

Field evaluation of Asphalt Concrete Pavement surface texture and skid characteristics

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Abstract:

The incorporation of safety characteristics into the traditional pavement design or in the functional evaluation of pavement condition has not yet established. The design has focused on the structural capacity of the road way so that the pavement can withstand specific level of repetitive loading over the design life. On the other hand, the surface texture condition was neither included in the AASHTO design procedure nor in the present serviceability index measurements.

The pavement surface course should provide adequate levels of friction and ride quality and maintain low levels of noise and roughness.

Many transportation departments perform routine skid resistant testing, the type of equipment used for testing varies depending on the preference of each transportation department. It was felt that incorporating the surface texture condition using different methods of testing may solve such problem.

In this work, Macro-texture and micro-texture of asphalt concrete pavement surface have been investigated in the field using four different methods (the sand patch method, out flow time method, sand cone method and British portable tester). Two different grain sizes of sand have been utilized in conducting both of the sand patch and the sand cone methods while the micro-texture was investigated using the British portable tester method at both dry and wet pavement surface conditions.

The test results of the four methods were modeled and correlated to each other and the skid number was determined. It was concluded that such modeling could provide instant data in the field for pavement condition evaluation which may help in pavement maintenance management.

Keywords: asphalt pavement, macro texture, micro texture, skid number, texture

1.0 Introduction

Deterioration of the pavement (smoothing or polishing of the pavement surface), along with surface water accumulation in the form of rain, snow, or ice, can result in inadequate provision of skid resistance. Inadequate skid resistance can lead to higher incidences of skid-related crashes. There is currently no agreement on what standards to use for optimizing skid resistance, or on a standardized testing procedure to adopt despite a significant amount of research conducted. Roadway pavements deteriorate with time as a result of repeated vehicle passes, environmental conditions, and at times, poor pavement management. If this deterioration is not properly addressed, the amount of surface distress that can affect skid resistance will increase and be prejudicial to traffic.

In this sense, pavement surface characteristics are a significant issue because of its influence in preserving roadway safety. Maintaining these characteristics during pavement construction or rehabilitation may mitigate or even prevent crashes and incidents related to loss of vehicle control, hydroplaning, and/or excessive skidding.

The surface quality of a pavement determines to a large degree the conditions under which safety can be maintained. Driver control of vehicles is strongly dependent upon pavement surface characteristics, geometrics, driver speed, and vehicle variables such as tire pressure, type of tread, and wheel loads. Important surface characteristics include pavement micro-texture, macro-texture, and drainage attributes.

Loss of adhesion between vehicle`s tires and the road surface occurs in many road accidents whether or not it is the actual cause of the accident. Over the years, tire manufacturers have done a lot of research into different types of rubber and tread pattern to improve the safety of motor vehicles. The pavement- tire interaction is affected by the texture characteristics of the pavement such as the coefficient of friction, skid resistance, and hydroplaning effect on wet surface.

Until recently, the most common test methods for determining macro-texture were labor intensive and time-consuming. New developments in high-resolution profiling have produced methods for estimating macro-texture depth at highway speeds. The fundamental questions that need to be addressed are: (1) how effectively does such equipment characterize pavement macro-texture and (2) how could this information be used if it were available.

2.0 Problem Statement

This work relates generally to the measurements of surface texture characteristics (macro and micro-texture) and skid number. The purpose of this study was to obtain a preliminary indication of the suitability of the sand cone apparatus for measuring macro-texture of pavement surfaces. This assessment was accomplished through comparison of this testing procedures and the traditional sand patch and out flow time test procedures using two types of sand, and two different cylinders volume for outflow time test.

The reference texture values for the various surfaces included in this study were also obtained using two techniques. The first and most traditional technique was the volumetric (or sand patch) method ASTM E965 (2002). This traditional method is based on a volumetric test that uses sand. The test is relatively simple to perform, but its results are operator dependent and therefore not very reproducible (Henry, 2000), the formation of almost circular shape sand patch is even questionable. The test is still performed using the traditional sand. Results from tests using the sand are adequate as long as the sand meets the required specifications. The second technique is the British pendulum tester.

Functional characteristics such as safety and comfort must be considered when selecting and designing hot-mix asphalt (HMA) wearing surfaces. This paper discusses an extensive investigation conducted to evaluate the texture and skid resistance properties. Variation in skid resistance and surface macro-texture and micro-texture measurements due to testing apparatus characteristics and testing conditions were analyzed.

3.0 Background

Micro-texture describes those features of a pavement surface that are less than 0.5 mm in length. In functional terms, micro-texture is the most significant contributor to low speed skid resistance. Features of the pavement surface that range from approximately 0.5 mm to 50 mm in length are classified as macro-texture which was shown to be the primary component of high speed wet skid resistance. Several methods are available for measuring the skid resistance force and results are commonly reported as skid numbers (SN), (Balmer, 1978; Balmer and Hegmon, 1980). Skid numbers at low speeds are primarily a function of the pavement micro-texture; at higher speeds, the macro-texture dominates the skid resistance. Changes in the aggregate structure and gradation can affect one or both of these parameters. The British pendulum tester is usually adopted for micro-texture determination. This device simulates the skid resistance offered by a road surface to a motor car travelling at 10 km/hr. it gives a number, being a percentage, somewhat akin to a coefficient of friction. Flintsch et al (2000) evaluated the surface characteristics of pavement, skid resistance was evaluated using a locked-wheel trailer while the macro-texture was evaluated using a laser device. Correlations between different measuring devices were investigated by Flintsch et al (2003) utilizing different HMA wearing surfaces. Excellent correlation was found between the CT Meter and the sand patch measurements. In addition, the Mean Profile Depth (determined using a laser profiler) correlates well with the sand patch measurements. Forster (1989) found that the micro-texture can be characterized by a single shape factor parameter that combines' measurements of the average height and average spacing of the micro-texture asperities. There is a fair correlation between this shape factor and the British Pendulum Test as used on pavement surfaces. Forster (1989) also presented data that confirmed the relationship between micro-texture, macro-texture and the skid numbers for a large number of actual in-service pavements. Lee et al (2005) examined the effect of macro-texture on the British pendulum measurements, the results demonstrated that the edge impact between coarse textured surface features and the pendulum slider would give rise to unreliable test measurements. Macro-texture has historically been measured with the sand patch test (ASTM E965, 2000) to determine the volume of voids on surface of the pavement. More recently, high frequency lasers have been employed to measure the mean profile depth (ASTM E1845, 2000). The mean profile depth, MPD, is empirically related to the estimated sand patch texture depth. Typical macro-texture depths ranges from about 0.2 to 3.0 mm according to Roe, et al (2003); (TRRL RR296, 1991). Balmer and Hegmon (1980) define macro texture as that beginning at about 0.5 mm. Mokarem (2007) studied the use of digital surface roughness meter to measure the surface texture of several concrete and asphalt surfaces. Measurements were compared with those of sand patch and CT meter apparatus. He concluded that there appear to be a good correlation among the results of the three methods. Galloway and Rose (1970) reported poor correlation between skid resistance and texture depth as measured with the sand patch equipment. Doty (1974) stated that the repeatability of sand patch test is poor, the relationship of texture depth as measured with sand patch and outflow meter tests was not definitive enough to use as a basis for minimum texture depth specification requirements. He also stated that neither

the sand patch nor the outflow time texture measuring procedure will provide a definitive measure of the skid number for the speed gradient of the pavement being tested.

McGhee and Flintsch (2003) conducted a study to validate high speed texture measuring equipment for use in highway application. Texture estimates recorded with the high speed (dynamic) equipment correlated well with the estimates made with static referencing method such as the sand patch. Skid resistance is most commonly determined in the field using a wet locked wheel skid test. A power law relationship exists between the macro-texture and the skid number at 65 km/h (Balmer and Hegmon, 1980). This relationship is also affected by the micro-texture as measured using the British Pendulum Test. Noyce et al (2007) studied the correlation between pavement skid friction values and crash frequency. The results of the study show a directly proportionate relationship between macro-texture as measured by sand patch method and skid resistance. McGhee (2005) explored the relationship between the uniformity of hot mix asphalt and measurable surface characteristics. The study revisits the texture fluctuation tool for ensuring uniformity and delves into an explained use of elevation profiles for promoting asphalt concrete uniformity.

Gee (1975) provides a system to measure the polarization characteristics of light reflected from the pavement surface. By illuminating the road surface with linearly polarized light such as from a laser source mounted on a moving vehicle. The reflected light will generally be elliptically polarized, the degree of ellipticity being dependent on the pavement surface characteristics.

Gardiner et al (2001) investigated the macro-texture of pavement surface of 18 projects using the laser system to measure macro-texture and the British pendulum to determine the skid resistance. Results indicate that nominal maximum size of aggregate seemed to be the key factor in change in pavement surface macro-texture. The long term pavement performance database shows that the skid number was estimated to be 40 or higher. Ergun et al (2005) predicted a model for road surface friction coefficients from only macro and micro-texture at all speeds, they have conducted a field testing using laser profilometer for macro-texture determination. The speed versus friction coefficient was established using the side force method.

4.0 Skid resistance, Micro-texture and Macro-texture requirements for HMA

Previous studies are in agreement that both the micro and macro-texture of a pavement surface influence the skid resistance of that pavement. Micro-texture refers to irregularities in the surfaces of the stone particles (fine-scale texture) that affect adhesion. These irregularities are what make the stone particles feel smooth or rough to the touch. The magnitude of micro-texture depends on initial roughness on the aggregate surface and the ability of the aggregate to retain this roughness against the polishing action of traffic. Accordingly, micro-texture is an aggregate-related property that can be controlled through the selection of aggregates with desirable polish-resistant characteristics. Macro-texture refers to the larger irregularities in the road surface (coarse-scale texture) that effect hysteresis.

These larger irregularities are associated with voids between stone particles. The magnitude of this component will depend on several factors, including the size, shape, and gradation of coarse aggregates used in pavement construction as well as the particular construction techniques used in the placement of the pavement surface layer. Macro-texture is also essential in providing escape channels to water during the tire-surface interaction, thus reducing hydroplaning. Hydroplaning is the loss of tire traction caused by a film of water that separates the tire from the road surface. The Committee on Surface Characteristics of the World Road Association (PIARC-1995) proposed the texture wavelength range for each of the categories as shown in Table 1.

Skid resistance of pavement (also referred to as skid friction) is the opposing force developed at the tire-pavement contact area. In other words, skid resistance is the force that resists the tire sliding on pavement surfaces. TRRL (1969) suggest the following requirements for skid resistance as shown in Table 2.

Table 1: Texture classifications according to wave length, PIARC (1995)

Texture classification	Relative wavelength
Micro-texture	$\lambda < 0.5 \text{ mm}$
Macro-texture	$0.5 \text{ mm} < \lambda < 50 \text{ mm}$
Mega-texture	$50 \text{ mm} < \lambda < 500 \text{ mm}$
Roughness	$0,5 \text{ m} < \lambda < 50 \text{ m}$

Table: 2 TRRL (1969) requirements for skid resistance

Category	Type of site	Minimum skid resistance
A	Roundabout, gradient, bends, approach	65
B	Heavily trafficked roads, urban	55
C	All other sites	45

Skid resistance has two major components: adhesion and hysteresis. Adhesion results from the shearing of molecular bonds formed when the tire rubber is pressed into close contact with pavement surface particles. Hysteresis results from energy dissipation when the tire rubber is deformed when passing across the asperities of a rough surface pavement. These two components of skid resistance are respectively related to the two key properties of asphalt pavement surfaces, that is micro-texture and macro-texture as presented in Figure 1.

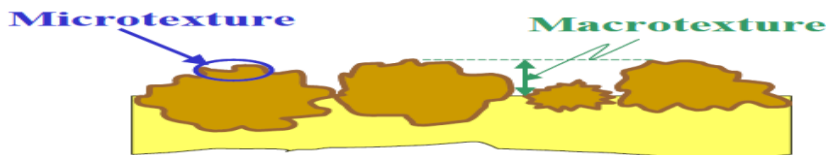


Figure 1: Components of skid resistance, Doty (1974)

Sandberg (1997) listed their influence in more detail in Table 3:

Table: 3 Influence of texture on some variables, Sandberg (1997).

Effect on vehicle, driver or environments	Road surface characteristics of importance	Magnitude of the influence
Skid resistance (friction)	Macro-texture	High
	Mega-texture	Moderate
	Micro-texture	Very high
Rolling resistance	Macro-texture	High
Fuel consumption	Mega-texture	Very high
Air pollution	Unevenness	High
Tire wear	Macro-texture	Moderate
	Micro-texture	Very high
Exterior noise	Macro-texture	Very high
	Mega-texture	Very high
Water runoff	Macro-texture	High

Splash and spray	Macro-texture	High
Light reflection	Macro-texture Micro-texture	High Little known
Interior noise	Macro-texture Mega-texture unevenness	High Very high high

The resistance to skidding on a road surface is largely affected by both micro-texture and macro-texture. Good pavement macro-texture allows for the rapid drainage of water from the pavement that, in turn, improves the contact between the tire and the pavement surface. It also provides the hysteresis component of the friction. Micro-texture provides direct tire-pavement contact and contributes to the adhesion component of the friction. Figure 2 illustrates the pavement texture variables.

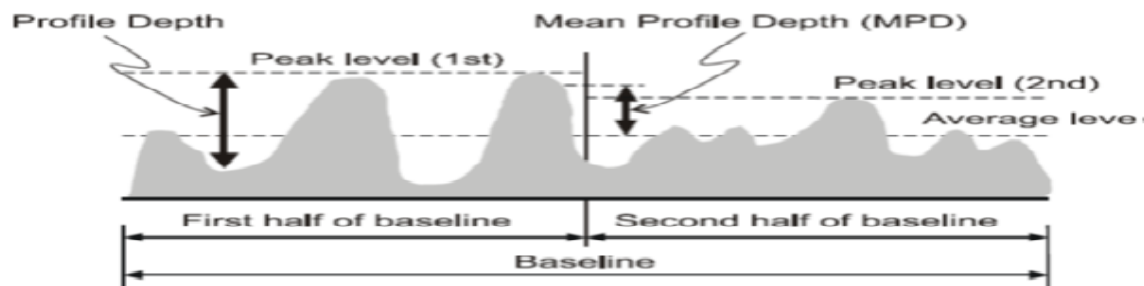


Figure 2: pavement texture variables, Doty (1974)

Surface texture has not been incorporated in HMA specification and requirements, Michigan, Ohio, Wisconsin, Nebraska, and Washington reported that they did not directly consider skid resistance requirements in HMA design specifications, as shown in Table 4.

Table: 4 Surveyed states requirements for skid resistance in HMA design Consideration

States	Skid resistance not considered	Skid resistance elements considered		
		Micro-texture	Macro-texture and Micro-texture	Other elements
FHWA regions five	Michigan, Ohio, Wisconsin	Illinois	none	Indiana
Selected others	Nebraska and Washington	Pennsylvania	Iowa and Missouri	none

Among the states that did consider skid resistance in their HMA design specifications, only Iowa and Missouri consider micro-texture and macro-texture. On the other hand, Finland suggests the following requirements for skid resistance as illustrated in Table 5. TRRL (1969) suggests the following classification for texture depth as shown in Table 6.

Table: 5 Typical skid resistance values in Finland

Speed (km/h)	Acceptable friction
≤ 80	0.4
≤ 100	0.5
≤ 120	≥ 0.6

Table: 6 TRRL suggestion for texture depth

Average texture depth (mm)	Texture classification
< 0.25	FINE
0.25 – 0.5	MEDIUM
> 0.5	OPEN

4.0 Testing program

Outflow time Method – The Outflow Meter, ASTM E2380-05 (2005), measures the required time for a fixed volume of water to escape from a specified cylinder with a rubber bottom through voids in the pavement texture. Measured time is related to both the mean hydraulic radius of paved surface and the mean texture depth. This test is suitable for evaluating the surface drainage or the internal drainage of the surface course of a pavement.

The outflow meter used in this method is a transparent vertical cylinder that rests on a rubber annulus placed on the pavement. A valve at the bottom of the cylinder is closed and the cylinder is filled with water. The valve is then opened, and the time that it takes the water level to fall by a fixed amount is measured with a stopwatch and was reported as the outflow time (OFT).

Two types of transparent cylinders have been implemented, a 250 cc and a 1000 cc volume capacity for the assessment of the effect of water head on the surface texture measurements. Figure 3 shows both cylinder types.



(A: 250 cc volume)



(B: 1000 cc volume)

Figure 3: Type of cylinders used for outflow time determination

Sand cone method – The traditional sand cone apparatus was adopted in the testing program, the base plate was withdrawn from the assembly, and the cone is placed directly on the pavement surface after it was subjected to brush cleaning. The apparatus container was filled with a known weight of sand (passing sieve 50 and retained on sieve 100) while the valve at the bottom of the container was closed. The valve is then opened and the sand flows and fills the cone and

pavement texture. The remaining weight of sand is measured. Figure 4 shows the assembly in the field. The following equations are adopted for calculation of pavement texture depth:

$$\text{Weight of Used sand} = \text{total weight of sand} - \text{remaining weight of sand} \quad \dots\dots (1)$$

$$\text{Mean Texture depth (cm)} = \text{Weight of used sand} / (\text{density of sand} \times \text{area of cone}) \quad \dots (2)$$

Volumetric Method (Sand patch method) - Historically, macro-texture measurement has been obtained by a volumetric technique. The sand patch method required spreading a specified volume of sand that passed a No. 50 sieve and that was retained on a No. 100 sieve. Figure 5 presents the sand patch method adopted. The sand is spread on the pavement with a spreading tool in a circular motion. A container plastic cover is commonly used as spreading tool. Calculation of the area of circular sand patch is done by averaging four equally spaced diameter measurements. Dividing the volume by the area provides the macro-texture depth (mean texture depth, MTD).



Figure 4: The sand cone apparatus



Figure 5: The sand patch method

Two sizes of sand have been implemented in this work; the first size is (P 50, R 100), while the second one is (P 25, R 52). The larger the amount of sand and the bigger the area covered the better for exact measurement of MTD. Nonetheless the MTD value can be obtained from the following equation whether the sand amount is small or large.

$$\text{MTD (cm)} = \text{Volume of sand} / \text{area of patch} \quad \dots\dots (3)$$

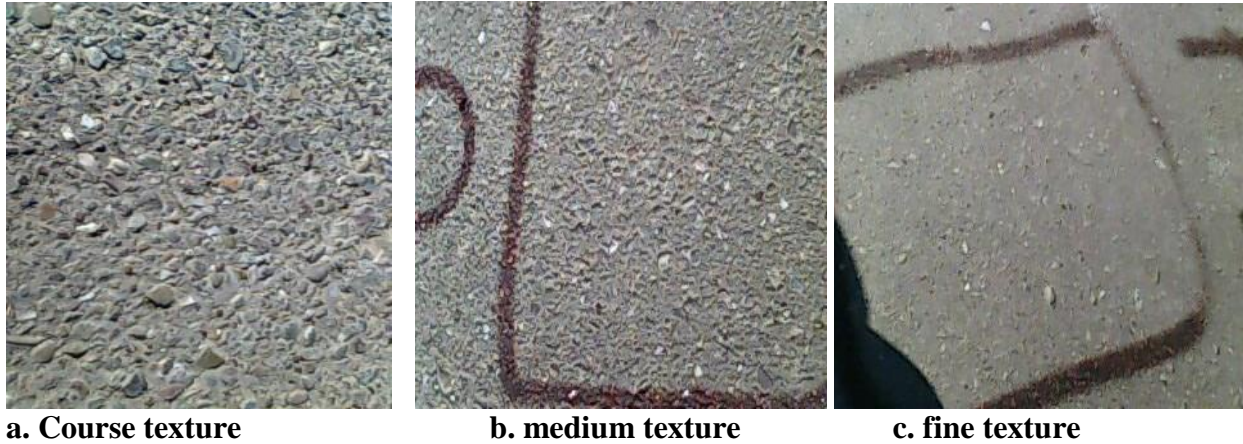


Figure 6: Typical type of surface texture tested

The British Pendulum number (BPN) - The British pendulum tester is one of the simplest and cheapest instruments used in the measurement of friction characteristics of pavement surfaces. It is extremely versatile in its applications to many test situations and has received acceptance worldwide. The test device measures low-speed friction (about 10 km/h) and is commonly used to assess the micro-texture of pavement surfaces. The test has been implemented in this investigation for both dry and wet pavement surface conditions.

A total of 30 test locations have been carefully selected at Baghdad University campus road network, representing different asphalt concrete surface texture condition. Such locations were subjected to the intensive testing program as explained above.

5.0 Modeling of pavement surface texture

Figure 7 pertains to the methods of measuring macro-texture. The y-axis refers to the sand patch test results (MTD) using fine sand while the x-axis is the corresponding MTD as determined using coarse sand. Clearly, noting the R^2 values of tests, the correlation between the MTD using both sand sizes is quite good.

Particularly considering the inherent operator dependence of the sand patch test and the amount of natural variability in surface texture, it is really quite remarkable that the results of the two tests agreed so well. A combined goodness-of-fit statistic of 0.88 is acceptable although many of the test locations within the assortment of surface types had varying texture characteristics as declared in figure 6 above. Table 7 illustrates the range of variables studied.

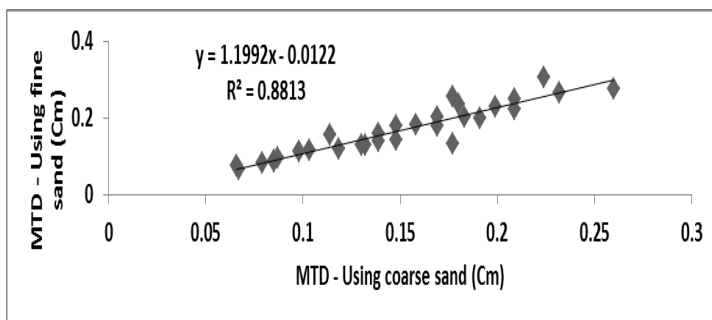


Figure 7: Effect of sand type on MTD

Figures 8 and 9 illustrate the relationship between outflow time when using 1000cc water volume and MTD using the traditional sand patch method for both sand types. The figures clearly demonstrate that the scatter of data about the regression line of the best fit curve is considerable when testing coarse texture, the effect of sand type was not significant since the coefficient of determination was almost the same for both sand types, this agrees well with findings by Doty (1974).

Table 7: Range of variables studied

Variable	Maximum value	Minimum value
MTD- using sand patch, fine sand (cm)	0.305	0.082
MTD- using sand patch, coarse sand (cm)	0.232	0.065
MTD- using sand cone, fine sand (cm)	0.676	0.168
Outflow time, using 250 cc water (seconds)	11	8.5
Outflow time, using 1000 cc water (seconds)	45	7
BPN, Dry surface	72	14
BPN, Wet surface	67	9
Skid number SN, using sand patch – fine sand	54.5	22.2
Skid number SN, using sand patch – coarse sand	72.4	23.6
Skid number SN, using sand cone	56	24

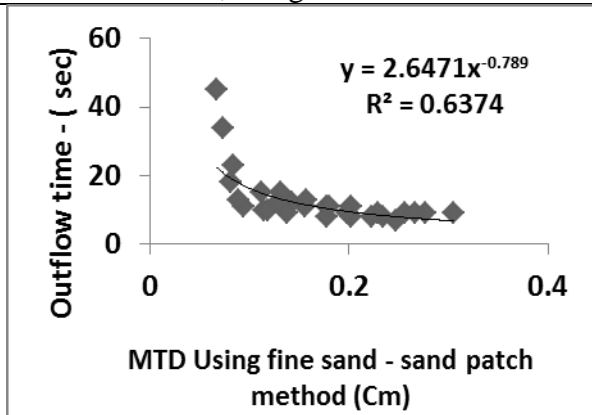


Figure 8: Outflow time and MTD relationship using 1000 cc water

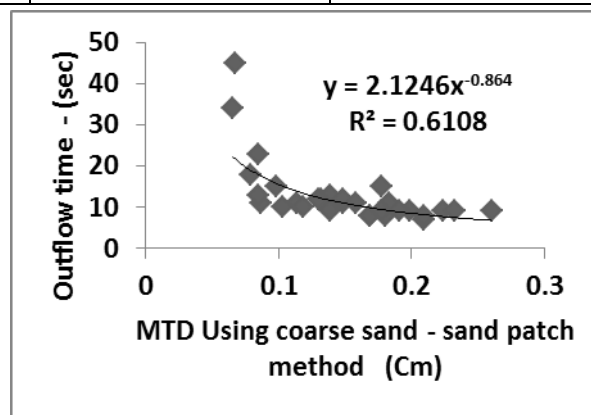


Figure 9: Outflow time and MTD relationship using 1000 cc water

On the other hand, figure 10 shows weak goodness-of-fit statistic of 0.311 when 250 cc water volume was implemented. It was felt that 250 cc of water was not sufficient for wetting the pavement surface then flowing through the pavement texture, a higher volume of water is recommended for such test. Figures 11 and 12 shows the MTD of pavement as determined in the field using both of the sand patch and the sand cone techniques, the fine sand shows higher coefficient of determination between the two test methods than that when using coarse sand.

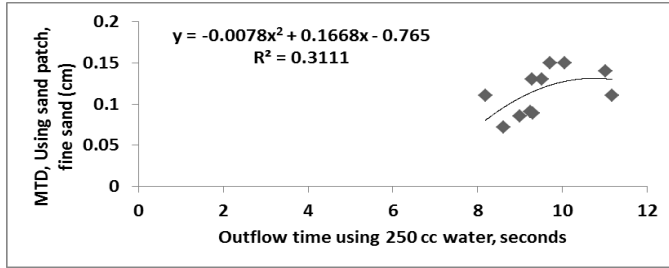


Figure 10 Outflow time and MTD using fine sand and 250 cc cylinders

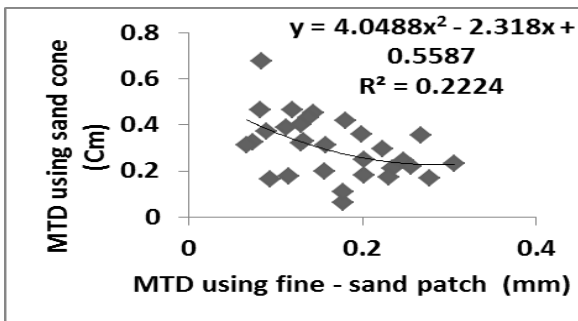


Figure 11 MTD using two testing methods and fine sand

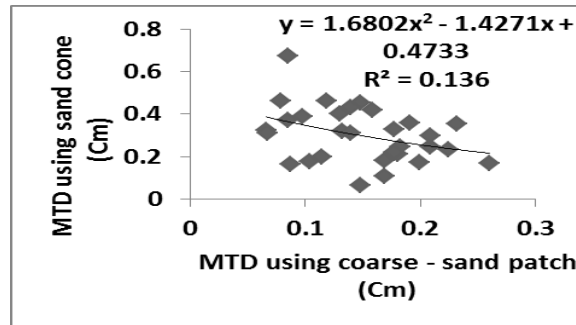


Figure 12 MTD using two testing methods and coarse sand

Figure 13 present the correlation between the outflow time and the MTD as measured by the sand cone apparatus. Coarse texture shows better correlation between the methods than fine texture as demonstrated by the scatter of data about the regression line of the best fit curve which is considerable. Figure 14 present the effect of pavement surface condition on BPN, the mathematical model shows good fit noting the R^2 values of tests, the correlation between the BPN using both wet and dry surface is quite good. Finally the skid number was calculated using the three different methods for MTD measurement. The following mathematical formulas suggested by TRRL were adopted for skid number SN determination, while Table 8 summarizes the developed mathematical models obtained from this field investigation.

$$SN = SNo \exp^{-(PNG/100) V} \dots\dots\dots(4) \text{ where SN : The skid number}$$

$$SNo = 1.32 BPN - 34.9 \dots\dots\dots(5)$$

$$PNG = 0.157 (MTD)^{-0.47} \dots\dots\dots(6)$$

BPN: The British pendulum number

MTD: Mean texture depth

PNG: Percent normalized gradient

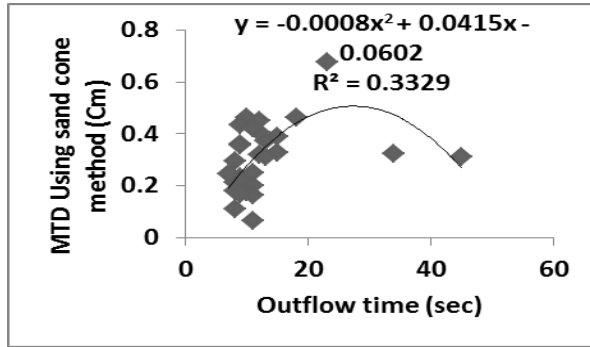


Figure 13 Outflow time and MTD using Sand cone method relationship

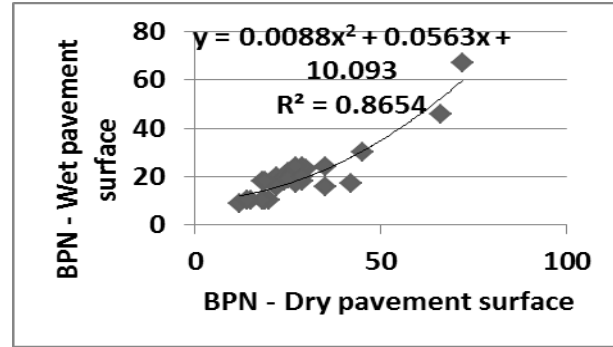


Figure 14: Effect of pavement surface condition on BPN

Table 8: The mathematical models developed

Mathematical model	Coefficient of determination	Notes on Y- coordinate	Notes on X- coordinate
$Y = 1.992 X - 0.0122$	$R^2 = 0.88$	Y= MTD, sand patch, fine sand, (cm)	X= MTD, sand patch, coarse sand, (cm)
$Y = 0.008 X^2 + 0.0563 X + 10.09$	$R^2 = 0.85$	Y= BPN, wet surface	X= BPN, dry surface
$Y = 2.647 X^{-0.789}$	$R^2 = 0.63$	Y= Outflow time, 1000 cc seconds	X= MTD, sand patch, fine sand, (cm)
$Y = 2.124 X^{-0.864}$	$R^2 = 0.61$	Y= Outflow time, 1000 cc seconds	X= MTD, sand patch, coarse sand, (cm)
$Y = - 0.0078 X^2 + 0.1668 X - 0.765$	$R^2 = 0.311$	Y= MTD, sand patch, fine sand, (cm)	X= Outflow time, 250 cc, seconds
$Y = - 0.0008 X^2 + 0.0415 X - 0.06$	$R^2 = 0.33$	Y = MTD, Sand cone	X= Outflow time, 1000 cc, seconds
$Y = 1.002 X - 0.0123$	$R^2 = 0.993$	Y=Skid number, sand patch, fine sand	X=Skid number, sand patch, coarse sand
$Y = 1.002 X + 0.2411$	$R^2 = 0.998$	Y=Skid number, sand cone	X=Skid number, sand patch, coarse sand
$Y = 1.004 X + 0.1295$	$R^2 = 0.999$	Y=Skid number, sand cone	X=Skid number, sand patch, fine sand
$Y = 1.112 X - 0.0366$	$R^2 = 0.995$	Y=Skid number, sand cone	Y=Skid number, outflow time
$Y = 1.279 X + 0.4541$	$R^2 = 0.993$	X=Skid number, sand patch, coarse sand	Y=Skid number, outflow time
$Y = 1.277 X + 0.3195$	$R^2 = 0.993$	X=Skid number, sand patch, fine sand	Y=Skid number, outflow time

Figure 15 illustrates good correlation between sand patch and sand cone methods when MTD is utilized to calculate the skid number; such results are not in agreement with Galloway and Rose (1970) findings as their macro-texture measurements were conducted using different techniques.

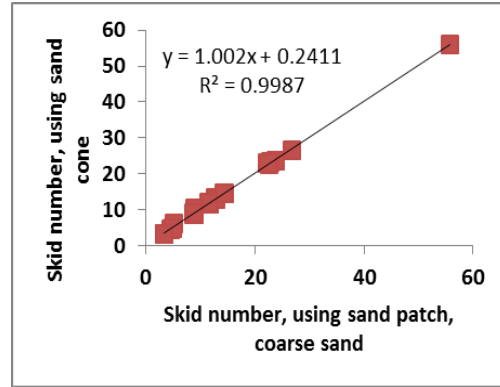
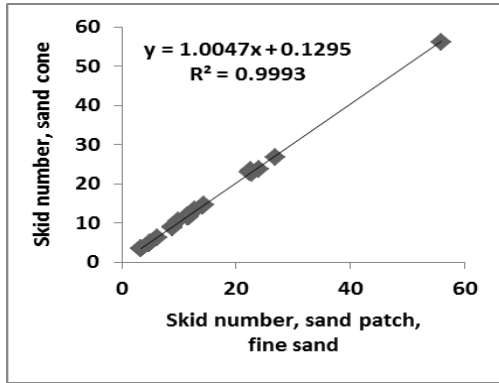


Figure 15: Skid number models using sand patch and sand cone methods

Figure 16 demonstrated that when the skid number was introduced through the empirical formula suggested by TRRL (1969), (Balmer and Hegmon, 1980), the three testing methods are suitable to make a judgment relating to the kinds of features supplying the texture, and is also consistent with findings from an earlier comparison, Flintsch et al (2003); Forster (1989).

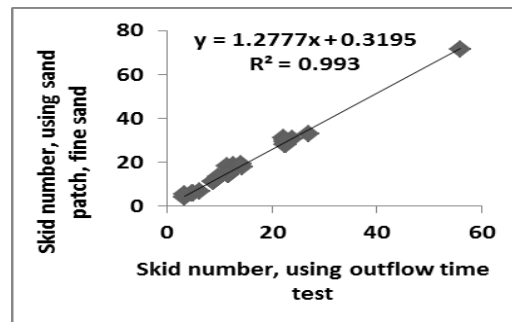
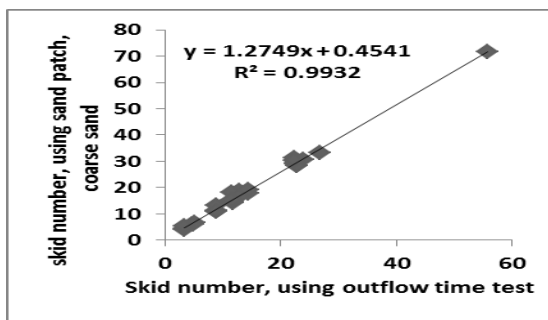
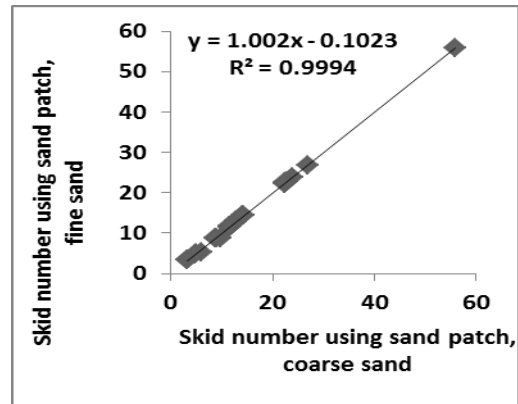
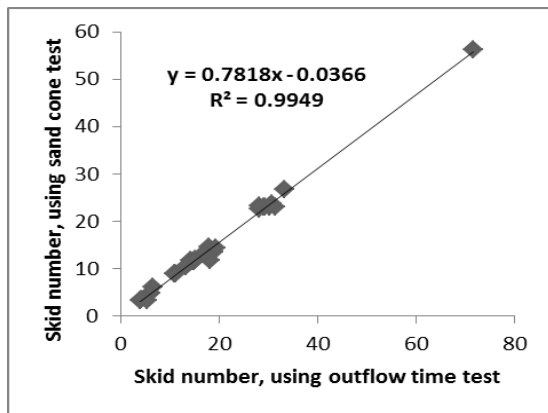


Figure 16: Skid number models using sand patch, outflow time, and sand cone methods

6.0 Conclusions

Based on the field testing program, the following conclusions may be drawn:

1. Each of the three investigated testing techniques used to evaluate the pavement macro-texture are good enough to be implemented in the field.
2. The contribution of sand size on micro-texture determination is nearly small enough to ignore. For the two sand sizes tested.
3. The outflow time technique is more suitable for coarse texture measurement, and the 1000 cc water volume is quite sufficient for such technique.
4. The testing techniques implemented for both micro and macro texture are best modeled when the skid number phenomena was introduced.
5. The mathematical models obtained through this field investigation could be successfully implemented for the determination of Asphalt pavement surface characteristics.

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