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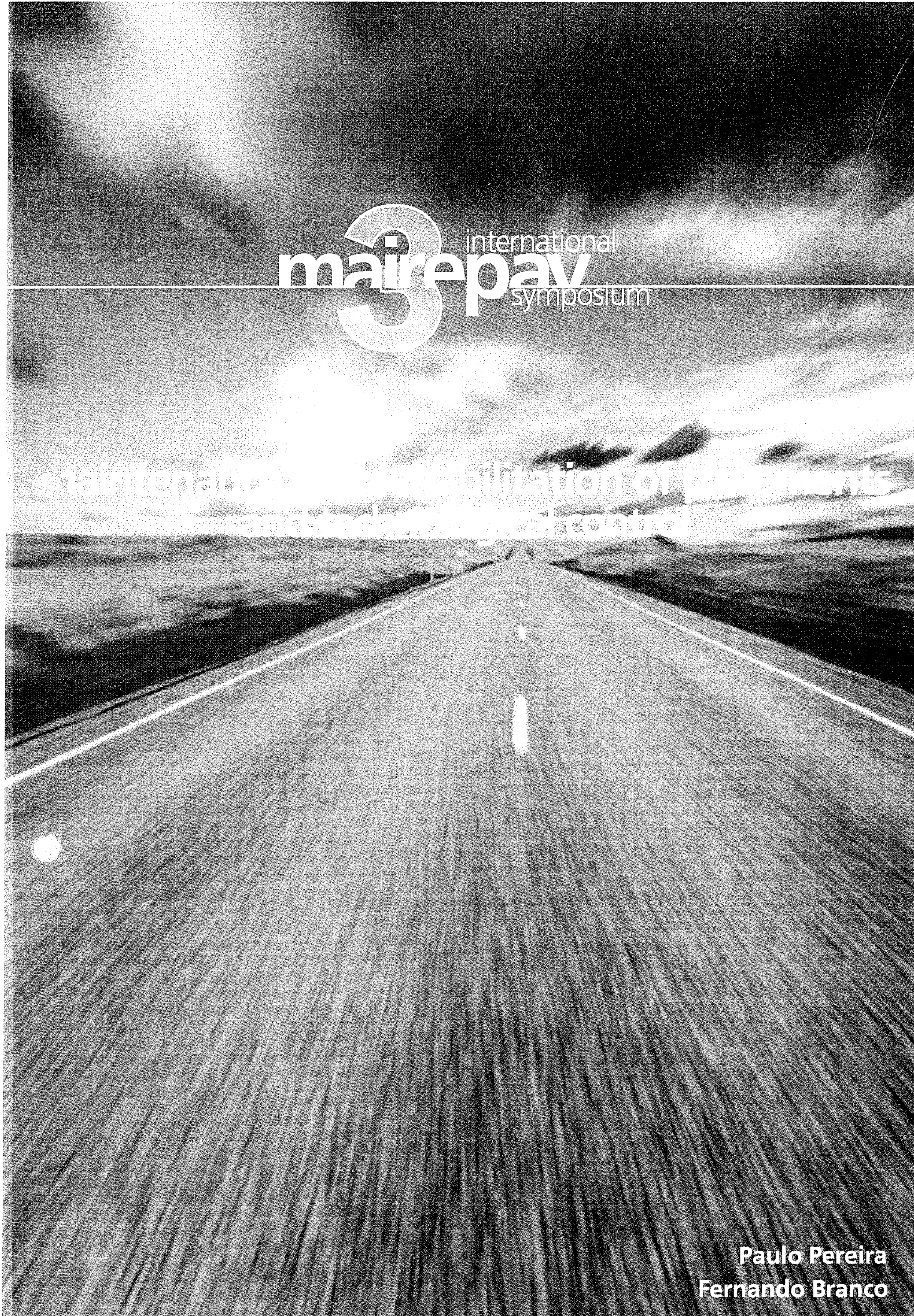

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Design and Evaluation of the Bearing Capacity of High Modulus Asphalt Concrete by Means of a Performance-Based Approach

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ABSTRACT: Pavement damage, induced by repeated passing of traffic coupled with climatic conditions, has a significant influence on the durability of roads. To improve the service life of pavements, innovative materials have to be used, with the aim of producing bituminous layers which could better resist distress phenomena, namely resistance to fatigue and to permanent deformation. Therefore, a project concerning the rehabilitation of a structural layer by using a high modulus bituminous mixture has been carried out. During the first stage, this study involved the laboratory design of the mix by conducting performance tests and constructing trial sections on the EN14 (Portuguese national road 14). In the next stage, specimens extracted from trial sections were submitted to a fundamental test (four-point bending) and a traffic simulation test (wheel tracking) to select the work mix formula to make the road base layer on the EN14. Finally, by using a compaction method which reproduces volumetric conditions obtained in the field, prismatic and cylindrical specimens have been produced in the laboratory. For several temperatures and loading conditions, fundamental tests have been performed (repetitive four-point bending and dynamic creep tests).

KEY WORDS: Bituminous mixtures, Fatigue behaviour assessment, High modulus asphalt concrete, Mixture design, Rutting resistance, Stiffness prediction.

1. INTRODUCTION

Following the development of hard grade bitumens (i.e. having penetration at 25°C lower than 25/10 mm) in the Eighties, the use of High Modulus Asphalt Concretes (HMAC) began. According to the French experience, the application of those materials can lead to a significant improvement in pavement life. In fact, they generally have a better mechanical behaviour than traditional asphalt concretes, considering the distress mechanisms often adopted in pavement design (fatigue cracking and excessive permanent deformation).

For French conditions, some studies (Capitão, 1996, Collop et al., 2002) have concluded that the use of HMAC results in typical thickness reduction of 25% to 45% compared to more traditional bituminous roadbase materials. The corresponding cost savings are up to 15%. In a similar analytical study carried out by the authors, for typical Portuguese traffic and subgrade conditions (Capitão, 1996) they have obtained a reduction in asphalt layer thickness from 20 to 30%, and cost savings between 7 and 12%.

In the last ten years, several countries, such as Spain and the United Kingdom, have started using HMAC to construct structural pavement layers, to find if, under their local conditions, they could get a performance similar to that obtained in France. The Portuguese Road Administration (IEP) has also included technical clauses in the contract specifications for that kind of material (IEP, 1998).

This paper focuses on design and evaluation of mechanical characteristics of HMAC established to build a structural layer on the EN14 (Portuguese national road 14), which was constructed for research purposes.

2. PERFORMANCE-BASED APPROACH USED FOR MIX DESIGN

The adopted mix design procedure incorporates the main principles of the most recent methods applied in countries where new mix design methodologies have been developed (Capitão et al., 2001). On the one hand, those procedures try not to be very time consuming but, on the other hand, they aim to provide a satisfactory mechanical characterization of trial mixtures. Moreover, in this project, one tried to follow, as much as possible, approaches which are commonly used in Portugal. Therefore, three main steps are included to design the work mix formula: aggregates and bitumen selection, trial compositions establishment and mechanical characterization of those mixes in the laboratory.

Granular materials are selected the same way they used to be in Portugal. Based on previous experience, minimum quality limits for their physical properties are set up and put together in specifications, which impose requirements concerning grading curve, cleanliness, Los Angeles abrasion resistance, flakiness and elongation indexes and water absorption, amongst others. If available materials do not satisfy entirely those specifications, aggregates can still be accepted. In fact, the use of aggregates having lower characteristics than specified limits involves, generally, a small structural risk, considering that the final mix composition is established based on criteria evaluated in a later stage.

For bitumen selection, samples are submitted to several "empirical" tests, according to Portuguese Specification LNEC E-80 (LNEC, 1997). Traditionally, to accept a binder, their properties must meet requirements indicated in that specification concerning, most importantly, penetration at 25°C and softening point. In this approach, when bitumen submitted to test does not meet specified limits, it can be rejected or selected. The decision to go ahead will depend on how closely the bitumen conforms to the specification. In fact, bitumen contributes significantly to the mechanical behaviour of final mixture. However, if the properties of selected bitumen are lower than requirements, it can still be used, because final mix composition is established by observing mixture performance in the laboratory.

The aggregate blend required to produce a specific bituminous mixture is determined according to a grading envelope. The grading curve resulting from the combination of available aggregates should respect established limits and its outline should follow the general envelope course. Once it is determined which mixtures will be tested, the "optimum" bitumen content for use in these laboratory test mixture(s) is predicted by calculation. This specific step can be accomplished by using the French formula (the-called Duriez formula), based on specific area, grading and density of aggregates, and richness of bitumen in the mix. Another way to do that is by using the analytical part of the Belgium Road Research Center method (C.R.R, 1987). Alternatively, bitumen content can also be estimated by using the Marshall method. Compared to the first two approaches, this one has the advantage of supplying additional indicative values well known by the technical community. Nevertheless, considering that the main objective is predicting "optimum" bitumen content, it is preferable to use one of the other methodologies, as the Marshall method is more time consuming.

Trial mixtures which are submitted to mechanical characterization tests were those obtained from the grading curves that are determined as indicated, and produced with bitumen contents in a range of ±0.5 % around the predicted value. Afterwards, final composition is set up based on observed results in the laboratory. The chosen composition is the one that best fulfils requirements previously established in terms of stiffness modulus, fatigue resistance and permanent deformation behaviour.

Stiffness modulus and evaluation of fatigue resistance are obtained from repetitive four-point bending tests. They are carried out at only one temperature, which is representative of variable temperatures that can occur in the pavement (in this case 25°C). That value can be determined by using a model developed, for Portuguese conditions, at the University of Coimbra (Picado-Santos, 1994). Modulus measurement is made by performing strain controlled frequency sweep tests, generally at 10, 5 and 1 Hz. In this project, only a frequency of 10 Hz was used. Strain level must be kept as low as possible (up to 100×10^{-6}), to avoid non-linear response of material under test. If no other reference value is available, the obtained stiffness modulus should be, at least, equal to the value considered in pavement design (in this project a value around 120×10^{-6} was adopted).

Submitting samples to repetitive loading until their stiffness is reduced 50 % is the adopted methodology for fatigue resistance evaluation. At least, three strain levels must be applied: a high level, an intermediate level and a low level. For simplicity, a sinusoidal load waveform is applied at a single frequency. In this case, tests were carried out at 25°C and at a frequency of 10 Hz, for strain values of 200×10^{-6}, 300×10^{-6} e 400×10^{-6}.

Permanent deformation resistance evaluation is made by performing wheel-tracking tests. They consist of measuring variation with time of rut depth induced by repeated passing of a wheel on a slab that rests on a base plate, under high temperature conditions. In Portugal, some laboratories have been using the Spanish wheel-tracking machine, which allows testing slabs with 30x30x5 cm^3, at 60°C, providing a contact stress of 900 kPa. Pass/fail criteria (NLT, 1984), although established for Spanish conditions, can be approximately adopted in Portugal. These criteria indicate rutting rate limits for slabs being submitted to testing based on predicted traffic and temperature conditions at the pavement site. The most demanding conditions impose that selected mixture composition had a maximum rutting rate of 15×10^{-3} mm/min. In the current project, slabs tested were extracted from the trial sections constructed on the EN14.

3. SUMMARY OF MIX DESIGN RESULTS

3.1. Establishment of compositions to submit to mix design performance-based approach

Two different sources of granitic granular materials, A and B, were available. After determination of their physical properties, it was concluded that, in general, all fractions met the requirements of Portuguese specifications (IEP, 1998). However, the coarse aggregates coming from source A had an elongation index slightly higher than the specified maximum and a weak adhesiveness to bitumen. Despite that, source A was selected because it was the nearest to the construction site. To improve adhesiveness, a small amount of a special "doping agent" was added to bitumen.

As far as granitic crushed sand 0/6 and filler is concerned, they both met the specified limits concerning cleanliness of fine material, namely maximum adsorption of methylene blue of 0.8g/100 g and a minimum sand equivalent of 60 %.

The mixture applied in trial sections was produced by using 25 % of 14/20 material, 8 % of 10/14 material, 16 % of 6/10 material, 49 % of 0/6 material and 2 % of limestone filler. These proportions were determined by assuming as reference curve the centerline of the grading envelope. Figure 1 shows the determined grading curve and the grading envelope proposed by Portuguese specifications.

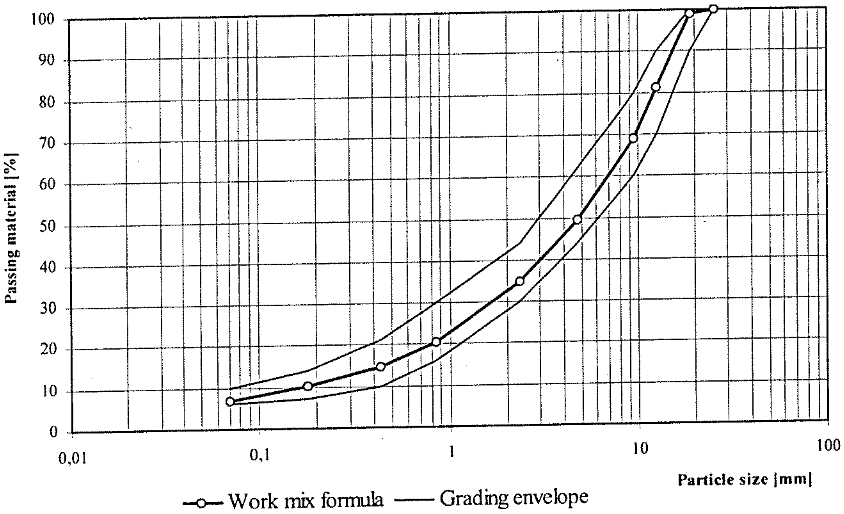

Figure 1: Aggregates work mix formula and grading envelope

The contractor had two hard bitumens (10/20 penetration grade), S1 and S2, from two different suppliers. Bitumen characterization, according to Portuguese specification, showed that binder S2 did not meet requirements, namely concerning softening point (SP), cinematic viscosity and SP after Rolling Thin Film Oven Test (RTFOT), because it was softer than required. Therefore, S1 was the selected bitumen.

The optimum bitumen content (bc) was predicted by using the so-called *Duriez* expression, assuming a richness modulus of 3.4 (Afnor, 1992). For the proposed aggregate mix, bc was predicted to be 5.3 %, which is very close to the estimation made by using the Belgian Road Research Center analytical method. In addition, traditionally, in Portugal bituminous mixtures are designed by means of the Marshall method. Thus, a set of Marshall tests was carried out with the aim of predicting bc. The obtained value (5.2 %) was very close to those calculated by other methodologies.

3.2. The work mix formula proposed

In view of the obtained results, six different compositions were proposed for the building of pavement trial sections, which consisted of two aggregate compositions. One of them was the aggregate blend described above (trial sections A1, A2 and A3) and, the other one was a variant of that containing 5 % of limestone filler instead of granitic filler (trial sections B4, B5 and B6). Bitumen contents applied were 4.8 %, 5.3 % and 5.8 % respectively (i.e. ±0.5 % around prediction of bitumen content).

Furthermore, the number of passes during compaction varied from one sub-section to another; in the first group of sub-sections: 30 passes were made, 20 by a 23 ton pneumatic-tyre roller and 10 by a deadweight tandem roller; in the second group of sub-sections: sub-sections 2: 22 passes were made by a 23 ton pneumatic-tyre roller and 6 by a deadweight tandem roller. In all, 12 sub-sections with 50 m length and 3.5 m width were constructed.

Stiffness modulus measurement and fatigue behaviour assessment were performed as mentioned in 2. Beams (60x9x9 cm^3) submitted to testing were sawn from slabs taken from the trial sections. Tables 1 and 2 summarize both, parameters of tests and the obtained results.

Table 1: Stiffness modulus (MPa) of HMAC (10 Hz, 25°C)

Str.	b_c = 4,8 %		b_c = 5,3 %		b_c = 5,8 %		b_c = 4,8 %		b_c = 5,3 %		b_c = 5,8 %	
10^{-6}	A1.1	A1.2	A2.1	A2.2	A3.1	A3.2	B4.1	B4.2	B5.1	B5.2	B6.1	B6.2
60	14770	17950	12420	11930	11330	14100	15000	14000	13460	11500	9900	12400
120	12900	14900	10950	9800	9530	10950	11800	11250	10560	10200	7200	8400

Table 2: Strain (x10^{-6}) which induces specimen ruin (50 % stiffness loss) after 10^6 load cycles (10 Hz, 25°C)

b_c = 4,8 %		b_c = 5,3 %		b_c = 5,8 %		b_c = 4,8 %		b_c = 5,3 %		b_c = 5,8 %	
A1.1	A1.2	A2.1	A2.2	A3.1	A3.2	B4.1	B4.2	B5.1	B5.2	B6.1	B6.2
87	63	82	95	167	104	---	25	58	104	54	---

Strain levels applied: 200x10^{-6}, 300x10^{-6} and 400x10^{-6}

As aforementioned, slabs with 30x30x5 cm^3 extracted from trial sections were submitted to wheel-tracking tests. Table 3 shows average results determined.

Table 3: Average results of rutting rate obtained in wheel-tracking tests after 105 min of test (10^{-3} mm/min)

b_c = 4,8 %		b_c = 5,3 %		b_c = 5,8 %		b_c = 4,8 %		b_c = 5,3 %		b_c = 5,8 %	
A1.1	A1.2	A2.1	A2.2	A3.1	A3.2	B4.1	B4.2	B5.1	B5.2	B6.1	B6.2
---	7	14	---	16	17	10	8	19	19	44	18

As Table 2 shows, almost all the mixtures have a stiffness modulus greater than 9000 MPa, which was the assumed value for design of the pavement.

As far as fatigue behaviour is concerned, according to table 2, mixes from sub-sections A have, in general, better fatigue resistance than those from sub-sections B. Furthermore, while for the first set of HMAC mixes resistance to fatigue tends to increase with bitumen content, for set B that behaviour is variable.

In addition, by taking into consideration results of HMAC fatigue resistance published in an international bibliography (referred to in Capitão, 1996), results show that fatigue resistance of tested material is acceptable but lower than expected. However, in this case, with the aim of reducing testing time, strain levels applied were 2 to 4 times greater than that of pavement design (120x10^{-6}). It must also be noted that 50% of modulus reduction appears to be inadequate to measure fatigue life of HMAC. In fact, considering an initial stiffness of 9000 MPa, for instance, fatigue failure of material would occur for a modulus value of 4500 MPa, which is excessive. Therefore, it seems preferable to adopt a different criterion to determine fatigue life of HMAC.

It is generally accepted that fatigue laws obtained as mentioned cannot be used directly in pavement design, because strain levels and test conditions applied do not reproduce exactly what happens in the pavement. Thus, fatigue life of materials tends to be underestimated.

Apart from material extracted from sub-sections A1.2, all mixtures from section A are expected to have adequate behaviour, considering that the derived laws were determined under more demanding conditions that those expected to occur in pavement.

The results presented in Table 3 show that resistance to permanent deformation decreases as bitumen content increases. In addition, aggregate blend containing more limestone filler (mixes B) has a lower resistance than aggregate mix A.

In the view of all obtained results, the job mix formula selected was mixture A, containing 5.3 % of bitumen.

4. EVALUATION OF MECHANICAL PROPERTIES OF HMAC IN THE LABORATORY

4.1. Production of specimens

Prismatic specimens were sawn from slabs taken from the pavement, while cores having 10 and 15 cm were directly extracted from the trial sections.

The hard bitumen chosen was heated to 170°C with the aim of reaching an adequate viscosity for mix operation. Aggregates were heated to 170-180°C. Once materials have reached target temperature, weighting dosing and mechanical mix operation were carried out.

In the laboratory, compaction must reproduce the volumetric properties and particle orientation of a mixture laid in the field. It has been observed that compaction methods that use principles similar to those of field compaction are the best to simulate what happens in pavement construction. Thus, after a period of temperature conditioning of the loose mixture, material was placed in a square mould (dimensions adjustable as required). Once the temperature is checked, the mixture is compacted by means of a small vibrating tandem roller, which has 350 kg of dead weight, aiming to produce a squared slab (thickness of 80 mm). Sawing slabs produces beams for submission to testing.

Cylindrical specimens of 150 mm in diameter and approximately 110 mm high were molded in a metallic mould. Each sample is compacted with a vibrating hammer, which can apply from 2000 to 4000 pulses per minute. Its weight is about 620 N. This equipment has a tamping foot with a diameter slightly smaller than the top of each specimen. Compaction is made by applying the hammer for three minutes on the top of each specimen. That time was established after some trial tests carried out with the aim of producing specimens having similar density to samples taken from pavement.

4.2. Stiffness modulus and phase angle determined

Measurement of stiffness modulus (S_m) and phase angle (ϕ) was made in sweep frequency tests similar to those described for mix design purpose. However, here tests were performed over a wider temperature and frequency range, as the objective was to determine the behaviour of HMAC for service conditions which represent the most typical that can occur in Portuguese pavements. Tables 4 to 6 summarize some of the obtained results for tested compositions.

Table 4: Stiffness modulus (MPa) and phase angle (degree) obtained on specimens produced in laboratory (strain level=120 microns)

Frequency Hz	Temperature °C	Lab.A1 (bit: 4.8%)	Lab.A2 (bit: 5.3%)	Lab.A3 (bit: 5.8%)	Lab.A1 (bit: 4.8%)	Lab.A2 (bit: 5.3%)	Lab.A3 (bit: 5.8%)
0.1	15	9223	9977	7198	15.9	20.7	24.3
	25	7380	5661	4263	26.4	35.9	39.1
1	15	11125	12633	9358	11.4	13.9	15.2
	25	9848	9661	6760	17	21.8	25.4
	40	2890	2087	1327	37.9	43.3	52.8
	45	2137	1560	963	41.9	46.7	55.9
5	15	13033	13902	10823	9.3	10.8	12.7
	25	12568	11938	9423	14	18.4	20.4
	40	4377	3513	2270	35.6	41.9	52.9
	45	3020	2720	1703	43.3	47.3	58.8
10	15	13427	13080	10583	9.5	11.3	13.3
	25	12653	12328	9940	13.8	17.5	18.8
	40	4857	3867	2530	33.4	39.8	52.7
	45	3357	3130	1967	42.5	47.1	58.1

Lab.A1, LabA.2 and Lab.A3 are similar to A1, A2 and A3 in terms of composition

Table 5: Stiffness modulus (MPa) for specimens extracted from trial sections (strain level=120 microns)

Frequency Hz	Temperature °C	Lab.A1 (bit: 4.8%)	Lab.A2 (bit: 5.3%)	Lab.A3 (bit: 5.8%)	Lab.A1 (bit: 4.8%)	Lab.A2 (bit: 5.3%)	Lab.A3 (bit: 5.8%)
0,1	15	12860	11485	9470	9978	7957	9350
	25	6867	9073	5015	5565	3838	4233
1	15	15508	14620	13275	13093	11083	12483
	25	9923	13288	8240	8415	5898	6653
	40	2960	2860	1610	1455	1065	1400
5	15	17628	16880	16618	15660	13520	14627
	25	12657	15393	10970	11705	9080	9693
	40	4775	4695	2830	2565	1940	2570
10	15	17040	16153	16615	15333	13410	14143
	25	12743	14807	11663	12375	9585	10465
	40	5345	5320	3210	2890	2275	2840

Table 6: Phase angle (degree) for specimens extracted from trial sections (strain level=120 microns)

Frequency Hz	Temperature °C	Lab.A1 (bit: 4.8%)	Lab.A2 (bit: 5.3%)	Lab.A3 (bit: 5.8%)	Lab.A1 (bit: 4.8%)	Lab.A2 (bit: 5.3%)	Lab.A3 (bit: 5.8%)
0.1	15	15.9	15.8	23.2	22.4	25.1	22.4
	25	30.0	30.3	40.0	37.6	42.4	43.1
1	15	11.6	11.5	15.0	14.2	15.3	14.8
	25	18.6	19.0	24.9	23.7	28.2	26.5
	40	39.8	39.1	50.5	51.6	57.8	53.2
5	15	8.0	8.5	11.4	10.5	11.9	11.6
	25	14.3	15.2	19.7	18.3	22.1	21.4
	40	38.3	37.5	48.7	48.8	55.2	50.75
10	15	8.4	8.5	11.5	10.3	11.6	11.8
	25	13.6	15.1	18.3	17.0	20.6	19.7
	40	35.8	35.5	47.3	46.9	54.1	48.5

Although specimens taken from pavement sections have similar density to those produced in the laboratory, results show that the former have a slightly different stiffness modulus. In fact, the ratio between correspondent moduli pairs determined from laboratory samples and specimens taken from pavement ($S_{m\text{-}lab}$ /$S_{m\text{-}pav}$) depends on test conditions adopted (Table 7). Generally speaking, at higher temperatures and for lower strain levels specimens taken from pavement have better stiffness moduli.

Table 7: $S_{m\text{-}lab}$/ $S_{m\text{-}pav}$ determined over test parameters adopted

Freq. (Hz)	$60x10^{-6}$		$120x10^{-6}$						$300x10^{-6}$					
	15 °C		15 °C		25 °C		40 °C		15 °C		25 °C		40 °C	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
0.1	0.76	0.92	0.72	1.05	0.81	1.13	---	---	0.77	1.15	1.01	1.25	---	---
1	0.78	0.99	0.72	0.96	0.74	1.17	0.95	1.43	0.80	1.20	0.93	1.11	0.68	1.12
5	0.74	0.92	0.74	0.89	0.82	1.09	0.88	1.37	0.85	1.41	0.90	1.04	0.78	1.10
10	0.72	0.91	0.75	0.85	0.85	1.06	0.89	1.34	0.89	1.55	0.90	1.05	0.82	1.07

The results presented concerning phase angles show that HMAC tested behave more as an elastic than as a viscous material. This is clearly confirmed by values measured at a higher strain level ($300x10^{-6}$), as phase angles observed are similar to those presented in Table 6.

4.3. Resistance to fatigue

The fatigue tests carried out so far have only been performed for conditions referred to in sections 2. As the range of parameters covered is still narrow, the fatigue laws presented in Table 8 must be regarded with caution. Fatigue evaluation of design mixtures will be improved in the near future.

Table 8: Fatigue laws ($\varepsilon t = a.N^{-b}$) determined in the laboratory (10 Hz, 25 °C)

A1.1	A2.1	A2.2	A3.1	A3.2
a = 0.0275	a = 0.0633	a = 0.2942	a = 0.0017	a = 0.0222
b = 0.4167	b = 0.4815	b = 0.5814	b = 0.1685	b = 0.3882

ε_t=level of strain; N=number of load repetitions

4.4. Resistance to rutting

As aforementioned, during mixture design process, permanent deformation behaviour of the material was made by means of wheel-tracking tests. This kind of mechanical evaluation only allows checking of pass/fail criteria of mixes. Therefore, it is a good methodology for the selection of a work mix formula. If any tested composition meets pass requirements, it can be accepted. Otherwise, different raw materials, composition or production conditions must be used. However, a wheel-tracking test does not supply any further information regarding the mechanical properties of tested material, such as stiffness, or the relationship between compression strain versus number of load repetitions.

Thus, with the aim of determining the more "fundamental" characteristics of the mixtures, a set of repetitive loading axial tests (RLAT) was performed on cylindrical specimens, at temperatures varying from 25 to 45 °C and a stress of 500 kPa. It must be noted that RLAT does not allow a quantitative prediction of the rutting but makes it possible to rank different mixtures.

The axial loading system used consists of two steel loading platens between which the specimen is placed. The axial dynamic load is applied by means of a servo-hydraulic system, able to generate pulse loads (adopted parameters: pulse duration=200 ms; rest period=800 ms; preloading=55 to 70 kPa). Rutting rate in the linear region (phase 2) was the parameter adopted to measure the resistance to permanent deformation. Table 9 shows some of the rutting rate values measured on RLAT for 150 mm diameter cores extracted from pavement.

Table 9: Rutting rate (mm/cycle) obtained from RLAT

	Cores extracted from pavement					
Temperature	A 1.1	A 1.2	A 2.1	A 2.2	A 3.1	A 3.2
25 °C	$5.29x10^{-5}$	$7.41x10^{-5}$	$1.18x10^{-4}$	$1.44x10^{-4}$	$2.34x10^{-4}$	$1.42x10^{-4}$
35 °C	$7.95x10^{-5}$	$9.55x10^{-5}$	$2.03x10^{-4}$	$2.01x10^{-4}$	$3.11x10^{-4}$	$3.01x10^{-4}$
45 °C	$1.71x10^{-4}$	$1.44x10^{-4}$	$3.34x10^{-4}$	$3.03x10^{-4}$	$5.05x10^{-4}$	$3.78x10^{-4}$

	Laboratory specimens		
Temperature	Lab.A1	Lab.A2	Lab.A3
25 °C	$2,39x10^{-5}$	$2,92x10^{-5}$	$3,47x10^{-5}$
35 °C	$3,39x10^{-5}$	$1,30x10^{-4}$	$1,15x10^{-4}$
45 °C	$3,23x10^{-4}$	$7,64\ x10^{-4}$	$7,35x10^{-4}$

The values of rutting rate appear to increase when mix compositions incorporate higher bitumen content. At 35°C, for instance, varying bitumen content from 4.8% to 5.8%, rutting rate increases, in average, by a factor of 3.5 and 3.4, for pavement cores and for laboratory specimens, respectively. The first factor reduces to 2.8 and the second one to 2.3 for tests carried out at 45°C.

5. CONCLUSIONS

This paper presents a performance-based approach for mix design. That methodology incorporates the main principles from methods recently developed by several countries, aiming to design bituminous mixes with better mechanical behaviour.

Taking into consideration that the adopted method provided a reasonable mechanical characterization of the designed material, the work mix formula is expected to behave well during service life.

The evaluation of stiffness modulus and phase angles of the studied HMAC made it clear that this material has a very good capacity to spread traffic loads, even if temperature conditions are particularly severe.

As far as fatigue resistance assessment is concerned, additional tests must be carried out to come to more definitive conclusions. Despite this, based on the results obtained so far, the composition selected is expected to have a sufficient fatigue performance.

In view of the results, it is clear that the studied mix compositions have a significant influence on the measured mechanical properties. Therefore, to design HMAC a performance-based methodology must be adopted. Moreover, considering that temperature and loading conditions are critical on the measuring of mechanical properties, those parameters should be obtained as rigorously as possible, to prevent unexpected behavior of material in the pavement.

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