Improvement of the Functional Pavement Quality with Asphalt Rubber Mixtures

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ABSTRACT. *Skid resistance and texture are important safety characteristics which need to be considered in flexible pavement design, maintenance and rehabilitation. The main objective of this paper is to optimize surface texture characteristics in asphalt rubber pavements, mainly macrotexture to reduce splash, spray and hydroplaning and microtexture to increase friction at low and high speeds. The objective was accomplished by measuring the friction surface with two different tests: (i) British pendulum; (ii) Volumetric Method. The specimens prepared in the laboratory represent the as-constructed pavement surface. In this study, two different mixtures grading (dense and gap) were produced using three types of binders: (i) conventional asphalt; (ii) asphalt rubber using terminal blend process; (iii) asphalt rubber using continuous blend process. The binder content influence in functional quality was tested by using the same configuration for mixtures with more 1% of asphalt rubber content.*

The results of this study were carried out to evaluate the effect of asphalt rubber production process and mixtures gradation on the pavement surface characteristics. The results showed that the mixture with gap grading exhibit higher texture in comparison of mixtures with a dense grade gradation. The asphalt rubber mixtures improved the skid resistance compared to conventional mixtures. This research indicates that the CRM (crumb rubber modified) production with rubber from the different processes have significant differences in pavement surface characteristics.

KEYWORDS: *Asphalt rubber, Surface characteristics, Texture.*

1. Introduction

The greatest emphasis in pavement design and rehabilitation has been done in structural design components. However, nowadays, the surface characteristics that contribute to the functional performance have largely been studied. Thus, there is an important focus on improving the functional pavement surface characteristics of new, reconstructed, rehabilitated, and pavement preservation projects (Larson *et al.*, 2004).

The integrity of the pavement structure is the key to whether a road requires reconstruction, resurfacing or a maintenance treatment. The failure mode observed can be a structural failure or a surface failure. Structural failures can result from poor design, excess traffic volumes or weights, poor drainage, poor materials and/or poor construction practices. Structural failures may also be associated with poor bonding between the bituminous layers. Surface failures may look similar to those caused by structural failures but their causes are different. Surface failures result from aging, surface abrasion, poor design (inappropriate asphalt content), poor materials (weak aggregates), poor construction practices or inappropriate use of a treatment (Caltrans, 2003).

In a study about surface characteristics, it is important to distinguish between the meanings of the terms "friction" and "skidding resistance". Friction refers to the forces that are developed between the tire and the pavement surface at a particular time and under particular conditions. It is influenced by a large number of parameters, such as: the road, tire and vehicle suspension characteristics, ambient temperature and presence of contaminants (including water). Skidding resistance is the term used to describe the contribution of the road to the development of friction (TRL, 2002).

Pavement skid resistance is defined as the ability of a traveled surface to prevent the traction lost. The term “skid resistance” can be applied to any measurement taken concerning the frictional properties of pavement surfaces (Davis, 2001).

Pavement friction during wet conditions is one of the major safety concerns for pavement design, maintenance and rehabilitation. In wet conditions, as vehicle speed increases, skidding resistance decreases. The extent to which this occurs depends of the texture depth. Generally, to a lower texture corresponds a greater lost of friction. Road surfaces must indeed ensure adequate levels of friction and skid resistance.

Many devices and methods have been developed to measure the friction and texture of pavements. In this study, the macrotexture was measured using the Volumetric Patch Method and the microtexture was measured using the British Pendulum Test in samples produced in laboratory.

The measurement of the friction surface was done through the tests: (i) British pendulum; (ii) Volumetric Method. In order to accomplish the objectives, two different mixtures grading (dense and gap) were produced using three types of binders: (i) conventional asphalt mix; (ii) asphalt rubber mix using terminal blend process; (iii) asphalt rubber mix using continuous blend process. Mixtures for all gradations with more 1% of asphalt rubber content were tested as well.

2. Pavement surface texture

In the PIARC World Congress in Brussels in 1987, three road surface texture ranges were defined by microtexture, macrotexture and megatexture (PIARC, 1995).

Pavement macrotexture is the deviation of a pavement surface from a true planar surface. The characteristic dimensions for the macrotexture vary in the range 0,5-50 mm. Peak-to-peak amplitudes may (normally) vary in the range 0,01-20 mm. This type of texture is the one which has wavelengths in the same order of size as tire tread elements in the tire/road interface (PIARC, 1995).

Pavement microtexture is the deviation of an aggregate from a true planar surface. The characteristic dimension for the microtexture is less than 0,5 mm. Peak-to-peak amplitudes usually vary in the range 0,001-0,5 mm. This type of texture is the texture which makes the surface feel more or less harsh but which is normally too small to be observed by the eye (PIARC, 1995).

Microtexture provides a gritty surface to penetrate thin water films and produce good frictional resistance between the tire and the pavement. 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. Currently, there is no system capable of measuring microtexture profiles at highway speeds. Therefore, microtexture is evaluated by using pavement friction at low speeds (Hanson *et al.*, 2004). The Figure 1 shows the difference between macrotexture and microtexture.

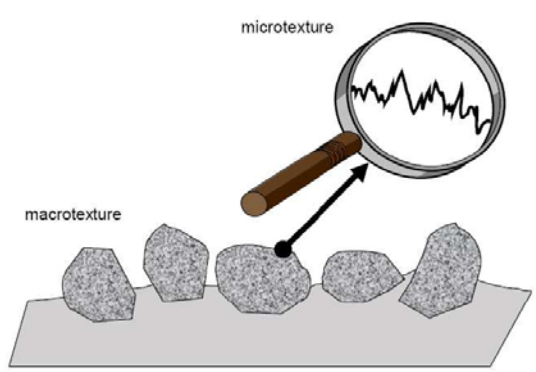

Figure 1. *Difference between macrotexture and microtexture (Source: Crow, 2003)*

Table 1 provides a guide, based on the needs of the road users, to the appropriate surfacing characteristics (TRL, 2002).

Table 1. *Property of surface characteristics*

Road user requirement	Key property of surface
Good low speed resistance	High polish resistant coarse aggregate
Good high speed resistance and prevention of hydroplaning	High polish resistant coarse aggregate and high surface texture
Visible road markings	High surface texture
Low spray generation	Porous surfacing or high surface texture
Low glare and specular reflection	High surface texture
Low tire/road noise	Porous surfacing or high surface texture

3. Macrotexture and microtexture measurement

3.1. *Volumetric Patch Method*

The sand patch method is the oldest and most common way to measure pavement surface texture and uses equipment extremely simple.

The test procedure used for this study follows the procedures contained in ASTM E965. It uses a volumetric approach to measure the pavement macrotexture.

The Volumetric Patch Method, also known as sand patch method has been used world-wide for many years to measure the road surface texture. It relies on a given volume (a known volume) of sand which is spread out on a road surface.

The sand is distributed to form a circular patch and the diameter is measured. By dividing the volume of sand by the area covered, a value is obtained which represents the average depth of the sand layer, the Mean Texture Depth (MTD).

The diameter of the area covered by the sand is measured and then used to calculate the mean texture depth of the pavement macrotexture.

The mean texture depth is calculated using Equation [1]:

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

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

V= Volume of the sample material used (mm^3);

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

3.2. *British pendulum tester*

The British pendulum test 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 British pendulum is a portable dynamic pendulum device that measures the energy absorbed by a rubber pad as it slides over a test surface and the value of the skid resistance obtained from this device is known as BPN (British Pendulum Number).

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 British Pendulum Tester consists of a rubber slider attached to the end of a pendulum arm. As the pendulum swings, it is propelled over the surface of the specimen. As the rubber slider contacts the surface of the specimen, the kinetic energy of the pendulum decreases due to friction. This energy lost is measured and reported as the British Pendulum Number (BPN). It is widely recognized as a measure of the microtexture (McDaniel *et al.*, 2003).

The values of the BPN vary from 0 to 140. The BPN is recorded using a specially constructed scale located on the tester, which measures the height of the pendulum after contacting the surface. Before the test, the test area is covered by water.

4. Materials

4.1. *Aggregates*

The aggregates for mixes production used in this study were granite and come from the northern of Portugal, which have similar characteristics as the one using in southern of Brazil (Santa Catarina State), with the following gradations:

– Grade 1 crushed granite stone, particles size 6 – 12 mm;

– Grade 2 crushed granite stone, particles size 4 – 10 mm;

– Grade 3 fine crushed granite stone, particles size ≤ 4 mm;

– Limestone filler was also used.

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 toughness of coarse aggregate was determined with the Los Angeles abrasion device. Table 2 presents the laboratory tests results.

Table 2. *Coarse aggregates test results*

Test	Grade	
	4-10 mm	6-12 mm
Flat	21%	23%
Elongation	19%	17%
Toughness	-	29%

4.2. *Asphalt binder and crumb rubber*

Conventional asphalt binder, crumb rubber and asphalt binder modified by the terminal blend process (from Brazil) were used in this research.

In this study, three types of asphalt were used as following:

– conventional asphalt, named CAP-20;

– asphalt rubber using the terminal blend process, named A and B;

– asphalt rubber using the continuous blend process, named C.

Two crumb rubber contents in the asphalt rubber produced from terminal blend process were used. The type “A” contains 20% of crumb rubber and the type “B”, 15%.

The asphalt rubber produced by continuous blend process was made in laboratory with the following characteristics: (i) 21% of crumb rubber; (ii) 90 minutes of digestion time; (iii) temperature of 180 ºC.

The physical properties of all asphalts binders were characterized in laboratory by the following tests: (i) penetration; (ii) resilience; (iii) softening point. Table 3 presents the characterization of asphalt binders.

Table 3. *Characterization of asphalt binders*

Test	Binder Type			
	CAP-20	A	B	C
Penetration, ASTM D 5 (1/10 mm)	51,5	42,0	40,0	25,8
Resilience ASTM D 5329 (%)	0	28,0	32,0	40,0
Softening Point ASTM D 36 (ºC)	51,5	62,0	60,8	65,5

The crumb rubber used in continuous blend process was produced from ground rubber in ambient grinding. The gradation of the crumb rubber is presented in Figure 2.

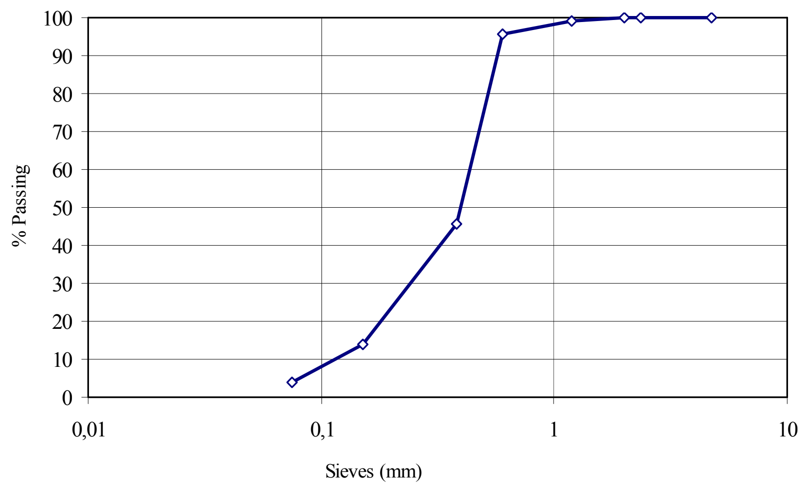

Figure 2. *Crumb rubber grading*

4.3. *Mixtures*

In order to optimize pavement surface, two types of mixtures were prepared with the same aggregates, which the studied variables were the: i) grading curve; ii) asphalt type and asphalt content. In this study, two dense graded mixes and one gap graded mix were studied. The Figure 3 shows the gradation curves of the mixtures.

The grading specifications of the mixtures are referred as following:

– DNER grade C – Departamento Nacional de Estradas de Rodagem ES 313/97 (in Portuguese);

– AI – Asphalt Institute grade IV – The Asphalt Handbook;

– Caltrans – California Department of Transportation, Standard Specifications, section 203-11.3, ARHM-GG.

The factorial of mixtures combinations resulted in ten types of mixtures resulting from the combination of the following variables: (i) aggregate gradation (DNER, AI, Caltrans); (ii) asphalt binder type (CAP-20, A, B, C); (iii) voids content (4%, 6%); iv) binder content (optimum, +1%).

Table 4 presents the matrix combination tested in this study.

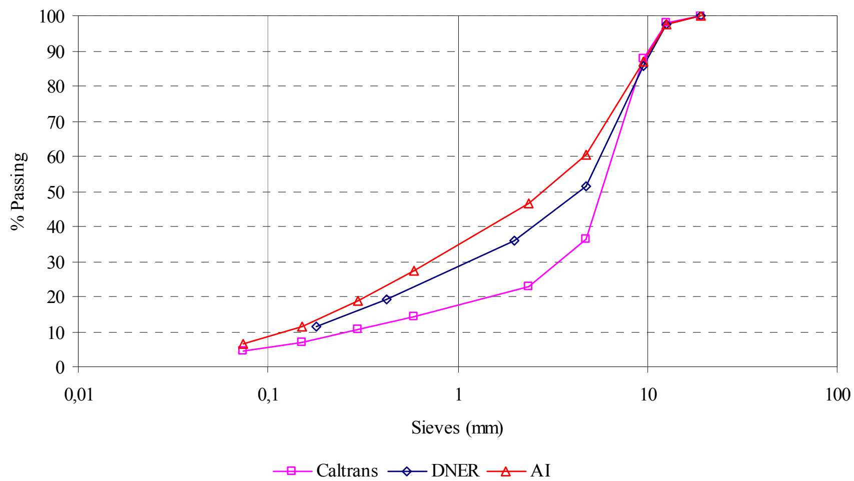

Figure 3. *Gradation curves of the mixtures*

Table 4. *Matrix combination of asphalt mixtures*

Gradation	Asphalt	Mixture	Asphalt content (%)	Voids content (%)
DNER C	CAP-20	MD1	5,5	4,0
DNER C	B	MD2	7,5	4,0
AI IV C	B	MD3	7,0	4,0
AI IV C	C	MD4	7,0	4,0
Caltrans	A	MG5	7,5	6,0
Caltrans	C	MG6	8,0	6,0
AI IV C	B	MD7	8,0	4,0
AI IV C	C	MD8	8,0	4,0
Caltrans	A	MG9	8,5	6,0
Caltrans	C	MG10	9,0	6,0

5. Results

To evaluate the macrotexture and the microtexture in laboratory specimens, asphalt slabs were prepared with these dimensions:

– thickness – 7,3 cm;

– width – 49,2 cm;

– length – 75,2 cm.

Asphalt mixtures were produced in a laboratory mechanical mixer. The compaction of the mixes was performed with a vibratory wheel roller in a metallic mould. An example of a compacted slab is presented in Figure 4.

Figure 4. *Compacted slab*

5.1. ***Macrotexture***

The visual observation was the first test to evaluate the macrotexture of the pavements specimens, considering the gradation in the different surfaces. The sand patch test method was used to quantify differences in the surface macrotexture.

The visual observation in the different gradation specimens (dense mixtures, DNER and AI; gap mixture, Caltrans) is presented in Figure 5.

(DNER) (AI)

(CALTRANS)

Figure 5. *Visual observation of the specimens with different gradations*

The visual analysis indicates that the gap graded mixture presented, apparently, the best macrotexture compared to dense mixtures. The gap gradation mixture, presented uniform and consistent abundance of coarse aggregate whereas the dense mixtures presented an excess of fine material in surface.

In all specimens (Table 4) it was measured the macrotexture based on the ASTM specification E965 “Measuring Pavement Macrotexture Depth Using a Volumetric Technique,” which is more commonly referred to as sand patch test.

The diameters of the sand patches were transformed to Mean Texture Depth (MTD) using the Equation [1]. The results of the mean texture depth for all mixtures are presented in Table 5.

Table 5. *Sand patch test results*

Gradation	Asphalt	Mixture	Average MTD (mm)
DNER C	CAP-20	MD1	1,0
DNER C	B	MD2	0,6
AI IV C	B	MD3	0,6
AI IV C	C	MD4	0,6
Caltrans	A	MG5	1,2
Caltrans	C	MG6	0,8
AI IV C	B	MG7	0,5
AI IV C	C	MG8	0,6
Caltrans	A	MG9	1,0
Caltrans	C	MG10	1,0

The analysis of the macrotexture results indicated that the dense gradations mixtures prepared with asphalt rubber have the lower texture compared to the gap gradation. When the binder content was increased in 1%, it was observed that, in the terminal blend mixtures, the texture decreases.

On the other hand, gap gradation, with the continuous blend asphalt rubber, when the binder content was increased 1%, the surface texture increases. This is due the fact that the rubber content contributes to increase the surface texture. For dense gradation, the results did not change. In contrast, the DNER mixture with the conventional binder presented a high texture when compared to the asphalt rubber. The Figure 6 shows all texture results for asphalt rubber mixtures produced with binder from terminal blend and continuous blend.

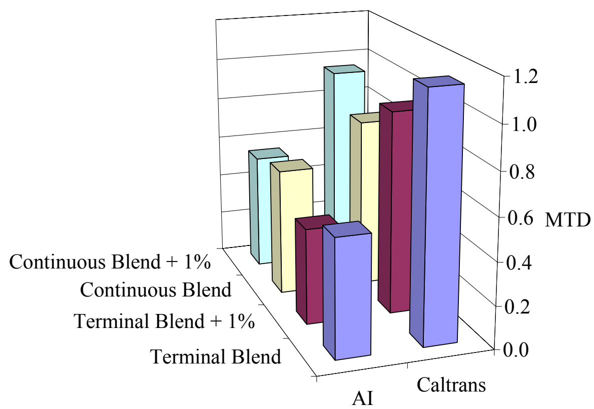

Figure 6. *Texture of asphalt rubber specimens*

5.2. ***Microtexture***

The British Pendulum Number (BPN) of wet specimens was measured in accordance with the procedure ASTM E303 and using the pad as specified in ASTM E501. In ASTM E303 standard, the water temperature correction was not specified. In this study, in order to correct the temperature of the water, the chart of EN 13036-4 was used. The measurements of the microtexture were done in the pavement specimens and are showed in Table 6.

In this test it was observed that the values of microtexture among asphalt rubber mixtures studied were very similar. On the other hand, it is important to show that mixtures with asphalt rubber present high microtexture compared to mixtures with conventional binders.

__Table 6.__ BPN values of asphalt mixtures

Gradation	Asphalt	Mixture	BPN
DNER C	CAP-20	MD1	74,9
DNER C	B	MD2	82,4
AI IV C	B	MD3	82,6
AI IV C	C	MD4	82,5
Caltrans	A	MG5	79,4
Caltrans	C	MG6	83,8
AI IV C	B	MD7	84,2
AI IV C	C	MD8	83,7
Caltrans	A	MD9	83,4
Caltrans	C	MD10	85,7

The Figure 7 presents the difference between the DNER mixtures. It is easily observed that the mixture with asphalt rubber has the high microtexture when compared with the conventional one.

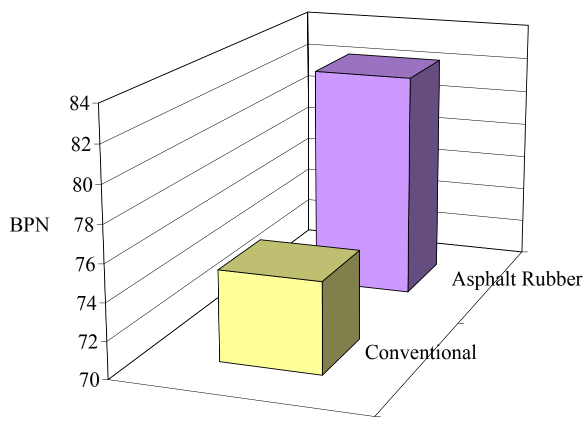

Figure 7. *Comparison between DNER mixtures with and without asphalt rubber binder~*

The analysis of the asphalt rubber mixtures with the terminal blend process and continuous blend process allows concluding that both mixtures present good microtexture values. When the binder content is increased, the microtexture is increased as well as for all mixtures, independently of the asphalt rubber production process used. Figure 8 shows this correlation.

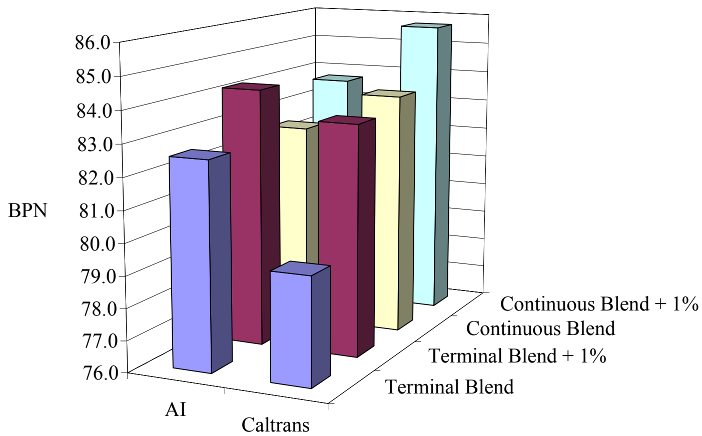

Figure 8. *BPN of all asphalt rubber mixtures*

6. 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 tests results showed that asphalt rubber mixtures can improve the safety characteristics, once exhibit better micro and macrotexture values when compared to conventional mixtures.

The visual analysis of gap-grade mixture presented the best macrotexture compared to dense mixtures due the abundance of coarse aggregate on the surface.

The mixture with asphalt rubber has the high microtexture when compared to the conventional one.

Both asphalt rubber mixtures prepared with binder from terminal blend and continuous blend presented interesting microtexture values.

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