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Assessment of Fatigue Resistance and Aging of Asphalt Mixtures in Portugal

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ABSTRACT: In Portugal, the stiffness modulus and the fatigue resistance of asphalt mixtures are generally assessed through four-point bending tests on prismatic shaped specimens (4PB) based on European standard EN 12697-24-Annex D. Traditionally, these tests are performed at a load frequency of 10 Hz. However, in the present context of European material specifications standards, namely EN 13108-20 concerning type testing, it also became necessary to evaluate the fatigue behavior in 4PB tests performed at a load frequency of 30 Hz. In addition, surface fatigue failure cracks which initiate from the top are becoming a more common pavement distress, mainly in thick pavements. In order to assess the influence of asphalt aging on fatigue resistance of asphalt mixtures for wearing courses, an experimental study was carried out, in which a typical Portuguese surface course asphalt mixture, produced with dense graded granite aggregates and with different penetration grade bitumen ($35/50\times10^{-1}$ mm and $50/70\times10^{-1}$ mm), was used. The assessment of the effect of aging was performed after submitting test specimens to laboratory simulated aging, and comparing the fatigue life of the aged and the un-aged prismatic specimens. This paper presents the main results achieved so far concerning the fatigue resistance assessed in 4PB tests performed at a load frequency of 30 Hz, and it may be concluded that the asphalt mixtures involved in this study have exhibited a satisfactory behavior, and have showed low sensitivity to aging.

KEY WORDS: Asphalt mixtures, Fatigue resistance, Aging, Four-point bending tests.

1. INTRODUTION

Most roads and highways in Portugal are made with flexible pavements, making relevant the study of the characteristics and behavior of asphalt mixtures used in this type of pavement.

In Portugal, the stiffness modulus and the fatigue resistance of asphalt mixtures are generally assessed through four-point bending tests on prismatic shaped specimens (4PB) based on European standard EN 12697-24-Annex D. Traditionally, these tests were performed at a load frequency of 10 Hz. However, in the present context of European material specifications standards, namely EN 13108-20 concerning type testing, it also became necessary to evaluate the fatigue behavior in 4PB tests performed at a load frequency of 30 Hz. Therefore, in this study, the fatigue resistance of two different asphalt mixtures was performed at a load frequency of 30 Hz.

In addition, surface fatigue failure cracks which initiate from the top are becoming a more common pavement distress, mainly in thick pavements (COST 333, 1999; Myers and Roque, 2001). An aspect often pointed out as a cause of surface crack initiation is the aging of the bitumen present in the wearing course, whose asphalt mixture becomes more brittle and susceptible to fatigue cracking (CALTRANS, 2003). Thus, aging is considered an important factor in the performance of asphalt mixtures, particularly in their resistance to fatigue. In order to understand the contribution of aging phenomenon on the fatigue behavior of traditional asphalt concrete mixtures, in this study, the effect of aging was performed after submitting some test specimens to laboratory simulated aging according to the Long-term Oven Aging (LTOA) process (Bell and Sosnovske, 1994; Bell *et al*., 1994).

2. EXPERIMENTAL PROGRAMME

In order to evaluate the influence of aging on the fatigue behavior of asphalt mixtures for wearing courses, two asphalt concrete mixtures were produced in laboratory, both using the same type of aggregates, but different penetration grade bitumen binders.

The assessment of the effect of aging was performed after submitting the test specimens to laboratory simulated aging, and comparing the fatigue life of the aged and the un-aged prismatic specimens.

2.1. Materials

Two traditional asphalt concrete mixtures were produced in the laboratory with dense graded aggregates, differing only in the type of bitumen used. The selected materials are of common use in Portugal: granite aggregates and 35/50 and 50/70 penetration grade bitumen binders for each mixture. Table 1 identifies the produced asphalt concrete mixtures and Table 2 presents its composition.

Table 1: Tested asphalt concrete mixtures identification

Mixture identification	Designation according EN 13108-1	Mixture gradation	Aggregates nature	Penetration grade bitumen
AC1	AC14 surf 35/50	Dense-graded	Granitic	35/50
AC2	AC14 surf 50/70	Dense-graded	Granitic	50/70

Table 2: AC1 and AC2 asphalt concrete mixtures composition

<table>
<tr><th colspan="2">Material</th><th>Percentage in asphalt mixture (%)</th></tr>
<tr><td rowspan="4">Mixture of aggregates</td><td>8/14 mm fraction</td><td>31,8</td></tr>
<tr><td>4/8 mm fraction</td><td>20,9</td></tr>
<tr><td>0/4 mm fraction</td><td>39,4</td></tr>
<tr><td>Filler</td><td>2,9</td></tr>
<tr><td colspan="2">Bitumen binder</td><td>5,0</td></tr>
</table>

2.2. Test specimens

Using AC1 and AC2 produced mixtures, slabs were compacted with a steel roller compactor according to EN 12697-33 and later cut into beam specimens with $50 \times 50 \times 400$ mm^3 approximate dimensions.

After preparing the test specimen their bulk density was determined according to standard EN 12697-6 - procedure B (bulk density – SSD). The mean values for both mixtures (AC1 and AC2) were identical as shown in Table 3.

Table 3: Test specimens' volumetric composition

Mixture identification	Average bulk density (kg/m^3)	Average maximum density (kg/m^3)	Average porosity (%)
AC1 and AC2	2428	2496	2,7

In order to simulate long-term field ageing, some specimens were submitted to laboratory accelerated aging according to the Long-Term Oven Ageing (LTOA) process, developed by Bell and Sosnovske (1994) and Bell *et al.* (1994) in the SHRP program. According to the LTOA procedure, test specimens were aged at 85 ºC for a period of 5 days.

2.3. Stiffness Modulus

Previous to the fatigue tests, a study was conducted to assess the stiffness modulus of the two asphalt concrete mixtures produced in the laboratory.

The stiffness modulus determination was carried out through four-point bending tests on prismatic shaped specimens, according to standard EN 12697-26 – Annex B. The same equipment of the fatigue bending tests was used.

The tests were carried out with controlled strain, with an amplitude of 50 microstrain and a temperature of 20 ºC. The load frequency was defined according to the range proposed by EN 12697-26 standard, i.e., with values of 1, 4, 8, 10, 30 Hz and 1 Hz again.

Figures 1 and 2 illustrate the results of the stiffness modulus for AC1 and AC2 mixtures, respectively. These figures also show the stiffness modulus for the specimens submitted to laboratory aging (LA), labeled respectively as AC1-LA and AC2-LA.

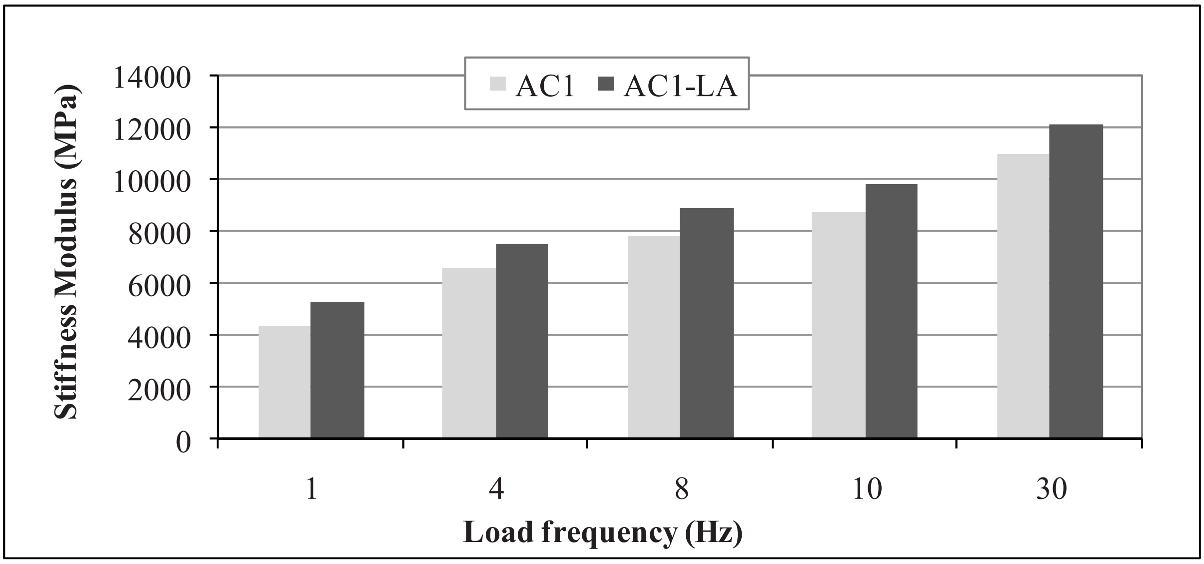

Figure 1: Stiffness modulus at 20ºC of aged and un-aged AC1 asphalt concrete test specimens

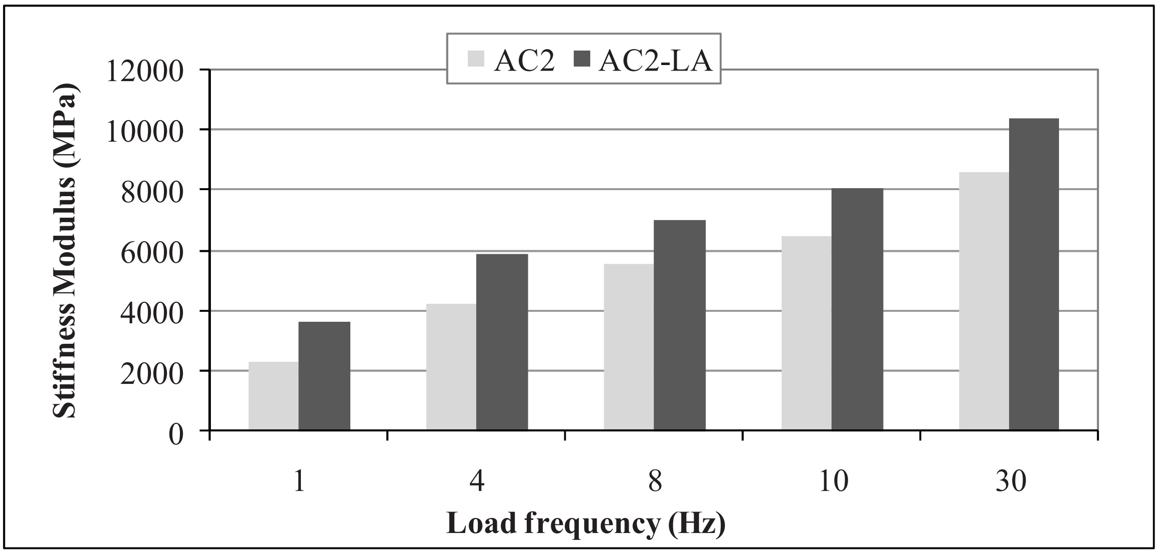

Figure 2: Stiffness modulus at 20ºC of aged and un-aged AC2 asphalt concrete test specimens

Figures 1 and 2 show that stiffness modulus values are higher for the AC1 mixture than for the AC2 mixture, which was expected since these mixtures were produced with a harder (35/50 pen) and softer (50/70 pen) bitumen binder, respectively.

The results also show that the aged asphalt concrete specimens have suffered an increase of the stiffness modulus comparatively to the un-aged specimens.

2.4. Needle penetration and Softening point

In order to characterize the bitumen binder both of the aged and un-aged test specimens, some of these specimens were used for determination of the penetration and the softening point. The bitumen binder was firstly recovered by the rotary evaporator method (EN 12697-3 standard). Afterwards tests for determination of the needle penetration and the softening point by the Ring and Ball method were carried out, according to EN 1426 and EN 1427 respectively. Table 4 presents the results for the recovered bitumen characterization.

Table 4: Needle penetration (Pen) and softening point (T_{RB}) of the AC1 and AC2 asphalt concrete mixtures recovered bitumen

Mixture identification		Pen (0,1 mm)	T_{RB} (ºC)
AC1	AC1 (un-aged)	36	54,4
	AC1-LA	34	56,1
AC2	AC2 (un-aged)	63	49,1
	AC2-LA	44	52,5

Table 4 shows that the AC2 mixture (produced with 50/70 pen bitumen) has hardened more than the AC1 mixture (produced with 35/50 pen bitumen) after being submitted to the LTOA process. In fact, AC1 has only suffered a small decrease in the bitumen penetration, after being submitted to the laboratory aging process (LTOA), which is not considered significant. Regarding the softening point, both AC1 and AC2 mixtures have increased their values for the recovered bitumen after being submitted to aging.

These results are consistent with the ones showed in Figures 1 and 2 since the AC2 mixture presented a higher increase of its stiffness modulus after being submitted to the LTOA process.

3. FATIGUE PERFORMANCE

The assessment of fatigue behaviour of the asphalt mixtures used in this study was carried out through four-point bending tests, according to test procedure based on standard EN 12697-24 - Annex D. Tests were performed with controlled strain, load frequency application of 30 Hz and at a temperature of 20ºC.

In this study, the fatigue life was defined as the number of repeated load cycles corresponding to a 50% reduction in initial stiffness.

Figures 3 and 4 present the fatigue life obtained for each of the asphalt concrete mixtures used in this study.

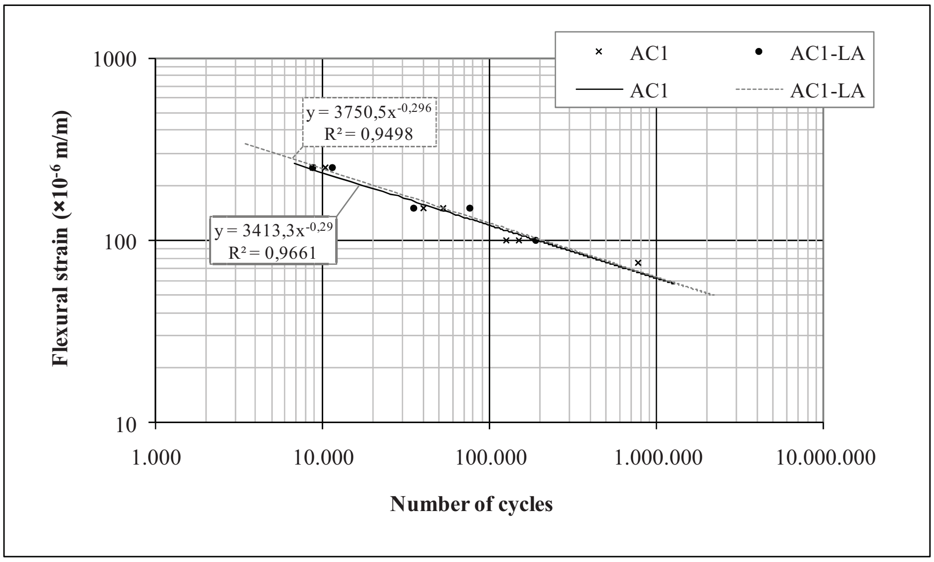

Figure 3: AC1 mixtures (aged and un-aged) fatigue life

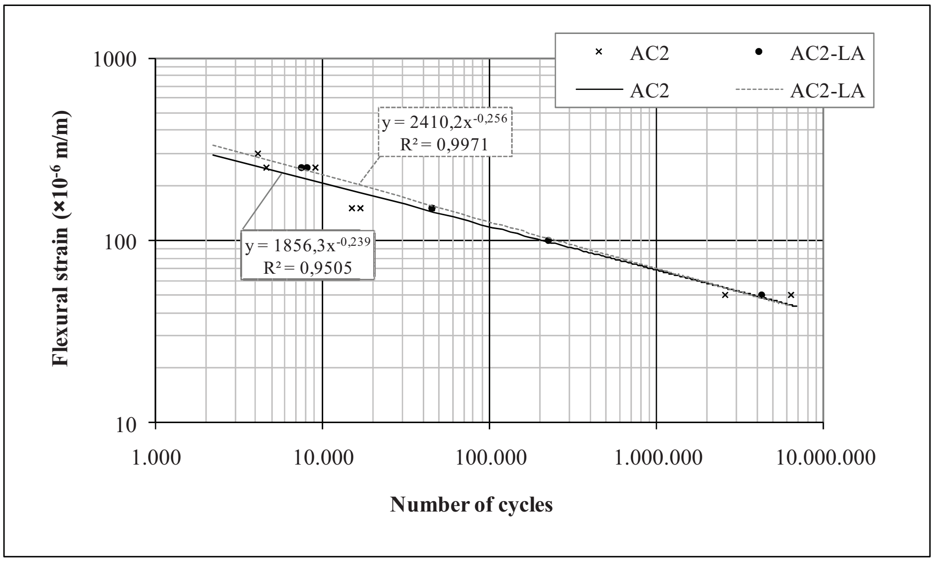

Figure 4: AC2 mixtures (aged and un-aged) fatigue life

Table 5 presents the results obtained for the fatigue life for both AC1 and AC2 asphalt concrete specimens, aged and un-aged. This table also presents the strain value at which a fatigue life of one million cycles can be expected (ε^6).

Table 5: Results of the fatigue life tests

Mixture identification		Fatigue life $ln (N) = A_0 + A_1 \times ln (\varepsilon)$ or $\varepsilon = a \times N^{-b}$				ε^6 (μm/m)
		A_0	$A_1 = p$	a	b = -1/p	
AC1	AC1 (un-aged)	28,0	-3,4	3413,3	0,290	62
	AC1-LA	27,8	-3,4	3750,5	0,296	63
AC2	AC2 (un-aged)	31,5	-4,2	1856,3	0,239	68
	AC2-LA	30,4	-3,9	2410,2	0,256	70

N = Number of cycles; ε = microstrain; p = slope of the fatigue line; ε^6 = initial microstrain corresponding with a fatigue life (N) of 10^6 cycles

From the results presented in Figures 3 and 4 and in Table 5 it is possible to notice that all tested asphalt concrete mixtures reveal similar fatigue behaviour, exhibiting values of ε^6 around 60 and 70 microstrain. These results correspond to a test frequency of 30 Hz. However, higher fatigue life values for the same mixtures tested at a load frequency of 10 Hz can be expected (Batista *et al*., 2008).

The slope of fatigue line (p) at 30 Hz, for the AC1 (around -3) and the AC2 (around -4) mixtures, is slightly higher than the value often considered for conventional mixtures (-5), when using the fatigue curve defined by Shell (1978).

The results obtained for aged (AC1-LA and AC2-LA) and un-aged (AC1 and AC2) laboratory asphalt concrete specimens show that fatigue life of these materials is not affected by the LTOA aging process.

4. FINAL REMARKS AND FUTURE WORK

This paper presents the results achieved so far of an on-going study concerning the fatigue resistance of Portuguese asphalt concrete mixtures. The tests were performed according to European standard EN 12697-24 and complied with testing conditions established by EN 13108-20.

This paper refer specifically to the fatigue behavior of two dense-graded asphalt mixtures produced with granite aggregates, with two different penetration grade bitumen binders: a 35/50 and 50/70 ($\times 10^{-1}$mm). The fatigue characterization of these mixtures was addressed using four-point bending repeated load tests for a load frequency of 30 Hz. The effects of laboratory accelerated aging (LTOA - Long-Term Oven Aging process) in the fatigue behavior of the asphalt concrete mixtures were also assessed.

The results presented in previous sections suggest that the asphalt concrete mixtures involved in this study have similar fatigue behavior. Indeed, after submitting asphalt concrete specimens to LTOA process (5 days at 85 ºC) the fatigue behavior of the tested mixtures remained identical to that of "new" mixtures. However, the stiffness modulus improved with aging and, as expected, a harder bitumen binder (lower penetration and higher softening point) was achieved after aging asphalt concrete specimens.

Based on earlier and present results, further research analyses are being developed, in particular: (1) fatigue resistance characterization of other Portuguese traditional asphalt concrete mixtures, including those prepared with different contents of bitumen binder and various types of aggregates; (2) assessment of the influence of load frequencies (i.e. 10 Hz and 30 Hz) on the flexural fatigue behavior of asphalt concrete mixtures; (3) characterization of in-service asphalt pavements' performance, particularly with regard to their fatigue resistance evolution with age; and (4) simulation and assessment of further laboratory aging methods for asphalt pavements which replicate in-situ real aging conditions.

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