EXTENDED ABSTRACT

INTRODUCTION

Recently the world population has become concerned about all the problems related to the environment, such as climate change and energy wasting.

Climate change is mainly caused by the greenhouse gases (GG) such as carbon dioxide (CO_2), which is produced every time burning occurs. For example, inside the burners aggregate dryer drums, where huge amounts of fuel is burnt.

Energy casting must be guided to renewable energies, lowering as much as it possibly can the waste of no-renewable ones.

Since Kyoto Protocol came to life in February 2005 to restrain the GG emissions in the atmosphere, it has become common the development of new bituminous mixtures inside transport infrastructures (Pérez and Pérez, 2010).

The most important parameter to control in the fabrication of roadway mixtures is the temperature. The higher it is, the larger the fuel waste will be and the larger the gradient burners will be as well, turning worse the two problems previously mentioned. That's why the new mixtures that are evaluated will try to reduce the temperature, fabricated ones and practical ones.

This project's objectives are:

1) Characterize the half-warm bituminous mixture stiffness for basement layer.
2) Characterize the fatigue of the mixture.
3) Compare the obtained results with the normal behaviour of the traditional bituminous mixtures of the same type.

To reach the objectives, different tasks development was prevented:

1) In the first part of the study we proceeded to mix the needed amounts (aggregated, bitumen and organic wax, Sasobit kind) to make half-warm bituminous mixture slabs in Pavement Mechanics Laboratory (LPAV) of the Science and Technology School of University of Coimbra (FCTUC). The Slab's compaction with drum vibratory roller was made in the Engineering Superior Institute of Coimbra (ISEC). After keeping them in the cast 24 hours, the slabs were retired and cut in beam shapes.

2) In the second part, the beams were tested to measure the stiffness and fatigue at the Transport and Infrastructures Laboratory (LVCT) of the Technical Superior Institute (IST).

3) After the treatment of the results we proceeded in comparing with other results for hot traditional mixtures, so that we could see if there was any chance of using half-warm bituminous mixtures in Portuguese technology.

HALF-WARM BITUMINOUS MIXTURES

Half-warm bituminous mixtures are those that aren't prepared neither hot or cold. These are mixtures made and carried out to practice with lower temperature then that that of the traditional ones, hotter, and can be used in transportation roadways doing the same functions as the other ones would.

The fact of lowering the temperature (below 120ºC instead of over 140ºC, as the hot mixtures) by using an additive, both organic and inorganic, that powers the bitumen sliminess without changing the mixture´s mechanical strength after it is put in practice.

In Figure 1 we can see a bituminous mixtures table according to the production temperature. We can verify that half-warm mixtures are divided at the same time in two sub kinds, being studied the mixtures with production temperature between 100ºC y 120ºC.

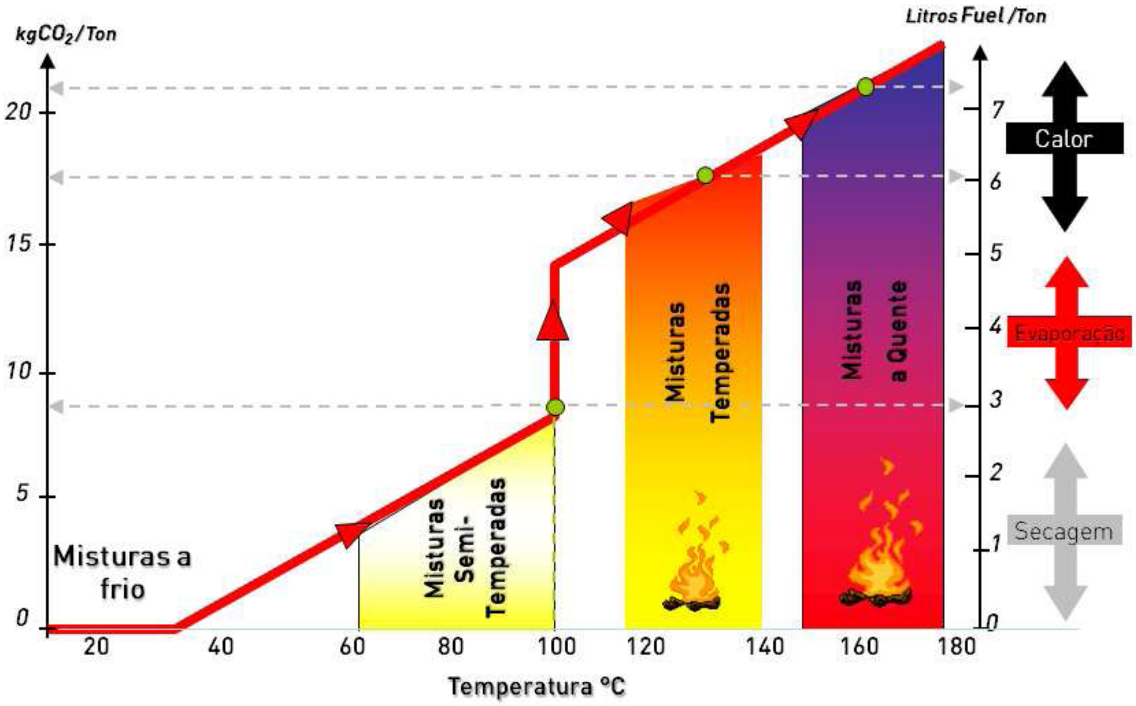

Figure 1 – Bituminous mixtures table according to production temperature (Silva et al, 2010)

The additive used to reduce the production temperature to that gap can be one of these:

1) Zeolites: silicates which the structures presents lots of spaces between molecules (porous materials) where the water associated to bitumen is held, especially in the cases when bituminous emulsions are used. When they are heated to low the temperature, this water in addition to the zeolite water vanishes into thin air, bitumen increases each volume and permits the mixture at that temperature. The heating is produced when bitumen and hot zeolite aggregated become in contact, leading to a bitumen floating waste (less slimy at lower temperature).

2) Waxes: organic compounds from those called lipids, that are formed by a diverse group of elements with different features (waxes are ester kind). They can be classified in different groups, as the paraffinic ones are mostly used in half-warm bituminous mixtures field. Paraffinic waxes are the result of a linear chain of saturated hydrocarbons (simple links between carbons). They are commercially known as Sasobit®.

3) Surfactant agents: additives that make the surface liquid tension reduce when they are added to the process of the mixture. This effect permits the mixture because it reduces bitumen sliminess. The most used agent in half-warm bituminous mixtures production is commercially known as Cecabase®.

WORK DONE

The analyzed mixture in this study is about a bituminous macadam with asphalt cement AC20 and bitumen 50/70, made for flexible roadway basement layers, which features are presented in Table 1. In Table 2 the filing of the aggregated used in mixture is showed.

Table 1 – Mixture features

Bitumen percent	Sasobit percent	Production temperature
3,7%	0,15%	120ºC

Table 2 – Particle size mixture

Gravel 1	Gravel 2	Dust
25%	30%	45%

The main propose of this experimental study is to characterize the mixture to stiffness and fatigue terms, just to contribute to the implantation of these compounds in Portuguese technology.

A four points flexion equipment made by Cooper Research Technology Company was used. The tests are made by satisfying the requirements in the rule EN 12697-24.

Previously 3 slabs were made, dimensioned 450x450x60 mm^3 using mixture compaction (with the drum vibratory roller) extended in a cast prepared for the occasion. After leaving the compacted mixture inside the cast during 24 hours, we proceeded to pull it out and to cut it in samples of 420 mm long, 60 mm wide and 50 mm high. From each slab we obtained 6 samples, making a total of 18 samples to be introduced inside the flexion equipment and then tested.

STIFFNESS FEATURE

To perform a good mixture feature in stiffness terms we followed what EN 12697-6 norm said, where the test conditions are explained to be adopted.

Specifically, to do the stiffness test, these features must be set so that they can be adjusted to the ones which the roadways will support where they will be placed, in this case Portugal.

1) Temperature. Taking into account that the range of reference temperatures for any bituminous layer thickness in Portugal is between 20ºC and 30ºC (Picado-Santos et al, 2010), tests were done at 20, 30 and 40ºC. With this last value we can verify a result in the most difficult condition, different from the usual ones.

2) Frequency. EN 12697-24 norm shows that it must be between 0,1 Hz and 50 Hz. In this study case the mixture stiffness was featured with three frequencies: 1 Hz, 5 Hz and 10 Hz. This way we could avoid the typical problems working at high frequencies that don't represent the average real rate in charges application (20 Hz answer to a heavy movement rate of 133 km/h, Shell 1990).

3) Way of charging. Two different ways in the software equipment can be chosen: controlled length and controlled tension. The first one was chosen with a maximum flexion amplitude of 50 µm/m, compatible with what it's said in EN 12697-26 norm.

In Figure 2 the module values for each sample tested at 20°C are shown.

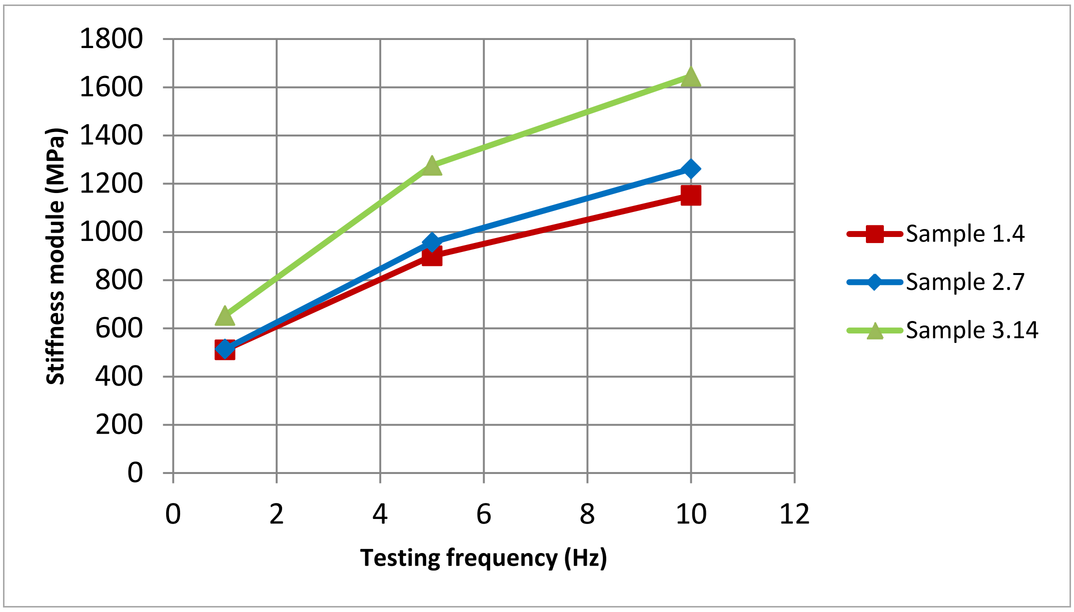

Figure 2 – Stiffness module at 20°C

FATIGUE FEATURE

In order to make a good mixture feature, talking in fatigue terms, we followed the indicated ones in EN 12697-24 norm.

The fatigue test shows a number of differences comparing to the stiffness test:

- It consists of a destructive test.
- Different numbers for the amplitude were used (70, 110 e 150 µm).
- Temperature was constant for all the tests (T=20°C).
- Frequency was constant for all the tests (f=10 Hz).
- Stiffness module is lowered until reaching half the starting module (canon chosen to finish the test).

The amplitude, temperature and frequency values chosen were established so that the number of replays for the smaller amplitude allowed each test would not to be more than 24 hours long.

The initial module value was calculated at the beginning of the tests, doing 100 repetitions to reach the correct one, as it is written in EN 12697-24 norm.

9 samples were tested exclusively to fatigue and 3 samples were recovered from stiffness tests (at 20°C) to test them to fatigue as well, getting 4 different results for each amplitude level.

In Figure 3 is represented the fatigue sample test evolution 3.13, which was observed to give the best result of the three tested, all of them in the same temperature and frequency conditions (20ºC, 10 Hz), as well as in stiffness and fatigue test.

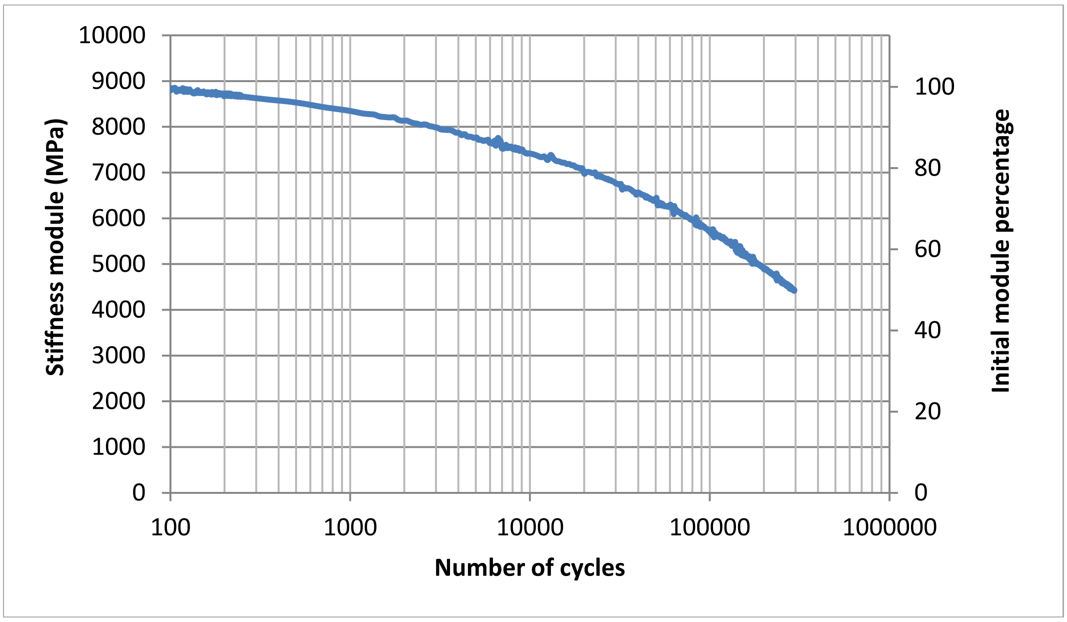

Figure 3 – Sample fatigue test 3.13

To analyze the mixtures in the test, we follow the fatigue norms for flexible roadways proposed by two institutions. Fatigue norms link the traction extension (ε) and the number of charge cycles at the end of the test (N). As seen, the expressions were practically the same:

- Shell → $\varepsilon_t = 0{,}003035 \times {N_{80}}^{-0{,}2}$
- JAE (Junta Autónoma de Estradas) → $\varepsilon_t = 0{,}003 \times {N_{adm}}^{-0{,}2}$

EN 12697-24 norm proposes to express the test results in two different ways that permit to obtain a number of parameters and compare the bituminous mixture test efficiency.

1) Fatigue straight. It consists on expressing the traditional fatigue law but using natural logarithms. We link sample lifelong *i* for the broken canon chosen *j* and the test conditions group *k* ($N_{i,j,k}$) with the initial scale amplitude measured at the hundredth charge cycle (ε_i). We get to this expression:

$$\ln(N_{i,j,k}) = 32{,}297 - 4{,}3 \times \ln(\varepsilon_i)$$

From here we get the fatigue line inclination value, A_1=-4,3.

2) Fatigue law general expression. As we said previously, it links the traction extension (ε) with the charge cycles number at the end of the test (N). We get to this expression:

$$\varepsilon = 1728{,}8 \times N^{-0{,}228}$$

From here we get the material amplitude value corresponding to one million cycles ($N=10^6$), $\varepsilon^6=74$ µm/m.

In Figure 4 fatigue general law expression and Shell and JAE proposed laws are represented.

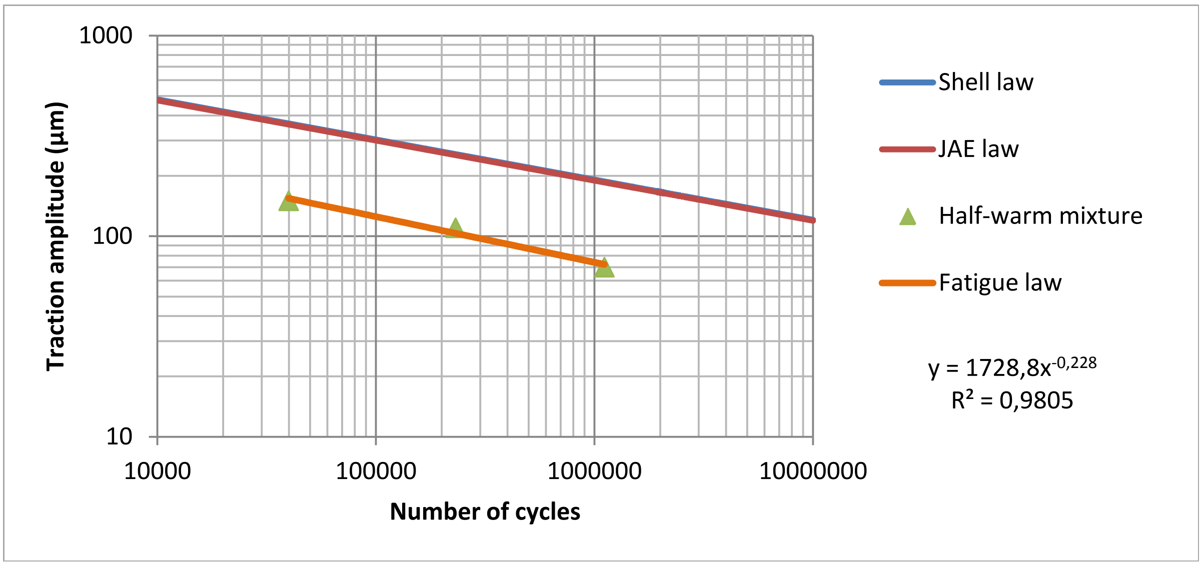

Figure 4 – Fatigue law and Shell and JAE laws representation.

COMPARISON WITH TRADITIONAL BITUMINOUS MIXTURES

To compare the bituminous studied mixture behaviour with other similar mixtures behaviour we used three different reference mixtures, two of them extracted from a PhD thesis (Baptista, 2006) and the other one extracted from a Journal of Transportation Engineering article, volume 136 (Picado-Santos et al, 2010).

Bituminous mixtures extracted from the thesis were designed E (30% recycled milling material) y F (40% recycled milling material), both a bituminous macadam with asphalt concrete AC20 and bitumen 50/70, meanwhile the bituminous mixture extracted from the article designed A, also bituminous macadam with asphalt concrete AC20 but bitumen 35/50.

In Table 3 the bituminous reference mixtures features are explained. As we can see, the only comparison to done is only approximate because we have data from a bituminous macadam (MB), mixture A, just the same kind as the test done but with more quantity of bitumen (4,2% instead of 3,7%) and made with stiffer bitumen (35/50 instead of 50/70), and we also have data from another two MB with more bitumen percentage (the same 50/70 kind) but with high percentages in milling materials included in its composition (30% in E mixture and 40% in F mixture).

Regarding the stiffness module conditions, the frequencies used (1, 5 and 10 Hz) are the same as the ones used in this study, although the set amplitude is different (100 μm for comparing mixtures and 50 μm for this study. Testing temperatures were also different: 20, 30 and 40°C for the one in the study; 15, 25 and 40°C to the comparing ones.

Table 3 – Bituminous reference mixtures features (Baptista, 2006 and Picado-Santos et al, 2010)

Assignation in this study	Assignation in the bibliography	TR (%)	Kind of bitumen	pb_{final} (%)	pb_{new} (%)
A	LA	0	35/50	4,2	4,2
E	LE	30	50/70	4,2	3,0
F	LF	40	50/70	4,2	2,6

In Table 4 we only present stiffness module results for frequency 10 Hz, generally used to feature bituminous mixtures. Mixture named M was the one tested along this work.

Table 4 – Deformation module results (10 Hz) for the mixture studied and the mixtures to compare.

Mixture	Module (MPa)		
M	6.068 (20)	2.315 (30)	1.353 (40)
A	7.071 (15)	3.401 (25)	1.078 (40)
E	11.136 (15)	7.897 (25)	4.085 (40)
F	9.763 (15)	7.992 (25)	4.460 (40)

(the values between brackets mean test temperature)

In Table 4 it can be verified that the module values for the studied mixture are very similar to the A reference mixture, despite the difference in the set extensions and specially in testing bitumen and temperatures. Actually we can see that at the same temperature (40 ºC) the mixture studied presents even a better behaviour, it means that probably the difference between bitumen sliminess would be partially compensated by the percentage difference itself.

The results are different for mixtures E and F, but we have to take into account that they consist on much more slimy bitumen mixtures than the bitumen 50/70 from the mixture studied, and that justify the difference related to reference mixture A.

About fatigue results, in Table 5 fatigue laws parameters (a,b) and traction amplitude corresponding to one million cycles (ε^6) are shown. These laws were obtained in the same conditions, except for the comparing mixtures, where its temperature was 25 ºC.

Table 5 – Fatigue law representative parameters for comparing mixtures

Mixture	a	b	ε^6 (µm/m)
M	1.728,8	-0,228	74
A	2.717,2	-0,181	223
E	2.743,0	-0,170	262
F	3.492,5	-0,187	264

In Figure 5 the fatigue laws from studied mixture and comparing ones as well, are described for a better comprehension of the differences between them.

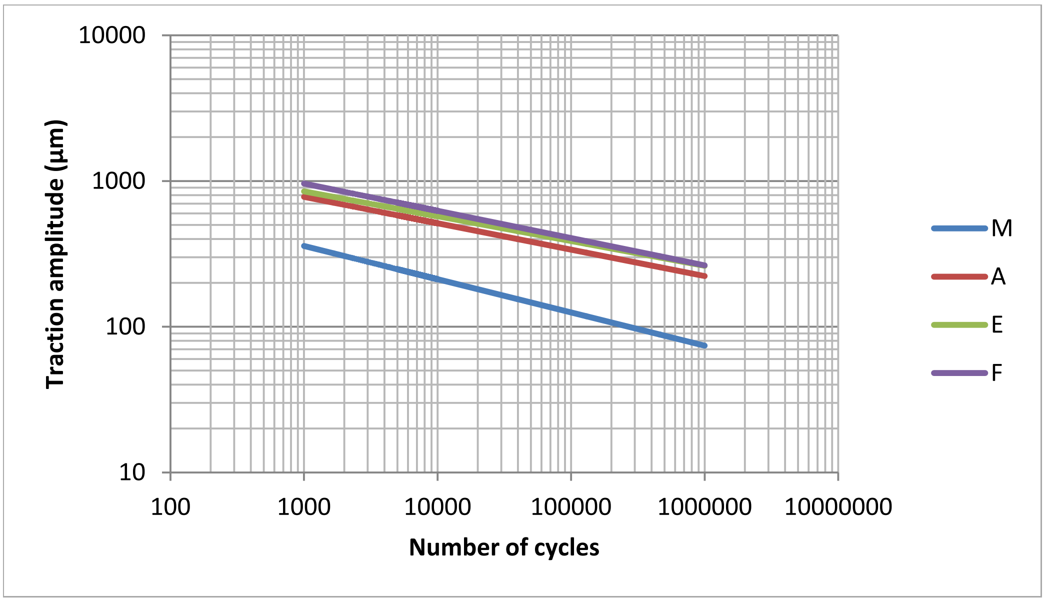

Figure 5 – Comparing mixtures fatigue laws representation.

From these results we can finish by saying that bitumen percentage has a vital role in the fatigue behaviour, which justifies M mixture behaviour being much worse than the rest. Despite this fact, this is softened by the fact that the testing temperature for this study mixture was 20 ºC, more adverse to the conditions than the rest at 25 ºC.

Definitely we can say that M mixture presents stiffness behaviour on the line than other mixtures of the same kind and the fatigue behaviour relatively is poor, due to the low bitumen percentage used in its production.

CONCLUSIONS AND FUTURE WORKS

By doing this study we could demonstrate how low fatigue resistance of the bituminous mixture studied was, otherwise it was expected because its low bitumen percentage and a stiffness behavior is similar to the one from the traditional mixtures made in the same way.

The half-warm bituminous mixtures development still has a long way to go to reach the point where it could be implemented in Portuguese technology. Some decisions to be adopted in the future to get this objective faster and in better conditions could be:

- To study other half-warm bituminous mixtures formulation behaviour, especially those with the more bitumen amount, because it is an important motive of the low fatigue efficiency presented.
- To do a higher number of tests like the ones made in this work to obtain more featured mixture points so that we could get a better representation of the analysis.
- To study traditional mixture behaviour with the same compounds than the half-warm mixture studied, to get a better evaluation of its efficiency.
- To study other kinds of applications for half-warm bituminous applications, as rolling layers used.
- To make experimental stretch using half-warm bituminous mixtures, in order to evaluate the practical efficiency of these mixtures throughout its life.

Finally, we consider it must be taken into account the half-warm bituminous mixtures development by its contribution to the environment preservation and by doing a more efficient use of the resources to apply in Portuguese road network preservation.

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