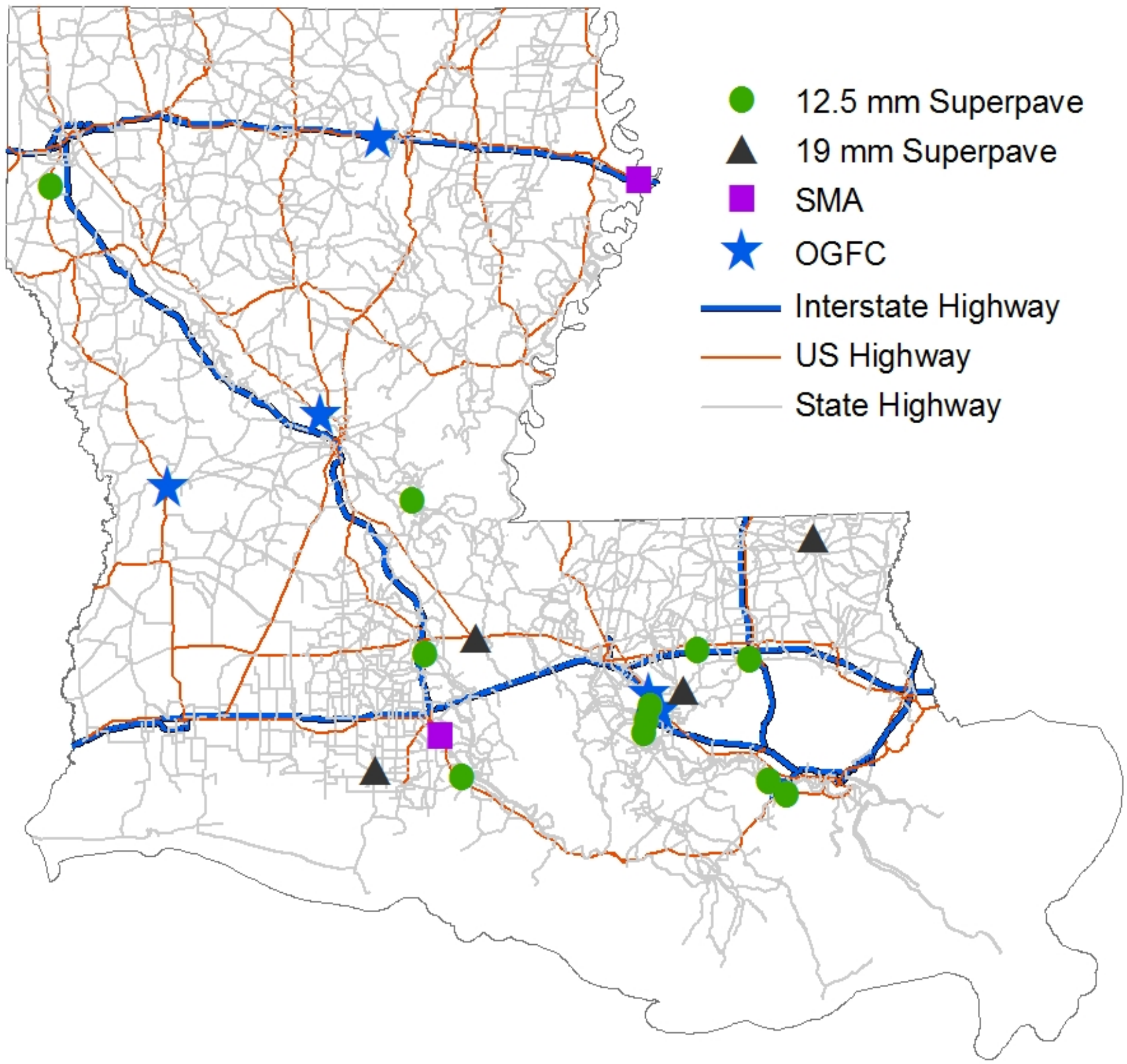


Figure 4
Location of test sections

Mixture and Aggregate Information

This study dealt with the influence of wearing course HMA mixtures and coarse aggregates to the pavement surface friction. A gradation and aggregate information of all selected test projects were obtained from DOTD database. Most of the test sections are Superpave (eleven 12.5-mm Superpave and four 19-mm Superpave). In addition to Superpave, two SMA and five OGFC sections were also tested. Gradation, aggregates and binder information of each project are presented in Table 6.

Table 6
Job mix formula of projects

Mixture Designation	**Route**				
	LA 22	**LA 405**	**LA 3160**	**LA31**	**LA29**
Mix Type	12.5-mm Superpave	12.5-mm Superpave	12.5-mm Superpave	12.5-mm Superpave	12.5-mm Superpave
Aggregate	AB13 30%	AA50 75%	AA50 60.8%	AA50 85%	AA50 57%
	AA50 6.9%	RP21 15%	AX65 16.3%	A702 10%	AB13 30%
	RP10 14.3%	AX59 10%	RP09 14.4%	AK71 5%	A82213%
	AL14 6%		A132 8.5%		
	AX72 6.8%				
	AX65 36%				
Binder Type	PG76-22		PG70-22		
Binder Content	4.80%	4.10%	5.10%	4.6%	4.60%
Metric (US)Sieve	Composite Gradation Blend				
37. 5 mm (1½ in.)	100	100	100	100	100
25.0 mm (1 in.)	100	100	100	100	100
19.0 mm (3/4 in.)	100	100	100	100	100
12. 5 mm (1/2 in.)	92	97	97	98	97
9. 5 mm (3/8 in.)	82	85	85	86	82
4. 75 mm (No. 4)	54	61	56	64	50
2. 36 mm (No. 8)	38	45	36	51	37
1. 18 mm (No. 16)	29	32	26	40	28
0.600 mm (No. 30)	24	24	21	32	22
0.300 mm (No. 50)	14	14	13	20	14
0.150 mm (No. 100)	8	8	9	11	7
0.075 mm (No. 200)	5.2	5.4	6.4	5.5	4.7

Table 6
Job mix formula of projects (continued)

Mixture Designation	Project Number				
	LA 63	**LA 675**	**LA 30**	**LA 621**	**US90[a]**
Mix Type	12.5-mm Superpave	12.5-mm Superpave	12.5-mm Superpave	12.5-mm Superpave	12.5-mm Superpave
Aggregate	AB13 30%	AA50 56%	AB13 45.4%	AA50 61%	AA50 68%
	AA50 6.9%	AB13 30%	AA50 34.3%	AH94 12%	AJ57 20%
	RP10 14.3%	A134 14%	RP09 14.3%	A134 27%	A608 12%
	AL14 6%		AX72 6 %		
	AX72 6.8%				
	AX65 36%				
Binder Type					PG76-22
Binder Content	5.40%	4.50%	4.60%	4.40%	3%
Metric (US)Sieve	Composite Gradation Blend				
37. 5 mm (1½ in.)	100	100	100	100	100
25.0 mm (1 in.)	100	100	100	100	100
19.0 mm (3/4 in.)	100	100	100	100	100
12. 5 mm (1/2 in.)	95	98	94	96	93
9. 5 mm (3/8 in.)	86	89	84	80	85
4. 75 mm (No. 4)	56	63	49	52	70
2. 36 mm (No. 8)	38	43	34	42	59
1. 18 mm (No. 16)	28	33	23	26	49
0.600 mm (No. 30)	21	26	19	21	37
0.300 mm (No. 50)	13	14	13	12	26
0.150 mm (No. 100)	8	7.4	8	7.6	19
0.075 mm (No. 200)	5.4	5.5	6.4	5.4	6.8

Table 6
Job mix formula of projects (continued)

Mixture Designation	**Project Number**				
	US171[a]	**LA35**	**LA14**	**LA25**	**US 190**
Mix Type	12.5-mm Superpave	19-mm Superpave	19-mm Superpave	19-mm Superpave	19-mm Superpave
Aggregate	AA44 72%	AA50 86%	AA50 72.8%	AB13 30%	AA50 72.4%
	AL22 15%	A134 14%	RP09 14.3%	AA50 13%	AX40 20.9%
	AA23 13%		A602 12.9%	RP09 14%	AX50 6.7%
				AX65 34%	
				A132 9%	
Binder Type	PG 70-22M				
Binder Content	5.00%	4.80%	4.00%	4.80%	4.60%
Metric (US)Sieve	Composite Gradation Blend				
37. 5 mm (1½ in.)	100	100	100	100	100
25.0 mm (1 in.)	100	100	100	100	98
19.0 mm (3/4 in.)	100	100	98	96	84
12. 5 mm (1/2 in.)	94	88	84	86	61
9. 5 mm (3/8 in.)	82	77	64	74	45
4. 75 mm (No. 4)	54	42	37	47	35
2. 36 mm (No. 8)	40	31	29	33	27
1. 18 mm (No. 16)	29	24	24	24	13
0.600 mm (No. 30)	24	19	20	19	7
0.300 mm (No. 50)	18	10	12	12	6.2
0.150 mm (No. 100)	9	6	6.2	7	5
0.075 mm (No. 200)	5	4	4.2	4.9	4.2

Table 6
Job mix formula of projects (continued)

Mixture Designation	**Project Number**				
	US 171[b]	**I-20**[b]	**US 61**[a]	**US 61**[b]	**US 71**
Mix Type	OGFC	OGFC	OGFC	OGFC	OGFC
Aggregate	AA44 100%	AA50 25%	AA50 30%	AA50 30%	AA50 20%
		AB13 75%	AB13 70%	AB13 70%	AB13 80%
Binder Type	PG 76-22M	PG 76-22M	PG82-22RM	PG82-22RM	PG 76-22M
Binder Content	6.50%	6.50%	6.5%	6.5%	6.5%
Metric (US)Sieve	Composite Gradation Blend				
37. 5 mm (1½ in.)	100	100	100	100	100
25.0 mm (1 in.)	100	100	100	100	100
19.0 mm (3/4 in.)	100	100	100	100	100
12. 5 mm (1/2 in.)	91	93	93	93	93
9. 5 mm (3/8 in.)	65	68	71	71	71
4. 75 mm (No. 4)	25	19	19	19	19
2. 36 mm (No. 8)	14	8	9	9	9
1. 18 mm (No. 16)	9	6	8	8	8
0.600 mm (No. 30)	7	6	7	7	7
0.300 mm (No. 50)	5	5	6	6	6.5
0.150 mm (No. 100)	4	4	4	4	4.2
0.075 mm (No. 200)	3	3.5	3.3	3.3	3.5

Table 6
Job mix formula of projects (continued)

Mixture Designation	Project Number	
	I-20[a]	**US 90[b]**
Mix Type	SMA	SMA
Aggregate	AA39 50.6%	AA39 60.2%
	ABBQ 49.4 %	AB29 39.8%
Binder Type	PG 76-22M	PG 76-22M
Binder Content	6.0 %	6.50 %
Metric (US)Sieve	Composite Gradation Blend	
37. 5 mm (1½ in.)	100	100
25.0 mm (1 in.)	100	100
19.0 mm (3/4 in.)	100	100
12. 5 mm (1/2 in.)	94	95
9. 5 mm (3/8 in.)	71	71
4. 75 mm (No. 4)	28	30
2. 36 mm (No. 8)	20	24
1. 18 mm (No. 16)	19	23
0.600 mm (No. 30)	18	22
0.300 mm (No. 50)	14	17
0.150 mm (No. 100)	12	11
0.075 mm (No. 200)	8	8

Friction Testing

In this research, field friction and texture values were measured using DFT, LWST, CTM, and LP. DFT and CTM devices require traffic-control and lane closure. To conduct the test, a 1000 ft. test section was marked on straight portion of each project. In each section, LWST with the laser profiler were run at 40 mph in two passes, one with the smooth tire locked and the other with the ribbed tire locked. Three skid number measurements were taken at three different points which are at the beginning, mid-point, and the end of each test section. Three DFT and three CTM tests were conducted within each segment at 4ft interval that LWST takes the skid number reading. The DFT and the CTM were run exactly at the same spot. A complete list of tests conducted in a typical test section is presented in Table 7. The layout of the field test section and the locations of test spots are shown in Figure 5.

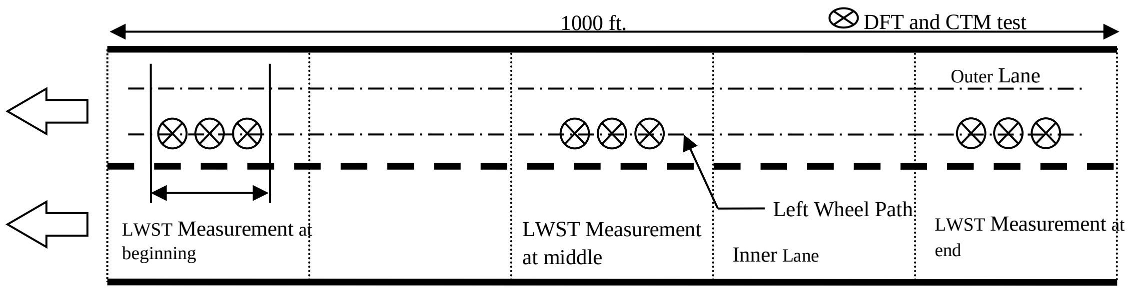


Figure 5
Typical test section

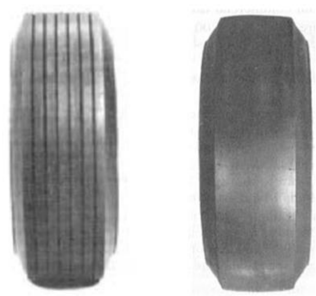
Table 7
Number of test in each section

Test Device	ASTM standard	Test speed (mph)	Number of test spots	Number of test per spot	Total number of test conducted
LWST – Smooth tire	E 274, E 524	40*	3	3	3×3 = 9
LWST – Ribbed tire	E 274, E 501	40*	3	3	3×3 = 9
CTM	E 2157	—	9	1	9×1 = 9
DFT	E 1911	—	9	1	9×1 = 9
Laser profiler	E 1845	40*	continuous	continuous	—

* For a number of selected sections, LWST were conducted at speeds of 30, 40, and 50 mph.

Locked Wheel Skid Trailer is the most common field friction test device in the United States. This device is able to measure the skid resistance of the pavement at normal traveling speeds. LWST is towed behind a test vehicle (as shown in Figure 6) and is often equipped with a smooth test tire and a ribbed test tire, one on each side of the trailer (Figure 7). The ASTM standard for friction devices using full-scale test tire was followed during the test which is ASTM E 274. ASTM E 501 for a ribbed tire and ASTM E 524 for a smooth tire were followed. Since the test tire is fully locked during the test, the slip speed of the tire on the pavement is equal to the traveling speed of the test vehicle. Most of the time, LWST was operated at a speed of 40 mph unless specified, although other speeds may be also used. Along with the skid test, high-speed laser-based devices for macro-texture measurement were mounted on the LWST.

Figure 6
Locked wheel skid trailer



(a) (b)

Figure 7
ASTM standard test tire: (a) ribbed , (b) smooth

The Dynamic Friction Tester was developed in Japan in 1990s. This device measures the rotational torque generated by the friction between three rotating rubber pads and the pavement surface (Figure 8). The three rubber pads are mounted on a motor-driven disk. During the test, the rubber pads are originally suspended above the pavement. The motor-driven disk rotates until the tangential speed of the rubber pads reaches 90 km/hr (55mph). Then water is applied to the pavement, the motor is disengaged, and the rubber pad is lowered to touch the pavement. The rotation torque generated by the friction is continuously monitored until the rubber pads reach stationary. Typically, friction numbers DFT20, DFT40, DFT60, and DFT80 at the slip speeds of 20, 40, 60, and 80 km/hr (12, 25, 37, and 50 mph) respectively are reported, of which DFT20 is often used as a measure of the micro-texture of the pavement. Besides testing in the field, DFT can also be used on laboratory-prepared pavement slab samples. The minimum laboratory sample size required by the DFT is 17.75 × 17.75 in. The ASTM standard for DFT test is ASTM E 1911.

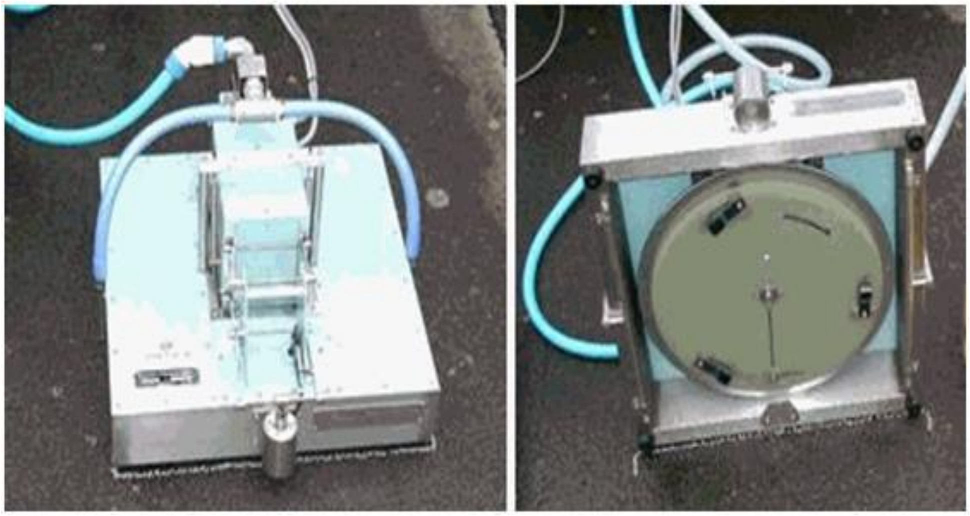


Figure 8
Dynamic friction tester

Circular Track Meter is a non-contact laser-based test device that has been widely used in recent years (Figure 9). CTM measures the surface profile along an 11.25 in. diameter circular path of the pavement surface at intervals of 0.034 in. The measured profile of the pavement surface is used to calculate MPD. CTM test was conducted according to ASTM E2157.

Figure 9
Circular track meter

LTRC has its own kneading compactor which can produce a HMA slab of size 320×260mm. However, CTM has a base area of 400×400 mm and DFT has 400×505 mm. The sizes required for DFT and CTM tests are larger than a single slab that LTRC can prepare. Hence, four slabs were assembled to fit with the CTM and DFT base. A supplemental study was conducted to check the possibility of future use of LTRC kneading compactor to produce laboratory slabs for friction design. The study was to investigate whether there is any significant effect of joints (formed while assembling four slabs) on DFT and CTM measurement. This analysis is presented in Appendix C.

British Pendulum Tester is a portable friction device developed in the UK (Figure 10) that has gained wide acceptance around the world. It can be used both in lab and field test and for both aggregate and asphalt mix surface. This device produces a low speed (usually around 6 mph) sliding contact between a standard rubber slider and the pavement surface. The elevation to which the arm swings after contact provides an indicator of the frictional properties. The measured friction number from the asphalt mix surface is named as British pendulum number (BPN) and aggregate surface as PSV. Since it is a low speed friction tester, BPT is more sensitive to the micro-texture of the pavement. The test is standardized as AASHTO T 278 and T 279 or ASTM E 303 and D3319. This test has been used by DOTD for the specification of aggregate to fulfill friction demand. In this study, the friction property of aggregates was measured using BPT after 10 hr. of polishing under British Wheel Polisher (BWP). Aggregates AA50, AB13, AA39 and AB29 were tested in the laboratory and the PSV of remaining aggregates were obtained from DOTD's Qualified Product List (QPL).

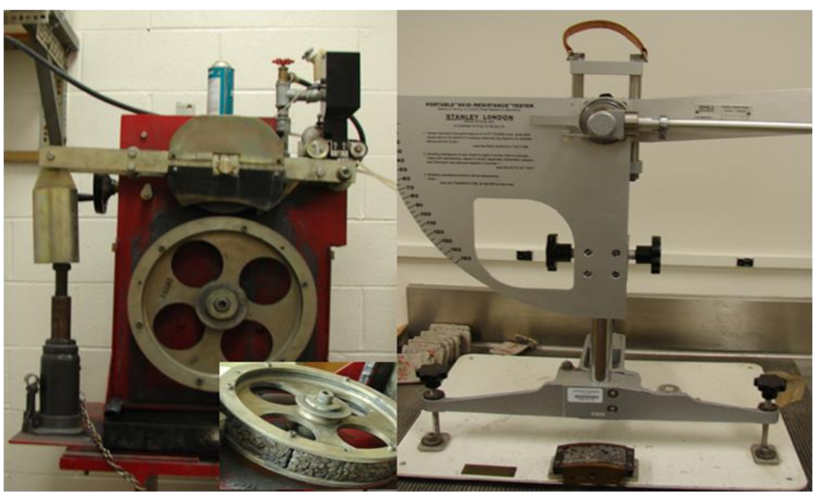


Figure 10
British pendulum tester

Analysis Procedure

A comprehensive statistical analysis was performed on the data collected. First, a number of necessary statistical correlations were developed: (1) correlations among different friction numbers [e.g., Skid number (SN), DFT and F60] and surface textures; (2) correlations among the skid number measurements obtained from both ribbed and smooth tires; (3) the correlation between the pavement surface textures measured from the high-speed laser profiler and the CTM; and (4) the relationship of the measured surface frictional characteristics between the laboratory- and field-compacted asphalt concrete mixtures. Second, the degradation of pavement friction and texture due to traffic polishing were evaluated based on different types of mixes and aggregates. The results were used to evaluate the current DOTD friction rating table. Finally, the aforementioned correlations and analysis results were used to (1) validate and update the correlations developed under the 09-2B study; (2) provide recommendation/revision of frictional mix design guidelines; and (3) develop useful correlations to assist in analyzing field test data and historical friction and texture test data for DOTD.

DFT and CTM data from previous 09-2B study were also used to correlate lab and field polishing. In addition to laboratory friction data, huge amounts of skid resistance data from Pavement Management System (PMS) were obtained from DOTD database. PMS has the skid number measurements at 0.5 mile interval for each control section. DOTD has a system that further defines the project number from the control section with predefined roadway length and work type. Using log mile information, skid numbers of the same pavement sections tested in this study were also obtained from PMS. However, skid resistance for PMS and current research were tested at different date on the same surface. Hence, they were assumed as skid numbers at different polishing levels of pavement surface. By combining them together in a skid degradation model, terminal skid numbers were calculated for each project. The calculated terminal skid numbers were then used to evaluate the current friction rating table. In addition to evaluation, skid numbers from PMS were also used to validate correlations developed in this study.

DISCUSSION OF RESULTS

This section contains the results of pavement surface texture and friction characteristics measured from the twenty-two selected pavement test sections. Comprehensive statistical analyses were performed among different measurements devices, various surface texture and frictional properties. In addition, historical skid number data retrieved from the DOTD PMS database as well as the surface texture and frictional measurements using the DFT and CTM on laboratory fabricated slabs were also included in the analysis of this study. The analysis results led to the development of prediction models of the pavement end-of-life skid resistance and a benchmark DFT rating table at 100,000 polishing cycles.

Aggregate Polishing Resistance

The available asphalt pavement surface friction resistance comes from the right combination of the micro-texture and macro-texture of the wearing course mixture under a given pavement condition. The surface micro-texture may be represented by the polishing resistance characteristic of coarse aggregates used in the mixture. The British Pendulum and aggregate accelerated polishing tests (AASHTO T 278 and T 279) were used to measure the polished stone values (PSVs) of coarse aggregate considered in the selected pavement projects. Table 8 presents the PSV test results together with the corresponding friction ratings of each aggregate tested. Note that a higher PSV value indicates larger micro-texture and better friction resistance of the tested aggregate after polishing. The friction rating value was determined based on the current DOTD Aggregate Friction Rating table (Table 502-3).

Table 8
PSV test results

Source Code	Aggregate Type	PSV	Friction Rating
AB13	Sandstone	36	II
AA44	Novaculite	35	II
AX65	Gravel	32	III
AX72	Gravel	32	III
AA39	Granite	32	III
AB29	Limestone	29	IV
ABBQ	Siliceous Limestone	26	IV
AA50	Limestone	26	IV

As can be seen in Table 8, the coarse aggregates used in the wearing course mixtures of the selected projects include sandstone, limestone, gravel, and Novaculite with a friction rating ranging from II to IV. As listed in Table 9, most of those mixtures contained more than one source of coarse aggregate. In this study, the polishing resistance of a coarse aggregate blend (termed as blend PSV) was determined for each of the wearing course mixtures based on the proportion percentages of individual coarse aggregates contained in the mix (Table 9). The blend PSV concept was originally presented in a former LTRC study, and thereafter has been used by other studies *[42, 43]*. Table 9 presents the blend PSV for the coarse aggregate blends used in each project considered.

Table 9
List of PSV of field projects

Mixture	Route	Coarse Aggregates	Blend PSV	Friction Rating
Superpave 12.5 mm	LA 22	AA50 (7.9%) +AB13 (34.4%) +AX65 (41.3%) +RP10 (16.4%)	33.1	II+ III+IV
	LA 405	AA50 (83%) +RP21 (17%)	26	IV
	LA 3160	AA50 (66%) +AX65 (18%) +RP09 (16%)	27.3	III+IV
	LA 31	AA50 (100%)	26	IV
	LA 29	AA50 (65%) +AB13 (35%)	29.5	II+IV
	LA 63	AA50 (7.9%) +AB13 (34.4%) +AX65 (41.3%) +RP10 (16.4%)	33.1	II+ III+IV
	LA 675	AA50 (65%) +AB13 (35%)	29.5	II+IV
	LA 30	AA50 (34.3%) +AB13 (45.4%) +AX72 (6%) +RP09 (14.3%)	31.7	II+ III+IV
	US90[a]	AA50 (100%)	26	IV
	LA621	AA50 (100%)	26	IV
	US171[a]	AA44 (82.7%) +AL22 (17.3%)	35	II
Superpave 19 mm	US 190	AA50 (100%)	26	IV
	LA 35	AA50 (100%)	26	IV
	LA14	AA50 (83.6%) +RP05 (16.4%)	26	IV
	LA 25	AA50 (14.2%) +AB13 (33%) +AX65 (37.4%) + RP09 (15.4%)	32.6	II+ III+IV
SMA	I-20[a]	AA39(50.6%)+ABBQ(49.4)	29.0	III+IV
	US 90[b]	AA39 (60.2%) +AB29 (39.8%)	30.8	III+IV
OGFC	US171[b]	AA44 (100%)	35	II
	I-20[b]	AA50 (25%) +AB13 (75%)	33.5	II+IV
	US61[a]	AA50 (30%) +AB13 (70%)	33	II+IV
	US61[b]	AA50 (30%) +AB13 (70%)	33	II+IV
	US71	AA50 (20%) +AB13 (80%)	34	II+IV

In Situ Friction Test Results

DFT and CTM Results

Table 10 presents the average test results of DFT20 and MPD values measured from the DFT and CTM tests for the 22 pavement sections considered. Each of DFT20 and MPD values were averaged from nine measurement readings. Note that the DFT20 is a surrogate of surface micro-texture and MPD is indicative of surface macro-texture. As shown in Table 10, the overall measured DFT20 values ranged from 0.13 to 0.38; whereas, the overall range for the MPD was 0.58 mm to 1.61 mm. The overall variation of the MPD measurements was found slightly higher than those of the DFT20 values.

Table 10
Field DFT and MPD test results

Mixture	Route	AGE	ADT	# Test	DFT20		MPD (mm)	
					Avg.	C.V. (%)	Avg.	C.V. (%)
Superpave 12.5 mm	LA 22	6.0	8600	9	0.29	3.2	0.86	10.9
	LA 405	7.2	440	9	0.30	5.2	0.80	7.3
	LA 3160	7.2	2800	9	0.30	4.3	0.76	6.2
	LA 31	4.8	3200	9	0.26	9.3	0.58	9.2
	LA 29	6.9	4700	9	0.28	3.7	0.74	5.7
	LA 63	6.1	8400	9	0.31	5.9	0.88	10.5
	LA 675	3.5	9500	9	0.21	5.9	0.72	7.4
	LA 30	6.2	10400	9	0.31	4.4	0.83	16.4
	US90[a]	12.4	23837	9	0.19	9.8	0.79	9.1
	LA621	16.5	18125	9	0.13	10.4	0.60	4.2
	US171[a]	2.7	32105	9	0.32	3.2	0.58	14.2
Superpave 12.5-mm Range					0.13~0.31		0.58~0.88	
Superpave 19 mm	US 190	7.9	10100	9	0.23	4.7	1.32	6.2
	LA 35	3.4	5400	9	0.26	4.2	0.70	15.3
	LA14	7.7	11600	9	0.21	2.4	1.20	12.5
	LA 25	6.4	5000	9	0.33	3.6	1.02	6.82
Superpave 19-mm Range					0.21~0.33		0.7~1.32	
SMA	I-20[a]	0.1	24100	9	0.27	4.2	0.73	15.6
	US90[b]	0.5	62000	9	0.28	4.9	N/A	N/A
SMA Range					0.27~0.28		0.73	
OGFC	US171[b]	3.4	19900	9	0.27	3.3	1.34	12.8
	I-20b	7.2	36200	9	0.34	3.2	1.16	7.46
	US61[a]	5.2	26100	9	0.27	9.7	N/A	N/A
	US61[b]	5.1	26100	9	0.24	3.2	1.61	6.30
	US71	10.7	1590	9	0.38	4.6	1.21	8.8
OGFC Range					0.24~0.38		1.16~1.61	
Overall Measurement Range					0.13~0.38		0.58~1.61	
CV% Range						2.4~10.4		4.2~16.4

To account for the influences of different source factors on the measured DFT and MPD results, an ANOVA analysis was performed. A term traffic index is defined by following equation (21) to account the effect of traffic polishing by considering both ADT and service life.

$$\text{Traffic Index (T.I.)} = \frac{\quad}{\quad} \qquad (21)$$

The following source factors were used in the ANOVA analysis and the corresponding results are presented in Table 11 and 12

- Mixture Type: Superpave 12.5 mm, Superpave 19 mm, SMA and OGFC;
- Aggregate type: Five category of friction rating (FR II, IV, II+IV,II+III+IV, III+IV)
- Traffic Index: 0~4, 4~10, 10~15, and >15;
- Replicates: 9 measurements for each 1000 ft long test section;

Table 11
ANOVA analysis of DFT measurements

Source	Degree of Freedom	Type I SS	Mean Square	F -Value	P-value
Aggregate	4	0.23	0.057	59.69	<0.0001
Mixture	3	0.09	0.03	30.41	<0.0001
T.I.	3	0.13	0.043	46.06	<0.0001
Replicate	8	0.001	0.0001	0.19	0.99
Error	160	0.17	0.00077		
Total	179	0.62			

Table 12
ANOVA analysis of CTM measurements

Source	Degree of Freedom	Type I SS	Mean Square	F -Value	P-value
Aggregate	4	2.21	0.55	33.9	<0.0001
Mixture	3	9.74	3.24	199.31	<0.0001
T.I.	3	1.18	0.39	24.13	<0.0001
Replicate	8	0.09	0.0001	0.67	0.72
Error	160	2.62	0.00077		
Total	179	15.82			

It can be seen in Table 12 that mixture type is a major source of variation of the CTM measurement, but it has minimal effect in the DFT measurements. Mixture type variation was sixty two percent (9.74/15.82) of total variation for CTM measurements and only 14 percent (0.09/0.62) of total variation for DFT measurements. On the other hand, aggregate type has dominant influence in DFT than CTM measurements, i.e., only 14% (2.21/15.782) source of variation was accounted for CTM while 37% (0.23/0.62) of the total variation of DFT measurements was from aggregate types. As expected, traffic polishing has shown significant effect on the DFT (about 21%) but not on CTM measurement (only about 7% contribution to the total source variations). It was also found that DFT and CTM measurements at nine different points within each project were not significantly different.

Figure 11 presents the measured DFT and MPD results grouped for different wearing course mix types. In general, the average DFT20 of OGFC is showed slightly higher than that of SMA, followed by the Superpave mixtures. This implies that the coarse aggregates used in the OGFC and SMA mixtures are more polishing-resistant (having higher micro-texture) than those of Superpave mixtures. On the other hand, the MPD results in Figure 11 are as expected, showing that OGFC had the highest surface macro-texture (due to its open-graded gradation), following by Superpave 19 mm, Superpave 12.5 mm (both are dense-graded). Because only one SMA project was measured in this study by the CTM test, the measured MPD value for the SMA Mix is relatively low, less than those of Superpave mixtures. More SMA projects should be measured by the CTM in future testing.

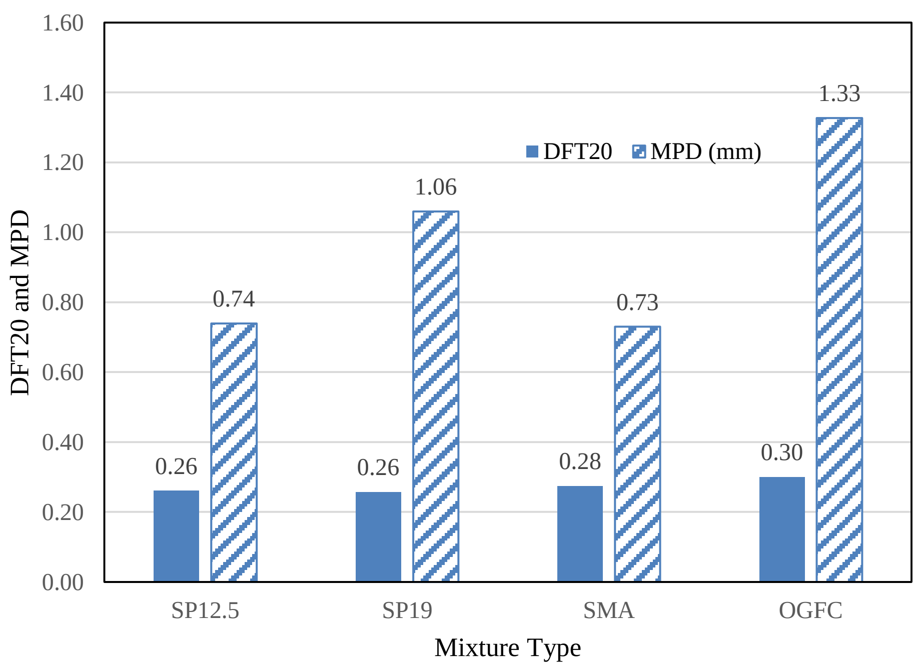


Figure 11
DFT20 and MPD values for different mix types

LWST and Laser Profile Test Results

Table 13 presents the average test results of skid number by ribbed tire (SN40R), skid number by smooth tire (SN40S), and MPD measured from the LWST and laser profile tests for the twenty-two 1000-ft. pavement sections considered. Note that the LWST skid number results were measured at 40 mph and each of the SNR and SNS values were averaged from three measurement readings.

Table 13
LWST and laser profile test results

Mixture	Route	Age	ADT	# Test	SN40S		SN40R		MPD from Laser Profiler	
					Avg.	C.V. (%)	Avg.	C.V. (%)	Avg. (mm)	C.V. (%)
Superpave 12.5 mm	LA 22	6.0	8600	3	32.2	3.3	43.6	2.7	2.6	25.2
	LA 405	7.2	440	3	34.3	6.7	49.0	3.4	2.3	27.9
	LA 3160	7.2	2800	3	30.2	5.3	45.7	0.9	3.2	5.3
	LA 31	4.8	3200	3	21.4	4.9	37.5	3.4	2.3	32.3
	LA 29	6.9	4700	3	28.4	4.4	41.2	3.1	1.5	12.9
	LA 63	6.1	8400	3	33.2	3.6	44.0	2.3	2.6	26.9
	LA 675	3.5	9500	3	28.4	4.4	41.2	3.1	1.5	12.9
	LA 30	6.2	10400	3	31.0	5.5	42.9	3.7	1.9	38.2
	US90[a]	12.4	23837	3	26.5	3.4	34.7	2.8	N/A	N/A
	LA621	16.5	18125	3	28.2	7.8	33.2	5.6	N/A	N/A
	US171[a]	2.7	32105	3	23.3	4.7	46.6	3.2	N/A	N/A
Superpave 12.5 mm Range					21.4~34.3		33.2~49.0		1.5~3.2	
Superpave 19 mm	US 190	7.9	10100	3	31.4	3.0	37.5	2.3	3.5	15.8
	LA 35	3.4	5400	3	25.2	7.1	44.0	2.3	2.7	22.1
	LA14	7.7	11600	3	28.2	5.8	31.8	2.3	4.3	43.3
	LA 25	6.4	5000	3	37.5	5.6	48.9	3.8	4.0	21.3
Superpave 19-mm Range					25.2~37.5		31.8~48.9		2.7~4.3	
SMA	I-20[a]	0.1	24100	3	24.1	18.3	40.2	14.1	N/A	N/A
	US90[b]	0.5	62000	3	39.7	5.1	40.9	4.1	N/A	N/A
SMA Range					24.1~39.7		40.2~40.9		N/A	
OGFC	US171[b]	3.4	19900	3	35.9	2.1	40.4	2.1	N/A	N/A
	I-20b	7.2	36200	3	46.9	1.3	50.1	1.6	N/A	N/A
	US61[a]	5.2	26100	3	37.9	4.3	39.6	3.0	N/A	N/A
	US61[b]	5.1	26100	3	35.3	10.7	32.6	7.5	N/A	N/A
	US71	10.7	1590	3	53.9	2.8	58.7	2.1	N/A	N/A
OGFC Range					35.3~53.9		32.6~58.7		N/A	
Overall Measurement Range					21.4~53.9		31.8~58.7		1.5~4.3	
CV% Range						1.3~18.3		0.9~14.1		5.3~43.3

As shown in Table 13, the overall measured SN40R and SN40S values ranged from 31.8 to 58.7 and from 21.4 to 53.9, respectively. The overall range for the MPD of laser profile was 1.5 mm to 4.3 mm, higher than those from the MPD of CTM readings. In fact, the overall measurement variations for the laser profile readings were very high, ranging from 5.3% to 43%. In general, the measurements of SN40S showed higher variations than those of SN40R. This is expected since a smooth tire is sensitive to both macro and micro texture and a ribbed tire is more to the micro texture of a pavement surface. A slight change in surface macro-texture would be picked up more by a smooth tire than a ribbed tire in skid number readings.

A similar ANOVA analysis of skid number was also performed by considering the same source of variation as for DFT and CTM and presented in Table 14 and 15.

Table 14
ANOVA analysis of SN40R measurements

Source	Degree of Freedom	Type I SS	Mean Square	F -Value	P-value
Aggregate	4	3354.67	838.67	72.86	<0.0001
Mixture	3	1635.82	545.27	47.37	<0.0001
T.I.	3	1225.53	408.51	35.49	<0.0001
Replicate	8	43.22	5.40	0.47	0.88
Error	160	2060.51			
Total	179	8319.75			

Table 15
ANOVA analysis of SN40S measurements

Source	Degree of Freedom	Type I SS	Mean Square	F -Value	P-value
Aggregate	4	4659.38	1164.84	63.56	<0.0001
Mixture	3	3521.15	1173.71	64.05	<0.0001
T.I.	3	303.87	101.29	5.53	0.0012
Replicate	8	73.76	9.22	0.5	0.85
Error	160	3280.42			
Total	179	11838.57			

From the ANOVA analysis of the skid number, it can be seen that aggregate has major and almost equal amount of influence on both ribbed and smooth tire. Of the total variation, 40% on SN40R and 39% on SN40S were from aggregates (Tables 14 and 15). On the other hand, mixture type has a larger influence on smooth tire than ribbed tire readings. Of the total variation, 30% and 20% was from mixture type on smooth and ribbed tire respectively (Tables 14 and 15). In addition to aggregate and mixture, there is also partial influence of traffic polishing especially on ribbed tire. Only 3% of influence was found from traffic on smooth tire variation where it has a 15% of total of variation on ribbed tire. The influence of replicate measurements on variation was almost negligible.

Figure 12 presents the average measured results of SN40R and SN40S grouped by different wearing course mix types. In general, the average SN40R of OGFC is the highest among the four mix types evaluated. However, the SN40R values for the other three mix types are similar to each other, indicating the skid number measured by a ribbed tire failed to differentiate skid resistance between different mix types. On the other hand, the SN40S results showed a promising trend on the skid resistance ranking, from high to low, respectively, are OGFC, SMA, 19-mm Superpave, and 12.5-mm Superpave mix types. This is expected since a smooth tire is sensitive to both macro and micro texture and a ribbed tire is more to the micro texture of a pavement surface. A slight change in surface macro texture would be picked up more by a smooth tire than a ribbed tire in skid number readings.

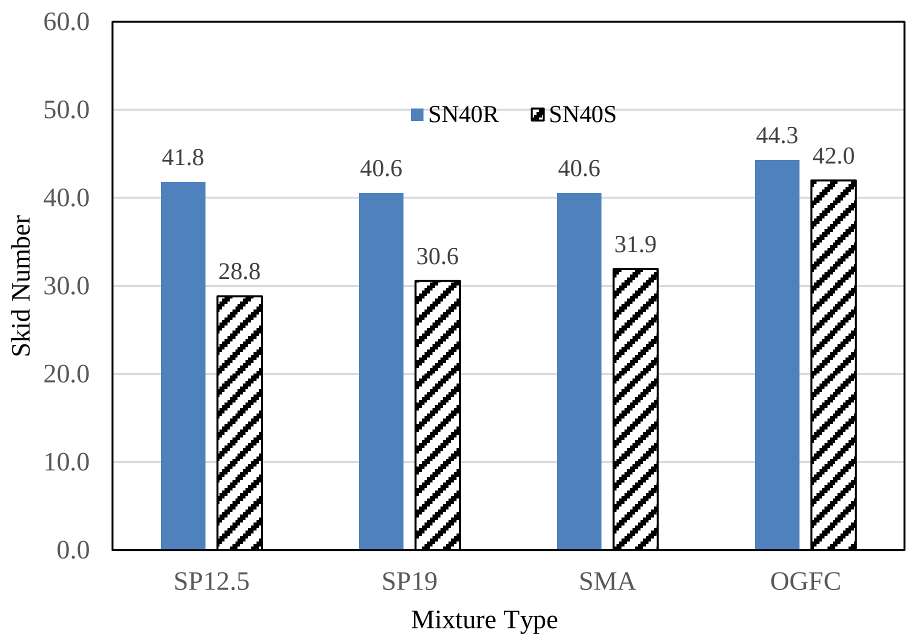


Figure 12
SN40R and SN40S values for different mix types

The overall summary of test results is presented in Table 16. Detailed project information and test result data are presented in Appendix A. Tested sections have covered the recently constructed pavement surface to very old (16.5 years) with an average of 6.2 years. DFT20 measurement showed a range of 0.13 to 0.38, where CTM measured MPD showed 0.58 to 1.61mm. Skid trailer with ribbed tire has shown higher value on the same surface than smooth tire. 21.4 was the lowest reading for smooth tire and 32.6 for ribbed tire. The maximum readings for ribbed and smooth tire were 58.7 and 53.9.

Table 16
Overall test results

	DFT20	MPD (mm) by CTM	SN40R	SN40S	Age (yr.)
Average	0.27	0.91	42.1	32.4	6.2
Range	0.13-0.38	0.58-1.61	31.8-58.7	21.4-53.9	0.1-16.5

Evaluation of PMS Skid Number Measurements

This section presents the network level skid number data analysis for the existing Louisiana asphalt pavements. A total of 57,739 skid number data were obtained from Pavement Management System (PMS) section of DOTD, measured for the years of 2009, 2011, 2012, and 2013 throughout the Louisiana. The database is comprised of both the ribbed- and smooth- tire LWST skid number test results of different road sections. First, smooth and ribbed tire skid numbers measured at speed 40 mph on asphalt surface were separated from total data. In such a way 11,966 data points fell on SN40S and 10,687 on SN40R.

Due to the fact that currently there is no universally adopted design skid number, the skid number data were further analyzed to have a baseline for SN40R and SN40S at the-end-of-design-life skid numbers for asphalt-surfaced pavement design. In order to do so, the skid number data of only those projects which has already passed the design life of 15 years were considered believing the surface already reached the terminal friction condition. The service lives of the projects were identified by matching the log mile and control section information from PMS skid data with DOTD online database. In such a way, a total of 2047 data points of SN40R and 2297 data points of SN40S were retrieved having service life more than 15 years (Figure 13 and 14). From Figure 13 and 14, it can be seen that most of the SN40R values are greater than 30 and SN40S values greater than 20. For the ribbed tire majority of that data falls in the range from 37 to 47 where for smooth tire it is in the range of 30 to 40.

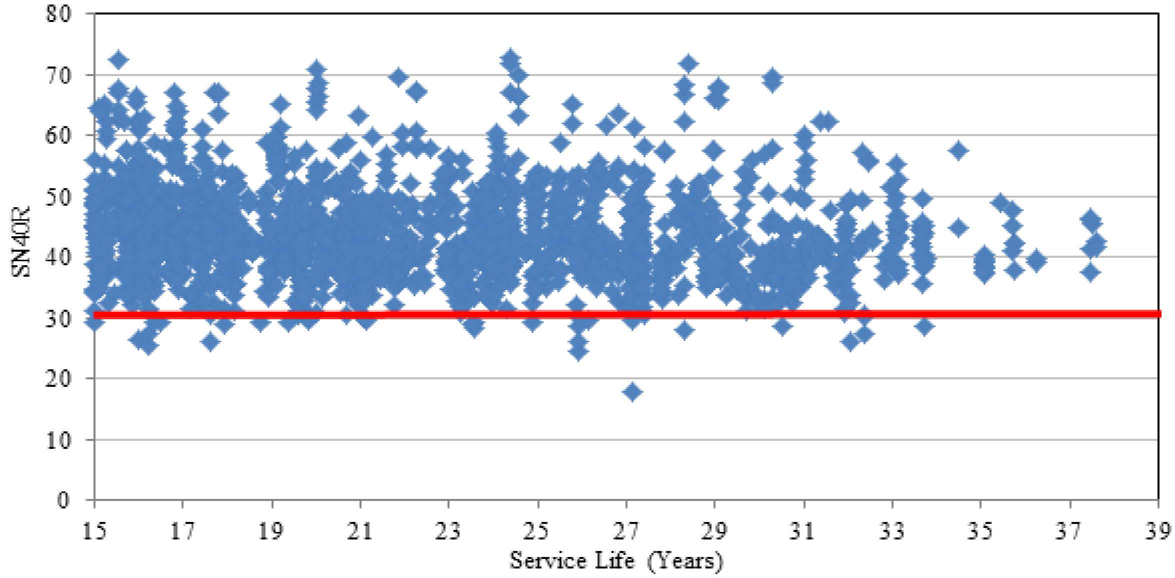


Figure 13
SN40R values for different sections

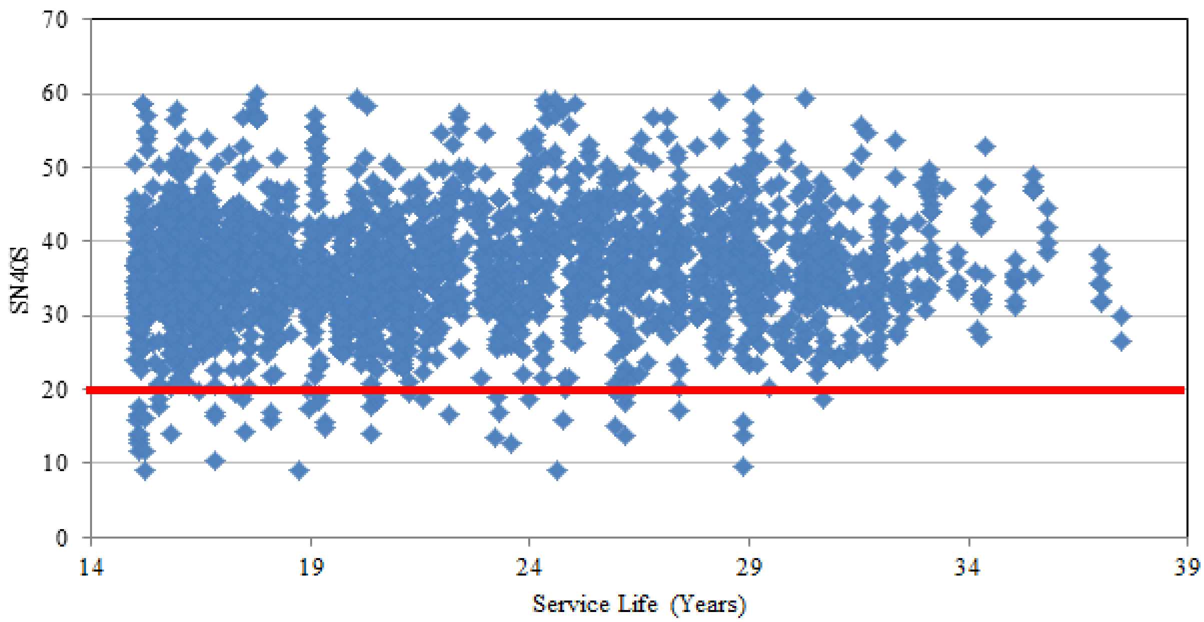


Figure 14
SN40S values for different sections

The *Guide for Pavement Friction* provides three methods to establish an intervention and investigatory threshold friction level *[4]*. Among them, Method 3 is considered the most robust approach as it allows agencies to decide the number of highway sections below a certain friction level depending on the needs and budget. Because of the lack of crash data, this method has not been fully adopted. The histogram of pavement skid distribution was analyzed to have a baseline for intervention threshold friction value. Using the data shown in Figure 13 and 14, histograms of skid distribution were plotted (Figure 15 and 16). The average value for the SN40R distribution was 43.7 with a standard deviation of 7.4. Similarly, for SN40S, the average was 36.1 with a standard deviation of 7.8. From the histogram plot, it was found that less than three percent of highway sections have the SN40R value lower than 30 and SN40S lower than 20. This provides the baseline to set the investigatory friction level as 30 for SN40R and 20 for SN40S. Since this study is related with the pavement friction design, such established investigatory friction level is also recommended as design skid number for Louisiana pavements. Regardless the method used, establishing design skid number is always dependent on safety requirements and budget and should be reviewed and revised as needed.

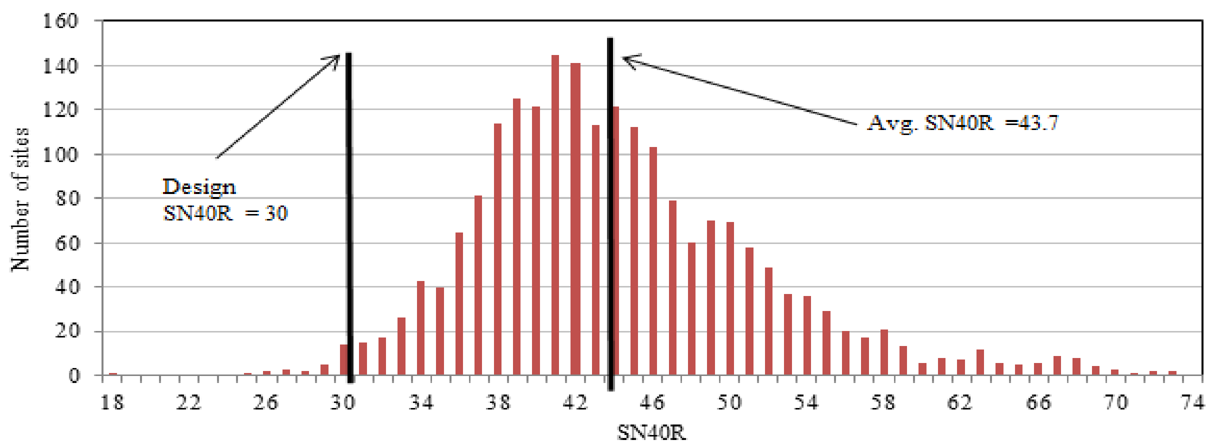


Figure 15
Estimation of design SN40R

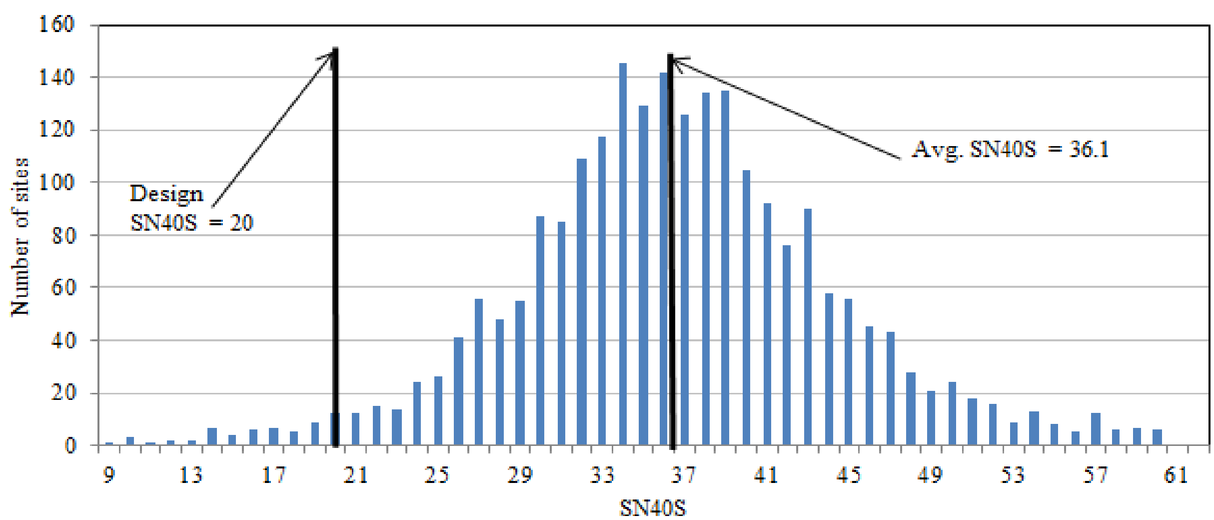


Figure 16
Estimation of design SN40S

Correlation Analysis among Field Measurements

This section presents the correlations among field measured friction and texture properties for the asphalt pavement projects considered.

SN40R vs. SN40S

Figure 17 plots the LWST measurement results for all selected projects in this study. In general, the LWST test results indicated that the skid numbers obtained using a ribbed tire (SN40R) can be expected to be constantly higher than those using a smooth tire (SN40S) measured on the same pavement surface. A poor linear relationship was obtained between the two sets of skid number measurement data with a R^2 value of only 0.31. The trend-up relationship also implied that an increase in SN40R would result in an increase in the SN40S measured on the same pavement surface.

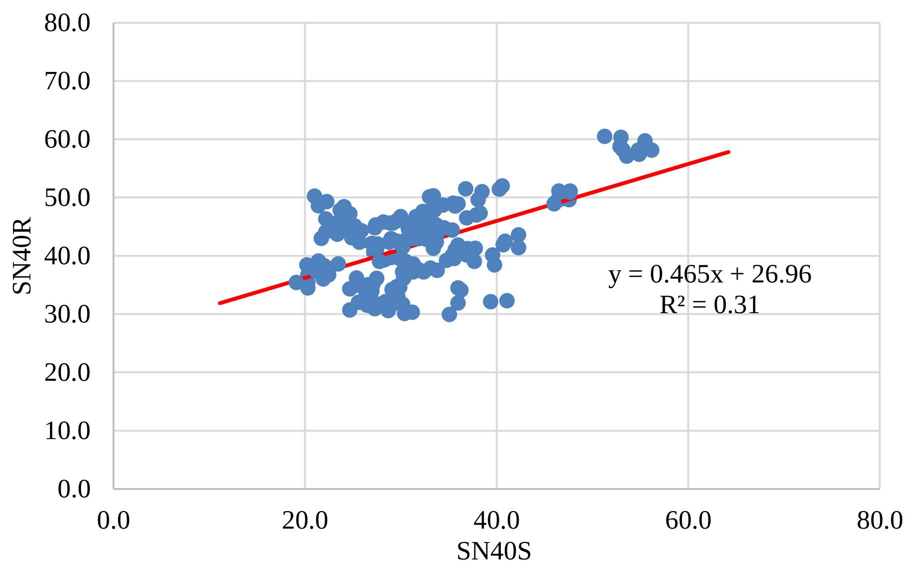


Figure 17
SN40R vs. SN40S

DFT vs. MPD

Figure 18 plots a potential relationship between the measured DFT20 and MPD (measured by CTM) results for all project considered. As shown in Figure 18, no obvious trend existed between these two measurement results. Since DFT20 represents for surface micro-texture and MPD for surface macro-texture, Figure 18 generally indicates that the micro and macro textures of a wearing course mixture are not necessarily correlated to each other. A mix with a high macro-texture may have a low micro-texture, and vice versa.

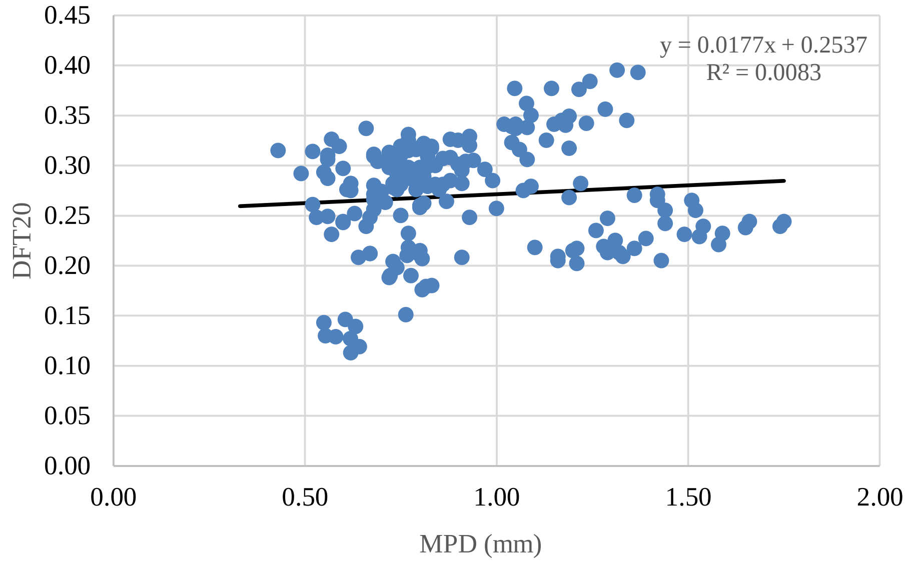


Figure 18
DFT20 vs. MPD

SN vs. DFT

Figure 19 and Figure 20 plot a potential relationship between the measured DFT20 verse SN40R and SN40S results for all project considered. A strong linear relationship was observed between SN40R and DFT20. On the other hand, a poor relationship was obtained between SN40S and DFT20. Since DFT20 is a surrogate for the micro-texture of a mixture, such results further confirmed that a ribbed tire is more sensitive to the micro texture of a pavement surface than a smooth tire.

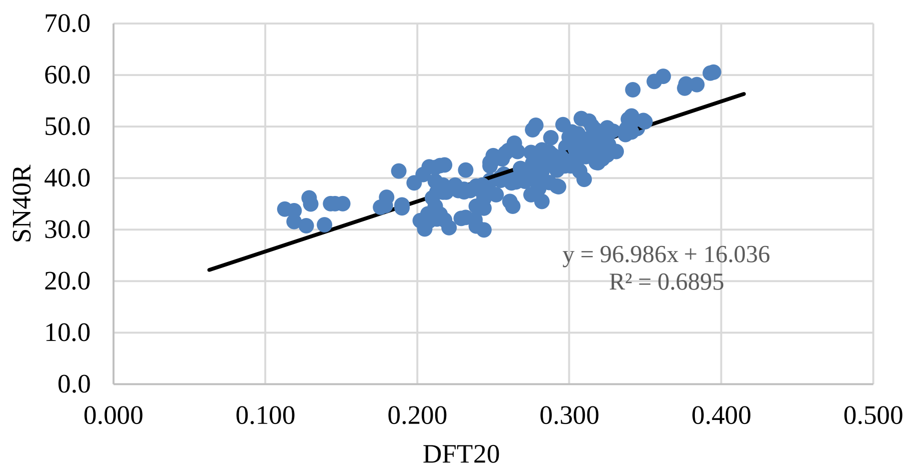


Figure 19
DFT20 vs. SN40R

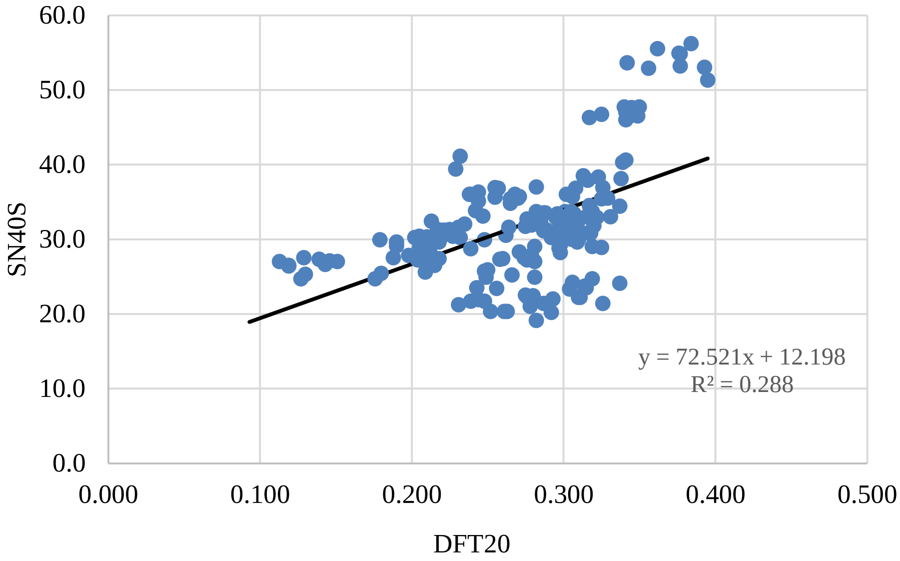


Figure 20
DFT20 vs. SN40S

SN vs. MPD

Figure 21 and 22 plot the relationships between SN40R vs. MPD and SN40S vs. MPD. As expected, the correlation between SN40S and MPD is slightly stronger than that between SN40R and MPD. This is because MPD is indicative of the macro-texture and the macro-texture may be detected more by a smooth tire.

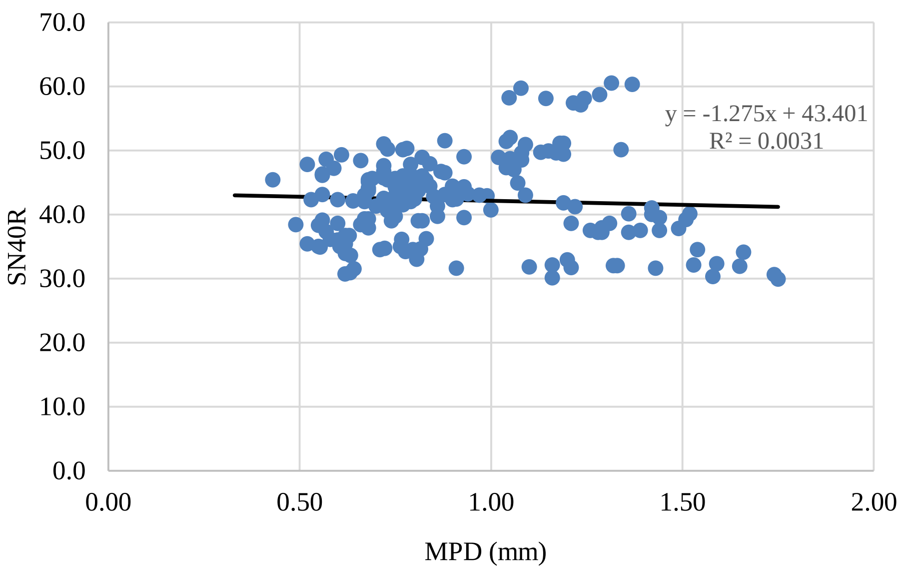


Figure 21
MPD vs. SN40R

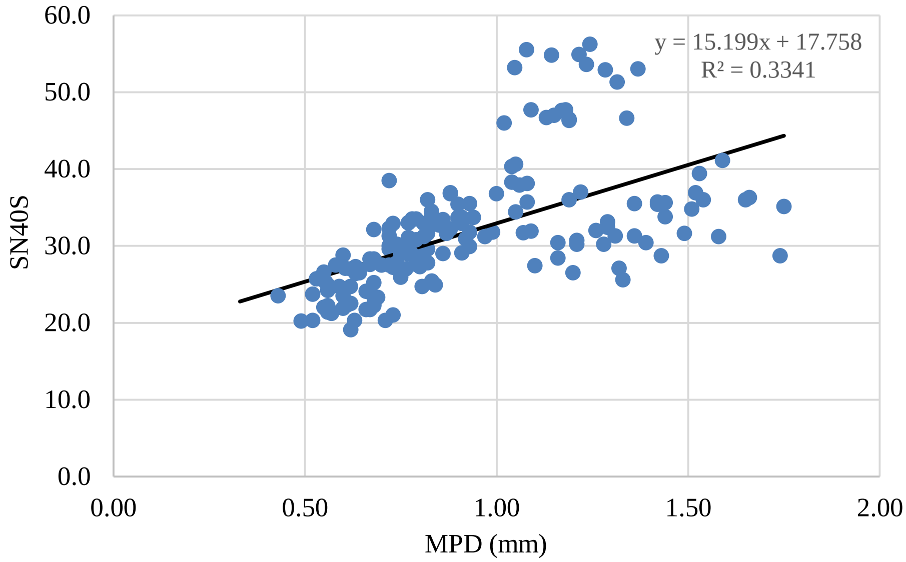


Figure 22
MPD vs. SN40S

Laser Profiler vs. CTM

As a part of this study, a correlation between texture measuring devices was also established The texture measuring devices used were vehicle mounted Laser Profiler and CTM. As shown in Figure 23, laser profiler appears to be linearly correlated with CTM.

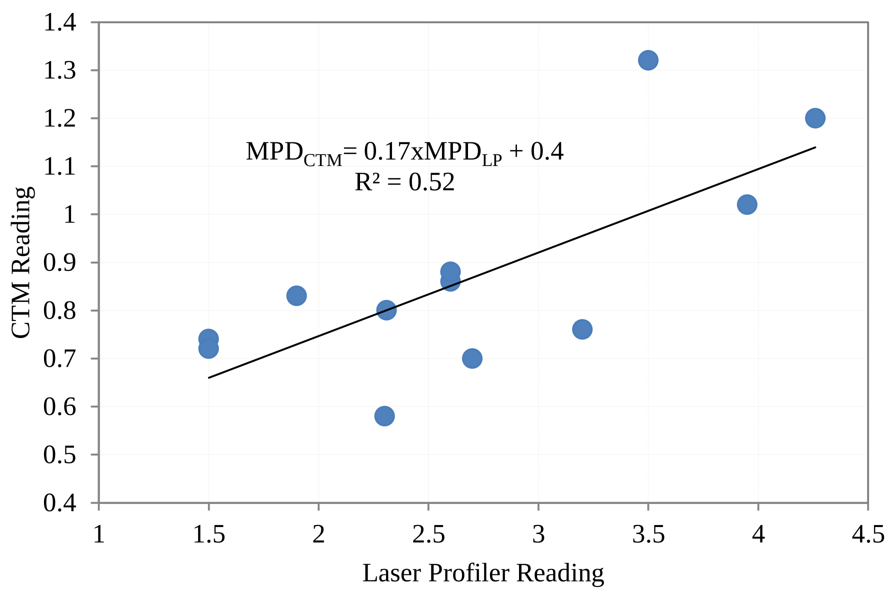


Figure 23
Laser Profiler vs. CTM

SNR vs. (SNS, MPD)

Furthermore, it was found that the difference between the ribbed and smooth tire skid number can be related to the macro texture of the pavement surface. Figure 24 shows the difference between ribbed and smooth tire decreasing with increase in MPD. Generally, in any surface, ribbed tire skid number used to be higher than smooth tire. But recent field tests have shown there might be higher smooth tire skid number than ribbed tire if the surface has higher macro texture. When MPD is 1.61 mm the smooth tire has shown relatively higher reading than ribbed tire (Figure 24).

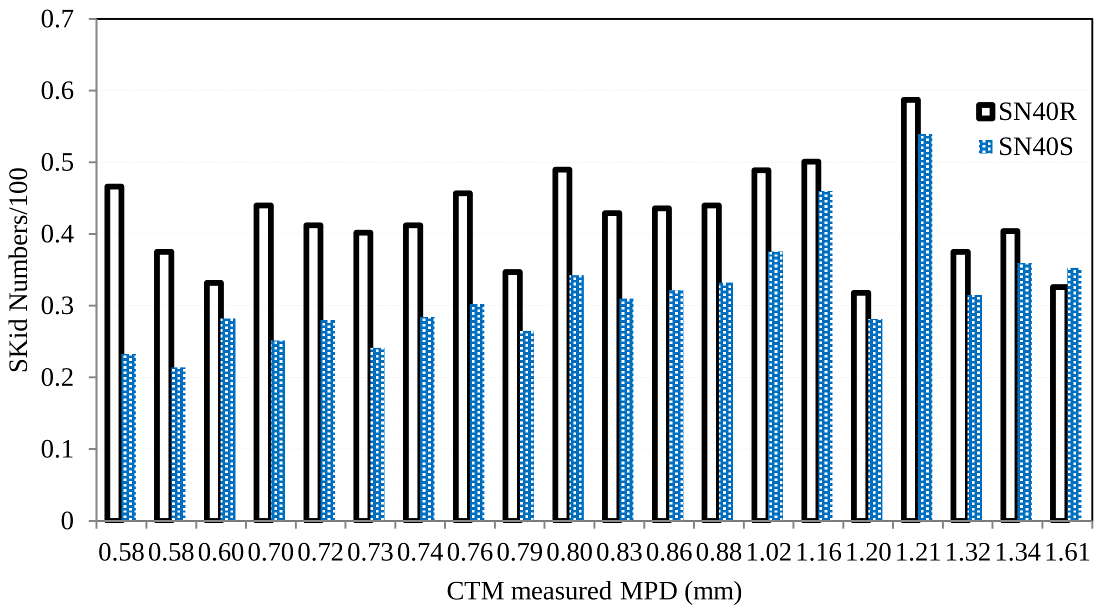


Figure 24
Difference in smooth and ribbed tire skid number with MPD

The data shown in Figure 24 was further used to establish the correlation between smooth and ribbed tire. A multiple regression analysis was performed using SAS and developed equation is given in equation (22). In addition, from Figure 19 through 22 it can be observed that, smooth tire is related to both DFT and CTM readings where ribbed tire is only related to DFT.

$$SN40R = 0.93 \quad SN40S - 0.16 \quad MPD + 0.26 \qquad (R^2 = 0.75) \qquad (22)$$

where,

SN40R = Skid number at 40 mph using ribbed tire divided by 100.

SN40S = Skid number at 40 mph using smooth tire divided by 100.

MPD = Mean profile depth measured using CTM in mm.

SNS vs. (DFT, CTM)

An attempt was made to predict the SN40S from DFT and CTM data. Several trial models were performed in SAS and a best fit nonlinear regression correlation is proposed as given by equation (23).

$$SN40S = 2.15 \times DFT20 \times \left(\frac{\quad}{\quad}\right) \qquad (R^2 = 0.73) \qquad (23)$$

where,

SN40S= Skid number at 40 mph using smooth tire divided by 100.

MPD = Mean profile depth measured using CTM

DFT20 = DFT reading at speed 20 km/hr

Speed Gradient Correlations

It is important to be able to estimate the skid number at designated speed from different speeds. This will ease the pavement management and help in attaining the skid numbers at the same speed for comparison. A study was performed to harmonize the skid number at different speed to 40 mph. A model addressing change in skid resistance with speed for Louisiana roads was developed. Skid trailers with both smooth and ribbed tires were used on four projects (three Superpave and one OGFC) at test speeds of 30, 40, and 50 mph. Three testing points data (beginning, mid, and end) within each project were used for the analysis. Previous researchers found that change in skid with speed is texture dependent. Separate analyses were completed for ribbed and smooth tires. Figures 25 and 26 show the change in skid number with speed at different surface texture level.

The data shown in Figures 25 and 26 were used to develop the skid prediction model from different speeds. A study by PIARC suggests a model to harmonize friction measurement at different speed into designated speed using single instrument as given in equation (7) to (9) *[29]*. Using similar concept a model to predict skid number at 40 mph from different speed is presented in equations (24) and (25).

$$SNR(V) = SN40R \times \left(\frac{\qquad}{\qquad}\right) \qquad (R^2=0.82) \qquad (24)$$

$$SNS(V) = SN40S \times \left(\frac{\qquad}{\qquad}\right) \qquad (R^2=0.88) \qquad (25)$$

where,

SNR (V) = Ribbed-tire Skid number at speed of V (mph)

SNS (V) = Smooth-tire Skid number at speed of V (mph)

MPD = mean profile depth in mm measured by CTM

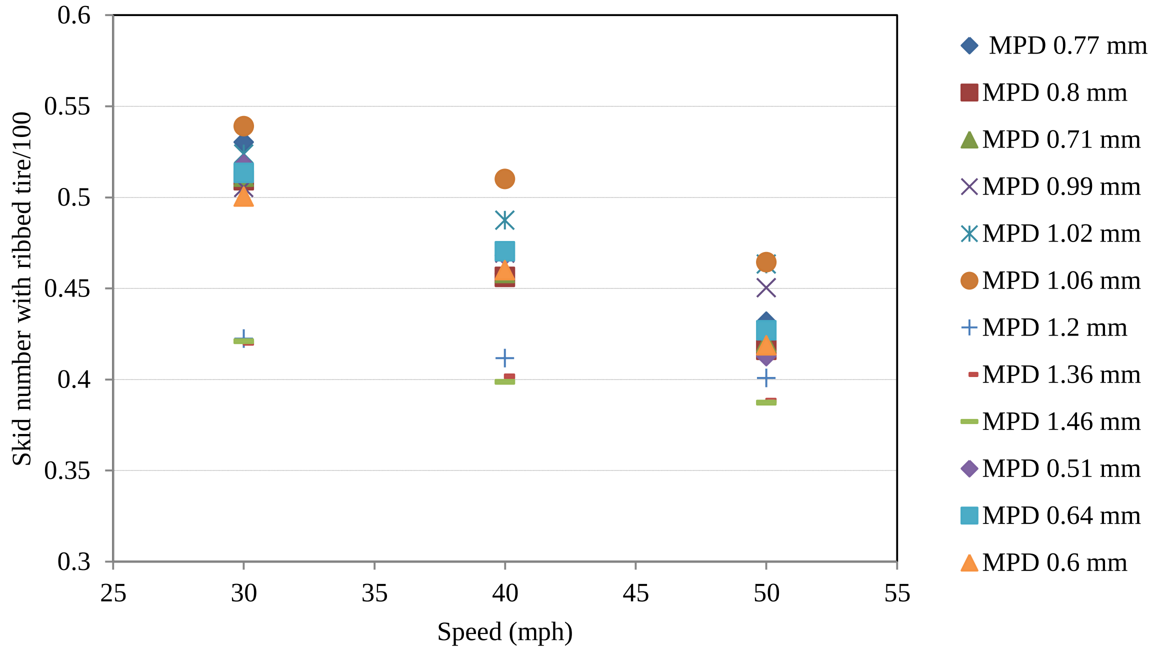


Figure 25
Plot of skid number with ribbed tire versus test speed at different texture level

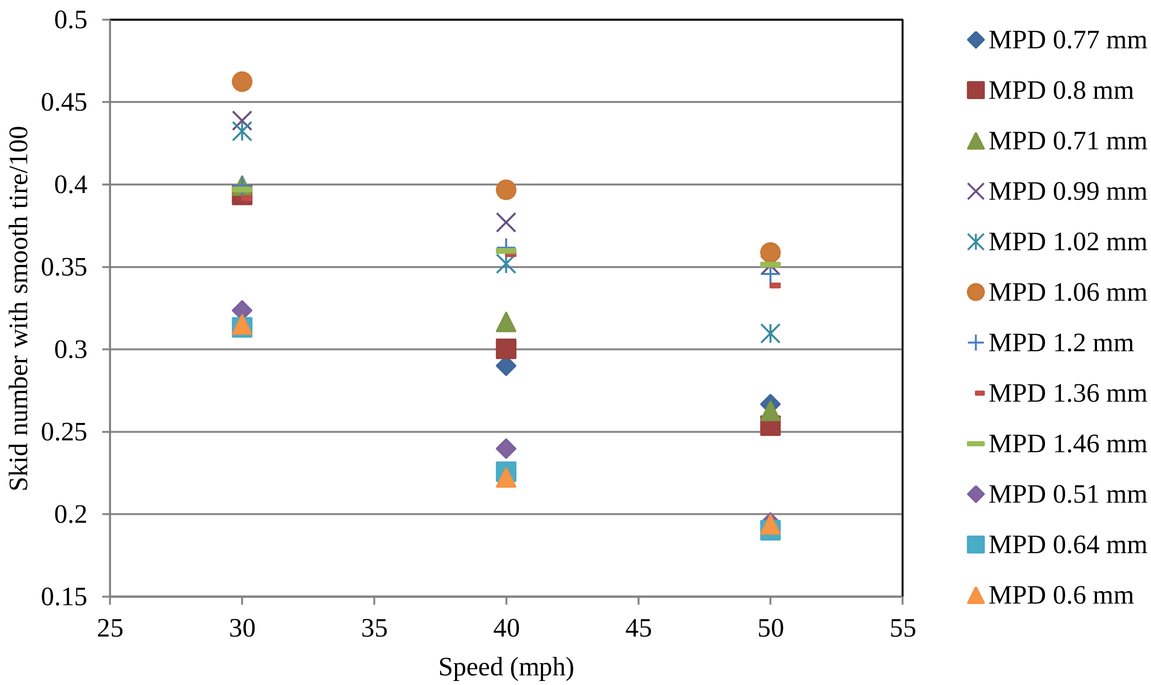


Figure 26
Plot of skid number with smooth tire-versus test speed at different texture level

Evaluation of Current Friction Rating Table

In order to evaluate the current aggregate friction rating table, ribbed tire skid numbers were used. The terminal skid number of each project was determined using PMS and in situ skid number test results based on the following degradation model *[44]*:

$$SN40R = SN40R_T + \Delta SN \times \qquad (26)$$

where,
$SN40R$ = Skid number at speed 40 mph by ribbed tire for given polish cycle
$SN40R_T$ = terminal skid number.
$SN40R_T + \Delta SN$ = Initial skid number
c = parameter for polishing rate.

The polishing parameter "c" for each mixture type was taken from the previous report 09-2B. Since the polishing parameter was from laboratory study, field traffic was also changed to equivalent laboratory polishing cycles by using equation (27). The analysis of correlation of lab and field are presented in Appendix B.

$$N = \qquad -5.33 \qquad (27)$$

where,
N = Laboratory polishing cycles using TWPD (in thousands);
T.I. = Traffic index, defined by the following equation (21).

Table 17 presents the prediction results of terminal ribbed tire skid numbers ($SN40R_T$) for selected field projects based on equation (25). The corresponding terminal smooth tire skid numbers ($SN40S_T$) were calculated using equation (21).

From Table 17, it can be found that the terminal skid number of SN40R ranged from 22 to 48, and the corresponding SN40S varied from 6 to 43, for the selected pavement test sections. According to the current DOTD specification, high friction rated aggregates are usually required to use for high traffic roads, which will result in high skid number for better friction resistance. However, this is not always the case. For example, Project LA621 had a design ADT of 9063, but a friction rating IV aggregate was selected, which had resulted a relatively low terminal SN40R of 32.6 and low terminal SN40S of 20.7. On the other hand, mixes with higher rated aggregates are not always having higher terminal skid numbers.

Table 17
Evaluation of friction rating table

ROUTE	ADT@design lane	Blend PSV	Friction Rating	$SN40R_T$	$SN40S_T$
LA 22	4300	33.1	II+III+IV	37.8	27.5
LA 405	220	26.0	IV	32.4	20.6
LA 3160	1400	27.3	III+IV	34.4	22.1
LA 31	1600	26.0	IV	22.2	5.9
LA 29	2350	29.5	II+IV	32.9	20.2
LA 63	4200	33.1	II+III+IV	39.9	30.1
LA 675	4750	29.5	II+IV	24.5	10.8
LA 30	5200	31.7	II+III+IV	39.5	28.8
US90[a]	5959	26.0	IV	34.2	19.1
LA621	9063	26.0	IV	32.6	20.7
US171[a]	8026	35.0	II	40.6	25.7
US 190	2525	26.0	IV	34.4	31.7
LA 35	2700	26.0	IV	26.4	12.5
LA14	5800	26.0	IV	29.3	24.2
LA 25	2500	32.6	II+III+IV	42.4	35.2
US171[b]	4975	35.0	II	32.5	30.0
I-20[b]	9050	33.5	II+IV	47.9	43.5
US61[a]	6525	33.0	II+IV	37.5	40.1
US61[b]	6525	33.0	II+IV	30.5	32.5

Figure 27 presents the skid number results in five aggregate friction rating groups. The results are simply mix-bagged; that is, difference in terminal skid numbers for same aggregates and sometimes higher skid number from low rating aggregates. This indicates that there exists a significant variation in terminal skid number (both SN40R and SN40S) within same friction rating aggregates. A project from the UK by Roe and Hartshorne also found that aggregate with same polishing resistance providing a range of skidding resistance at same traffic level *[45]*. Such mix-bagged results simply confirm that it is difficult to control pavement surface friction by using only the PSV-based friction rating table, which only captures the micro-texture contribution to the friction resistance.

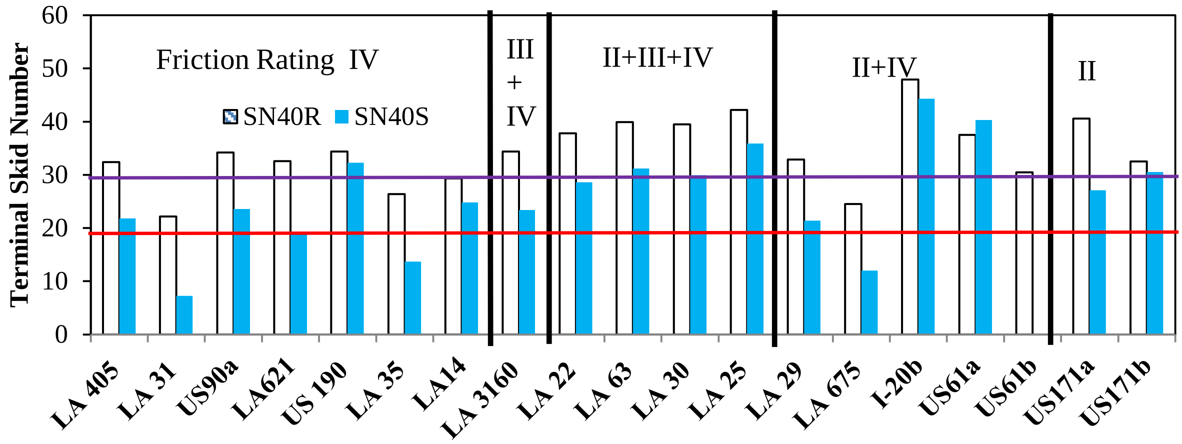


Figure 27
Evaluation of friction rating

On the other hand, Figure 28 shows that a possible linear trend exists between terminal skid numbers measured using the smooth tire (SN40S) and the blend PSV values used in each mixture considered in this study. This is an interesting observation because many studies found that it is hard to develop a link between the pavement terminal (or final) friction resistance and its mixture's PSV value. The observed linear trend in Figure 28 demonstrates that such a relationship between the pavement terminal friction resistance and PSV could be developed using SN40S (terminal) as a surrogate for pavement terminal friction resistance and the blend PSV as a representative polish stone value for a mixture.

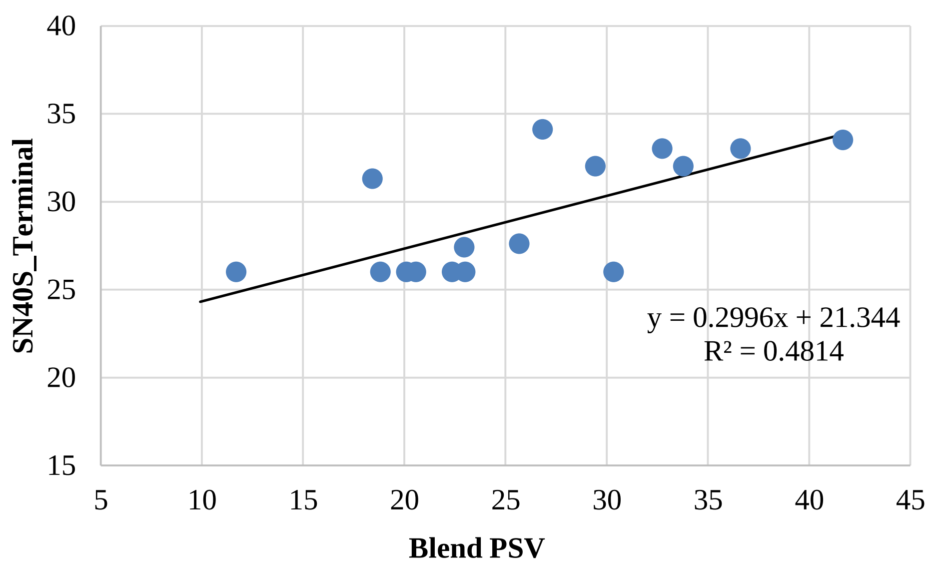


Figure 28
Terminal skid numbers vs. blend PSV

As shown in Figure 28, a fair linear relationship exists between the SN40S at end of pavement design life and the blend PSV used in the wearing course mixtures. Since SN40S is sensitive to the macro- texture (mixture type) and micro texture (aggregate polishing resistance), this can be used as a surrogate of the friction resistance for a wearing course mixture used in pavement design.

Relationship of Mixture and Aggregate Properties with Friction /Texture

From the analysis of variance, it was found that DFT measurements can be predicted by aggregate properties at given traffic level. It is widely accepted that PSV is a measure of aggregates frictional property hence choose as one of the parameter to predict DFT. A nonlinear regression analysis was performed to develop a DFT degradation model [equation (28)] with traffic.

$$DFT20 = A\times \quad (\quad) + C\times PSV + D \times \quad (\quad) \qquad (R^2 = 0.88) \qquad (28)$$

where, A = 0.13, B = -0.056, C = 2.6 and D = -0.5 are regression coefficients. In the above equation PSV is divided by 100.

From analysis of variance, it can be seen that MPD is strongly related to mixture type. A study from Texas by Masad et al. developed a model to predict MPD using mixture gradation properties based on the Weibul distribution as shown in equation (29) *[46]*. The MPD prediction model using the Weibul distribution parameters of K and is presented in equation (30). In this study, the values of K and from Weibul distributions of aggregate gradation for every project were determined. The predicted MPD values using equation (30) were compared with the measured ones are presented in Figure 29. In general, a fairly good fit was obtained.

$$(\quad) \qquad (\;-) \qquad (29)$$

$$MPD = 0.14\times \quad + 0.09\times \quad \text{——} \qquad (30)$$

where,
x = Aggregate size in milimiters

K = Shape factor of Weibul distribution

λ = Scale factor of Weibul distribution

MPD = Mean profile depth measured by CTM.

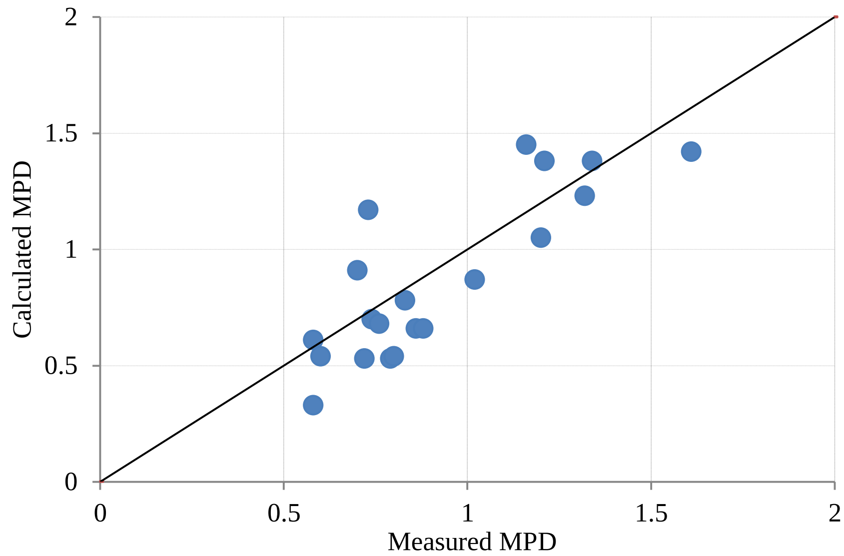


Figure 29
Measured MPD versus calculated MPD

Guidelines for Selection of Coarse Aggregates

The results from this project have clearly shown that the skid resistance of a HMA surface is in a degradation trend with polishing, which may be a function of aggregate gradation, macro-texture, micro-texture, and traffic. The influence of certain aggregate parameter (e.g., PSV) on mixture skid resistance also depends on the type of mixture design. Therefore, a method is presented in Figure 30 to predict the skid number of asphalt pavements as a function of traffic based on aggregate characteristics and mixture design gradation. This system will be very useful in selecting the optimum combination of aggregate type and mixture design in order to achieve the desired level of skid resistance.

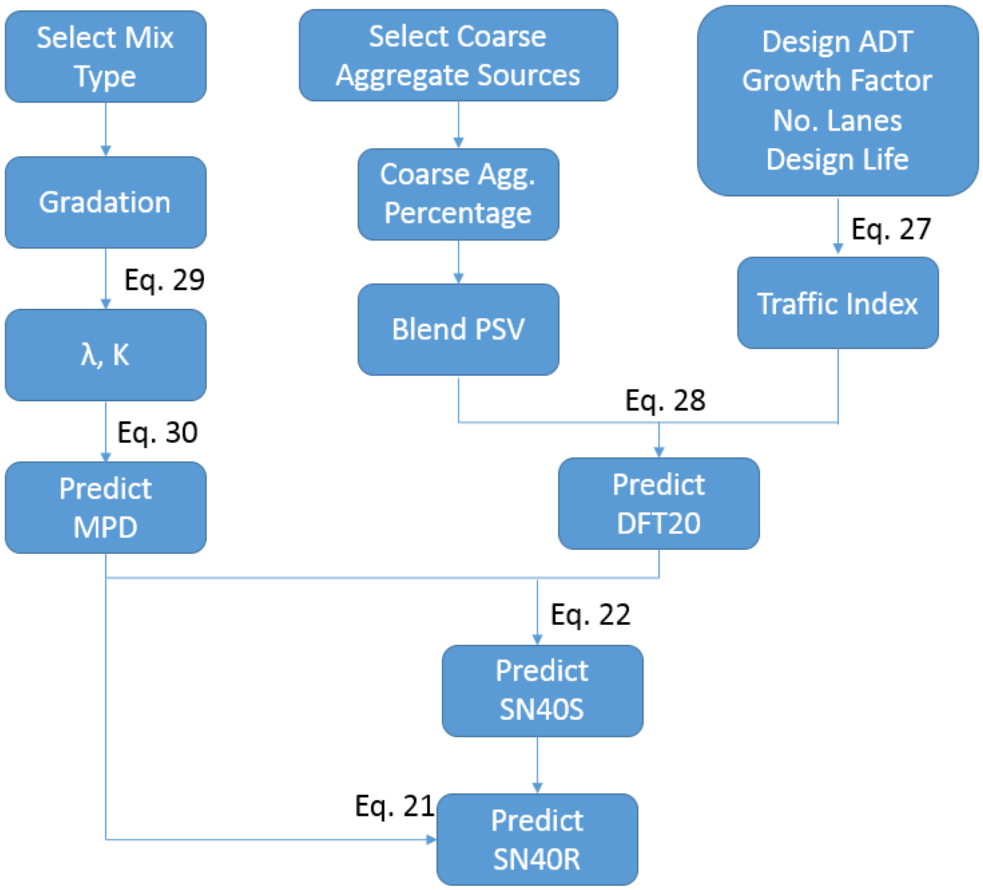


Figure 30
Prediction of skid numbers

To select the optimum combination of aggregate type and mixture design in order to achieve the desired level of skid resistance during a wearing course mix design:

- Determine the friction demand for a specific mix design and select a design skid number at the end of design life (e.g., SN40S = 20);
- Compute the design traffic index using equation (21):

$$(\quad) \quad \frac{\qquad}{\qquad}$$

- Select a mixture type (i.e., 19-mm or 12.5-mm Superpave, SMA, and OGFC) with aggregate gradation;
- Calculate and K from the selected aggregate gradation using equation (29).

$$(\qquad) \qquad ^{(\;-)}$$

- Predict the macro-texture (MPD) for the mixture considered using equation (30).

$$MPD = 0.14\times \quad + 0.09\times \quad \frac{\qquad}{\qquad}$$

- Back-calculate the required DFT20 at the end of design life (the minimum allowed DFT20 value) using equation (23).

$$SN40S = 2.15 \times DFT20 \times (\quad)$$

- Predict a required micro-texture, or PSV_{req} using equation (28).

$$DFT20 = A \times (\quad) + C \times PSV + D \times (\quad)$$

Where, A = 0.13, B = -0.056, C = 2.6, and D = -0.5 are regression coefficients. In the above equation PSV is divided by 100.

- Choose a coarse aggregate blend used in the mix that has a blend PSV value higher than PSV_{req}. The blend PSV can be determined by the following equation:

$$\text{Blend PSV} = PSV_{agg1} \times \text{Percent of agg1} + PSV_{agg2} \times \text{Percent of agg2} + \ldots$$

A simple Excel spread sheet program was developed for selecting an aggregate blend based on PSV values. It consists of three parts: Design Input, Calculations and Design Check. As shown in Figure 31, the first input is the design skid number (SN40S) which is a skid value that designers want to achieve at the end of design life, followed by the ADT at design lane, the design (service) life in years, and traffic (vehicle) growth rate. The PSV of coarse aggregates selected in a mix design needs also to be considered as inputs, which check whether it would fulfill the design skid number or not. The final inputs are gradation parameters K. Note that these two parameters need to be calculated from gradation data using the "Solver" function available in MS Excel.

Three terms are determined in calculations using above developed correlation. Calculation of traffic index involves the ADT and design life, MPD is calculated using K as given in equation 30. The DFT at given design life and ADT is calculated based on PSV of aggregate used in the surface.

Finally, the skid number based on MPD and DFT is determined. If the calculated Skid number is greater than the design skid number it shows pass. If it shows fail then either aggregate or mixture types need to be changed.

Pavement Friction Design	
Project Number	
Design Inputs	
Design Skid Number (SN40S)	0.20
ADT at Design Lanes	10000
Service Life (years)	15
Vehicle Growth Rate (%)	3
Aggregate PSV	0.38
K (From Weibull distrubution)	0.80
lemda(From Weibul distribution)	6.00
Calculations	
Traffic Index (T.I.)	54.75
MPD(mm)	0.81
DFT20	0.186978555
Design Check	
Skid Number Check	0.206718332
Pass/Fail	Pass

Figure 31
Excel spreadsheet for friction design

Table 18 is an example of the required minimum blend PSV using engineering judgement for different mixtures to ensure SN40S of 20 at the end of design life. Typically, four mixtures types were selected and representative , K values were used based on recent field test. Fifteen years of design life and four categorical ADT level were chose as given in Table 18. The different range of ADT were expected to represent interstate, US highways, state highways, and farm to market sections of Louisiana.

Table 18
Aggregate selection criteria based on blend PSV

Mixture	For 15 years design life			
	ADT @ design lane			
	0-3000	3000-7000	7000-10000	>10000
	PSV	PSV	PSV	PSV
OGFC	18	25	30	32
SMA	20	27	32	33
19-mm Superpave	22	30	34	36
12.5-mm Superpave	24	31	36	37

As expected, the PSV requirement increases with increase in traffic. As already discussed, that friction is a combination of micro and macro texture hence OGFC needed less PSV compared to other mixes. Since OGFC is an open graded mixture associated with the higher macro texture. 12.5-mm Superpave is dense graded mixture among four mixture type hence needed higher micro texture to fulfill the required friction. Surface with OGFC mixture can be ranked as high performing mixture followed by SMA and Superpave. Previous LTRC laboratory study also concluded the same hierarchy of friction performance of mixtures *[11]*.

The current friction rating table can also be evaluated comparing with Table 18. From the table, it can be seen that OGFC and SMA mixtures never require a friction rating I or II aggregate. At low traffic, the lower friction performing aggregates can be used to fulfill the design skid number which is prohibited by the current friction rating table.

Validation of Skid Prediction System

In order to check the strength of skid prediction model, thirteen different projects from PMS were identified. The details of each project required to predict skid number are given in Table 19.

First, for each project the DFT and MPD were calculated using PSV, traffic, **λ,** and K data. Then using calculated DFT20 and MPD values, the SN40S of each project were calculated using equation (22). Figure 32 is a comparison plot between calculated and field measured skid number showing strong prediction capability at 95 percent confidence level.

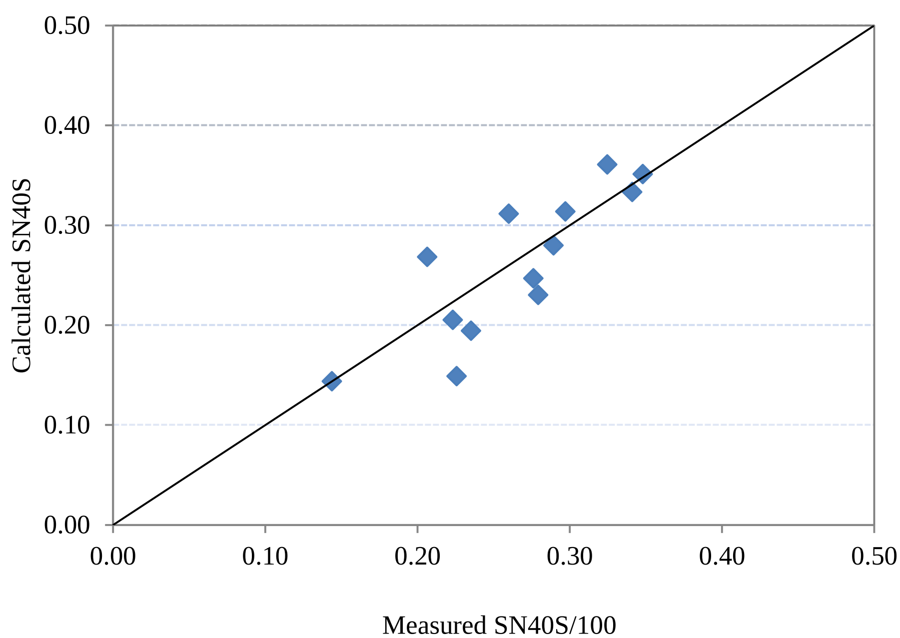


Figure 32
Measured versus calculated skid number

Table 19
Detail of PMS data used for validation

Route	Const. Date	ADT	Test Date	No. of Tests	SN40S (mean)	S.D.	λ	K	PSV/100
US 84	8/15/2000	5266	10/17/2009	14	0.35	0.038	8.62	0.77	0.31
LA 2	9/5/2003	2580	11/3/2011	6	0.30	0.026	6.15	0.86	0.30
LA 1	10/17/2002	2838	5/30/2013	5	0.29	0.038	5.43	0.72	0.31
LA 28	7/1/2002	10069	10/13/2009	13	0.21	0.038	6.08	0.77	0.28
I-20	9/14/1999	39482	10/25/2009	5	0.23	0.017	4.65	0.79	0.31
LA 433	12/22/1999	1387	7/11/2013	6	0.32	0.048	7.02	0.90	0.31
LA 496	9/21/2000	2912	8/20/2012	10	0.28	0.036	4.90	0.70	0.31
LA 447	7/25/2000	34200	7/16/2013	9	0.22	0.029	8.04	0.77	0.31
LA 191	7/11/2000	4626	7/31/2012	6	0.26	0.021	10.14	0.53	0.31
LA 1077	1/24/2003	12421	7/13/2013	7	0.24	0.023	5.44	0.72	0.31
LA 5	11/4/1994	4302	7/13/2012	7	0.14	0.054	4.02	0.69	0.30
US 165	5/24/2002	6907	10/17/2009	4	0.28	0.057	5.10	0.70	0.31
LA 10	1/26/1999	4868	5/30/2013	4	0.34	0.029	8.14	1.09	0.31

Determination of Laboratory DFT20 to Fulfill Field Skid Requirements

This section correlates the friction measurement results obtained in a previous laboratory study with the field measured skid number of SN40S *[11]*. The DFT and CTM results of 12 different laboratory mixtures were analyzed and all the analyses were designed to achieve a minimum SN40S value of 20 at the end of 15 years of design life. Table 20 shows the maximum ADT allowed in the field if same mixtures were used in the field as used in laboratory, where a 100% limestone (AA50), 100% sandstone (AB13) and a blend of 30% AB13, and 70% AA50 were used for those wearing course mix design. Different correlations developed in this study were involved in the development of Table 20, which include the relationships between lab and field MPD, between field SN40S, DFT20 and MPD, and between field DFT20, traffic index and PSV. Table 20 indicates that the 12.5-mm Superpave mixtures with a 100% limestone (AA50) aggregate blend have some limitations to be used as a wearing course mixture when the ADT of a design lane is greater than 3250. This is consistent with the current friction rating table requirement. However, if the 100% AA50 limestone aggregate blend used in a mixture design with high macro texture (e.g., SMA and OGFC) its capacity to resist the traffic wearing may be significantly improved.

Table 20
Maximum ADT

Mixture	ADT @ design lane
12.5SP LS	3250
12.5SP SS	unlimited or (>10,000)
12.5SP LS/SS	unlimited or (>10,000)
19SP LS	3700
19SP SS	unlimited or (>10,000)
19SP LS/SS	unlimited or (>10,000)
SMA LS	5150
SMA SS	unlimited or (>10,000)
SMA LS/SS	unlimited or (>10,000)
OGFC LS	8100
OGFC SS	unlimited or (>10,000)
OGFC LS/SS	unlimited or (>10,000)

The aforementioned analysis led to the development of a benchmark table of DFT20 after 100,000 laboratory polishing cycles based on design traffic level and mixture type. Table 21 presents the prediction results of various minimum required DFT20 values under different design traffic levels for the twelve asphalt mixtures designed in 09-2B. Since the limestone aggregate source had a relatively low polishing resistance (low PSV value), the corresponding required DFT20 values are shown higher in Table 21 than those using the sandstone aggregate having high polishing resistance. Note that the DFT20 values in Table 21 were determined based on the design life of 15 years.

Table 21
Predicted DFT20 under different ADTs

Mixture	Aggregate polishing resistance	DFT20 requirement at 100,000 cycles				
		ADT @ design lane				
		<1000	1000<ADT<3000	3000<ADT<5000	5000<ADT<7000	>10000
12.5-mm SP	Low	0.246	0.301	0.326	0.337	0.343
	Medium	0.242	0.299	0.324	0.330	0.331
	High	0.218	0.292	0.321	0.326	0.329
19-mm SP	Low	0.241	0.298	0.321	0.331	0.337
	Medium	0.227	0.294	0.318	0.328	0.329
	High	0.205	0.287	0.314	0.324	0.327
SMA	Low	0.204	0.266	0.303	0.321	0.333
	Medium	0.203	0.265	0.299	0.312	0.328
	High	0.200	0.260	0.295	0.306	0.321
OGFC	Low	0.195	0.265	0.294	0.307	0.314
	Medium	0.189	0.251	0.285	0.304	0.314
	High	0.184	0.246	0.282	0.304	0.311

CONCLUSIONS

Twenty-two asphalt pavement test sections covering a wide range of material type and traffic conditions (including four typical wearing course mixture types: 12.5-mm and 19-mm Superpave, SMA, and OGFC, and eight commonly-used aggregate types, 0 ~ 16.5 service years, and ADT of 200~20,000), were selected throughout Louisiana and tested in this study. Field measurements included skid numbers, surface texture by laser profile, DFT, and MPD. In addition, multi-year network measurements of skid numbers retrieved from the DOTD's PMS database as well as the laboratory DFT and MPD measurements from the LTRC project of 09-2B were also included in the analysis of this study. The collected data and measurements were used to perform comprehensive statistical analyses of the influence of aggregate properties and mixture design on skid resistance value and its variability. The following observations and conclusions can be drawn:

- OGFC mixes generally had higher skid numbers than 12.5-mm and 19-mm Superpave mixes, which are conventional dense-graded. In addition, 19-mm Superpave mixes exhibited a slightly better skid resistance than 12.5-mm Superpave mixes, presumably owing to its larger surface macro-texture (MPD). The field skid performance of SMA mixes was inconclusive due to only two similar SMA mixture sections tested in this study.
- The analysis results of the effect of aggregate type on skid resistance showed that there was high interaction between aggregate performance, mix type in which aggregate is used, and traffic level. Some aggregate types showed the mix-bagged performance in different mixes and traffic levels. In general, to classify the skid resistance of an aggregate, both mixture type and traffic level should be pre-specified.
- The results of the macro-texture measurements by the CTM showed that the OGFC mixes had higher MPD values compared with Superpave and SMA mixes. This is in agreement with the laboratory finding in 09-2B project. On the other hand, the friction measured using the DFT, which is an indication of micro-texture, showed that the DFT20 of a wearing course mixture depended on aggregate type and traffic index (a wear factor considering both ADT and service years).
- Correlation analyses indicated that a fair linear relationship existed between SN40R and DFT20; whereas, poor linear correlations existed between SNR40 vs. SNS40, SNS40 vs. DFT20, and SN40S vs. MPD. No linear relationships were found between DFT20 vs. MPD and SN40R vs. MPD.
- The results of correlation analysis suggest that the measured skid number is affected by both macro-texture (mixture type) and micro-texture (aggregate type). As expected, the SN40R was found to be more sensitive to the micro-texture, while the SN40S was

sensitive to both micro- and macro-textures. Consequently, a regression model was developed to predict the SN40R based on SN40S and MPD, and a non-linear relationship was regressed to predict the SN40S based on DFT20 and MPD.

- ANOVA analyses indicated that DFT measurements may be predicted by aggregate properties at a given traffic level. A nonlinear regression analysis was performed to developed a DFT20 degradation model based on the PSV of coarse aggregates used in a wearing course mix and the corresponding traffic index.
- The correlation analyses led to the development of a procedure for predicting pavement end-of-life skid resistance based on the design traffic, aggregate blend polish stone value and gradation parameters. The developed friction prediction procedure can be used to update the current DOTD coarse aggregate friction table by specifying the pavement friction requirements under different traffic levels through selection of different mixture and aggregate types.
- Finally, the field DFT and MPD measurements were compared with those obtained in the laboratory of the 09-2B project. A benchmark DFT rating table based on the traffic level and mixture type was proposed for the DFT20 value after 100,000 polishing cycles, which can be used to evaluate the friction resistance of the new aggregate sources to be certified by DOTD.

RECOMMENDATIONS

It is recommended that the Materials and Testing Section implement the developed end-of-pavement-life skid resistance prediction procedure by considering the design traffic, aggregate blend polish stone value and gradation parameters in its routine wearing course mix design. The PSV-and-Traffic-based friction rating table - Table 502-3 in the current DOTD's Road and Bridges Specifications may be replaced by a new wearing course mix design friction table based on blend PSV, mixture type and traffic, such as Table 18 in this report.

The benchmark DFT rating table developed in this study demonstrates that a friction aggregate source may be certified by the laboratory DFT test and loaded-wheel polishing slab test (such as the TWPD test at NCAT). The developed DFT table was based on the four mix types used in the 09-2B study, and based on different traffic levels. To further develop the certification procedure of friction aggregate sources, the key will be to standardize the mixture components. It is recommended using only one mix type (such as 12.5 mm Supeprave or SMA) that contains 60 percent of the test aggregate as all coarse aggregates (i.e., all aggregates from the maximum aggregate size to the #8 sieve) and a common, non-modified asphalt binder. After the TWPD testing on a very good coarse aggregate and a poor coarse aggregate, the minimum required DFT values can be established based on different traffic levels (or polishing cycles) for a mix design.

The Pavement Management Section may use the developed speed gradient equations (equation (24) for ribbed tire skid number and equation (25) for the smooth tire skid number) in converting the skid number measurements of different speeds into one common speed based skid number measurement values, such as SN40S, SN40R and etc. The unified, statewide skid number testing results may be used to establish a set of threshold (or minimum) skid number values for roads under different road design speeds. When a road section's skid number reaches below its threshold value, an intervention investigation must be performed on such road section.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
BPT	British Pendulum Tester
BPN	British Pendulum Number
CTM	Circular Track Meter
DFT	Dynamic Friction Tester
DOTD	Department of Transportation and Development
ESAL	Equivalent Single Axle Load
FHWA	Federal Highway Administration
FR	Friction Rating
HMA	Hot Mix Asphalt
IFI	International Friction Index
JMF	Job Mix Formula
LTRC	Louisiana Transportation Research Center
LWST	Locked Wheel Skid Trailer
MPD	Mean Profile Depth
MTD	Mean Texture Depth
NCAT	National Center for Asphalt Technology
NCHRP	National Cooperative Highway Research Program
OGFC	Open Graded Friction Course
PIARC	Permanent International Association of Road Congress
PMS	Project Management System
PSV	Polish Stone Value
QPL	Qualified Product List
SAS	Statistical Analysis System
SMA	Stone Mastic Asphalt
TWPD	Three Wheel Polishing Device

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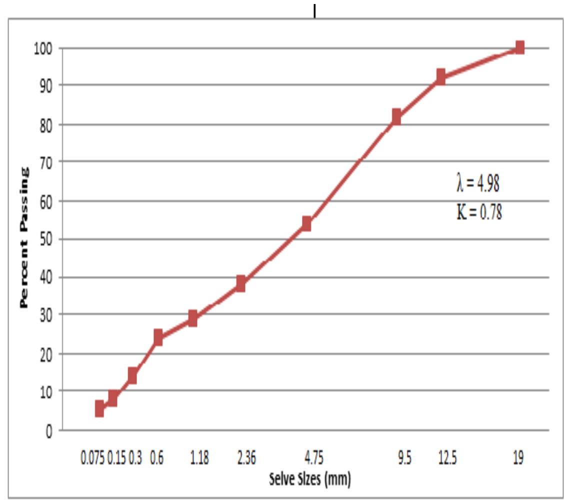
APPENDIX A

Detailed Information about the Selected Projects

Project ID: **261-03-0017**
General Information:
Parish: Tangipahoa, Route: LA 22, Traffic index: 10.12, Age: 6, Design Lane ADT: 4300, Surface coarse aggregate: Limestone (AA50 7.9%) +Sandstone (AB13 34.4%) + Gravel (AX65 41.3%) + RAP (RP10 16.4%),

Mixture Gradation Information:

Mix Type	12.5 mm Superpave
Binder Type	PG76-22
Binder Content	4.80%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	92
9. 5 mm (3/8 in.)	82
4. 75 mm (No. 4)	54
2. 36 mm (No. 8)	38
1. 18 mm (No. 16)	29
0.600 mm (No. 30)	24
0.300 mm (No. 50)	14
0.150 mm (No. 100)	8
0.075 mm (No. 200)	5.2



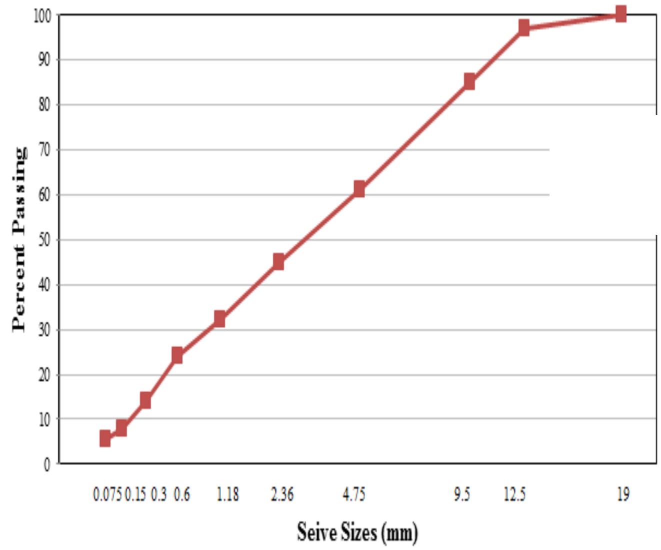
Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.28	0.85	0.21	1	42.8	32.7	1.16
1-b	0.29	0.99	0.22	1	42.9	31.8	2.78
1-c	0.30	0.97	0.23	1	43.0	31.2	2.76
Avg.	0.29	0.94	0.22	Avg.	42.9	31.9	2.23
2-a	0.28	0.91	0.22	2	42.4	33.7	1.30
2-b	0.30	0.91	0.22	2	44.0	32.9	2.97
2-c	0.29	0.81	0.21	2	44.4	31.2	3.10
Avg.	0.29	0.88	0.22	Avg.	43.6	32.6	2.46
3-a	0.29	0.78	0.21	3	42.5	33.5	1.30
3-b	0.31	0.72	0.22	3	45.7	31.3	3.09
3-c	0.29	0.77	0.21	3	45.0	31.1	2.89
Avg.	0.3	0.76	0.21	Avg.	44.4	32.0	2.43

Project ID: **231-01-0006**
General Information:
Parish: Ascension, Route: LA 405, Traffic Index: 0.63, Age: 7.2, Design Lane ADT: 220, Test Date: 08/01/2012, Surface Coarse Aggregate: Limestone (AA50 83%) +RAP (RP21 17%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	4.1%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	97
9. 5 mm (3/8 in.)	85
4. 75 mm (No. 4)	61
2. 36 mm (No. 8)	45
1. 18 mm (No. 16)	32
0.600 mm (No. 30)	24
0.300 mm (No. 50)	14
0.150 mm (No. 100)	8
0.075 mm (No. 200)	5.4



Friction Measurement Results

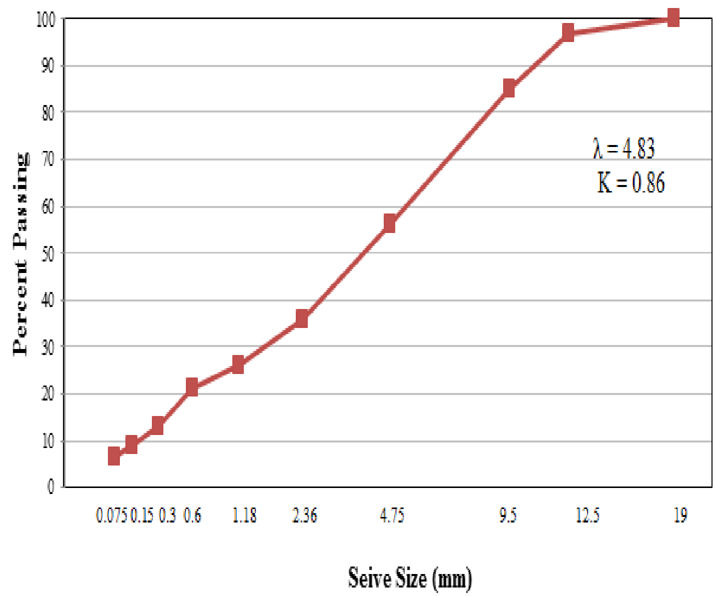
Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.31	0.72	0.22	1	51.0	38.5	2.50
1-b	0.32	0.77	0.22	1	50.1	33.0	2.75
1-c	0.30	0.78	0.22	1	50.3	33.4	2.64
Avg.	0.31	0.76	0.22	Avg.	50.5	35.0	2.63
2-a	0.31	0.88	0.23	2	51.5	36.8	2.71
2-b	0.30	0.84	0.22	2	47.9	33.2	2.38
2-c	0.30	0.72	0.21	2	47.6	32.3	2.39
Avg.	0.30	0.81	0.22	Avg.	49.0	34.1	2.49
3-a	0.30	0.82	0.22	3	48.9	36.0	2.98
3-b	0.29	0.79	0.21	3	47.8	33.5	2.85
3-c	0.26	0.87	0.21	3	46.7	31.6	2.81
Avg.	0.28	0.83	0.21	Avg.	47.8	33.7	2.88

Project ID: **845-21-0003**

General Information:
Parish: St Charles, Route: LA 3160, Traffic Index: 4.01, Age: 7.2, Design Lane ADT: 1400, Test Date: 09/27/2012, Surface Coarse Aggregate: Limestone (AA50 66%) +Gravel (AX65 18 %) + RAP (RP09 16%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	PG70-22
Binder Content	5.1%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	97
9. 5 mm (3/8 in.)	85
4. 75 mm (No. 4)	56
2. 36 mm (No. 8)	36
1. 18 mm (No. 16)	26
0.600 mm (No. 30)	21
0.300 mm (No. 50)	13
0.150 mm (No. 100)	9
0.075 mm (No. 200)	6.4



Friction Measurement Results

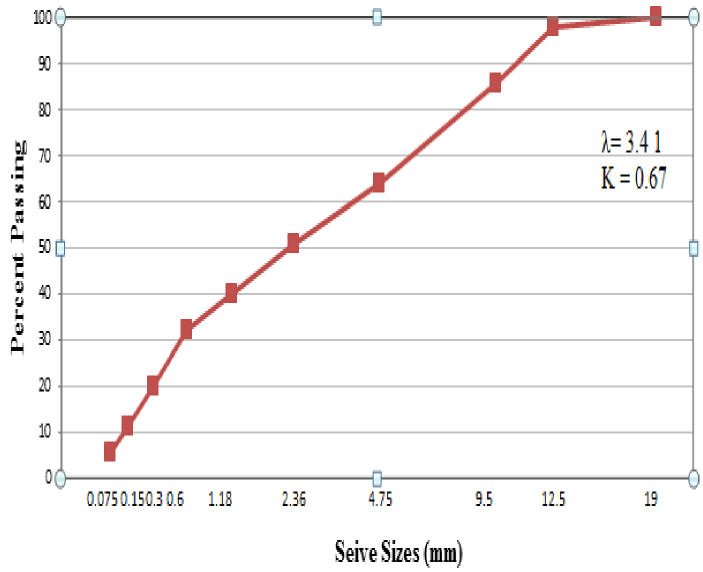
Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.30	0.77	0.22	1	46.0	29.6	3.13
1-b	0.31	0.75	0.08	1	45.6	29.2	2.98
1-c	0.29	0.80	0.08	1	45.8	28.2	2.95
Avg.	0.30	0.77	0.13	Avg.	45.8	29.0	3.02
2-a	0.30	0.82	0.22	2	45.3	31.6	3.31
2-b	0.31	0.82	0.22	2	46.0	29.6	3.44
2-c	0.33	0.77	0.23	2	45.6	28.9	3.28
Avg.	0.31	0.80	0.22	Avg.	45.6	30.0	3.34
3-a	0.31	0.68	0.21	3	45.4	32.1	3.27
3-b	0.31	0.72	0.22	3	46.7	30.0	3.07
3-c	0.28	0.73	0.21	3	45.4	32.9	3.36
Avg.	0.30	0.71	0.21	Avg.	45.8	31.7	3.23

Project ID: **056-07-0016**

General Information:
Parish: St Landry, Route: LA 31, Traffic Index: 2.98, Age: 4.8, Design Lane ADT: 1600, Test Date: 7/24/2012, Surface Coarse Aggregate: Limestone (AA50 100%)

Mixture Gradation Information

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	4.6%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	98
9. 5 mm (3/8 in.)	86
4. 75 mm (No. 4)	64
2. 36 mm (No. 8)	51
1. 18 mm (No. 16)	40
0.600 mm (No. 30)	32
0.300 mm (No. 50)	20
0.150 mm (No. 100)	11
0.075 mm (No. 200)	5.5



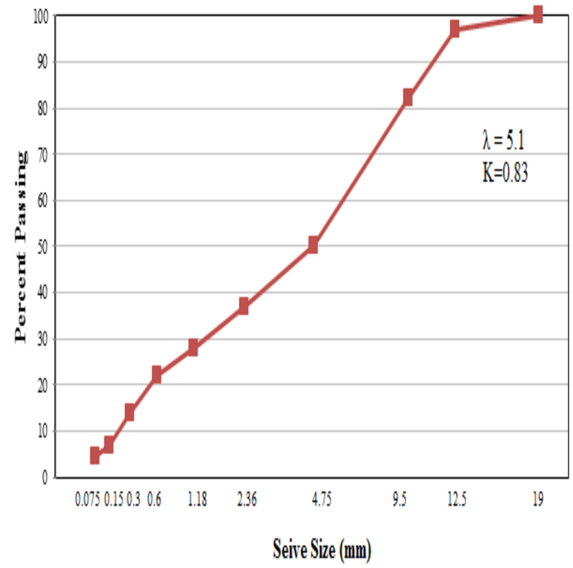
Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP) (mm)
1-a	0.24	0.60	0.18	1	38.6	23.5	2.2
1-b	0.24	0.66	0.18	1	38.4	21.7	2.3
1-c	0.23	0.57	0.17	1	37.3	21.2	3.0
Avg.	0.24	0.61	0.18	Avg.	38.1	22.1	2.5
2-a	0.24	0.60	0.18	2	36.0	21.9	2.5
2-b	0.26	0.52	0.18	2	35.4	20.3	3.0
2-c	0.25	0.63	0.19	2	36.7	20.3	3.4
Avg.	0.25	0.58	0.18	Avg.	36.0	20.8	3.0
3-a	0.29	0.55	0.19	3	38.3	22.0	2.2
3-b	0.29	0.49	0.19	3	38.4	20.2	2.8
3-c	0.29	0.56	0.19	3	39.1	21.4	3.1
Avg.	0.29	0.53	0.19	Avg.	38.6	21.2	2.7

Project ID: 033-01-0032
General Information:
Parish: Avoyelles, Route: LA 29, Traffic Index: 6.45, Age: 6.9, Design Lane ADT: 2350, Test Date: 07/24/2012, Surface Coarse Aggregate: Limestone (AA50 65%) + Sandstone (AB13 35%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	4.60%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	97
9. 5 mm (3/8 in.)	82
4. 75 mm (No. 4)	50
2. 36 mm (No. 8)	37
1. 18 mm (No. 16)	28
0.600 mm (No. 30)	22
0.300 mm (No. 50)	14
0.150 mm (No. 100)	7
0.075 mm (No. 200)	4.7



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.29	0.74	0.21	1	41.5	30.2	1.42
1-b	0.30	0.72	0.21	1	42.5	29.6	1.48
1-c	0.30	0.75	0.21	1	42.4	30.1	1.50
Avg.	0.30	0.74	0.21	Avg.	42.1	30.0	1.47
2-a	0.28	0.82	0.21	2	39.0	27.8	1.28
2-b	0.27	0.68	0.20	2	39.3	28.3	1.73
2-c	0.27	0.70	0.20	2	41.3	27.5	1.36
Avg.	0.27	0.73	0.20	Avg.	39.9	27.9	1.46
3-a	0.28	0.74	0.20	3	40.6	27.2	1.34
3-b	0.28	0.75	0.21	3	42.1	27.0	1.62
3-c	0.28	0.79	0.21	3	42.0	27.6	1.77
Avg.	0.28	0.76	0.21	Avg.	41.6	27.3	1.58

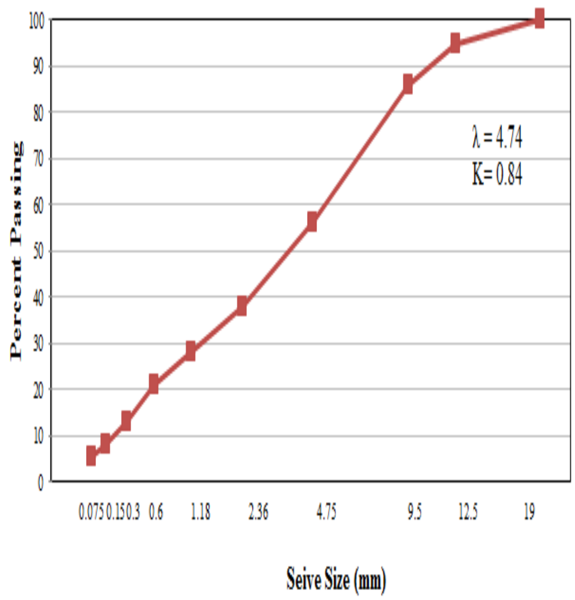
Project ID: **272-02-0012**

General Information:

Parish: Livingston, Route: LA 63, Traffic Index: 10.13, Age: 6.1, Design Lane ADT: 4200, Test Date: 07/26/2012, Surface Coarse Aggregate: Limestone (AA50 7.9%) + Sandstone (AB13 34.4%) + Gravel (AX65 41.3%) + RAP (RP10 16.4%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	5.4%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	95
9. 5 mm (3/8 in.)	86
4. 75 mm (No. 4)	56
2. 36 mm (No. 8)	38
1. 18 mm (No. 16)	28
0.600 mm (No. 30)	21
0.300 mm (No. 50)	13
0.150 mm (No. 100)	8
0.075 mm (No. 200)	5.4



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.29	0.88	0.22	1	43.1	32.2	2.96
1-b	0.30	0.90	0.23	1	42.3	33.7	3.65
1-c	0.28	1.09	0.22	1	43.0	31.9	3.14
Avg.	0.29	0.96	0.22	Avg.	42.8	32.6	3.25
2-a	0.33	0.90	0.24	2	44.4	35.4	2.68
2-b	0.33	0.77	0.23	2	45.1	33.0	2.69
2-c	0.32	0.81	0.23	2	43.7	32.9	3.25
Avg.	0.33	0.83	0.23	Avg.	44.4	33.8	2.87
3-a	0.32	0.83	0.23	3	44.8	34.5	3.01
3-b	0.32	0.83	0.23	3	45.3	33.7	3.25
3-c	0.32	0.93	0.24	3	44.3	31.8	3.15
Avg.	0.32	0.86	0.23	Avg.	44.8	33.3	3.14

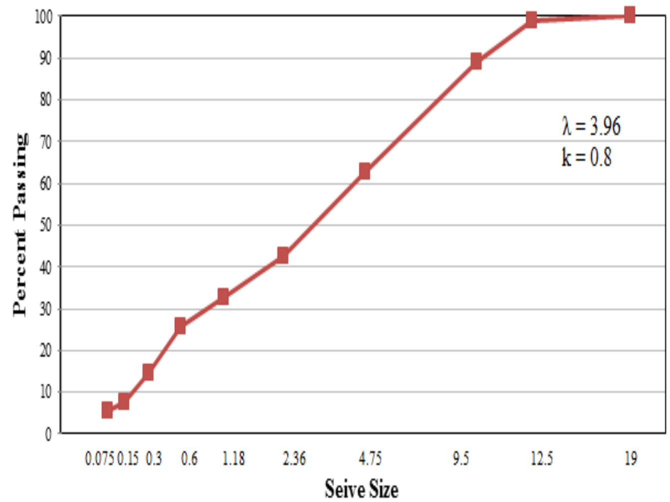
Project ID: **823-02-0027**

General Information:

Parish: Iberia, Route: LA 675, Traffic Index: 6.32, Age: 3.5, Design Lane ADT: 4750, Test Date: 08/07/2012, Surface Coarse Aggregate: Limestone (AA50 65%) + Sandstone (AB13 35%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	4.5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	98.8
9. 5 mm (3/8 in.)	89
4. 75 mm (No. 4)	62.8
2. 36 mm (No. 8)	42.6
1. 18 mm (No. 16)	32.8
0.600 mm (No. 30)	25.8
0.300 mm (No. 50)	14.4
0.150 mm (No. 100)	7.4
0.075 mm (No. 200)	5.48



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.23	0.77	0.19	1	41.5	30.2	1.42
1-b	0.22	0.77	0.18	1	42.5	29.6	1.48
1-c	0.22	0.80	0.18	1	42.4	30.1	1.50
Avg.	0.22	0.78	0.18	Avg.	42.1	30.0	1.47
2-a	0.20	0.74	0.17	2	39.0	27.8	1.28
2-b	0.21	0.67	0.17	2	39.3	28.3	1.73
2-c	0.19	0.72	0.16	2	41.3	27.5	1.36
Avg.	0.20	0.71	0.17	Avg.	39.9	27.9	1.46
3-a	0.20	0.73	0.17	3	40.6	27.2	1.34
3-b	0.21	0.64	0.17	3	42.1	27.0	1.62
3-c	0.21	0.67	0.17	3	42.0	27.6	1.77
Avg.	0.21	0.68	0.17	Avg.	41.6	27.3	1.58

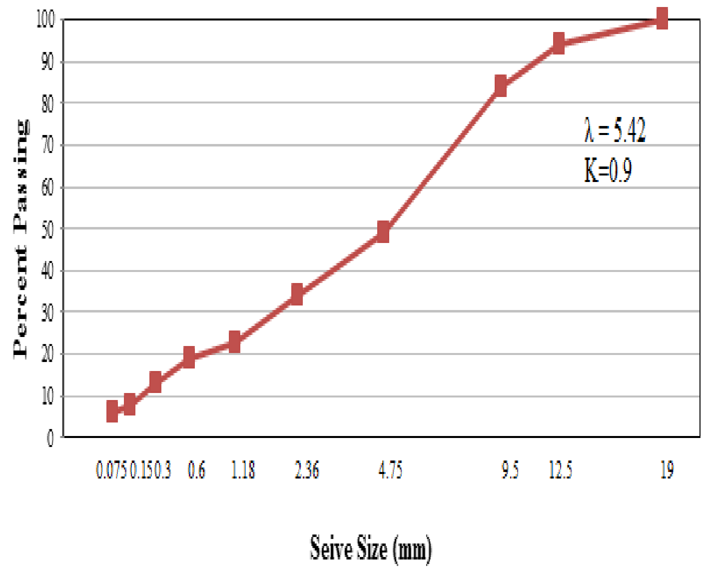
Project ID: **414-03-0024**

General Information:

Parish: Ascension, Route: LA 30, Traffic Index 12.67, Age: 6.2, Design Lane ADT: 5200, Test Date: 08/01/2012, Surface Coarse Aggregate: Limestone (AA50 34.3%) + Sandstone (AB13 45.4%) + Gravel (AX72 6%) + RAP (RP09 14.3%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	4.60%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	94
9. 5 mm (3/8 in.)	84
4. 75 mm (No. 4)	49
2. 36 mm (No. 8)	34
1. 18 mm (No. 16)	23
0.600 mm (No. 30)	19
0.300 mm (No. 50)	13
0.150 mm (No. 100)	8
0.075 mm (No. 200)	6.4



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.32	0.78	0.23	1	43.0	30.8	1.31
1-b	0.30	0.92	0.23	1	43.9	30.9	1.14
1-c	0.32	0.79	0.23	1	44.6	30.8	2.56
Avg.	0.31	0.83	0.23	Avg.	43.8	30.8	1.67
2-a	0.31	0.75	0.22	2	39.7	30.0	1.36
2-b	0.30	0.60	0.20	2	42.3	28.8	1.31
2-c	0.32	0.75	0.22	2	42.9	29.0	3.06
Avg.	0.31	0.70	0.21	Avg.	41.6	29.3	1.91
3-a	0.31	0.86	0.23	3	41.3	33.4	1.16
3-b	0.31	0.94	0.23	3	43.2	33.7	1.11
3-c	0.28	1.07	0.22	3	44.9	31.7	2.79
Avg.	0.30	0.96	0.23	Avg.	43.1	32.9	1.69

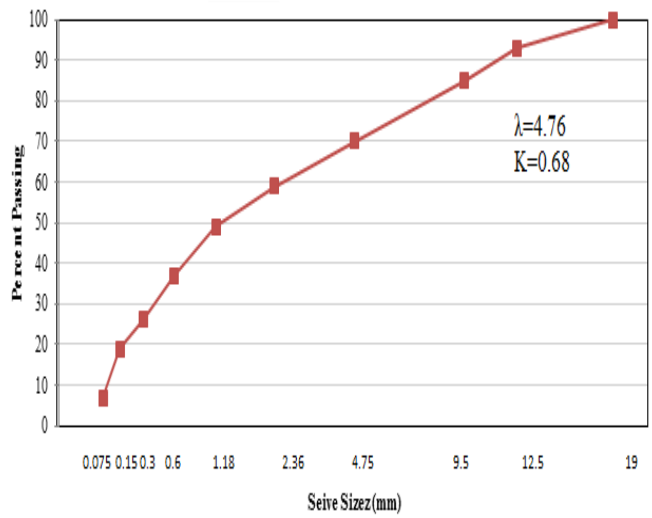
Project ID: 005-09-0033

General Information:

Parish: St Charles, Route: US90[a], Traffic Index: 32.0, Age: 12.4, Design Lane ADT: 5959, Test Date: 9/26/2013, Surface Coarse Aggregate: Limestone (AA50 100%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	3%
Metric (US)Sieve	Composite Gradation Blend
37.5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12.5 mm (1/2 in.)	93
9.5 mm (3/8 in.)	85
4.75 mm (No. 4)	70
2.36 mm (No. 8)	59
1.18 mm (No. 16)	49
0.600 mm (No. 30)	37
0.300 mm (No. 50)	26
0.150 mm (No. 100)	19
0.075 mm (No. 200)	6.8



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP) (mm)
1-a	0.19	0.72	0.16	1	34.7	29.6	N/A
1-b	0.19	0.78	0.17	1	34.2	29.1	N/A
1-c	0.21	0.77	0.18	1	36.1	30.3	N/A
Avg.	0.20	0.76	0.17	Avg.	35.0	29.7	N/A
2-a	0.21	0.81	0.18	2	33.0	29.7	N/A
2-b	0.18	0.82	0.16	2	34.6	29.9	N/A
2-c	0.21	0.80	0.18	2	34.5	29.7	N/A
Avg.	0.20	0.81	0.17	Avg.	34.0	29.8	N/A
3-a	0.18	0.81	0.16	3	34.3	24.7	N/A
3-b	0.15	0.76	0.15	3	35.0	27.0	N/A
3-c	0.18	0.83	0.16	3	36.2	25.4	N/A
Avg.	0.17	0.80	0.16	Avg.	35.2	25.7	N/A

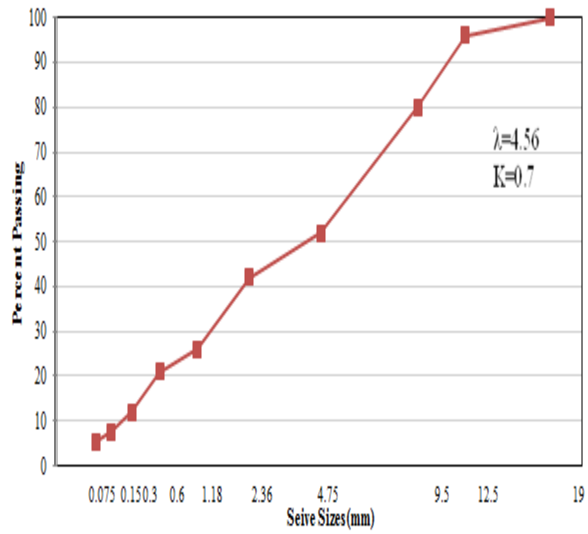
Project ID: **803-08-0015**

General Information:

Parish: Ascension, Route: LA 621, Traffic Index: 69.16, Age: 16.5, Design Lane ADT: 9063, Test Date: 10/09/2013, Surface Coarse Aggregate: Limestone (AA50 100%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	
Binder Content	4.4%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	96
9. 5 mm (3/8 in.)	80
4. 75 mm (No. 4)	52
2. 36 mm (No. 8)	42
1. 18 mm (No. 16)	26
0.600 mm (No. 30)	21
0.300 mm (No. 50)	12
0.150 mm (No. 100)	7.6
0.075 mm (No. 200)	5.4



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP) (mm)
1-a	0.13	0.58	0.13	1	36.1	27.5	N/A
1-b	0.14	0.55	0.14	1	35.0	26.6	N/A
1-c	0.13	0.55	0.13	1	34.9	25.3	N/A
Avg.	0.13	0.56	0.13	Avg.	35.3	26.5	N/A
2-a	0.11	0.62	0.13	2	33.9	27.0	N/A
2-b	0.15	0.61	0.14	2	35.0	27.1	N/A
2-c	0.12	0.63	0.13	2	33.6	26.4	N/A
Avg.	0.13	0.62	0.13	Avg.	34.2	26.8	N/A
3-a	0.14	0.63	0.14	3	30.9	27.3	N/A
3-b	0.12	0.64	0.13	3	31.5	26.5	N/A
3-c	0.13	0.62	0.13	3	30.7	24.7	N/A
Avg.	0.13	0.63	0.13	Avg.	31.0	26.2	N/A

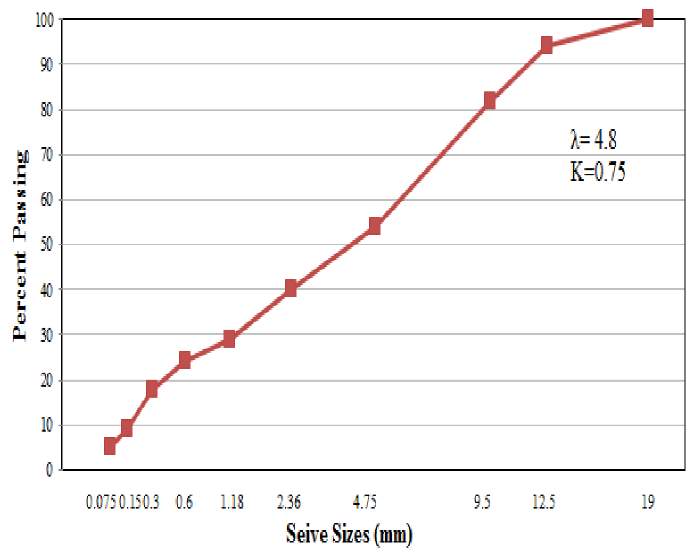
Project ID: **025-08-0060**

General Information:

Parish: Caddo, Route: US171[a], Traffic Index 8.07, Age: 2.7, Design Lane ADT: 8026, Test Date: 10/09/2012, Surface Coarse Aggregate: Novaculite (AA44 82.7%) +RAP (AL22 17.3%)

Mixture Gradation Information:

Mix Type	12.5mm Superpave
Binder Type	PG70-22M
Binder Content	5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	94
9. 5 mm (3/8 in.)	82
4. 75 mm (No. 4)	54
2. 36 mm (No. 8)	40
1. 18 mm (No. 16)	29
0.600 mm (No. 30)	24
0.300 mm (No. 50)	18
0.150 mm (No. 100)	9
0.075 mm (No. 200)	5



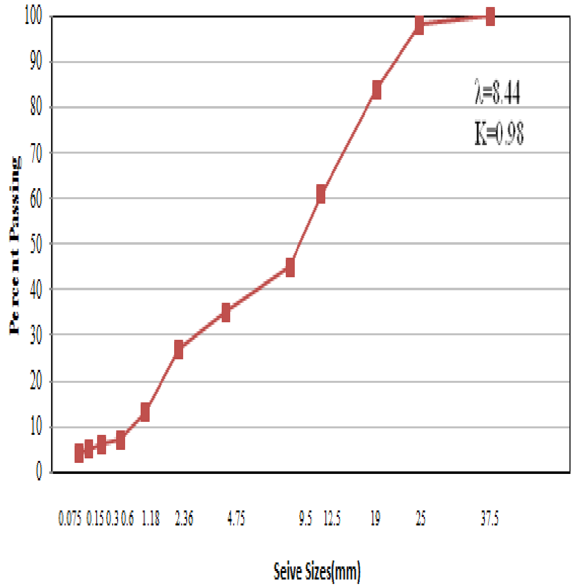
Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.32	0.43	0.19	1	45.4	23.5	N/A
1-b	0.32	0.59	0.21	1	47.2	24.7	N/A
1-c	0.31	0.52	0.20	1	47.8	23.7	N/A
Avg.	0.32	0.51	0.20	Avg.	46.8	24.0	
2-a	0.33	0.57	0.21	2	48.6	21.4	N/A
2-b	0.34	0.66	0.22	2	48.4	24.1	N/A
2-c	0.31	0.68	0.21	2	44.1	22.2	N/A
Avg.	0.33	0.64	0.21	Avg.	47.0	22.6	
3-a	0.31	0.56	0.20	3	46.3	22.2	N/A
3-b	0.31	0.56	0.20	3	46.1	24.2	N/A
3-c	0.30	0.69	0.21	3	45.6	23.3	N/A
Avg.	0.31	0.60	0.20	Avg.	46.0	23.2	

Project ID: **008-04-0057**
General Information:
Parish: St. Landry, Route: US190, Traffic Index: 8.02, Age: 7.9, Design Lane ADT: 2525, Test Date: 7/24/2012, Surface Coarse Aggregate: Limestone (AA50 100%)

Mixture Gradation Information:

Mix Type	19mm Superpave
Binder Type	
Binder Content	4.6%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	98
19.0 mm (3/4 in.)	84
12. 5 mm (1/2 in.)	61
9. 5 mm (3/8 in.)	45
4. 75 mm (No. 4)	35
2. 36 mm (No. 8)	27
1. 18 mm (No. 16)	13
0.600 mm (No. 30)	7
0.300 mm (No. 50)	6.2
0.150 mm (No. 100)	5
0.075 mm (No. 200)	4.2



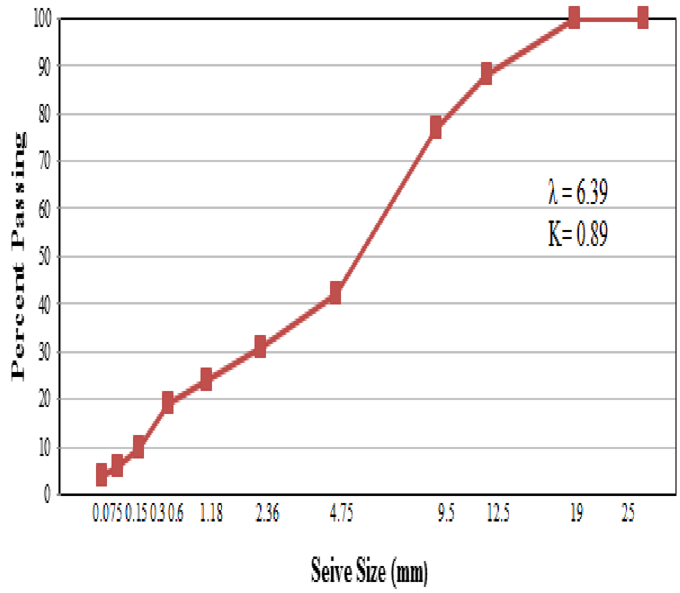
Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.25	1.29	0.21	1	37.9	33.1	3.37
1-b	0.23	1.31	0.20	1	38.6	31.3	3.40
1-c	0.22	1.21	0.20	1	38.2	30.7	3.78
Avg.	0.23	1.27	0.20	Avg.	38.3	31.7	3.52
2-a	0.21	1.29	0.20	2	37.2	32.4	3.56
2-b	0.22	1.36	0.20	2	36.0	31.3	3.59
2-c	0.22	1.28	0.20	2	36.6	30.2	4.38
Avg.	0.22	1.31	0.20	Avg.	36.6	31.3	3.84
3-a	0.23	1.49	0.21	3	37.8	31.6	3.39
3-b	0.24	1.26	0.21	3	37.5	32.0	3.77
3-c	0.23	1.39	0.21	3	37.6	30.4	4.13
Avg.	0.23	1.38	0.21	Avg.	37.6	31.3	3.76

Project ID: **207-03-0014**
General Information:
Parish: Vermilion, Route: LA 35, Traffic Index: 3.51, Age: 3.4, Design Lane ADT: 2700, Test Date: 08/07/2012, Surface Coarse Aggregate: Limestone (AA50 100%)

Mixture Gradation Information:

Mix Type	19 mm Superpave
Binder Type	PG76-22
Binder Content	4.80%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	88
9. 5 mm (3/8 in.)	77
4. 75 mm (No. 4)	42
2. 36 mm (No. 8)	31
1. 18 mm (No. 16)	24
0.600 mm (No. 30)	19
0.300 mm (No. 50)	10
0.150 mm (No. 100)	6
0.075 mm (No. 200)	4



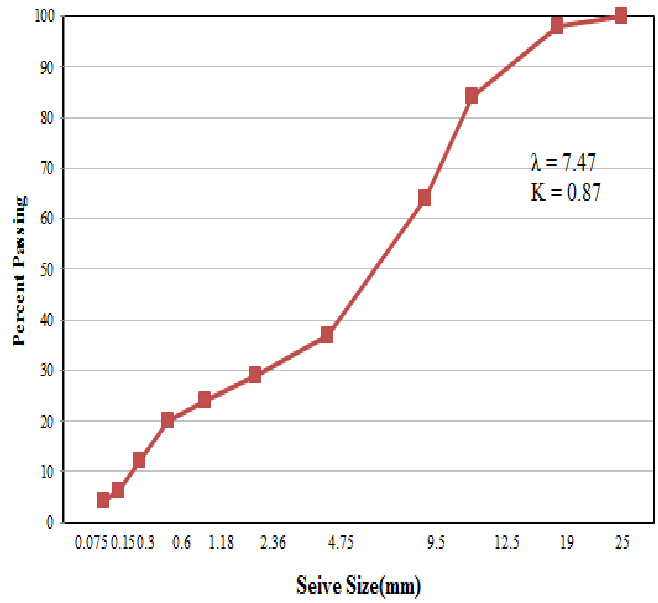
Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.25	0.56	0.18	1	43.1	24.9	1.55
1-b	0.25	0.53	0.18	1	42.3	25.7	3.15
1-c	0.25	0.67	0.19	1	43.0	21.7	3.10
Avg.	0.25	0.59	0.18	Avg.	42.8	24.1	2.60
2-a	0.28	0.84	0.21	2	44.4	24.9	1.50
2-b	0.27	0.68	0.20	2	45.1	25.2	2.31
2-c	0.26	0.68	0.19	2	43.7	23.4	2.88
Avg.	0.27	0.73	0.20	Avg.	44.4	24.5	2.23
3-a	0.26	0.80	0.20	3	44.8	27.3	1.61
3-b	0.26	0.80	0.20	3	45.3	27.4	2.90
3-c	0.25	0.75	0.19	3	44.3	25.9	2.24
Avg.	0.26	0.78	0.20	Avg.	44.8	26.9	2.25

Project ID: **260-02-0034**
General Information:
Parish: Livingston, Route: LA14, Traffic Index 18.04, Age: 7.7, Design Lane ADT: 5800, Test Date: 07/17/2012, Surface Coarse Aggregate: Limestone (AA50 83.6%) +RAP (RP05 16.4%)

Mixture Gradation Information:

Mix Type	19mm Superpave
Binder Type	
Binder Content	4.00%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	98
12. 5 mm (1/2 in.)	84
9. 5 mm (3/8 in.)	64
4. 75 mm (No. 4)	37
2. 36 mm (No. 8)	29
1. 18 mm (No. 16)	24
0.600 mm (No. 30)	20
0.300 mm (No. 50)	12
0.150 mm (No. 100)	6.2
0.075 mm (No. 200)	4.2



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.21	0.91	0.18	1	31.6	29.1	1.58
1-b	0.22	1.20	0.19	1	32.9	26.5	3.28
1-c	0.21	1.33	0.19	1	32.0	25.6	3.76
Avg.	0.21	1.15	0.19	Avg.	32.2	27.1	2.87
2-a	0.21	1.16	0.19	2	30.1	30.4	1.93
2-b	0.21	1.16	0.19	2	32.1	28.4	4.86
2-c	0.22	1.10	0.19	2	31.8	27.4	7.98
Avg.	0.21	1.14	0.19	Avg.	31.3	28.7	4.92
3-a	0.20	1.21	0.19	3	31.7	30.2	1.71
3-b	0.21	1.43	0.19	3	31.6	28.7	3.50
3-c	0.21	1.32	0.20	3	32.0	27.1	7.96
Avg.	0.21	1.32	0.19	Avg.	31.8	28.7	4.39

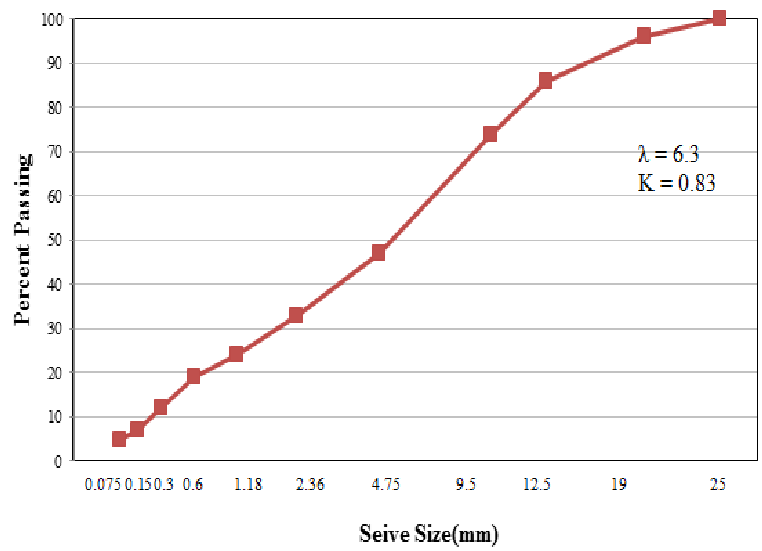
Project ID: 059-04-0018

General Information:

Parish: Washington, Route: LA25, Traffic Index 6.36, Age: 6.4, Design Lane ADT: 2500, Test Date: 08/08/2012, Surface Coarse Aggregate: Limestone (AA50 14.2%)+Sandstone (AB13 33%)+Gravel (AX65 37.4%) + RAP (RP09 15.4%)

Mixture Gradation Information:

Mix Type	19mm Superpave
Binder Type	
Binder Content	4.8%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	96
12. 5 mm (1/2 in.)	86
9. 5 mm (3/8 in.)	74
4. 75 mm (No. 4)	47
2. 36 mm (No. 8)	33
1. 18 mm (No. 16)	24
0.600 mm (No. 30)	19
0.300 mm (No. 50)	12
0.150 mm (No. 100)	7
0.075 mm (No. 200)	4.9



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.32	1.04	0.24	1	47.3	38.3	3.34
1-b	0.32	1.06	0.24	1	47.0	37.9	3.59
1-c	0.33	0.88	0.24	1	46.5	36.9	3.55
Avg.	0.32	0.99	0.24	Avg.	46.9	37.7	3.49
2-a	0.33	0.93	0.24	2	49.0	35.5	3.00
2-b	0.31	1.08	0.24	2	48.5	35.7	3.31
2-c	0.34	1.05	0.25	2	48.7	34.4	3.41
Avg.	0.33	1.02	0.24	Avg.	48.7	35.2	3.24
3-a	0.34	1.05	0.25	3	52.0	40.6	3.62
3-b	0.34	1.04	0.25	3	51.4	40.3	5.36
3-c	0.34	1.08	0.25	3	49.6	38.1	6.16
Avg.	0.34	1.06	0.25	Avg.	51.0	39.7	5.05

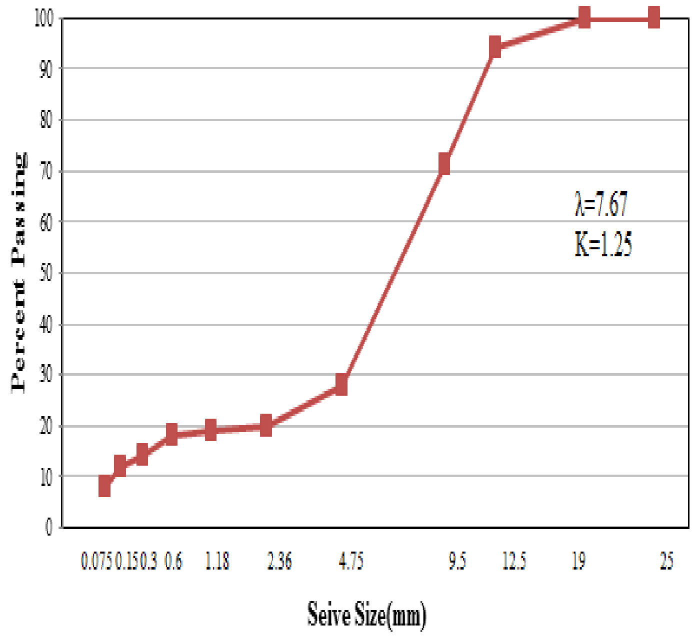
Project ID: 451-08-0078

General Information:

Parish: Madison, Route: I20[a], Traffic Index 0.18, Age: 0.1, Design Lane ADT: 6025,
Test Date: 10/10/2012, Surface Coarse Aggregate: Granite (AA39 50.6%) +Siliceous Limestone (ABBQ 49.4%)

Mixture Gradation Information:

Mix Type	SMA
Binder Type	PG76-22M
Binder Content	6.0%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	94
9. 5 mm (3/8 in.)	71
4. 75 mm (No. 4)	28
2. 36 mm (No. 8)	20
1. 18 mm (No. 16)	19
0.600 mm (No. 30)	18
0.300 mm (No. 50)	14
0.150 mm (No. 100)	12
0.075 mm (No. 200)	8

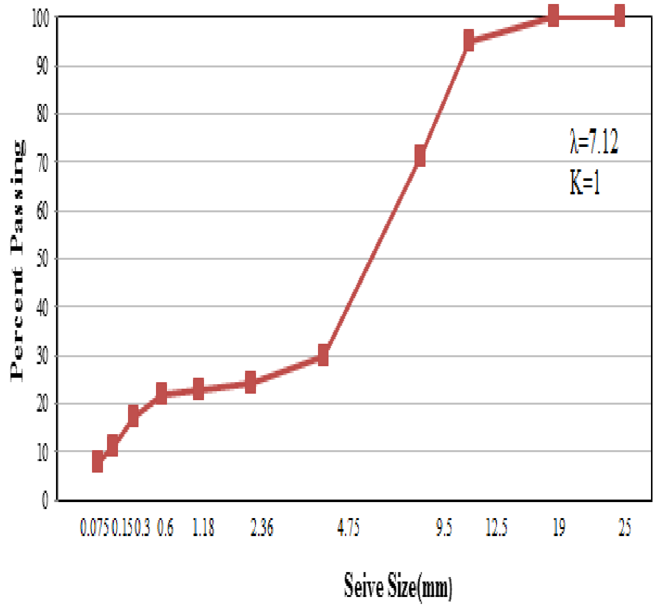


Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN50R	SN50S	MPD(LP)(mm)
1-a	0.25	0.93	0.20	1	39.5	29.9	N/A
1-b	0.26	0.81	0.20	1	39.0	30.5	N/A
1-c	0.28	0.86	0.21	1	39.7	29.0	N/A
Avg.	0.26	0.87	0.20	Avg.	39.4	29.8	
2-a	0.28	0.62	0.19	2	36.7	22.5	N/A
2-b	0.28	0.61	0.19	2	49.3	22.3	N/A
2-c	0.28	0.68	0.20	2	37.9	22.4	N/A
Avg.	0.28	0.64	0.19	Avg.	41.3	22.4	
3-a	0.26	0.71	0.20	3	34.5	20.3	N/A
3-b	0.28	0.73	0.20	3	50.2	21.0	N/A
3-c	0.28	0.62	0.20	3	35.4	19.1	N/A
Avg.	0.27	0.69	0.20	Avg.	40.0	20.1	

Project ID: **424-02-0088**
General Information:
Parish: Lafayette, Route: US90[b], Traffic Index 1.88, Age: 0.5, Design Lane ADT: 10333, Test Date: 11/28/2012, Surface Coarse Aggregate: Granite (AA39 60.2%) + Limestone (AB29 39.8%)
Mixture Gradation Information:

Mix Type	SMA
Binder Type	PG76-22M
Binder Content	6.5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	95
9. 5 mm (3/8 in.)	71
4. 75 mm (No. 4)	30
2. 36 mm (No. 8)	24
1. 18 mm (No. 16)	23
0.600 mm (No. 30)	22
0.300 mm (No. 50)	17
0.150 mm (No. 100)	11
0.075 mm (No. 200)	8



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.29	N/A	N/A	1	43.6	42.3	N/A
1-b	0.29	N/A	N/A	1	42.5	40.9	N/A
1-c	0.30	N/A	N/A	1	41.4	42.3	N/A
Avg.	0.29			Avg.	42.5	41.8	
2-a	0.28	N/A	N/A	2	38.4	39.8	N/A
2-b	0.28	N/A	N/A	2	39.0	37.7	N/A
2-c	0.27	N/A	N/A	2	40.4	36.6	N/A
Avg.	0.28			Avg.	39.3	38.0	
3-a	0.29	N/A	N/A	3	41.9	40.7	N/A
3-b	0.28	N/A	N/A	3	40.1	39.6	N/A
3-c	0.27	N/A	N/A	3	41.3	37.8	N/A
Avg.	0.28			Avg.	41.1	39.4	

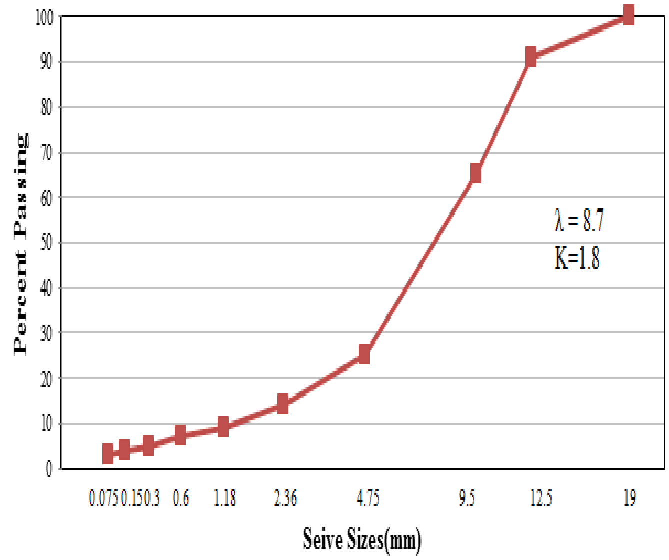
Project ID: 025-01-0019

General Information:

Parish: Vernon, Route: US171[b], Traffic Index 6.49, Age: 3.4, Design Lane ADT: 4975, Test Date: 10/09/2012, Surface Coarse Aggregate: Novaculite (AA44 100%)

Mixture Gradation Information:

Mix Type	OGFC
Binder Type	PG76-22M
Binder Content	6.5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	91
9. 5 mm (3/8 in.)	65
4. 75 mm (No. 4)	25
2. 36 mm (No. 8)	14
1. 18 mm (No. 16)	9
0.600 mm (No. 30)	7
0.300 mm (No. 50)	5
0.150 mm (No. 100)	4
0.075 mm (No. 200)	3



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.27	1.19	0.22	1	41.8	36.0	N/A
1-b	0.27	1.42	0.23	1	41.0	35.7	N/A
1-c	0.26	1.00	0.21	1	40.7	36.8	N/A
Avg.	0.27	1.20	0.22	Avg.	41.2	36.2	
2-a	0.27	1.36	0.23	2	40.1	35.5	N/A
2-b	0.28	1.22	0.23	2	41.2	37.0	N/A
2-c	0.27	1.51	0.23	2	39.2	34.8	N/A
Avg.	0.27	1.36	0.23	Avg.	40.2	35.8	
3-a	0.26	1.44	0.22	3	39.5	35.6	N/A
3-b	0.27	1.42	0.23	3	40.0	35.4	N/A
3-c	0.26	1.52	0.22	3	40.1	36.9	N/A
Avg.	0.26	1.46	0.22	Avg.	39.9	36.0	

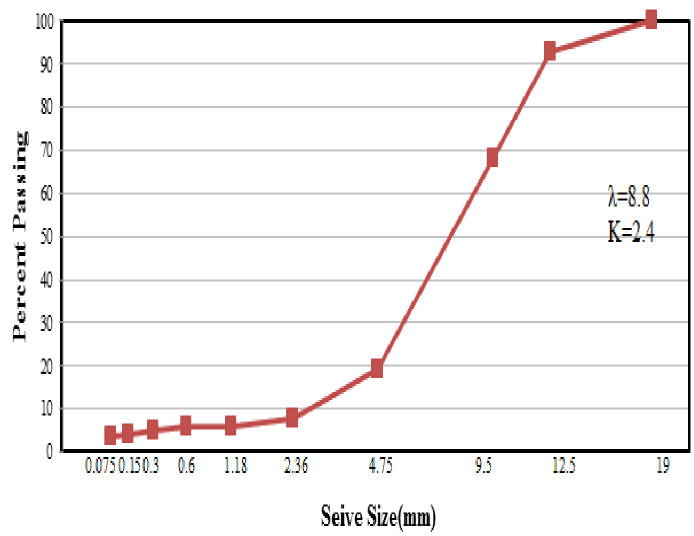
Project ID: **451-06-0127**

General Information:

Parish: Ouachita, Route: I20[b], Traffic Index 26.15, Age: 7.2, Design Lane ADT: 9050, Test Date: 10/10/2012, Surface Coarse Aggregate: Limestone (AA50 25%) +Sandstone (AB13 75%)

Mixture Gradation Information:

Mix Type	OGFC
Binder Type	PG76-22m
Binder Content	6.50%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	93
9. 5 mm (3/8 in.)	68
4. 75 mm (No. 4)	19
2. 36 mm (No. 8)	8
1. 18 mm (No. 16)	6
0.600 mm (No. 30)	6
0.300 mm (No. 50)	5
0.150 mm (No. 100)	4
0.075 mm (No. 200)	3.5



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN50R	SN50S	MPD(LP)(mm)
1-a	0.35	1.34	0.27	1	50.1	46.6	N/A
1-b	0.33	1.13	0.25	1	49.7	46.7	N/A
1-c	0.35	1.09	0.26	1	50.9	47.7	N/A
Avg.	0.34	1.19	0.26	Avg.	50.2	47.0	
2-a	0.32	1.19	0.25	2	49.4	46.3	N/A
2-b	0.34	1.02	0.25	2	48.9	46.0	N/A
2-c	0.35	1.19	0.26	2	51.1	46.5	N/A
Avg.	0.34	1.13	0.25	Avg.	49.8	46.3	
3-a	0.34	1.15	0.26	3	49.9	47.0	N/A
3-b	0.35	1.17	0.26	3	49.6	47.6	N/A
3-c	0.34	1.18	0.26	3	51.1	47.7	N/A
Avg.	0.34	1.17	0.26	Avg.	50.2	47.4	

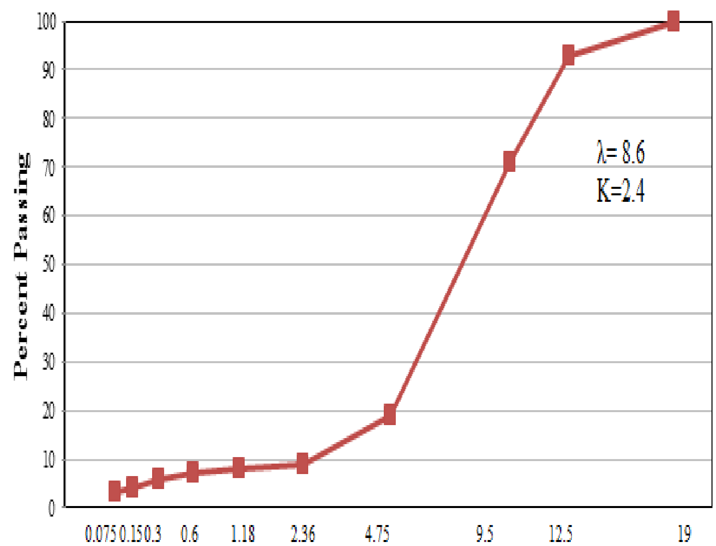
Project ID: **007-07-0049(1)**

General Information:

Parish: Ascension, Route: US61[a], Traffic Index 13.18, Age: 5.2, Design Lane ADT: 6525, Test Date: 11/07/2012, Surface Coarse Aggregate: Limestone (AA50 30%) +Sandstone (AB13 70%)

Mixture Gradation Information:

Mix Type	OGFC
Binder Type	PG82-22RM
Binder Content	6.5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	93
9. 5 mm (3/8 in.)	71
4. 75 mm (No. 4)	19
2. 36 mm (No. 8)	9
1. 18 mm (No. 16)	8
0.600 mm (No. 30)	7
0.300 mm (No. 50)	6
0.150 mm (No. 100)	4
0.075 mm (No. 200)	3.3



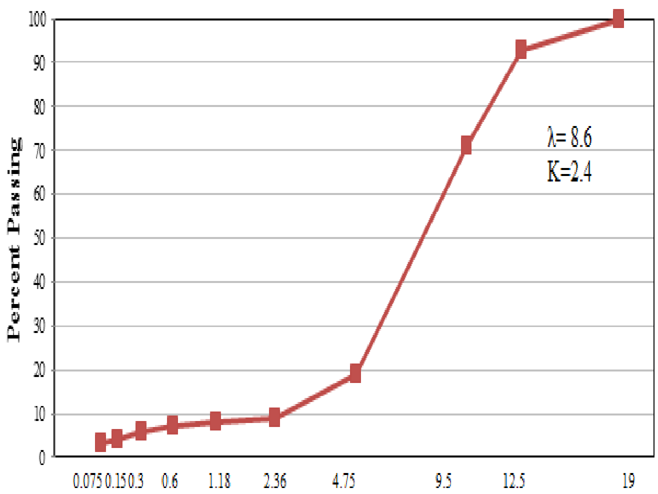
Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.31	N/A	N/A	1	41.4	38.3	N/A
1-b	0.28	N/A	N/A	1	40.9	39.2	N/A
1-c	0.30	N/A	N/A	1	41.0	40.5	N/A
Avg.	0.30			Avg.	41.1	39.3	
2-a	0.24	N/A	N/A	2	39.0	35.0	N/A
2-b	0.27	N/A	N/A	2	38.5	38.0	N/A
2-c	0.29	N/A	N/A	2	38.3	38.3	N/A
Avg.	0.27			Avg.	38.6	37.1	
3-a	0.26	N/A	N/A	3	39.7	35.9	N/A
3-b	0.23	N/A	N/A	3	38.5	37.4	N/A
3-c	0.25	N/A	N/A	3	39.1	38.3	N/A
Avg.	0.25			Avg.	39.1	37.2	

Project ID: **007-07-0049(2)**
General Information:
Parish: Ascension, Route: US61[b], Traffic Index 13.02, Age: 5.1, Design Lane ADT: 6525, Test Date: 11/29/2012, Surface Coarse Aggregate: Limestone (AA50 30%) +Sandstone (AB13 70%)

Mixture Gradation Information:

Mix Type	OGFC
Binder Type	PG82-22RM
Binder Content	6.5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	93
9. 5 mm (3/8 in.)	71
4. 75 mm (No. 4)	19
2. 36 mm (No. 8)	9
1. 18 mm (No. 16)	8
0.600 mm (No. 30)	7
0.300 mm (No. 50)	6
0.150 mm (No. 100)	4
0.075 mm (No. 200)	3.3



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.23	1.59	0.21	1	32.3	41.1	N/A
1-b	0.24	1.54	0.22	1	34.5	36.0	N/A
1-c	0.24	1.44	0.21	1	37.5	33.8	N/A
Avg.	0.24	1.52	0.21	Avg.	34.8	37.0	
2-a	0.23	1.53	0.21	2	32.1	39.4	N/A
2-b	0.24	1.66	0.22	2	34.1	36.3	N/A
2-c	0.24	1.65	0.22	2	31.9	36.0	N/A
Avg.	0.24	1.61	0.22	Avg.	32.7	37.2	
3-a	0.22	1.58	0.21	3	30.3	31.2	N/A
3-b	0.24	1.74	0.22	3	30.6	28.7	N/A
3-c	0.24	1.75	0.22	3	29.9	35.1	N/A
Avg.	0.23	1.69	0.22	Avg.	30.3	31.7	

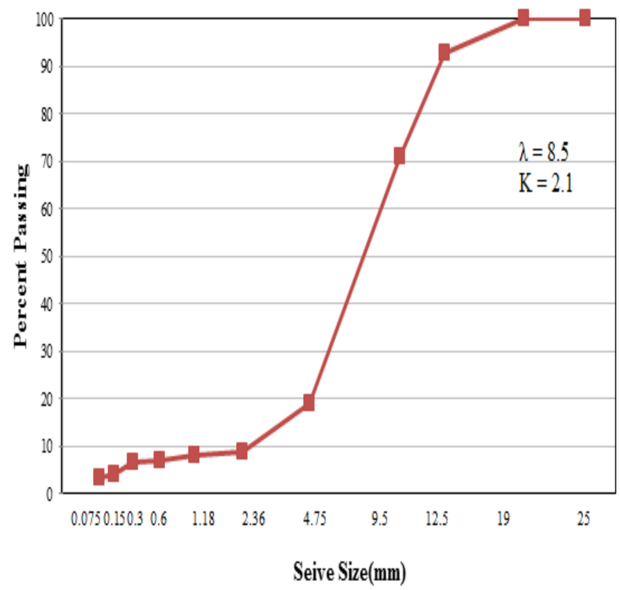
Project ID: **009-02-0018**

General Information:

Parish: Grant, Route: US71, Traffic Index 3.6, Age: 10.7, Design Lane ADT: 795,
Test Date: 02/26/2014, Surface Coarse Aggregate: Limestone (AA50 20%) +Sandstone (AB13 80%)

Mixture Gradation Information:

Mix Type	OGFC
Binder Type	PG76-22M
Binder Content	6.5%
Metric (US)Sieve	Composite Gradation Blend
37. 5 mm (1½ in.)	100
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	100
12. 5 mm (1/2 in.)	93
9. 5 mm (3/8 in.)	71
4. 75 mm (No. 4)	19
2. 36 mm (No. 8)	9
1. 18 mm (No. 16)	8
0.600 mm (No. 30)	7
0.300 mm (No. 50)	6.5
0.150 mm (No. 100)	4.2
0.075 mm (No. 200)	3.5



Friction Measurement Results

Test Section for DFT and CTM	DFT20	MPD(CTM) (mm)	F(60)	Test Section for Skid Trailer	SN40R	SN40S	MPD(LP)(mm)
1-a	0.39	1.37	0.30	1	60.3	53.0	N/A
1-b	0.40	1.31	0.29	1	60.5	51.3	N/A
1-c	0.36	1.08	0.27	1	59.7	55.5	N/A
Avg.	0.38	1.25	0.29	Avg.	60.2	53.3	
2-a	0.38	1.14	0.28	2	58.1	54.8	N/A
2-b	0.38	1.24	0.28	2	58.1	56.2	N/A
2-c	0.38	1.05	0.27	2	58.2	53.2	N/A
Avg.	0.38	1.15	0.28	Avg.	58.1	54.7	
3-a	0.34	1.23	0.26	3	57.1	53.6	N/A
3-b	0.36	1.28	0.27	3	58.7	52.9	N/A
3-c	0.38	1.22	0.28	3	57.4	54.9	N/A
Avg.	0.36	1.24	0.27	Avg.	57.7	53.8	

APPENDIX B

Laboratory and Field Polishing Correlations

This section includes the study to connect the recent field test with previous laboratory study reported as LTRC 09-2B report. The previous study provides the friction design guidelines based on laboratory measurements. The laboratory study includes four different mixture and three different aggregates. All together 36 different slabs (3 replicate of each mixture and aggregate) were prepared by using a kneading compactor and polished at different polishing cycle using three wheel polishing device (TWPD). Friction and texture of slabs were measured using DFT and CTM at prescribed polishing cycles. To support a field DFT prediction model, laboratory DFT20 readings at different polishing cycles were analyzed.

The relationship between laboratory polishing by TWPD and field polishing by traffic was established based on DFT20 data. For this correlation analysis, DFT20 data of seven field test sections were used whose coarse aggregate is limestone (AA50) and mix is Superpave. And also lab DFT20 readings of Superpave slabs having Limestone (AA50) as only surface coarse aggregate at different polishing cycles were used. It can be seen from Table 22 that, DFT20 readings of six different slabs (three 19-mm and three 12.5-mm Superpave mixture with AA50) at one level of polishing cycles are not significantly different. The coefficient of variation of six different slabs (three replicate of each mixture) is less than 5% at each polishing cycles. Therefore, average DFT20 values of six slabs at each polishing cycle were used as representative DFT20 for those polishing cycles.

Similar DFT20 degradation patterns of lab and field pavement surface under polishing can be observed from Figure 33 and 34. But, it can be noticed from Figure 33 and 34 that the lab DFT20 is always higher than field DFT20. This might be because of the difference in DFT instrument used for field and lab test. Jackson (2008) and recent NCAT DFT workshop (Heitzman at el. (2013)) also advocated the possible difference in DFT readings at the same surface from different DFT devices.

In order to establish relationship between laboratory polishing cycles and traffic index, the lab and field DFT20 data under different polishing level were separately fit in the degradation model developed by Mahmoud, et al. (2005) as given in equation (31) and (32). Note that DFT20 values of both lab and field pavement surface of Superpave mix and only Limestone (AA50) aggregates were used in this analysis.

Table 22
DFT reading at 20 Km/hr of laboratory slabs

	19-mm Superpave			12.5-mm Superpave				
No. of Polishing Cycles (In Thousand)	slab 1	slab 2	slab 3	slab 1	slab 2	slab 3	Avg.	C.V.
5	0.44	0.45	0.43	0.45	0.46	0.46	0.45	2.77
10	0.39	0.44	0.45	0.44	0.44	0.42	0.43	4.46
30	0.39	0.42	0.36	0.41	0.40	0.39	0.40	4.97
50	0.36	0.41	0.41	0.40	0.39	0.39	0.39	5.00
100	0.35	0.36	0.35	0.34	0.35	0.34	0.35	2.10

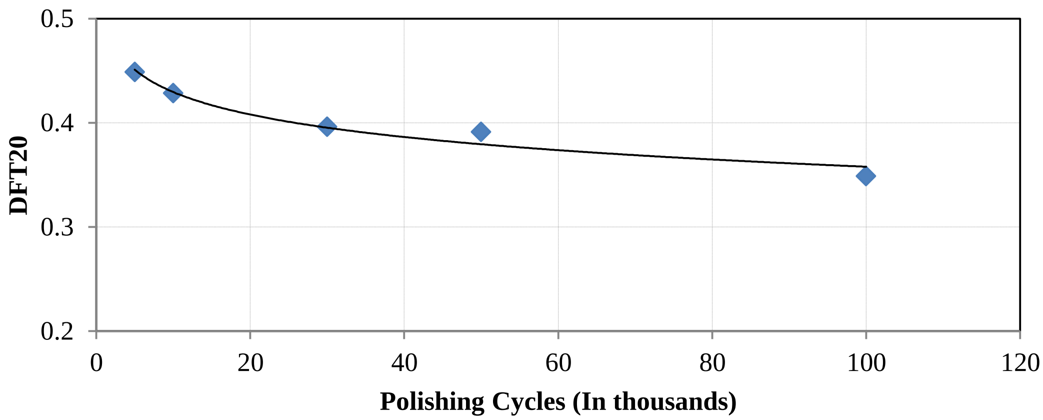


Figure 33
Lab friction degradation

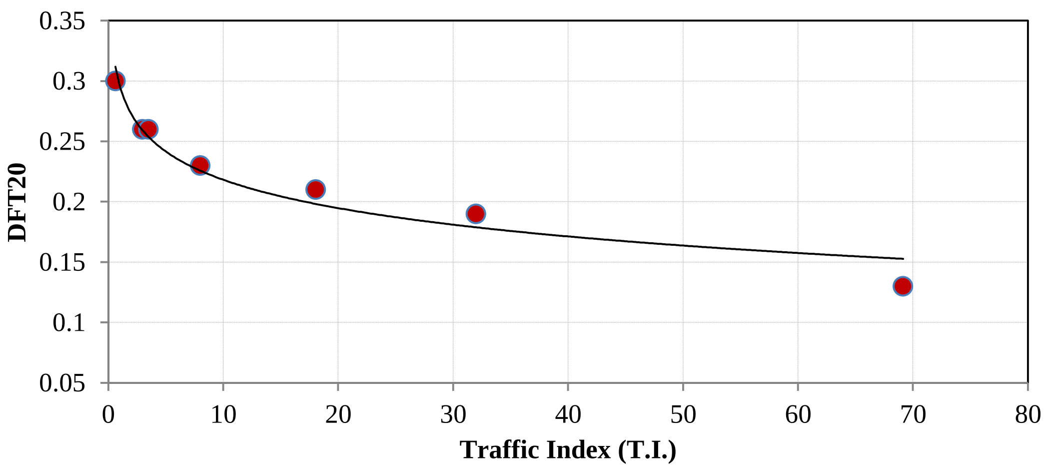


Figure 34
Field friction degradation

$$DFT20_{Lab} = 0.32+0.13\times \qquad (31)$$

$$DFT20_{Field} = 0.15+0.14\times \qquad (32)$$

where,

$DFT20_{Lab}$ = Laboratory DFT20 at given polishing cycle (N)

$DFT20_{Field}$=Filed DFT20 at given traffic index (T.I.)

N= Number of polishing cycles in thousands

T.I.= Traffic index

The values 0.32 and 0.15 from the equation (31) and (32) are terminal DFT20 values for lab and field surfaces. Since both lab and field surfaces are made up of similar aggregate and mixture, it is assumed that the terminal skid numbers should also be same. Based on this assumption, the difference in DFT20 reading because of different DFT instrument used during the lab and field tests were established as 0.17. Equations (31) and (32) were solved by equating after adding 0.17 to the equation (32) to establish the relationship between N and T.I. and expressed in equation (33).

$$N = \qquad - 5.33 \qquad (33)$$

Side by Side DFT Tests

To have a more confidence in difference in DFT measurements, a DFT comparison test was performed between DFTs used in lab and field Test. The DFT used in lab was termed as DFT_{lab} and field as DFT_{field}. First, four different laboratory prepared slabs from NCAT (Figure 35) were tested by DFT_{lab} and then by DFT_{field} at different time interval. Table 23 presents the difference in DFT20 results.

Table 23
Comparison of lab and field DFT

Slab	DFT_{lab}	DFT_{field}	Difference
N5-C	0.41	0.19	0.22
N12-A	0.5	0.25	0.25
S2-B	0.41	0.24	0.17
S6-C	0.3	0.18	0.12

The above results are in agreement with the earlier mentioned claim that there is a possibility of difference in DFT20 results at same surface using different DFT devices. To have further confidence in difference in DFT readings, a side by side testing was arranged at NCAT. Five different surfaces as given in Figure 36 were tested using both DFTs. The surfaces were selected in such way that represents the different range of friction surface, from very low friction surface (steel plate) to high friction surface (stripping). Table 24 presents DFT results on those five surfaces from two different DFT instruments. It can be seen that there is a significant difference in DFT results. It is also found that the difference between DFT measurements is increasing with the increase in surface friction.

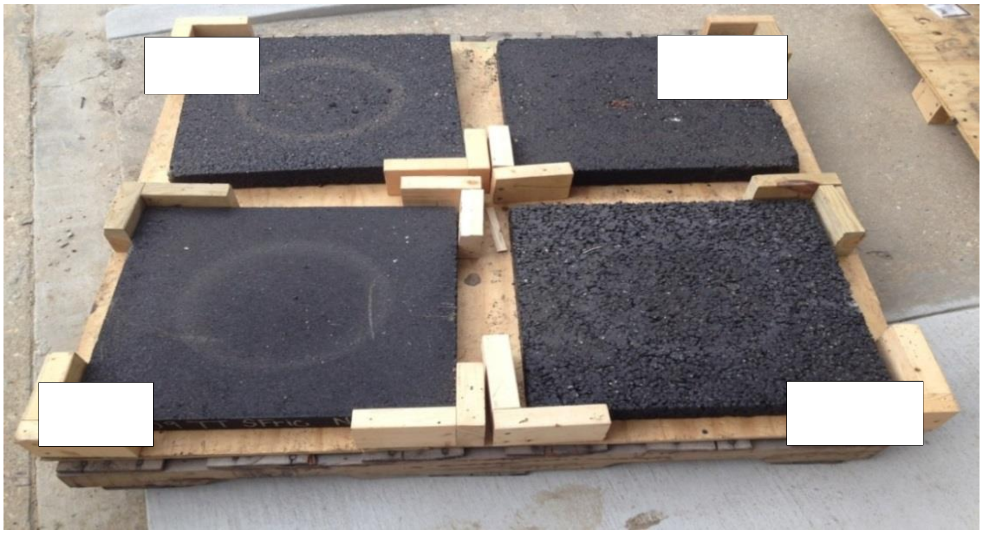


Figure 35
Laboratory slab used for comparison

Figure 36
Five different surfaces used for side by side testing

Table 24
Comparison of lab and field DFT

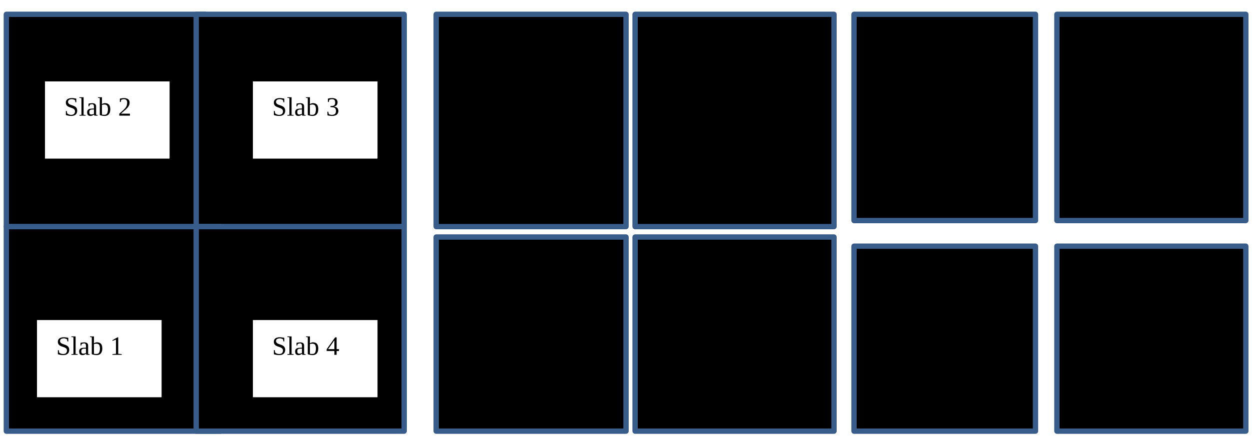
Surface	DFT_{field}			DFT_{lab}			Differences		
	20 km/h	40 km/h	60 km/h	20 km/h	40 km/h	60 km/h	20 km/h	40 km/h	60 km/h
Steel plate	0.17	0.15	0.13	0.31	0.27	0.23	0.14	0.12	0.10
Slab 1	0.18	0.18	0.16	0.31	0.32	0.32	0.13	0.14	0.16
Slab 2	0.24	0.23	0.19	0.42	0.42	0.43	0.18	0.19	0.24
Slab 3	0.26	0.25	0.21	0.41	0.41	0.43	0.15	0.16	0.22
Stripping	0.25	0.26	0.22	0.45	0.48	0.52	0.20	0.22	0.30

APPENDIX C

Analysis of DFT and CTM Measurements on Assembled Laboratory Slab

This section presents the possibility of using the LTRC kneading compactor to produce asphalt slabs for DFT and CTM tests. The kneading compactor at LTRC can only produce a HMA slab of size 320×260×80 mm. But the sizes of DFT and CTM instruments are larger than the slab which can be produced at LTRC. CTM has a base area of 400×400 mm and DFT has 400×505 mm. Hence, four slabs were needed to be prepared to fit with the CTM and DFT base. The main objective of this study was to check the possibility of use of LTRC kneading compactor by analyzing the effect of joints while arranging four slabs.

Since this study dealt with the measure of only surface characteristics, no mix design was performed in the lab. The readily available three different asphalt mixtures were used to prepare three sets of slab. Where, each set consist four slabs of same material and weight. SMA and OGFC's volumetric were referenced for the amount of material to be used for compaction because of the limited availability of the material. Then, HMA mixtures were continuously heated for four hours at 270^0F before placing into compaction. The compacted slabs were left for 12 hours to cool down and taken out. Since the objective of the study was to check the effect of the joints, each set of slabs were tested in three different conditions. First the slabs were placed as much tightly as possible, second the slabs were placed at gap of 0.25-in. and third the slabs were placed at gap of 0.5-in. as shown in Figure 37.



(a) No gap (b) 0.25-in. gap (c) 0.5-in. gap

Figure 37
Slab arrangements

Since CTM has different base area than DFT, each test was done by different technique. CTM were tested by placing five different ways and DFT was tested in three different ways as shown in layout below (Figure 38 and 39). First both CTM and DFT were tested by placing centrally. Then CTM were tested by placing more portions towards each slab. DFT were tested by moving to cover more portions of two slabs at a time termed as south (lower half) and north (upper half) part.

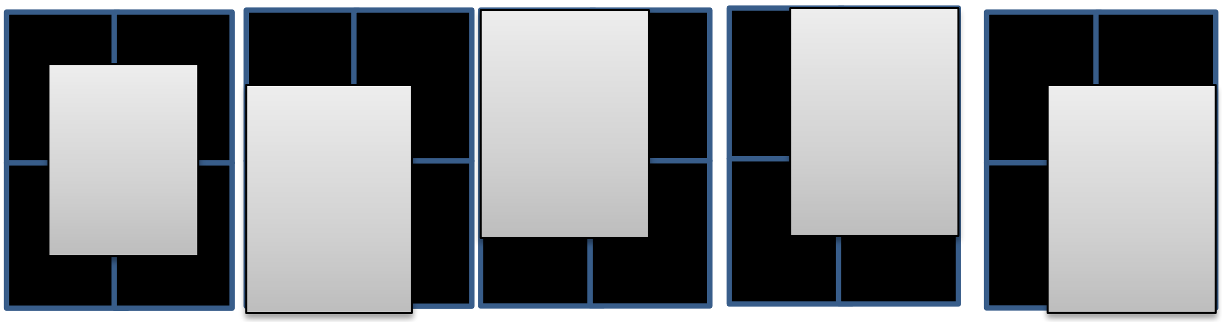


Figure 38
CTM test arrangements

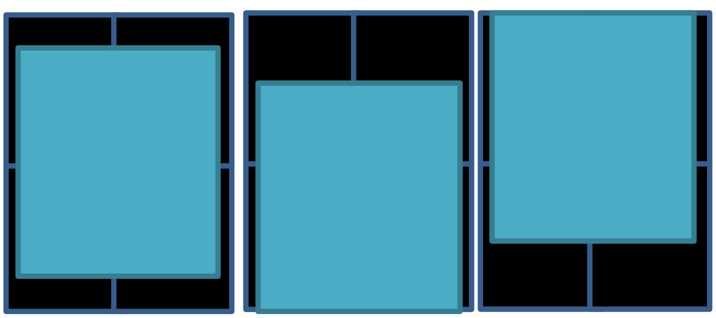


Figure 39
DFT test arrangements

Table 25 and 27 present the CTM and DFT test results of each set of slab tested as described above. From Table 25 and 27 it can be seen that the range of test results are not much different at given condition of gap. Further to see the effect of joints while arranging the slabs, a Tukey pairwise comparison was performed at 95 percent confidence level to see is there significant difference in mean because of the gap. The results for CTM and DFT are presented in Table 26 and 28 respectively. From the analysis, it can be said that there was not significant effect on CTM results because of the gap. DFT also showed not influenced by the gap except in second slab between no gap and 0.5-in. gap. Which can be neglected based on the majority of results.

Table 25
CTM test results

First Slab			
Location	No gap	0.25" gap	0.5" gap
Centrally located	1.35	1.44	1.37
More portion on slab1	1.58	1.60	1.50
More portion on slab2	1.29	1.21	1.64
More portion on slab3	1.37	1.53	1.54
More portion on slab4	1.24	1.29	1.32
Second Slab			
Location	No gap	0.25" gap	0.5" gap
Centrally located	2.06	2.03	2.39
More portion on slab1	2.15	2.33	2.00
More portion on slab2	2.11	2.11	2.12
More portion on slab3	2.06	2.08	2.60
More portion on slab4	2.13	2.07	2.39
Third Slab			
Location	No gap	0.25" gap	0.5" gap
Centrally located	1.52	1.52	1.62
More portion on slab1	1.86	1.87	1.70
More portion on slab2	1.70	1.82	1.75
More portion on slab3	1.51	1.58	1.73
More portion on slab4	1.50	1.40	1.37

Table 26
Comparison significance level (P-values) of CTM values at different gaps

First Slab			
Gap	No gap	0.25" gap	0.5" gap
No gap		0.62	0.22
0.25" gap	0.62		0.54
0.5" gap	0.22	0.54	
Second Slab			
Gap	No gap	0.25" gap	0.5" gap
No gap		0.71	0.10
0.25" gap	0.71		0.18
0.5" gap	0.10	0.18	
Third Slab			
Gap	No gap	0.25" gap	0.5" gap
No gap		0.86	0.87
0.25" gap	0.86		0.97
0.5" gap	0.87	0.97	

Table 27
DFT20 test results

First Slab			
Location	No gap	0.25" gap	0.5" gap
Centrally located	0.299	0.28	0.3
Shifted to north	0.232	0.27	0.25
Shifted to south	0.265	0.27	0.25
Second Slab			
Location	No gap	0.25" gap	0.5" gap
Centrally located	0.39	0.36	0.34
Shifted to north	0.40	0.35	0.33
Shifted to south	0.41	0.42	0.36
Third Slab			
Location	No gap	0.25" gap	0.5" gap
Centrally located	0.22	0.20	0.22
Shifted to north	0.25	0.27	0.23
Shifted to south	0.24	0.25	0.24

Table 28
Comparison significance level (P-values) of DFT20 values at different gaps

First Slab			
Gap	No gap	0.25" gap	0.5" gap
No gap		0.70	0.96
0.25" gap	0.70		0.71
0.5" gap	0.96	0.71	
Second Slab			
Gap	No gap	0.25" gap	0.5" gap
No gap		0.36	0.01
0.25" gap	0.36		0.23
0.5" gap	0.01	0.23	
Third Slab			
Gap	No gap	0.25" gap	0.5" gap
No gap		0.89	0.56
0.25" gap	0.89		0.67
0.5" gap	0.56	0.67	

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