COMPARISON BETWEEN TENSILE, STIFFNESS AND FATIGUE LIFE TESTS RESULTS

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Abstract
A laboratory mechanical test is being implemented in the University of Minho to evaluate the asphalt-aggregate interaction. This test measures the tensile properties of the bituminous mixture in the interface between the asphalt and the aggregates. By using the tensile test it is intended to observe how the asphalt-aggregate interaction influences the mechanical properties of the bituminous mixtures, namely, stiffness modulus and fatigue life. The tensile test results must have a good correlation to the ones of the stiffness and fatigue life tests in order to assure that the tensile test can be used to investigate the influence of the asphalt-aggregate interaction in the mechanical behaviour of the bituminous mixtures. Thus, this paper presents the comparison between the tensile strength results and the fatigue life and stiffness modulus results of the corresponding mixtures.

1. Introduction

A laboratory test for the characterization of the asphalt-aggregate interaction is being developed at the University of Minho. This test evaluates the tensile strength of the bituminous mixture in the interface between the asphalt and the aggregates.

Since the mechanical mix behaviour depends on the asphalt-aggregate interaction, the tensile test can be used to evaluate not only the asphalt-aggregate interaction but also its influence in the performance of the whole mixture. So, to investigate the selection of the tensile test to observe the influence of the asphalt-aggregate interaction in the mixture behaviour, standard fatigue and stiffness tests were executed on bituminous mixtures with different aggregate gradations and correlated to the results of the tensile test (di Benedetto & de La Roche, 1998).

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The tests were performed in bituminous mixtures used in wearing and base courses. For each type of mixture, five mixtures were defined, by changing the gradation curve (from more to fewer fines). With the aim of evaluating stiffness and fatigue, tests were executed on a four point bending beam on controlled strain, whereas for the evaluation of the tensile strength, tests were performed in simple tension.

The main objective of this paper is to analyse if the tensile test implemented in the University of Minho simulates accurately the mechanical behaviour of a bituminous mixture, including not only the asphalt-aggregate interaction but also the stiffness and the fatigue.

The achievement of a good correlation between tensile, stiffness and fatigue life tests results demonstrates the capabilities of the tensile test to investigate the influence of asphalt-aggregate interaction in the mechanical behaviour of a bituminous mixture.

2. Material characterization

In this study two types of bituminous mixtures were used: a dense graded bituminous mixture for base courses and a bituminous mixture for wearing courses, following the Portuguese normalization (APORBET, 1998). Based on each aggregate gradation, more four mixtures were used: two mixtures where the gradation curve is below and two mixtures where the gradation curve is above the gradation curve defined by the Portuguese normalization. These four gradation curves were defined by changing the amount of aggregates in the sieves with a dimension lower than 2.000 mm.

Thus, the gradation curve proposed by the Portuguese normalization for wearing courses was used to produce mix number 1 (more fines) to 5 (fewer fines), as presented in Table 1, and the gradation curve proposed by the Portuguese normalization for base courses was used to define mixes 6 (more fines) to 10 (less fines), as presented in Table 2.

Table 1. Aggregate gradations used for wearing course bituminous mixtures (0/14)

Sieve dimension (mm)	Percentage of material passing				
	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
19.000	100.0	100.0	100.0	100.0	100.0
12.500	84.0	84.0	84.0	84.0	84.0
9.500	71.3	71.3	71.3	71.3	71.3
4.750	55.4	55.4	55.4	55.4	55.4
2.000	36.4	36.4	36.4	36.4	36.4
0.850	30.6	29.7	23.7	24.7	22.4
0.425	27.0	25.5	15.6	17.2	13.3
0.180	15.7	14.0	10.5	9.3	7.1
0.075	8.7	6.9	7.4	4.3	3.3

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Table 2. Aggregate gradations used for base course bituminous mixtures (0/19)

Sieve dimension (mm)	Percentage of material passing				
	Mix 6	Mix 7	Mix 8	Mix 9	Mix 10
25.000	100.0	100.0	100.0	100.0	100.0
19.000	96.2	96.2	96.2	96.2	96.2
12.500	80.0	80.0	80.0	80.0	80.0
9.500	72.5	72.5	72.5	72.5	72.5
4.750	59.2	59.2	59.2	59.2	59.2
2.000	42.9	42.9	42.9	42.9	42.9
0.850	36.3	35.2	30.8	28.4	25.7
0.425	32.3	30.4	23.1	19.1	14.5
0.180	18.5	16.7	13.7	10.2	7.7
0.075	9.8	8.1	7.9	4.6	3.5

Binder and air-void content for all mixtures are presented in Table 3. For each mixture studied, the binder content (optimum) was calculated using a formula based on the specific surface of the aggregates.

Table 3. Binder content, binder/filler ratio and air-void content of the mixtures studied

Mix	Binder Content	Binder/Filler Ratio	Air-void Content	Mix	Binder Content	Binder/Filler Ratio	Air-void Content
1	6.0 %	0.69	1.3 %	6	6.0 %	0.61	4.9 %
2	5.8 %	0.84	2.9 %	7	5.8 %	0.72	7.4 %
3	5.8 %	0.78	1.2 %	8	5.8 %	0.73	4.0 %
4	5.4 %	1.26	5.0 %	9	5.3 %	1.15	6.6 %
5	5.2 %	1.58	7.7 %	10	5.1 %	1.46	10.8 %

The different void content of the mixtures studied is due to their different workability, because the compaction method was always the same. It is important to observe the air-void content influence in the results obtained (Sousa et al, 1998).

In the Table 3, it is also presented the Binder/Filler ratio, were the Filler was considered to be the material passed in the sieve with a dimension of 0.075 mm.

3. Stiffness and fatigue life

Four point bending beam tests were conducted according to the AASHTO TP 8-94. They are intended to simulate pavement distress due to traffic loads during its expected design life. They also determined fatigue life and stiffness modulus of the beams. Fatigue life is defined as the number of cycles until a 50% decrease of the initial stiffness of the test beam is achieved (Pais, 1999). Tests were undertaken at 25ºC and at 10 Hz frequency rate of loading. Stiffness was obtained for a strain level of 150E-6.

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Figure 1 presents stiffness modulus of all the bituminous mixtures studied as a function of applied frequency.

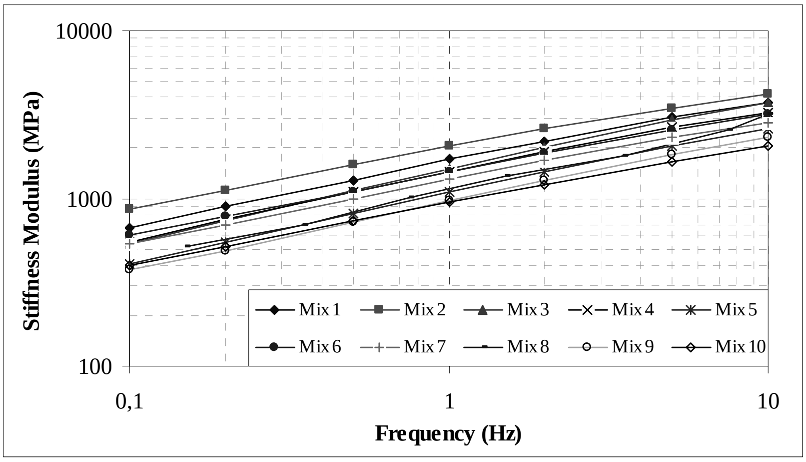

Figure 1. Stiffness modulus plotted against frequency (temperature = 25ºC)

In Figure 2 the stiffness modulus at 10 Hz is plotted to shows the ranking of studied mixes and it can be concluded that the increase of fines increases the stiffness modulus. The horizontal lines represent the average value for each type of mix.

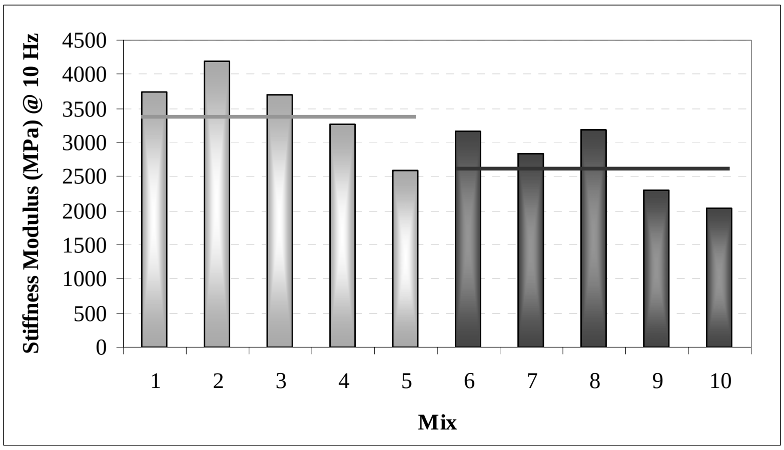

Figure 2. Stiffness modulus at 10Hz (temperature = 25ºC)

The ranking of the bituminous mixtures in the fatigue tests can be found in Figure 3 where the fatigue life at 100×10^{-6} is presented. The analysis of this figure shows that the decrease of fine aggregates increases the fatigue life.

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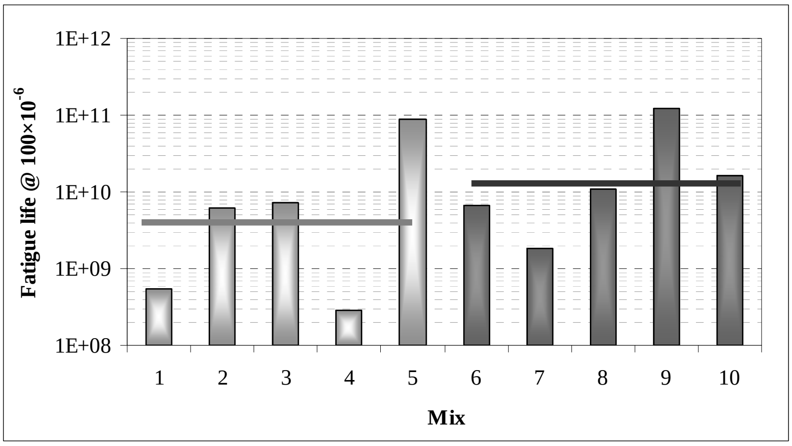

Figure 3. Fatigue life at a strain of $100x10^{-6}$ (temperature = 25ºC)

4. Tensile strength

The test used to evaluate the tensile strength of the bituminous mixtures was a simple tension test. The type of loading is like the one used to evaluate the asphalt-aggregate interaction. In Figure 4 it can be seen a specimen being tested in simple tension.

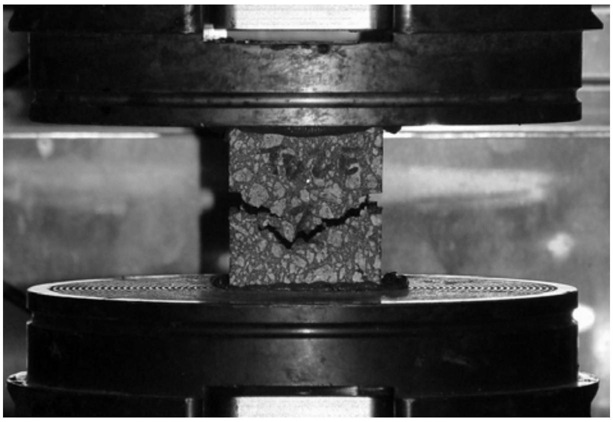
Figure 4. Specimen used in the tensile test being tested

In Figure 5, one can observe the typical result of a tensile test. The specimens were tested in simple tension at a constant deformation rate of 2 mm/min, quickly reaching rupture and the maximum value of resistance. The overall results of the tensile tests regarding the influence of mastic gradation are presented in Figures 6 and 7. The fact that these tests had been done in specimens prepared with bituminous mixture should be remembered.

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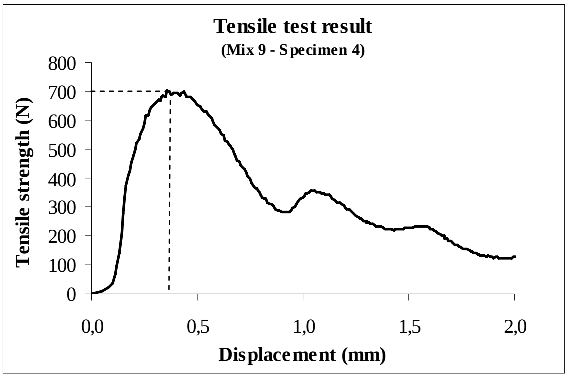

Figure 5. Typical result of a tensile test (temperature = 25ºC)

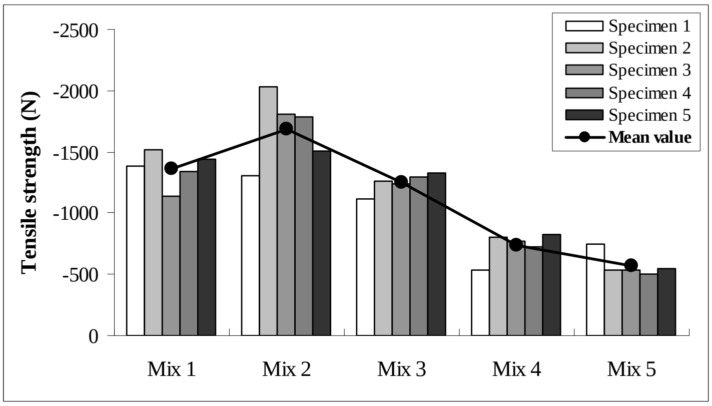

Figure 6. Results of the tensile test on the wearing course bituminous mixtures (0/14)

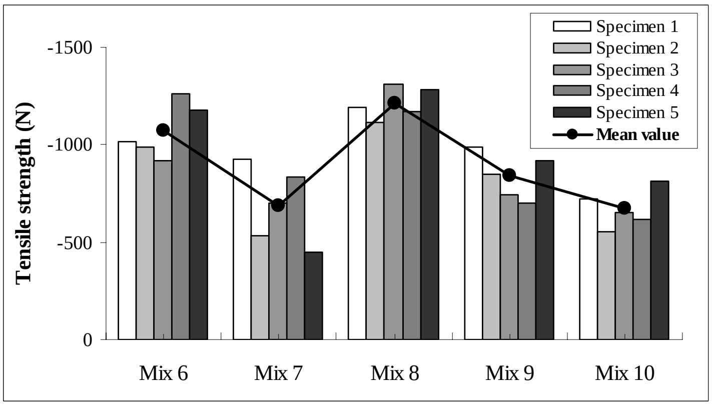

Figure 7. Results of the tensile test on the base course bituminous mixtures (0/19)

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The tensile test has been shown to be an option to predict the mechanical behaviour of a mix. The test reproducibility is good. The simplicity and speed of production and of test for a large number of specimens make this tensile test a good choice for evaluation and study of the mechanical behaviour of a mix. It was observed that the mixtures with higher mastic content (associated with elevated binder and fines content) had the bigger tensile strength.

Finally, the results obtained in the tensile test have been correlated to the stiffness modulus and the fatigue life of the corresponding mixtures, as shown in Figures 8 and 9. These correlation graphics correspond to the comparison between the results presented in Figures 2, 3, 6 and 7, and they will permit to analyse if the tensile test simulates accurately the mechanical behaviour of a bituminous mixture.

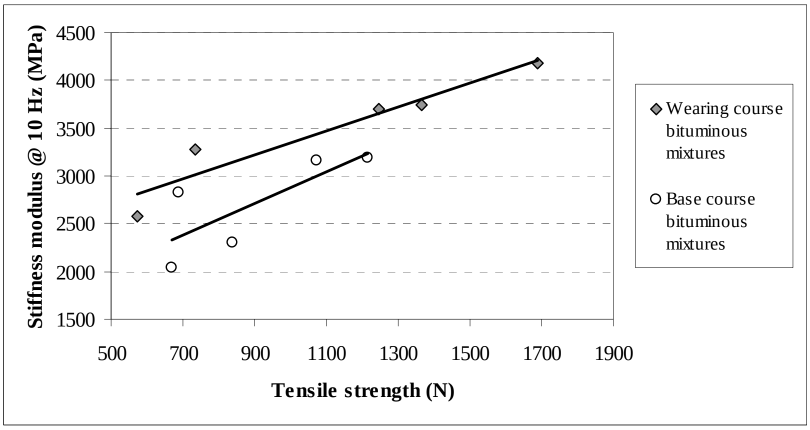

Figure 8. Correlation between the tensile strength and the stiffness modulus

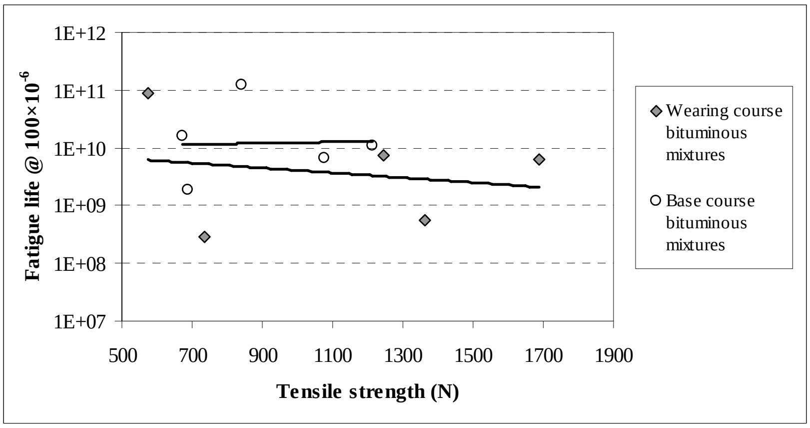

Figure 9. Correlation between the tensile strength and the fatigue life

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5. Conclusions

This paper presented an evaluation of fatigue and stiffness performance of bituminous mixtures with different aggregate gradations based on the ones proposed by the Portuguese normalization for wearing and base courses. Moreover, the results of a tensile test, similar to the one developed in the University of Minho to evaluate the interaction between the asphalt and the aggregates of a bituminous mixture, are also presented.

The comparison between the tensile test and the stiffness and fatigue tests allows us to evaluate the capabilities of the tensile test to investigate the influence of asphalt-aggregate interaction in the mechanical behaviour of a bituminous mixture.

From the analysis of each test and from the comparison between them, the following conclusions can be drawn:

- The increase of fine aggregates tends to increase the tensile strength and to decrease the fatigue life;
- The results of the tests are dependent on the air-void content of the mixtures: usually the reduction in the air-void content implies a better behaviour of the bituminous mixture;
- The correlation between the results of the tensile test and the stiffness modulus of the same mixture is very good;
- The correlation between the results of the tensile test and the fatigue life of the same mixture is poor;
- A repetitive tensile test will be developed, in the future, in order to simulate in a more accurate way the fatigue behaviour of bituminous mixtures.

6. References

1. di Benedetto, H. & de La Roche, C., “State of Art on Stiffness Modulus and Fatigue of Bituminous Mixtures” in *RILEM Report 17 – Bituminous Binders and Mixes*, (1998), 137-180.
2. APORBET, *Misturas Betuminosas. Contribuição para a Normalização do Fabrico e Aplicação*, Lisboa, (1998).
3. Sousa, J.B., Pais, J.C., Prates, M., Barros, R., Langlois, P. & Leclerc, A.M., “Effect of Aggregate Gradation on Fatigue Life of Asphalt Concrete Mixes” in *Transportation Research Board*, (1998).
4. Pais, J.C., *Reflective Cracking in Flexible Pavement Overlay Design (in Portuguese). Ph.D. Thesis.* University of Minho, Braga, Portugal, (1999).

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