Characterization of the Skid Resistance and Mean Texture Depth in a Permeable Asphalt Pavement

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Characterization of the Skid Resistance and Mean Texture Depth in a Permeable Asphalt Pavement

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Abstract. Road pavements need a deep characterization of the surface layer, with which the vehicles have direct contact and, therefore, must provide security to the users. The use of permeable asphalt pavements (PAP) with porous layers has provide obvious advantages in reducing runoff and the rainwater infiltration into the soil or for storage. However, the study of the interaction between the pavement surface layer and the tire rubber requires additional tests in terms of texture and friction, since they are important parameters for the design, construction, management, maintenance and roads safety. Considering the application of a PAP in a parking lot, the study objective was to characterize in the field the pavement surface in terms of mean texture depth (MTD) and skid resistance (Pendulum test value, PTV). The methods used were the volumetric technique by the patch test and the pendulum test, according to EN 13036-1 and EN 13036-4, respectively. The double layer porous asphalt (DLPA) at the surface is characterized by having a structure with high voids content that led to results of clearly rougher macrotexture and good skid resistance. The normalized limit values were met, however, a very strong correlation between MTD and PTV was not observed. A comparison was also made with porous surfaces of other studies and it was found that porous asphalt has a good behaviour at the start of construction which may tend to improve in the long term. From the study, it is concluded that the PAP presents good performance of the surface layer, providing road safety to users.

1. Introduction

Pavements are the main element of road infrastructure and therefore the road pavement design must provide a solid structure capable of withstanding the loads induced at the application site during its useful life without excessive damage. The surface performance of the pavements is the most important factor for its users, namely safety, skid resistance, low noise and good visibility at night and during rainy periods. A traditional hot mix asphalt does not guarantee these pavement needs, so mixtures with higher voids content are required, such as porous asphalt mixtures (PA). Its application aims to improve rainwater drainage, reducing surface runoff during more intense rainfall. This has been the focus of many organizations that study climate change. With a void content of 18-25 %, PA mixtures also reduce noise contact of the tire/pavement [1–3]. In addition, as a result of high porosity and good aggregate quality (microtexture), PA provides good skid resistance and significant reductions in the splash and spray effects under wet conditions [4–6]. One of the problems pointed to these porous surfaces is the clogging, considered the main cause of the acoustic performance decrease of the porous surface throughout the pavements life cycle [6]. To deal with this problem in urban areas a double layer porous asphalt (DLPA) was developed to minimize the clogging effects [6]. Its constitution is explained in the

following section. The PA concept was most recently applied to permeable asphalt pavements (PAP), where PA or DLPA were applied to the surface layer. The PAP main benefits include total infiltration of rainwater, water quality improvement and groundwater recharge, in addition to the urban heat island reduction [7].

The PAP surface performance includes the evaluation of two fundamental properties that influence the safety level in road driving: skid resistance and texture. Skid resistance is referred to as the "property of the trafficked surface which limits the relative movement between the vehicle tyre contact (skid) and the surface" [8]. The skid resistance lack or wet pavement sticking is one of the main causes responsible for the accidents high percentage, leading to loss of pedestrian or driver control, contributing to 20 to 30% of all occurrences in humid climates [9]. The macrotexture influences the skid resistance in wet pavements, as it decreases as the speed increases [9,10]. Kogbara et al. [11] report that the skid resistance is essentially independent of the film thickness of water at low speeds (30-50 km/h), however, it decreases with the water film thickness at higher speeds. This is due to the area decrease of tire/pavement contact by the water in the surface which leads to the friction reduction. According to Celko et al. [12] when the road friction coefficient has decreased to 0.45 the accident risk increases by 20 times, while if decreasing to 0.30 the risk is 300 times higher. The studies generality consider that the skid problems occur due to friction deficiencies in wet pavements, however a recent study has shown that friction also affects pavements in dry conditions [13]. The main factors influencing this property include: tire pressure, contact area, tire rubber composition, alignment, texture and friction characteristics of the pavement surface, vehicle speed, and weather conditions before the test (wet or dry) [8]. Among the environmental factors that influence tire friction on the pavement are temperature, precipitation and contaminants. There are several friction measuring equipment with high technology and continuous characterization [11]. The British Pendulum is the simplest, economically viable and versatile equipment in various applications that allows the longitudinal friction coefficient measurement (Pendulum Test Value, PTV) and has been used in several studies [12,14].

Porous asphalt pavements improve skid resistance and visibility on wet pavements [15]. In the initial phase after construction, it has a low skid resistance since the aggregates are surrounded by a thick film of bitumen. However, after the bitumen excess is removed by vehicles passage, the values may be increased or maintained at a stable level [1,16]. Porous asphalt surfaces provide an increase in texture which, together with internal drainage, can result in a significant reduction in hydroplaning [17]. The tests performed by van der Zwan et al. (1990) cited in Noyce et al. [17] showed that at high speeds the porous pavement provides a greater resistance to skid than conventional pavement, in agreement with other authors [15].

The pavement surface texture "is defined as the pavement surface deviation from a plain surface" [18]. The surface texture classification is defined according to the wavelengths of the irregularities [18], considering the intervals: 0 to 0.5 mm microtexture; 0.5 to 50 mm macrotexture; 50 to 500 mm megatexture; and 500 mm at 50 m irregularity. The microtexture and macrotexture presence on the pavement surface influences tire noise on the road. Larger micro and macrotexture amplitudes increase friction in wet pavements, reducing the accidents risk [19]. The macrotexture is typically constituted by the shape and size of the aggregate particles on the pavement surface and is affected by the spacing and arrangement of the coarse aggregate particles [11,20]. The main aspects that change the macrotexture are: maximum aggregate size, coarse quality and types and fine aggregates, mixture viscosity bitumen content, particle size and void content. The particle size and final quality of the mixture determine the surface macrotexture, which in turn affects drainage of the pavement surface [2]. From the study by Ongel et al. [21], it can be deduced that higher voids content and thicker granulometry increase the macrotexture, while denser granulometries reduce it. Other studies referenced by Praticò and Vaiana [22] report that surface texture affects pavement performance at the level of tyre/road friction, noise emission, rolling resistance, tyres wear, operating costs and greenhouse gas emissions.

The most common way of measuring the macrotexture is the volumetric method of sand patch used in several studies [19,22–25]. Other more recent methods include laser measurement [9,26–28], however, these equipments are more expensive and refer to the sand patch test to validate the proposed

methods reliability. The most common parameters to characterize the macrotexture are the mean texture depth (MTD) and the mean profile depth (MPD). The volumetric method of sand patch provides the MTD and corresponds to the volume portion of the total area covered by the material. Recently the sand has been replaced by glass spheres, due to the particles irregular shape that don't spread so easily. MPD is defined as the mean of all mean depths of the segment of all surface profile segments, obtained by a set of measurements generated by a laser-based system. Several studies have related the MTD parameters with MPD in order to compare results between different methods [19,23,25,26,29]. The sand patch test is suitable for asphalt pavements surfaces and concrete with a texture depth greater than 0.25 mm and is affected by the surface and the mixture internal structure [22]. The sand patch test use on porous surfaces has been discussed because of the some material loss into the pores of the mixtures [22,23]. Some studies of texture average depth emphasize the need to investigate the effect of pavements surface variability [30].

The resistance to friction strongly depends on the pavement texture characteristics. Since the accidents rate on wet roads is greater than on dry roads, the PAP use is a good solution to this problem because of the porous surface that reduces runoff when precipitation occurs. Therefore, this study objective is to evaluate the friction and texture properties in a PAP meeting the users' fundamental needs thus reducing the probability of road accidents occurrence.

2. Materials and Methods

The experimental work began with the construction of the PAP with a total area of 37.5 m^2, corresponding to three parking spaces. Its structure consists of a 15/25 aggregate reservoir with 25 cm thick, a 5/15 aggregate regularization layer with 9 cm and a double layer porous asphalt (DLPA) with 7 cm thick.

DLPA consists of a porous asphalt upper layer with fine aggregates (PA1) and a lower layer with coarse aggregates (PA2). The function of the upper layer is to act as a sieve which reduces the ingress of sediment that accumulates in the pores of the PA1 and prevent the lower layer PA2 from becoming obstructed in order to facilitate drainage of the following layers and subsequently to the soil or storage deposit. In this case, the mixture PA1 has a thickness of 3 cm and PA2 has a thickness of 4 cm. The porous asphalt that make up the surface layer DLPA present the granulometry of figure 1. The maximum aggregate size in PA1 is 10 mm and in PA2 is 15 mm. These mixtures composition include coarse aggregates (5/10 gravel and 5/15 gravel), fine aggregates (stone dust and limestone), cellulosic fibres and 50/70 bitumen. The mix design and the voids content are presented in table 1.

The pavement surface layer characterization was carried out after construction, in the initial phase of opening to the users. The properties presented in this study correspond to the macrotexture and skid resistance of the PAP's DLPA. Each test point location is shown in figure 2. The methods used are presented in the following subsections.
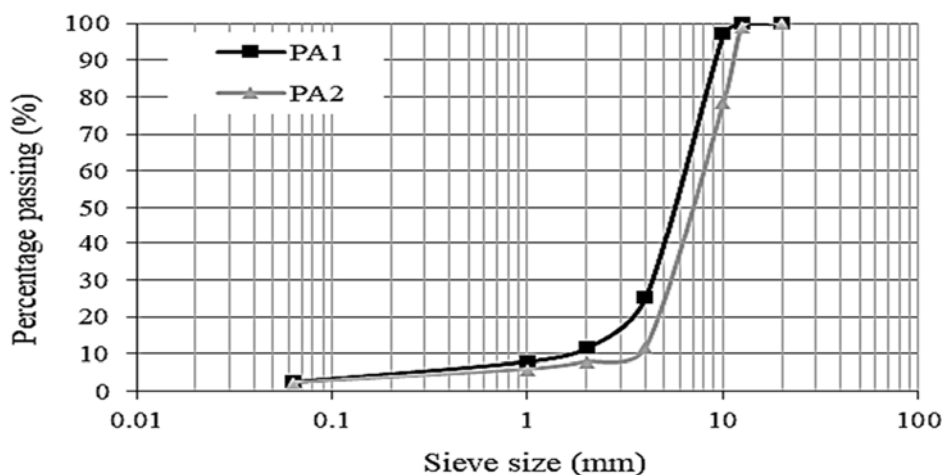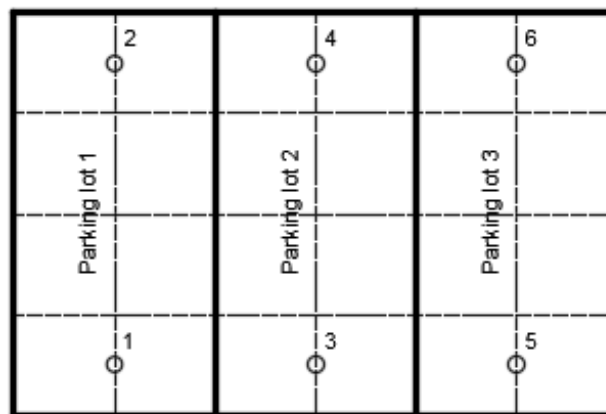

Figure 1. Porous asphalt grading curves

Table 1. Porous mix design and voids content

Mix properties (%)	PA1	PA2
Coarse	84.9	89.2
Stone dust	7.5	3.8
Limestone	1.9	1.9
Fibres	0.5	0.5
Binder	5.2	4.6
Voids content	16.6	19.0

Figure 2. Test points location in the PAP three parking lot

2.1. Mean texture depth (MTD)
The average depth of the pavement surface macrotexture was measured using the volumetric patch technique according to European Standard EN 13036-1 [31]. According to this standard a known volume of material is carefully applied to the surface and subsequently the total area covered is measured. The material used to perform the method was classified according to the standard. Essentially round solid glass spheres were used and calibrated sand was also used as recommended by the previous test method to compare with other studies. The MTD value according to EN 13036-1 was obtained by dividing the volume of the material in the covered area with the average diameter of the circular area at each point (the diameter was measured in 4 axes), according to equation 1.

$$MTD = \frac{4V}{\pi D^2} \ (mm) \tag{1}$$

2.2. Skid resistance
European Standard EN 13036-4 [8] describes the method for determining the skid resistance of a surface on the field or on laboratory with non-homogeneous characteristics such as the presence of grooves or a rough texture (exceeding 1.2 mm patch test) using a device that remains stationary at the test site. The device used in this study was the British Pendulum. The readings obtained on C scale of the device correspond to the PTV value (Pendulum Test Value) representing the loss of power as the slider assembly slides across the test surface. This value represents the friction coefficient that indirectly characterizes the friction between a tire and a pavement surface. The higher the value of PTV, the greater the resistance offered by the surface of the pavement to the passage of the pendulum rubber. The PTV value corresponds to the average of five measurements considered, which was later normalized to the

temperature of 20 ºC according to the correction of EN 13036-4. Pavement surface temperatures can significantly influence the results of skid resistance.

3. Results and discussions

The MTD value obtained for each test point is shown in table 2 for the two volumetric methods used. It is verified that the MTD according to the sand patch test obtains higher values of macrotexture, with an average of 2.1 mm, than with glass spheres, with a mean of 1.8 mm. Figure 3 complements the analysis with the differences between MTD with the two volumetric methods. These differences are not significant, as they do not exceed 0,4 mm. However, the larger sand particles tend to enter the mixture pores at the surface and cause smaller diameters that lead to increased MTD values as reported by other authors [17].

Table 2. Mean texture depth obtained by the sand and glass spheres patch test

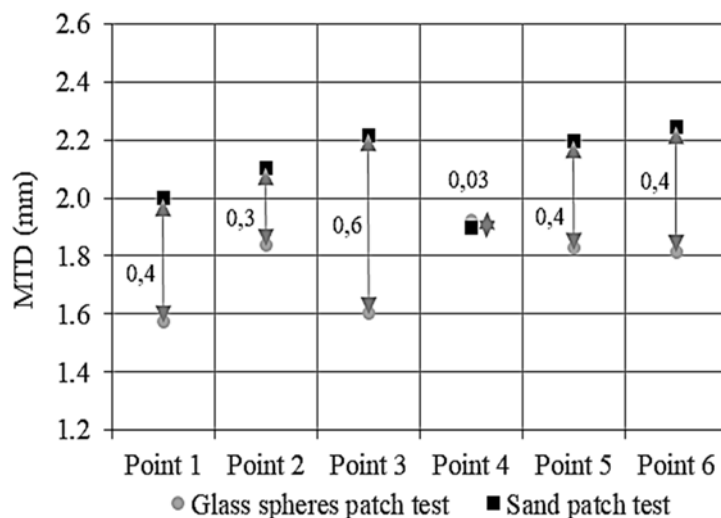| Test point	MTD (mm) Glass spheres	MTD (mm) Sand
1	1.6	2.0
2	1.8	2.1
3	1.6	2.2
4	1.9	1.9
5	1.8	2.2
6	1.8	2.2
Mean	1.8	2.1
MTD > 1,2 mm	✓	✓

Figure 3. Comparison between volumetric methods

The Portuguese Road Administration [32] indicates a MTD for PA mixtures greater than 1.2 mm. Both methods meet this indication. Srirangam [33] presents the classification of Yager (1983) regarding the hydroplaning risk associated with the macrotexture depth of different surfaces types. Considering the open texture or porous friction course surface types, the MTD value should be greater than 1.8 mm obtained by the sand patch test, thus leading to a low hydroplaning potential. Because of this, the DLPA surface studied is characterized by low hydroplaning potential.

Table 3 shows the PTV values obtained in the same six test points. All the tests had a PTV value of over 60, complying with the Portuguese Road Administration specifications [32]. After correcting

values due to temperature differences recorded on the surface after wetting, the results of PTV_{CORR} comply with the condition.

It is important to analyse whether wet skid resistance in PAP with the British Pendulum is related to its MTD obtained with the sand patch test. In figure 4 it is possible to observe the results obtained with numerical and graphical comparison. It is verified that in spite of the results differences, these are little significant, showing that the PAP obtained in the six points has similar behaviour.

Table 3. Pendulum test value obtained by British Pendulum

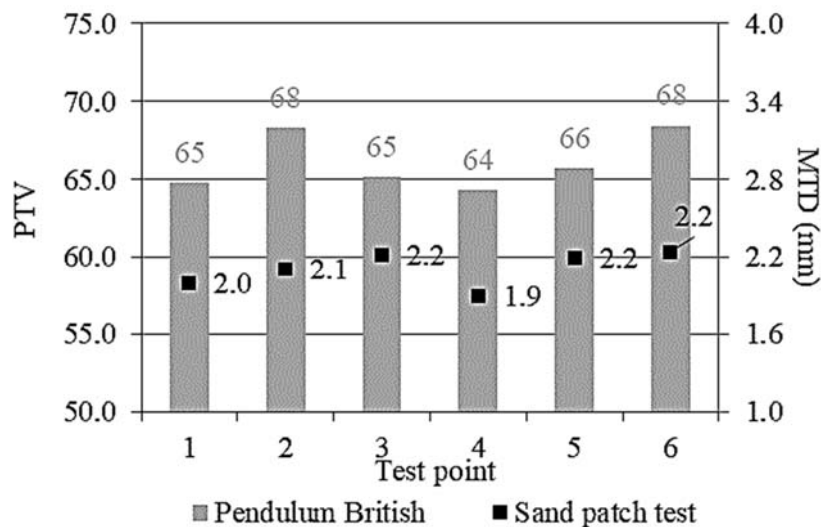| Test point	PTV	Water temperature on the surface (ºC)	PTV_{CORR}
1	67	12.0	65
2	71	13.5	68
3	67	14.8	65
4	67	13.4	64
5	68	14.5	66
6	70	15.6	68
Mean	68	14.0	66
PTV ≥ 60	✓	-	✓

Figure 4. Comparison of skid resistance results with surface texture at PAP different points

Figure 5 shows the correlation of the PTV measurements performed at the six parking test points as a function of the texture obtained with the MTD in the sand patch test. The correlation drawn in the graph does not present linearity, since there is no direct dependence (0.32) of the skid resistance on the wetted DLPA surface with the measured texture depth. However, there is an increasing trend of skid resistance with increasing texture depth. For the case of PAP under study, figure 5 indicates that an estimate of MTD is not enough to deduce the surface mixture skid resistance studied. Torbruegge and Wies [14] also reached the same conclusion, since the macrotexture parameters do not classify the pavement microtexture, nor the surface roughness spatial distribution, generally associated to the results of skid resistance.
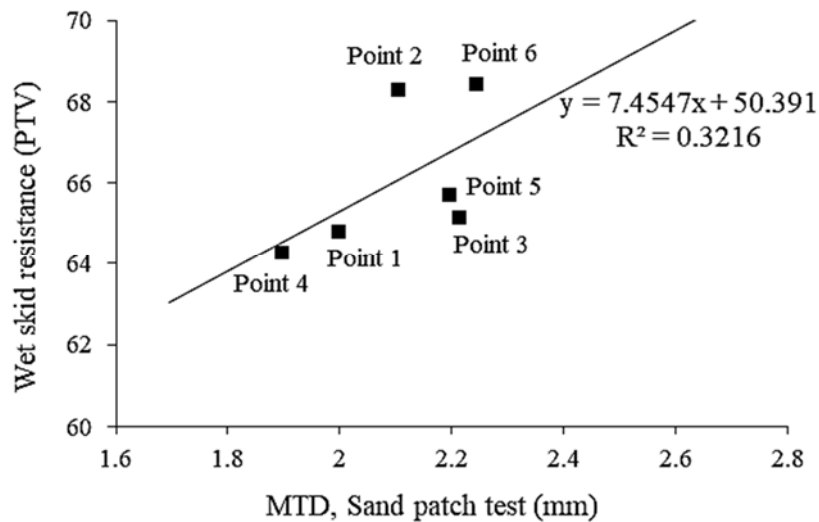
Figure 5. Skid resistance variation with surface texture at PAP different points

Since there are not many field studies with porous asphalt, more concretely in permeable asphalt pavements, other studies have been found with pavement surface mixtures SMA (stone mastic asphalt), open-graded friction (OGFC) and open graded asphalt can be compared with the results obtained in this study due to the proximity between granulometries constituting the mixtures. In addition, values obtained in dense asphalt were considered. The parameters considered for comparison were: MTD, performed with the sand patch test, and BPN (British pendulum number), carried out with the British Pendulum Tester, equivalent to PTV. Table 4 summarizes the values found in previous investigations.

Table 4. Summary of MTD and PTV values in studies performed

Researches	Surface mixtures	MTD, mm (Sand patch test)	BPN (British Pendulum)
Ahammed and Tighe (2012) [9]	Conventional dense asphalt	0.76 – 0.87	> 60
	SMA	1.53 – 1.75	> 70
Fisco and Sezen (2013) [23]	Dense graded asphalt	0.70	-
	SMA	2.86	-
	Open graded asphalt	7.89 – 11.85	-
Qian and Lu (2015) [34]	SMA	1.21	72.3
	OGFC, PA	1.77	78.8
Araújo et al. (2015) [35]	Hot mix asphalt	0.40	67
Praticò and Vaiana (2015) [22]	Dense graded friction course	0.49	-
	SMA	0.77 – 1.14	-
	Porous European mixes	3.63 – 3.58	-
Miao et al. (2016) [24]	Dense asphalt concrete	0.78	-
	SMA	0,90	-

Referring to prior studies with surfaces mixtures other than DLPA, lower MTD values were found for dense mixtures between 0.40 and 0.87 mm. Therefore, the PA have higher macrotextures because of the higher void content, as expected. The values obtained in the studies reported in table 4 show larger differences between SMA mixtures, with a minimum value of 0.77 mm and a maximum value of 1.75 mm, excluding the SMA surface of the study Fisco and Sezen [23] with an MTD value of 2.86 mm. The SMA mixture is characterized by an enclosed interior with the punctual presence of large voids and a rough surface. Thus, the MTD variety in SMA mixtures shows medium to high surface roughness in the order of PA mixtures magnitude of this study with a 2.1 mm mean. With a relatively lower MTD of 1.77

mm, there is the OGFC type mixture, in Europe designated PA. Other porous mixtures in Europe obtain higher texture depths, above 3.0 mm. They thus exceed the PA studied. The open graded asphalt present values divergent from the other mixtures. In terms of the point friction coefficient, the lowest value is observed for the dense mixtures, however they comply with a 60 BPN minimum. The remaining mixtures show higher values, above 70 BPN. The PAP performance surface in relation to the friction coefficient obtained minimum values of 64 PTV and maximum of 68 PTV, corresponding to the normative requirements and with an average level in comparison with the other mixtures. This skid resistance performance may improve in the long run relative to other surfaces because of its high roughness properties, as reported Miao et al. [24] in his study of SMA mixtures.

There is a variety of results among the above mixtures. However, the pavement surface skid resistance is a function of several complex factors, such as the level of texture, the aggregates, the mixtures properties and the contact at the tire/pavement interface. As mentioned in EN 13036-4, skid resistance is not a constant because it varies with the weather, traffic and the effect of these on the characteristics of the surface material itself. Ahammed and Tighe [9] concluded that both the texture depth and the skid resistance of ribbed tires increased with the addition of coarse aggregates in the content leading to their interdependence. Therefore, surfaces with thicker aggregate mixtures lead to better results, as demonstrated by both the PA mixture and the other mixture of the reported studies with a coarse aggregates high percentage.

4. Conclusions

Surface performance for skid resistance (tire/pavement interaction) and road safety is affected by the pavement texture. It is of extreme importance to evaluate these properties in a totally porous pavement in order to ascertain their superficial performance, since there are still not many studies with PAP related to this topic. The surface layer with a DLPA was subjected to tests characterized by the following functional properties: skid resistance, in this study evaluated by the Pendulum Test Value (PTV) according to EN 13036-4 and mean texture depth (MTD), evaluated by the volumetric method according to EN 13016-1. While PTV reflects friction at low speeds, MTD reflects high speed friction on wet pavements and their combination reflects the overall friction performance of the pavement surface mixture. The results showed that the requirements for a PA pavement according to Portuguese Road Administration [32] were met. In addition, the comparison with other studies of porous surfaces (without porous base layers) also showed good performance regarding surface roughness and friction coefficient. Although the study was performed on the same surface, the values diverged, as it showed a low correlation between PTV and MTD. The surface mixtures granulometry is very significant for estimating the MTD value. This study results contribute to the PAP evaluation in situ, helping researchers and professionals in the surface mixtures choice in road pavements.

Acknowledgments

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