STUDY OF LABORATORY PROPERTIES OF OGFC CONSIDERING STONE-ON-STONE CONTACT

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ABSTRACT

In recent years the major performance problem found with dense graded asphalt mixture used in all bus lanes in São Paulo City is permanent deformation. The damage is accelerated by the low speed of the buses, which average around 25 km/h, and the high temperatures during eight months of the year. For these reasons, it is common to find premature rutting in these pavements. On the other hand, the literature reports many cases where stone mastic asphalt (SMA) and Open-Graded Friction Course (OGFG) applications were used to minimise rutting and promote the best tire/pavement contact.

The aim of this paper is to present the research conducted to overcome the rutting problem. This research was focused on the laboratory properties of OGFC with regard to stone-on-stone contact. All mixtures and test specimens were compacted with the Marshall apparatus and the volumetric properties for each mixture were determined. Unconfined static creep tests were conducted at 25 ^oC, 40 ^oC and 50 ^oC.

1. INTRODUCTION

Regarding permanent deformation, in the literature we can find some information about Stone Matrix Asphalt (SMA) which is recognised as an ideal surface layer for heavy and slow traffic conditions (Stephenson and Bullen, 2002; Lanchas, 1999; Brown, 1992) due to good rut resistance properties that are attributed to the stone-on-stone contact of the mix skeleton. In general, the void content is around 4% and the surface is impermeable.

However, for tire/pavement adherence, better performance is related to the mixture designated as Open-Graded Friction Course (OGFC). This category of mixture is mentioned in the literature as having been used in the United States for over fifty years (Watson et al., 1993), while others (Sadzik et al., 1999) affirm that in South Africa porous asphalt mixes have been used since the 1970s originally as friction courses to improve skid resistance and, according to some authors, in some cases to absorb excess binder.

On the other hand, in São Paulo City, there is a high concentration of buses consisting of 11 000 units and an extensive bus line network. Due to the narrowness of the lanes in this bus corridor (3,00 m wide) and the heavy traffic, there is a huge concentration of buses travelling slowly at approximately 20 km/h in the lanes. This situation, associated with the high temperature, makes the pavement conditions worse. The permanent deformation is accelerated by the sum of these effects.

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In terms of experience, there is little road construction where SMA and OGFC were used. Considering the importance of these types of mix and the high costs of construction, it is very important to carry out initial laboratory studies and then only to build.

The objectives of this research are:

- to obtain better performance in terms of permanent deformation of some gradations where coarse aggregate stone-on-stone contact exists, but with a high degree of porosity;
- to compare the performance of these mixtures and the gradations usually used by the São Paulo City Government (PMSP) in bus lanes and to compare the performance of different mixes with and without type SBS polymer additive (styrene-butadiene-styrene).

2. SUMMARY OF LITERATURE REVIEW

2.1 Stone Matrix Asphalt – SMA

SMA has been reported as an ideal surface layer for heavy traffic conditions. It is recommended as a high-performance rut-resistance mixture. The behaviour of the mix is due to stone-on-stone contact of the mix skeleton.

The SMA mixture initially appeared in Germany at the end of the 1960s and was aimed at increasing the resistance of pavements to studded tire wear (Lanchas, 1999). According to this author, the first SMA paving was used on the Freiligrath of Wilhelmshaven Street in Germany on 30 July 1968, and it was still in an excellent condition in 1999. According to Brown (1992), this asphalt mix model has been studied in the US since 1991. The rationale of the procedure is based on the structuring of the discontinuous coarse aggregate skeleton (Brown, 1997; Bolzan, 2002) so that 65% to 85% is retained on a 4.75-mm sieve. Due to the high percentage of coarse aggregate present in the mix, the efforts resulted in stone-on-stone with the fine aggregate mix playing a passive role, primarily filling up the voids in the coarse aggregate skeleton.

The SMA concept can only be used if there is stone-on-stone contact. Bearing in mind that the coarse aggregate diameter exceeds 4.75 mm, in order to assure contact among the mixes studied, the method shown by Brown and Haddock (1997) and suggested by Brown and Mallick (1994) was used. This method is based on the ratio between the coarse aggregate voids (VCA) in the SMA asphalt mix and the coarse aggregate voids in the mixture containing only the coarse aggregate fraction (aggregate ≥ 4.75 mm) compacted with low-content asphalt (VCA_{LA}) in the Marshall compactor.

In this procedure, if the VCA/VCA_{LA} ratio is lower than 1, stone-on-stone contact is assumed. According to Brown and Mallick (1994) the coarse aggregate voids (VCA) in an asphalt mixture are defined by:

$$VCA = 100 - [(\gamma_m / \gamma_{agr}) \times P_{ag}] \qquad (1)$$

Where:

VAC = voids in the coarse aggregate of asphalt mixture, expressed in percentage

γ_m = bulk specific gravity of the compacted specimen, expressed in kN/m^3

γ_{agr} = bulk specific gravity of the course aggregate, expressed in kN/m^3

γ_{ag} = percentage of coarse aggregate (> 4.75 mm) in the mixture, expressed in %

The voids in the coarse aggregate compacted with low asphalt binder are defined by:

$$VCA_{LA} = \{[(\gamma_{agr} \times \gamma_a) - \gamma_{agD}] / (\gamma_{agr} \times \gamma_a)\} \times 100\% \qquad (2)$$

Where:

VCA_{LA} = coarse aggregate voids compacted with low asphalt binder, expressed in %;

γ_{agr} = bulk specific gravity of the compacted specimen, expressed in kN/m^3;

γ_a = unit weight of water, expressed in kN/m^3;

γ_{agD} = unit weight of the course aggregate fraction, expressed in kN/m^3.

To meet the requirements of the SMA concept, the gradation curve must be discontinuous so that changing from coarse to fine aggregate must also be discontinuous, with void formation that will be filled up by fine aggregate mortar and asphalt binder.

2.2 Open-Graded Asphalt Friction Course (OGFC)

Open-Graded Friction Course is considered a hot mix asphalt (HMA) mixture with high interconnecting voids, so it is very porous and permeable. Excess water can enter into the surface and be drained. The macrotexture with high voids facilitates drainage so that the water is removed more quickly from the pavement surface and thus potential hydroplaning is minimised.

When compared with dense-graded HMA, OGFC has demonstrated some advantages according to the literature: reduced vehicle splash and spray behind vehicles; high frictional qualities; reduced potential for hydroplaning; and reduced tyre-pavement noise.

Kandhal and Mallick (1997) have observed that OGFC has been used in the USA since 1950. According to these authors, the experience in the United States with OGFC has been widely varied. They affirm that many transportation agencies have reported good performance, while others have stopped using this kind of mix because of poor performance. Some important findings related by those authors (Kandhal and Mallick, 1997 and 1998) were: more than 70% of the agencies which use OGFC reported service life of eight or more years; about 80% of the agencies using OGFC (Figure 1) have standard specifications for design and construction, and a vast majority of agencies report good experience using polymer-modified asphalt binder.

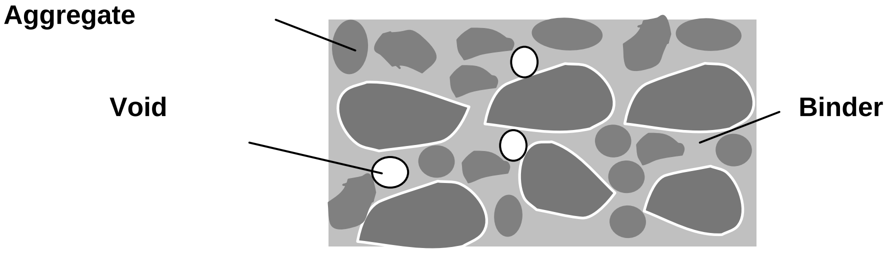

Figure 1: Schematic representation of OGFC

3. MATERIALS

Aggregates used in this research were obtained from a place near São Paulo City and their origin is granite. Table 1 shows six different gradation types that are commercially used. All gradations used in this research were developed with a combination of these six gradations. The apparent specific gravity of the granite is 27 kN/m^3.

Table 1: Six different gradations of aggregate used in this research

Sieve Size (mm)	**Percent Passing/Aggregate Type**					
	A	B	C	D	E	F
	Crushed rock # 1" Embú2	Crushed rock # 1"	Crushed rock ½" Embú2	Crushed rock ½"	Small shower of crushed rock	Fine aggregate (stone powder)
25.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	88.2	99.4	100.0	100.0	100.0	100.0
12.5	61.0	55.7	98.2	100.0	100.0	100.0
9.5	6.0	31.4	65.0	69.0	100.0	100.0
4.75	1.5	4.3	3.3	2.0	23.2	100.0
2.36	1.4	1.5	3.0	2.0	7.6	71.4
0.42	1.4	0.5	2.8	2.0	3.9	28.8
0.175	1.0	0.3	2.6	2.0	3.0	15.5
0.075	0.1	0.1	2.1	1.2	2.2	6.7
Los Angeles Abrasion (%)						25.1
Shape Index #1						Cubic
EA (sand equivalent) – Fine aggregate (stone powder) (%)						66.0
Theoretical maximum density #1 (kN/m^3)						27.00
Fine aggregate (stone powder) theoretical maximum density (kN/m^3)						25.83
Sand theoretical maximum density (kN/m^3)						25.15

The asphalt mixes used throughout this study were asphalt cement AC-20 and polymer-modified asphalt (PMA). The polymer used was styrene-butadiene-styrene (SBS). The properties of the binder are given in Table 2.

Table 2: Properties of the asphalt cement used in this study

Test	**Test Results**	
	AC-20	**PMA**
Specific Gravity, 25 C (g/cm^3)	1.023	1.040
Penetration 25 C, 100 g, 5 s	54.0	50.0
Viscosity SSF – 135 C (s)	202	-
Viscosity SSF – 155 C (s)	78	-
Viscosity SSF – 177 C (s)	35	-
Flash Point (C)	295	235
Softening Point (C)	49.5	75
Viscosity at 175 C (cP)	65	450
Elastic recovery (%) 25 C	0	85
Thermal susceptibility index	1.3	2.0

4. EXPERIMENTAL RESEARCH

A test plan was developed using two procedures: three samples were obtained with the Marshall method compacted with 50 blows per face for each AC content, and M1 and M2-mix samples milled from a plaque which were compacted using a vibratory plate resulting in 98% Marshall Density (Figure 2).

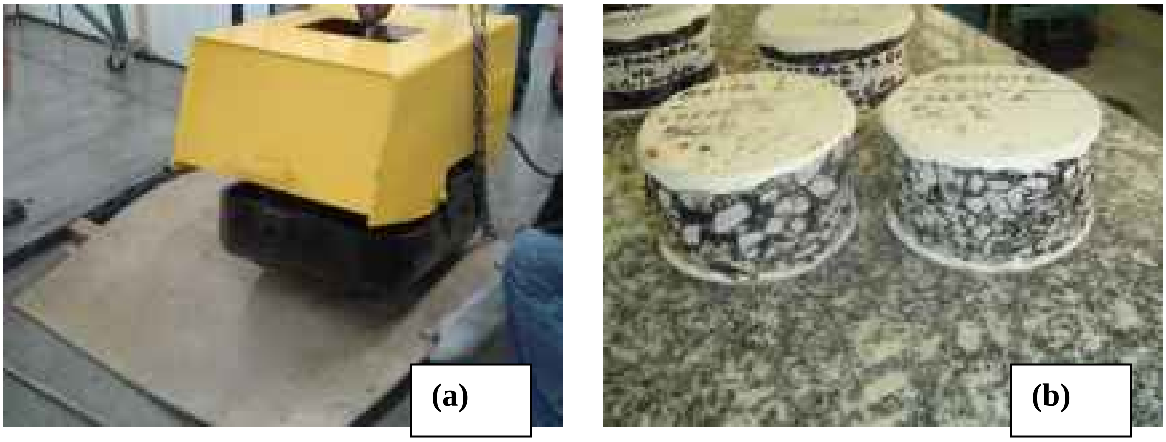

Figure 2: (a) Sample being compacted with vibratory plaque (b) milled samples

The asphalt content of the GII and GIII mixes was determined in accordance with the procedure described in the Marshall method. In the case of mixes M1, M2, M8 and M10, it was determined that stone-on-stone contact existed, and then the optimum asphalt content was determined.

The study of permanent deformation was made using the Static Creep Test described by Fortes and Merighi (2004) at 25 ^{o}C, 40 ^{o}C and 50 ^{o}C. The advantages of using unconfined static creep to evaluate and predict the mixture performance in terms of permanent deformation are that this laboratory test requires simple equipment, and it shows the best correlation with the experimental field rutting as presented by Kalousk and Witczak (2002).

The composition of the mixes used in this research is shown in Table 3. The aggregate gradations are listed in Table 2 and all the mixes studied met the requirements described in 2.1, except mixes GII and GIII because they are dense HMA. Figure 3 shows the distribution of the six gradation curves studied.

Table 3 Composition of the mixes studied

MIXES	M1	M2	M8	M10	GII	GIII
# 2"			-	-	15	-
# 1" Embú2	80					
# 1"				-	15	25
½" Embú2		80				
# ½"			83	78	15	15
Small shower of crushed stone				8	15	15
Fine aggregate (stone powder)	20	20	17	14	40	45

5. RESULTS AND ANALYSIS

The results obtained from these studies are shown in Tables 4, 5 and 6. The permeability test was conducted using the Florida DOT falling-head laboratory permeability test according to the recommendations of Kandhal and Mallick (1997, 1998.). The M1 and M2 samples were milled from the plaque.

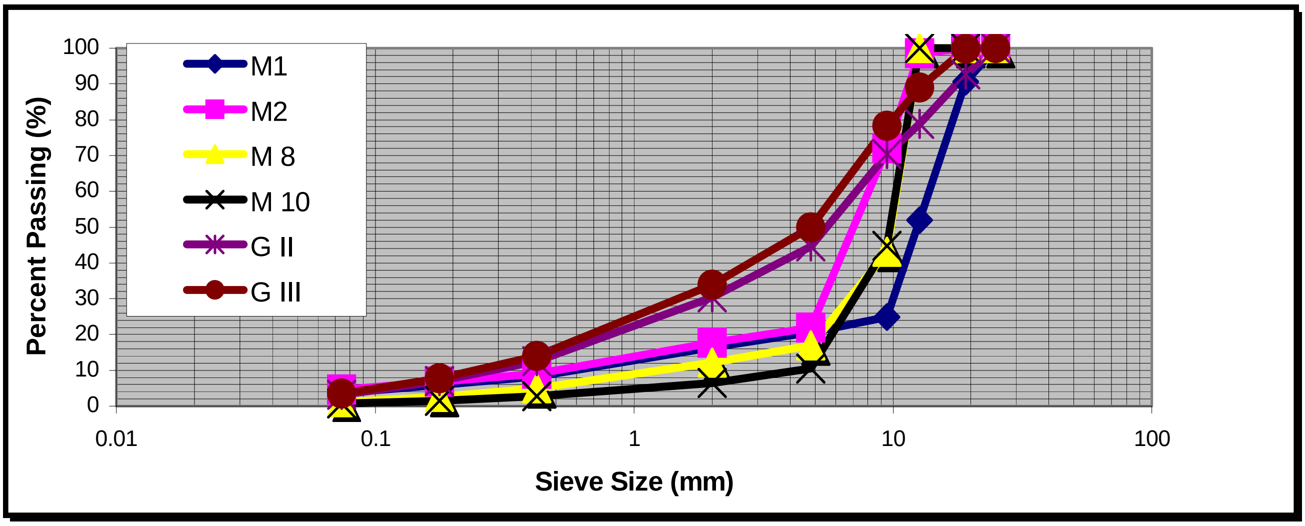

Figure 3: Gradation of the aggregates that were studied

Table 4: Test Results for the trial gradation blends

Trial blend/ Property	γ_m (kN/m^3)	γ_{agr} (kN/m^3)	Air Voids (%)	VMA (%)	VCA (%)	VCA$_{LA}$ (%)
M1	19.70	27.00	21.5	30.7	30.6	43.4
M2	20.02	27.00	19.5	29.0	28.8	46.1
M8	19.00	27.00	27.3	31.0	41.0	41.6
M10	18.46	27.00	29.4	33.0	38.7	39.6
GII	24.24	27.00	4.6	15.3	-	-
GIII	24.07	27.00	3.6	14.5	-	-

Table 5: Results of volumetric, strength and permeability properties

PROPERTIES/ MIXTURE	AC$_{CONTENT}$ (%)	γ_m (kN/m^3)	VMA (%)	Air void (%)	Marshall Stability 60 C (kN)	σ_{T25} (MPa)	Permeability (cm/s)
M1	4.8	19.70	30.7	21.5	4.21	0.42	3.4×10^{-3}
M2	4.8	20.02	29.0	19.5	5.10	0.51	3.0×10^{-3}
M8 AC-20	5.0	19.91	29.9	20.2	3.92	0.55	7.2×10^{-3}
M8 AC-20	5.5	20.13	29.6	18.7	3.75	0.51	3.0×10^{-3}
M8 AC-20	6.0	20.28	29.4	17.5	3.29	0.47	1.2×10^{-3}
M8 Polymer SBS	5.3	20.15	29.5	19.8	4.25	0.75	4.2×10^{-2}
M10 AC-20	4.8	20.35	28.3	18.7	1.72	0.86	4.6×10^{-3}
M10 AC-20	5.3	20.59	27.8	17.1	4.76	0.73	3.5×10^{-3}
M10 AC-20	5.8	20.80	26.2	14.2	4.01	0.78	2.8×10^{-3}
M10 Polymer SBS	5.0	20.45	30.7	18.5	5.12	1.05	4.6×10^{-2}
G II AC-20	4.8	24.24	15.1	4.6	12.70	2.00	6.0×10^{-6}
G III AC-20	5.3	24.07	15.9	3.6	11.45	1.32	7.2×10^{-7}

Figure 4 summarises the air voids as determined in the mix design. It can be observed that both mixes M1 and M2, and M8 and M10, with and without polymer, retain proportionally the same percentage of air voids. In general, the percentage of air voids decreases with the addition of AC.

Figure 5 illustrates the variation of tensile stress for different mix designs. The GII and GIII mixes, both dense-graded mixes with a low percentage of air voids, show high tensile stress when compared with other mixes. The presence of polymer in the mixes increases the tensile strength.

Table 6: Results of the static creep test

Mixture	Permanent Deformation (mm) x Temperature (C)		
	25	40	50
$M1_{SBS}$	0.12	0.22	0.27
$M2_{SBS}$	0.00	0.07	0.20
$M8_{AC-20}$	0.27	0.45	0.49
$M8_{AC-20}$	0.28	0.51	0.56
$M8_{AC-20}$	0.29	0.54	0.60
$M8_{SBS}$	0.20	0.38	0.41
$M10_{AC-20}$	0.29	0.35	0.45
$M10_{AC-20}$	0.33	0.40	0.48
$M10_{AC-20}$	0.32	0.41	0.55
$M10_{SBS}$	0.25	0.32	0.44
$G\ II_{AC-20}$	0.34	0.42	0.51
$G\ III_{AC-20}$	0.51	0.77	0.92

The effects of air voids, mix design and binder modifiers on permeability are shown in Figure 6. The dense-graded mix was found to be impermeable (permeability coefficient = k < 10^{-6} cm/s). In other cases, the permeability coefficient decreases with the addition of AC, but as shown in Figure 6, it increases when asphalt is modified with polymer. Naturally when the air voids increase, the permeability coefficient increases. It can be observed that M2 gives the best performance in terms of permanent deformation (Figure 7).

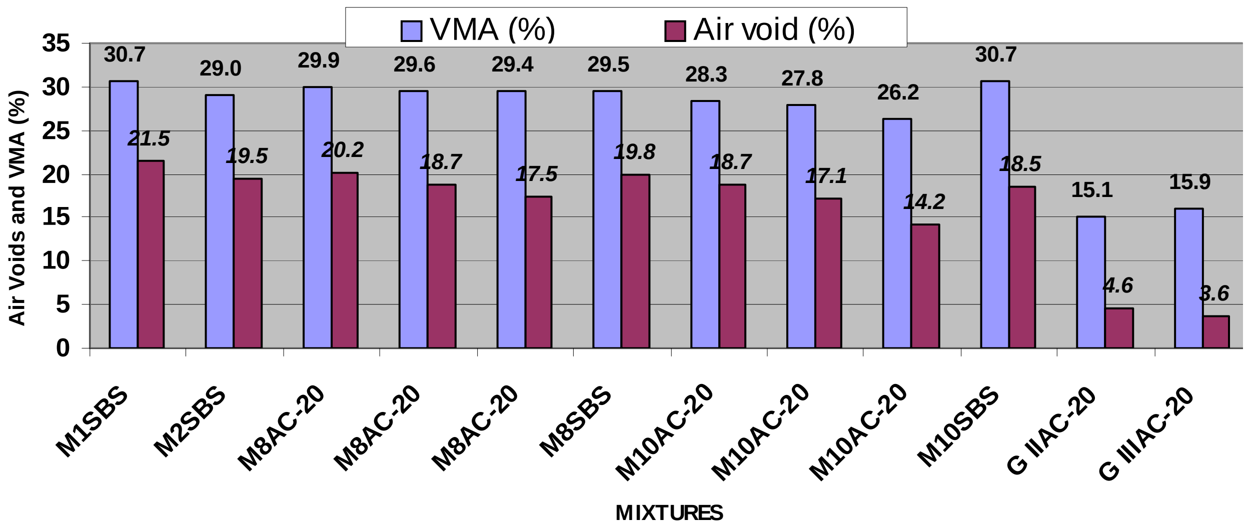

Figure 4: VAM - air void versus AC content for all mixes studied

The Pavement Macrotexture Depth was measured using a volumetric technique (ASTM, 1996-2001). Figure 8 shows that the value obtained in the test was 3.06 mm.

Regarding Pavement Macrotexture Depth, it is possible to confirm that in the dense HMA the value observed was about 0.8 mm, whereas in the OGFC #19 mm it was 3.00 mm, and in the OGFC #12.5 mm it was 2.1 mm, approximately 4 and 2.5 times bigger respectively.

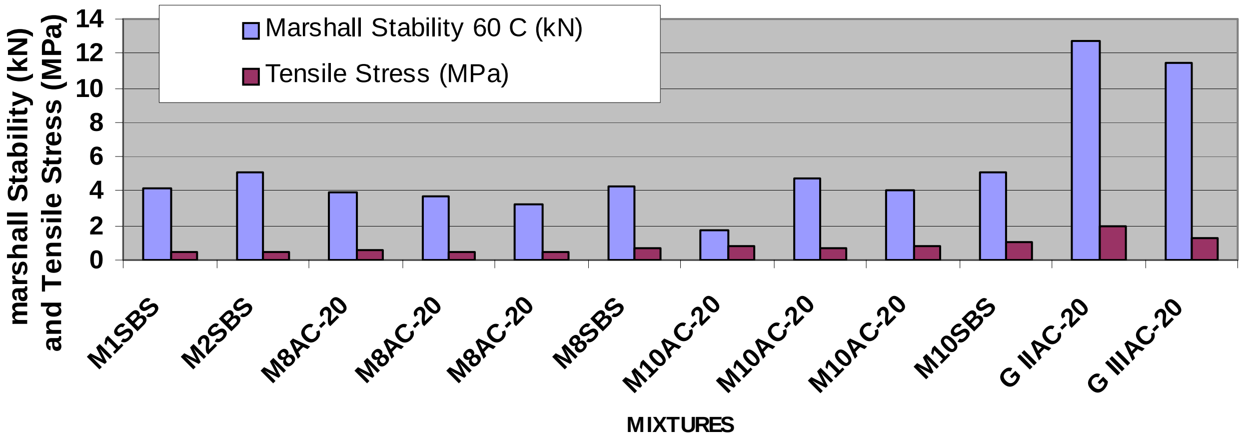

Figure 5: Variation of tensile stress (T25C) and Marshall Stability for different mixtures

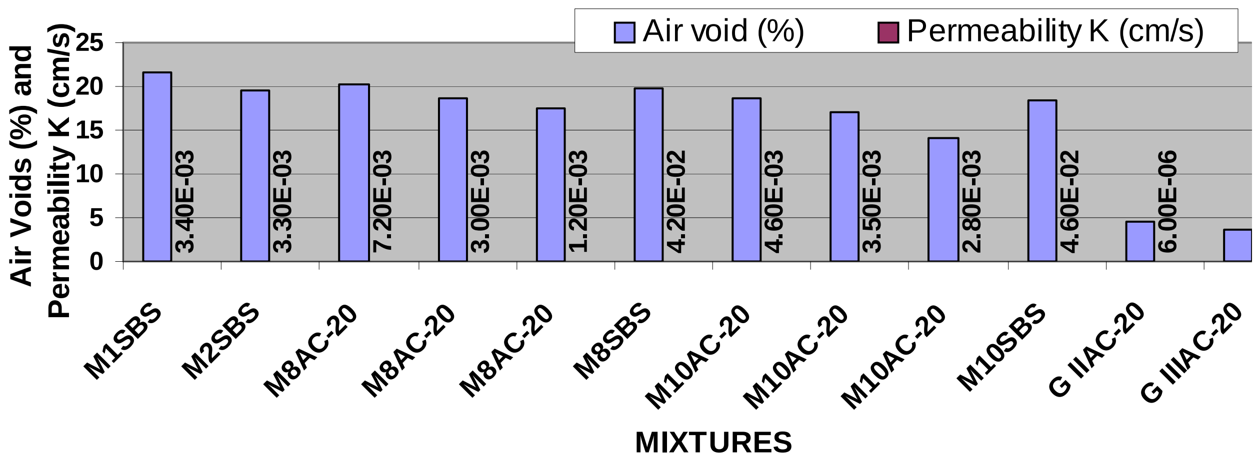

Figure 6: The effect of mix type on permeability

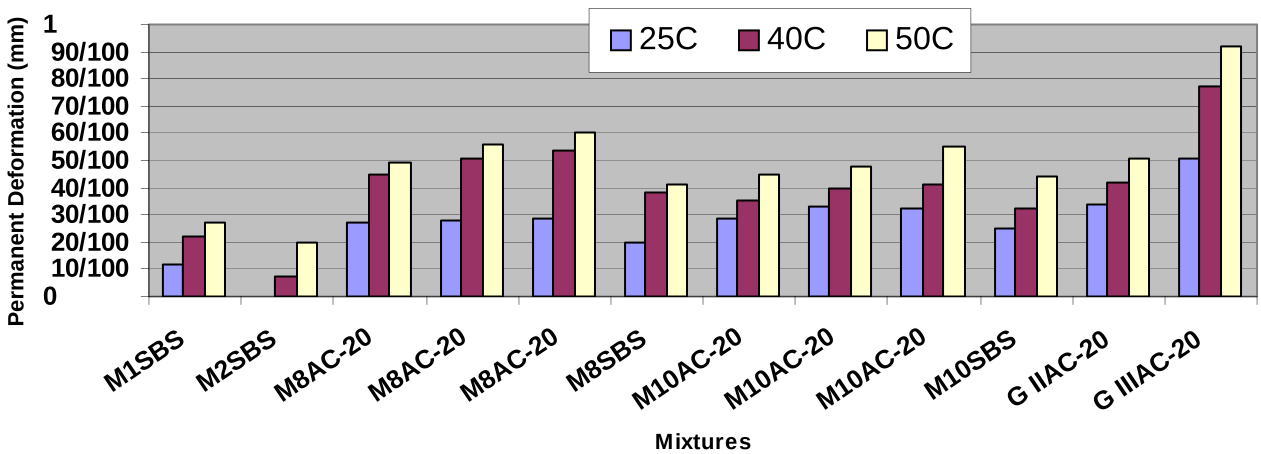

Figure 7: Permanent deformation vs. temperature x AC content for all mixtures studied

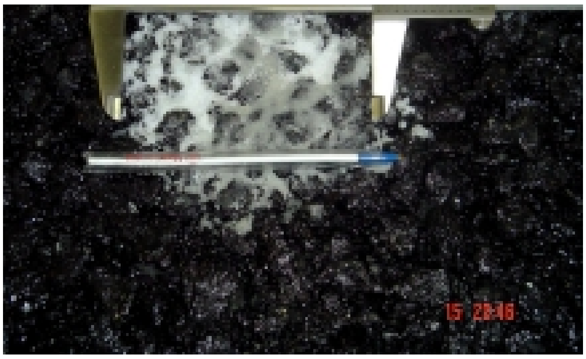

Figure 8: Measuring the Surface Macrotexture Depth OGFC #19.0 mm

6. CONCLUSIONS AND RECOMMENDATIONS

The performance in terms of permanent deformation, permeability and tensile stress was studied using samples obtained in the laboratory and samples milled from a plaque compacted using a vibratory plate.

The following conclusions and recommendations can be drawn from this research:

Four mixes that contained stone-on-stone contact were evaluated. They were: M1, M2, M8 and M10.

The M2 mix complied with the requirement of stone-on-stone contact and showed the best results in terms of relation VCA/VCA_{LA}, permanent deformation and γ_{t25} when the binder utilised was polymer.

The gradation GIII performed worse than GII. In São Paulo, this mixture is used in the superficial layer in order to modify the PMSP recommendations.

Although the performance of the GII gradation better than that of GIII, the permeability coefficient was very low for both, so the adherence of tyre to pavement may not be satisfactory in wet conditions.

According to Table 5, it is possible to observe that mixtures modified with SBS polymer give the best performance in terms of permanent deformation resistance and permeability.

Regarding permanent deformation and permeability, the M2 mix confirmed what was expected. It presented bigger permanent deformation resistance than the mix (GIII) overlay recommend by PMSP.

The authors intend to expand their research by doing more experimental field tests.

7. ACKNOWLEDGEMENTS

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