

SKID RESISTANCE AND TEXTURE OF COMPACTED ASPHALT MIXES EVALUATED FROM THE IFI IN LABORATORY PREPARATION

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Abstract

The greatest emphasis in pavement performance has been done in structural design components. However, the pavement friction is also important and is one of the factors that determining pavement safety. The wet skidding crashes are largely reduced when friction between a vehicle tire and pavement is high. Skid resistance and texture are important safety characteristics which need to be considered when pavement mixes are tested in laboratory. The objective of this study was to evaluate the skidding based on macrotexture and microtexture used in the International Friction Index (IFI). This study was conducted in asphalt mixtures compacted slab produced in laboratory. Two different mixtures grading (dense and gap) were produced using conventional asphalt and asphalt rubber. The characterization of the macrotexture and microtexture of asphalt pavements surfaces was obtained by the following tests: (i) British pendulum; (ii) Volumetric Method. IFI values were calculated by the pair of the parameters Sp and F60. The results showed that the mixture with gap grading had higher texture in comparison of mixtures with a dense grade gradation. The asphalt rubber mixtures improved the skid resistance compared to conventional mixtures.

1. INTRODUCTION

In the road, besides the real importance that the pavement structural design represents, the texture surface is a great concern in terms of the ride safety. Providing an adequate texture depth has been shown to improve pavement friction test results at high speeds and reduce crash rates on high speed facilities. Reduced visibility caused by splash and spray may increase the probability of wet-weather crashes, which is dependent on the mixture gradation. As a result, the pavement design should consider the combination of the structural and skid factors in way to assure and to guarantee the safety and the quality of the road.

According to Shaffer et al. (2006), pavement surface characteristics contribute to several important driving-related factors, among which are:

- surface integrity, which can contribute to tire damage and/or reduced vehicle control due to suspension interaction with large scale road irregularities;

- pavement friction, for which a minimum must be provided to ensure sufficient traction for safe vehicle braking, cornering, lateral maneuvering and forward acceleration;
- splash from heavy trucks during wet driving conditions, for which a maximum allowable level is needed to prevent obscuring the visibility of other road users.
- noise from pavement/tire interaction, for which a minimum is sought to prevent either hearing damage or a negative impact on residential property value.

Many factors affecting the pavement surface texture such as mix-related characteristics (Shaffer et al., 2006; FHWA, 2005):

- proper texture characteristics of asphalt surfaces are very much influenced by asphalt content, voids in the mineral aggregate, dust to binder ratio, and void content;
- surface characteristics of asphalt surfaces are also dependent on aggregate characteristics and this is particularly important after the surface is exposed to wear from traffic and weather conditions.
- frictional resistance of the wearing course is improved when angular aggregates are used in the asphalt mixtures, which means, increasing fractured faces of the coarse aggregate will improve stability of the mixture;
- soundness is also an indication of an aggregate's resistance to weathering;
- toughness is an indication of an aggregate's resistance to abrasion and degradation during handling, construction, and in-service;
- polish resistance.

Caltrans (2003) assert that asphalt rubber mixtures, mainly gap and open gradations provide a durable, highly flexible pavement surface with enhanced drainage and frictional characteristics that reduces splash and hydroplaning in wet conditions in comparison to dense gradation.

In this study, the skid properties of the laboratory slabs surfaces, which represent the as-constructed pavement surface, were evaluated. The main objective was measured the friction surface of two different mixtures: (i) conventional mixtures; (ii) asphalt rubber mixture. The conventional mixtures were produced using conventional asphalt in a dense gradation, while the asphalt rubber mixture was a gap graded.

The aggregates used in the mixtures were tested in order to evaluate their characteristics. To determine the friction properties in terms of microtexture and macrotexture, two tests were conducted in laboratory using the British pendulum and the Volumetric Method. After the tests, the International Friction Index (IFI) was calculated to supply a previous indication and the contribution of the rubber in the texture surface.

2. MICROTTEXTURE AND MACROTTEXTURE

Pavement surface texture is made up of the deviations of the pavement surface from a true planar surface. These deviations occur at three distinct levels of scale, each defined by the wavelength (λ) and peak-to-peak amplitude (A) of its components. The three levels of texture, as established by the Permanent International Association of Road Congresses (PIARC, 1995), are macrotexture, microtexture and megatexture.

Microtexture, macrotexture and megatexture are defined by texture wavelengths in units of meter.

Microtexture is defined as a surface roughness quality at the sub-visible/microscopic level with these characteristics: $\lambda < 0,5 \text{ mm}$ and $A = 1 \text{ to } 500 \text{ }\mu\text{m}$. It is a function of the surface properties of the aggregate particles within the asphalt or concrete paving material. Microtexture provides a rough surface to penetrate thin water films and produce good frictional resistance between the tire and the pavement and it is evaluated by using pavement friction at low speeds (PIARC, 1987; Hanson & Prowell, 2004).

Macrotexture has $\lambda = 0,5 \text{ to } 50 \text{ mm}$ and $A = 0,1 \text{ to } 20 \text{ mm}$ and the surface roughness quality is defined by the mixture properties (shape, size, and gradation of aggregate) of an asphalt paving material and the method of finishing/texturing (dragging, tining, grooving; depth, width, spacing and orientation of channels/grooves) used on a concrete paving material. Macrotexture provides drainage channels for water expulsion between the tire and the pavement, allowing better tire contact with the pavement to improve frictional resistance and prevent hydroplaning (PIARC, 1987; Hanson & Prowell, 2004).

At higher speeds, microtexture and adhesion still play a small role in skid resistance; however, macrotexture has a greater effect on maintaining skid resistance and on wet weather travel (Shaffer et al., 2006).

Megatexture this type of texture among $\lambda = 50 \text{ to } 500 \text{ mm}$ and $A = 0,1 \text{ to } 50 \text{ mm}$ is the texture which has 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 (NCHRP, 2006).

In addition, Henry (2000) proposed that wavelengths longer than the upper limit (500 mm) of megatexture are defined as roughness or unevenness. Figure 1 illustrates the three texture ranges, as well a roughness/unevenness representing wavelengths longer than the upper limit of megatexture (Sandburg & Ejsmont, 1998).

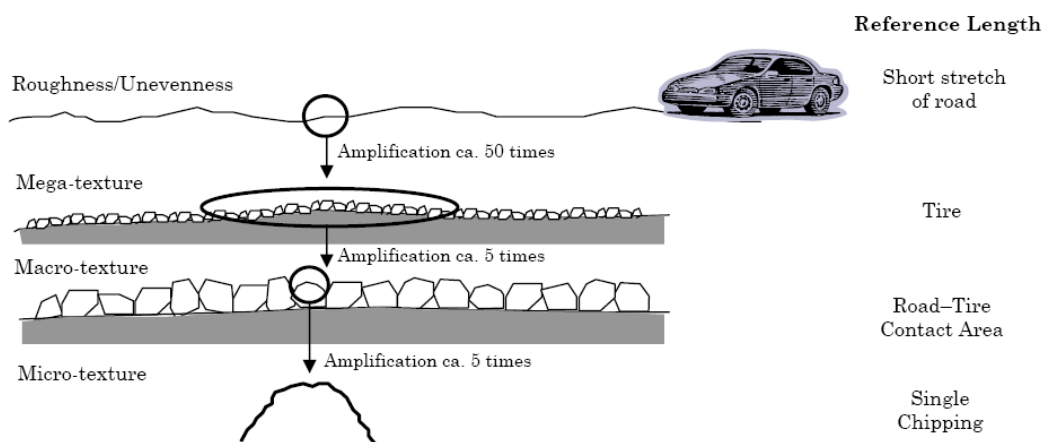


Figure 1. Simplified illustration of the various texture ranges that exist for a given pavement surface (Sandburg & Ejsmont, 1998)

Selecting the proper surface aggregates will help assure friction needs in wet weather. Aggregate angularity, shape, and texture are important parameters for defining pavement surface microtexture and macrotexture. Fine aggregates that exhibit angular edges and cubical or irregular shapes generally provide higher levels of microtexture, whereas those with rounded edges or elongated shapes generally produce lower microtexture. For coarse aggregates, sharp and angular particles interlock and produce a deep macrotexture as compared to more rounded, smooth particles. Moreover, in asphalt mixes, platy (i.e., flat and elongated) aggregate particles tend to orient themselves horizontally, resulting in lower macrotexture depth (NCHRP, 2006).

The British pendulum tester (BPT) is one of the most common laboratory test methods to determine the low-speed microtexture related to the skid resistance properties of pavement surface. The test procedure follows the procedures described in ASTM E303. This test method provides a measure of a frictional property, microtexture, either in the field or in a laboratory.

The BPT is a portable device that measures the frictional properties of a road surface or laboratory specimen in contact with a rubber slider. The value obtained, the British Pendulum Number (BPN), is a measure of the energy absorbed when the rubber slider contacts the test surface during the swing of a pendulum. Because the sliding speed is low, approximately 10 km/hr the BPN is related to the microtexture of the test surface (Shaffer et al., 2006).

Macrotexture measurements can be divided into two main classes: static measurements and dynamic measurements. Common static macrotexture measurement methods include the sand patch method, the outflow meter, and the circular texture meter.

The sand patch method or volumetric patch method, ASTM E965, is a volumetric approach of measuring pavement macrotexture. A known volume of sand (or glass beads) is spread properly on a pavement surface to form a circle, thus filling the surface voids up with sand. The diameter of the circle on which the sand material has been spread is measured and used to calculate Mean Texture Depth (MTD) (Flintsch et al., 2003).

Because of operator dependency, the test results have poor repeatability. However, since there is great deal of past research, this volumetric test is still used as the reference “ground-truth” standard throughout the world (Henry, 2000). The mean texture depth is calculated using Equation 1:

$$MTD = \left(\frac{4 \times V}{\pi \times D^2} \right) \quad (1)$$

where:

MTD= Mean texture depth of the pavement macrotexture (mm);

V= Volume of the sample material used (mm³);

π = number pi (3,1416);

D= average diameter of the area covered by the material (mm).

3. INTERNATIONAL FRICTION INDEX (IFI)

Friction indices have been in use for a long time. In 1965, ASTM started the use of the Skid Number (SN) (ASTM E 274) as an alternative to the coefficient of friction. In later years, AASHTO (American Association of State Highway and Transportation Officials), adopted the ASTM E 274 as AASHTO T 242 test method and changed the terminology from Skid Number to Friction Number (FN). In 1995, PIARC developed the International Friction Index (IFI), based on the PIARC international harmonization study (NCHRP, 2006).

The IFI was developed as a common reference scale for quantifying the pavement surface frictional properties. To calculate the IFI, it is necessary to have at least one friction measurement and one macrotexture measurement. The IFI is reported in two parameters: the normalized wet friction value at 60 km/hr (F60) and a speed constant (Sp). A transformation equation has also been established to allow for calculation of the wet friction value at speeds other than 60 km/hr. The designation and reporting of this index is IFI(F(60),SP) (Wambold et al., 1995; Flintsch et al., 2003; NCHRP, 2006).

F(60) indicates the friction at a slip speed of 60 km/hr measured using any standardized friction test method. It is a harmonized friction value, which adjusts for the speed at which a particular friction test method is performed, as well as the type of measurement device used.

The speed number Sp defines the relationship between measured friction and vehicle tire free rotation or slip speed. It is calculated using the pavement macrotexture measured using any standardized texture measurement method. The PIARC experiment strongly confirmed that Sp is a measure of the macrotexture influence on friction (NCHRP, 2006).

The IFI can be estimated by following the steps below (PIARC, 1995; NCHRP, 2006):

(i) measure pavement friction and macrotexture – using a selected friction device, measure pavement friction FR(S) at a given slip speed S (in km/h). Also, using a selected texture measuring device, measure pavement macrotexture and compute MTD (ASTM E 965) (in millimeters).

(ii) estimate the IFI Speed Number Sp – using the computed MTD, calculate Sp (in km/h) as Equation 2:

$$Sp = a + b \times Tx \quad (2)$$

where:

Tx = (MTD) macrotexture parameter (mm);

a, b = calibration constants dependent on the method used for determining. In the case, for sand patch method, a = -11,6 and b = 113,6.

(iii) convert friction measurement FR(S) at slip speed S to friction at 60 km/hr – adjust the friction FR(S) measured by the selected friction device at slip speed S using the Equation 3:

$$FR(60) = FR(S) \times e^{\left(\frac{S-60}{Sp}\right)} \quad (3)$$

where:

FR(60) = adjusted value of friction measurement FR(S) at a slip speed of S to a slip speed of 60 km/h;

FR(S) = friction value at selected slip speed S;

S = Selected slip speed (km/h), in case, 10 km/h.

(iv) calculate the IFI Friction Number F(60) – using the speed-adjusted friction value FR(60) and the with the Equation 4, compute F(60):

$$F(60) = A + B \times FR(60) + C \times TX \quad (4)$$

where:

F(60) = IFI Friction Number;

A, B, C = Calibration constants for the selected friction measuring device. For the British pendulum, the values of the constants are: A = -0,008; B = 0,056 and C = 0;

TX = value of MTD;

FR(60) = adjusted value of friction measurement FR(S) at a slip speed of S to a slip speed of 60 km/h;

4. AGGREGATES AND MIXTURES CHARACTERIZATION

The aggregates for mixes production used in this study were granite with the following gradations: (i) grade 1 crushed granite stone, particles size 6 – 12 mm; (ii) grade 2 crushed granite stone, particles size 4 – 10 mm; (iii) grade 3 fine crushed granite stone, particles size ≤ 4 mm; (iv) limestone filler.

The aggregates were characterized using laboratory tests: (i) grading; (ii) shape; (iii) durability. The flat and elongation shape of coarse aggregate properties were measured. The hardness of coarse aggregate was determined with the Los Angeles abrasion device. Table 1 presents the laboratory tests results and Figure 2 showed the aggregates gradation curves.

Two types of mixtures with different grading curve (gap and dense) were prepared with the same aggregates. Dense graded mixture is a dense, continuously graded mixture of coarse and fine aggregates, mineral filler, and asphalt cement while refers to a gradation that contains only a small percentage of aggregate particles in the mid-size range.

In this study, were available a dense graded mixture named CAUQ (*Concreto Asfáltico Usinado à Quente*) specified by DNIT grade C – *Departamento Nacional de Infra-Estrutura de Transportes ES 31/2006 (in Portuguese)*; and a gap graded mixture was from Caltrans (California Department of Transportation), as standard specifications, section 203-11.3, ARHM-GG (Asphalt Rubber Hot Mix Gap Graded). The dense mixture was produced using a conventional asphalt (CAP-50/70), classified by penetration and the Caltrans ARHM-GG mixture used an asphalt rubber with 20% of rubber content (terminal blend process). The Figure 4 shows the grading curves of the mixtures. The mixtures design results are presents in Table 2.

Table 1. Aggregates characteristics

Test	Standard	Specification	Results	
Toughness (Los Angeles Test)	ASTM C 131	30%	26%	
Flat	BS 812	25%	Grade 4/10	23%
			Grade 6/12	12%
Elongation	BS 812	25%	Grade 4/10	23%
			Grade 6/12	17%

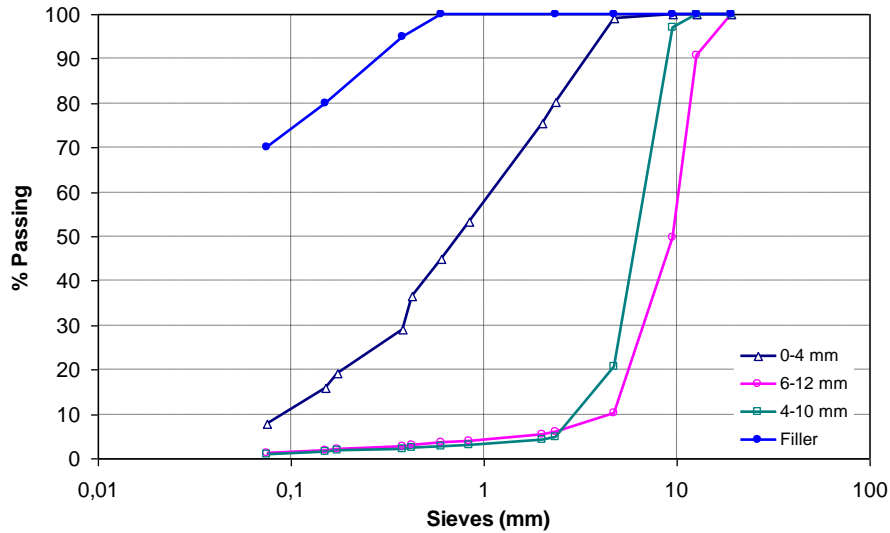


Figure 2. Aggregates gradation curves

A set of tests measured in the laboratory to evaluated aggregates used in this study, shown that they have appropriated resistance to be used in asphalt mixtures.

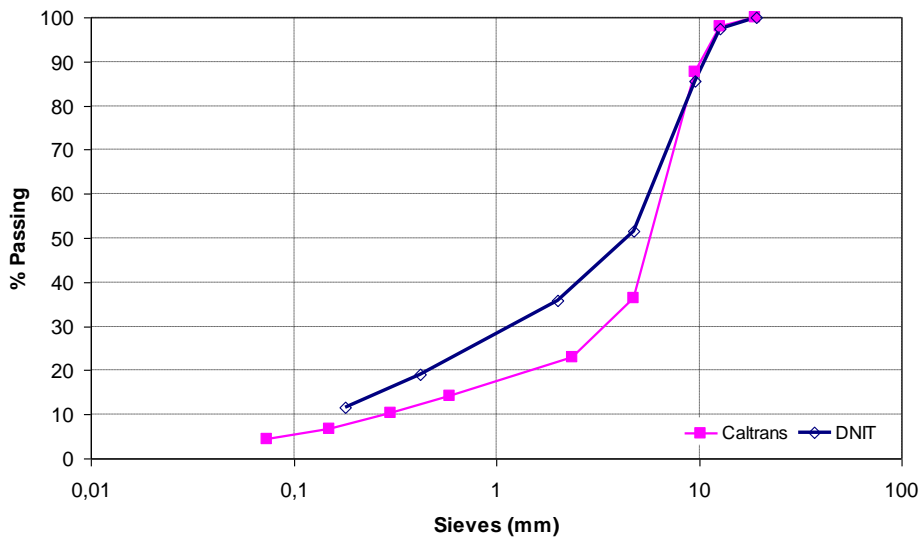


Figure 3. Mixtures gradation curves

Table 2. Mixtures characteristics

Gradation	Asphalt	Asphalt content (%)	Voids content (%)	Specific gravity (g/cm ³)
DNIT C	conventional	5,5	4,0	2,44
ARHM-GG	AR	7,5	6,0	2,41

5. SKID RESISTANCE AND TEXTURE TESTS

To evaluate the macrotexture and the microtexture in laboratory specimens, the asphalt mixes were compacted in a metallic mould with the dimensions: height 7,3 cm; width 49,2 cm and length 75,2 cm.

To evaluate the microtexture of the mixtures, the average British Pendulum Number (BPN) of the wetted specimens was measured in accordance to ASTM E303. In order to correct the temperature of the water, was used the chart of EN 13036-4. The macrotexture was measurement using the sand patch test, followed the ASTM E 965 (Measuring Pavement Macrotexture Depth Using a Volumetric Technique). The tests results represents the average of four measured and are presented in Figure 4.

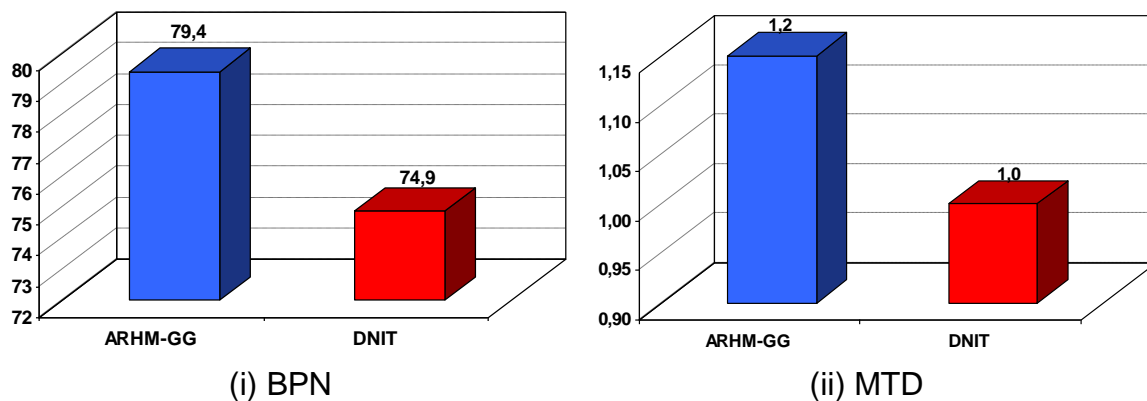


Figure 4. Laboratory test results

The mixture with asphalt rubber presented high microtexture compared to the conventional mixture. The analysis of the macrotexture results indicated that the dense gradation mixture (DNIT) presented the lower texture compared to the gap gradation with asphalt rubber (ARHM-GG).

6. INTERNATIONAL FRICTION INDEX (IFI) RESULTS

The International Friction Index (IFI) is used for consideration of skid resistance and macrotexture in a probabilistic pavement performance and provides a friction scale that can be used for comparisons at international level. The IFI results is a good indication of the friction and texture measurements in order to determine if microtexture or macrotexture, or both, are inadequate and need of improvement. Table 3 presents the results of IFI.

Table 3. IFI results

Mixture	Tx (mm)	FRS (BPN)	IFI	
			Sp	F ₆₀
DNIT C.	1,0	74,9	102,0	0,42
ARHM-GG	1,2	79,4	119,0	0,47

Starting from the IFI results, it can be represented the reference curves of each mixture, the any sliding speed, as presented in Figure 5.

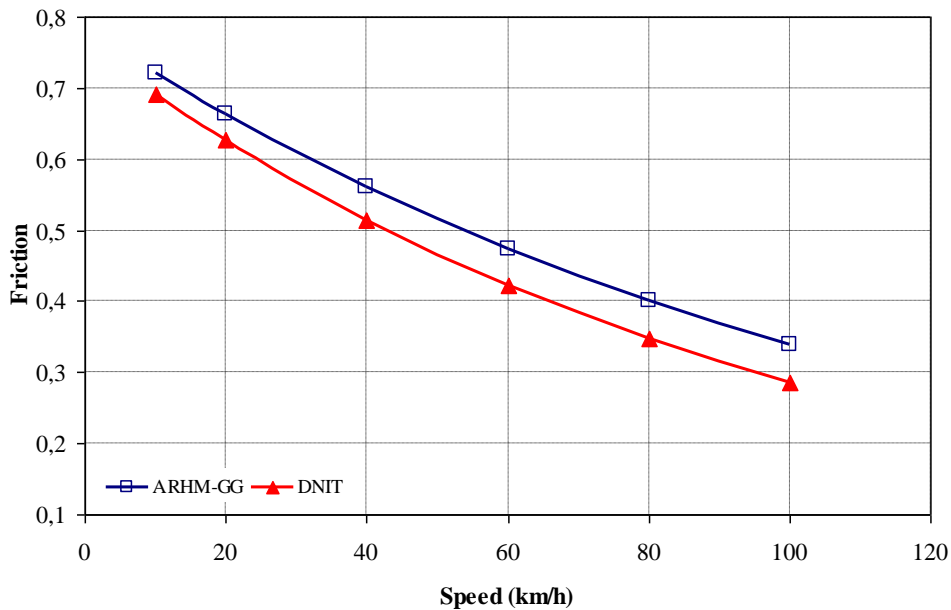


Figure 5. Reference curves of the mixtures

According to Figure 5, the ARHM-GG mixture presents a better skid resistance at low and high speeds. These results are an indicator that using mixtures with gap gradation has a ride quality can be improvement. The presence of rubber in ARHM-GG mixture contributed to improve the roughness surface.

7. CONCLUSIONS

Experimental laboratory research to correlate safety properties such as macrotexture and microtexture was presented, evaluated by the sand patch method and British pendulum tester. The IFI results and the reference curve of the mixtures were also presented.

The texture of the pavement surface is primarily a function of the type and gradation of the aggregates that are used in the mixture. Two mixtures were tested, a conventional dense graded (DNIT) and a gap graded with asphalt rubber (ARHM-GG). In this study, the same aggregates were used to produce the mixtures.

The results showed that ARHM-GG presented high macrotexture, which results in good skid resistance at high speeds. The microtexture of the pavement is a function of the type of aggregate and the same aggregates were used in the mixtures. As ARHM-GG presented a microtexture higher than the DNIT indicated that the gap gradation and the asphalt rubber microtexture contribute to good skid resistance at low speeds. Another detail is that these tests were performed in laboratory specimens and some wearing of the aggregate surface must occur to remove the initial asphalt film and expose adequate microtexture. Consequently, the tests should be done in real scale in field.

International Friction Index (IFI) model can be used to evaluate the contributions of the pavement surface to low and high-speed skid resistance and showed a good indicator to ride quality improvement.

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