[CI-25]

Sousa, J.B., **Pais, J.C.**, Pereira, P.A.A., Way, G.B.

"Mode of loading on flexural fatigue laboratory properties of conventional and asphalt-rubber mixes: a model validation"

6th International RILEM Symposium on Performance Testing and Evaluation of Bituminous Materials, Zurich, Switzerland, 2003, p. 364-371

Proceedings
PRO 28

Performance Testing and Evaluation of Bituminous Materials

PTEBM'03

Proceedings of the
6th International RILEM Symposium

Edited by M.N. Partl

RILEM Publications S.A.R.L.

Contents

SESSION 1: SPECIAL SESSION RILEM TC 182-PEB CONTRIBUTIONS

Moderator: Manfred N. Partl

SESSION 2: CHARACTERIZATION OF BITUMINOUS BINDERS AND MASTIC

Moderator: Ilan Ishai

SESSION 3: AGING

Moderator: Hussein Bahia

SESSION 4: BITUMINOUS BINDER-AGGREGATE INTERACTION

Moderator: Dariusz Sybilski

SESSION 5: MIX DESIGN
Moderator: Yves Brosseaud

SESSION 6: MODULUS
Moderator: Ann Vanelstraete

SESSION 7: FATIGUE

Moderator: Hervé Di Benedetto

SESSION 8: TEMPERATURE INDUCED CRACKING
Moderator: Ulf Isacsson

SESSION 9: PERMANENT DEFORMATION
Moderator: Chantal de la Roche

SESSION 10: FIELD AND ACCELERATED PAVEMENT TESTING

Moderator: Jorge Sousa

SESSION 11: STRUCTURAL PAVEMENT DESIGN AND MODELING

Moderator: Herald Piber

MODE OF LOADING ON FLEXURAL FATIGUE LABORATORY PROPERTIES OF CONVENTIONAL AND ASPHALT RUBBER MIXES: A MODEL VALIDATION

Jorge B. Sousa*, Jorge C. Pais**, Paulo Pereira**, George Way***

*Consulpav, **University of Minho, ***Arizona Department of Transportation,

Abstract

Traditionally the correct modeling and prediction of asphalt fatigue mechanisms, has relied on the use of the appropriate mode of loading in laboratory tests. The mode of loading chosen should, as closely as possible, reflect the mode of loading that causes crack propagation in the field. However recent formulations may be opening the door to the determination of key parameters from either mode of loading.

Fatigue characterization using any model must recognize that controlled load or displacement will induce significantly different fatigue lives in laboratory tests. When those lives must be correlated to actual field performance the magnitude and the accuracy of the shift factor is strongly affected by the mode of load selected in the laboratory material characterization phase.

Asphalt-Rubber Hot-Mix (ARHM) has shown a higher resistance to flexural than conventional Dense Graded Asphalt Concrete (DGAC). This paper presents the results of four point flexural fatigues tests performed under load and under displacement control on conventional and asphalt rubber mixes and investigates the applicability of an intrinsic damage law in light of the observed experience.

1. Introduction

The purpose of this paper is to investigate the applicability of a damage function for characterizing the reduction of the moduli during flexural fatigue tests. The basic data was obtained from four point flexural fatigue tests under stress and strain control for dense grade and gap-graded asphalt rubber mixes. The damage function was developed for homogenous tests and appears to be a promising tool to characterize the fatigue phenomena.

2 Material Properties

The aggregates used for the asphalt and asphalt rubber mixes were derived from Portuguese granite of good quality. It was graded to meet a dense gradation similar to that used in Arizona and California for the neat asphalt mixes. Similarly, the same aggregate was gap-graded in a manner similar to that used in Arizona and California for the (wet process) asphalt rubber mixes. The rubber used for the modification of the bitumen is supplied as crumb (ambient grind); the grading of the rubber presented in [Sousa, 2000]

The asphalt cement used were a PG 70-10 for the neat asphalt mixes. For the AR mixes, the PG 64-16 (also referred to as a 35/50 penetration asphalt) asphalt cement was interacted with 20% crumb rubber for one binder type referred to as the Arizona "Type A" AR binder. The binder content for the neat asphalt mix (DGAC) was 5% and for the AR gap-graded mix (ARHM) 8%, consistent with Arizona and California mix values derived from Marshall and Hveem mix designs respectively.

The material used in this study was crushed granite to which a 1% lime was added which is consistent with the use of this material. In the ARHM case, the bitumen was modified through the addition of 20% tire crumb rubber. The addition of rubber was achieved through a rotational mixer, at 180° C temperature and approximately 60 minutes reaction time. Compaction was done with a steel roller in a heating mould, in order to maintain compaction temperature as per AASHTO PP3-94: The compacted slabs were sawed and cored with the appropriate dimension for each type of test.

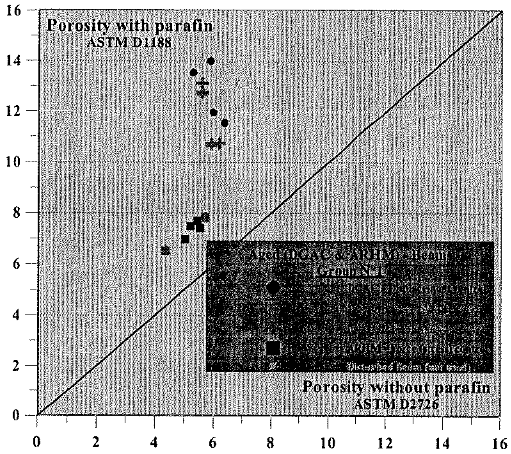

Figure 1 - Air void contents for the specimens tested (see Fig 3 for legend)

To determine flexural fatigue life, beam specimens of 380 mm long by 50 mm thick by 63 mm wide (15 inches, 2 inches, 2.5 inches) were used. The specimens were submitted to bulk density tests, with and without paraffin, respectively in accordance with ASTM D 1188-96 and - ASTM D 2726 -96a.

The theoretical maximum density test at 25°C (ASTM D 2041-95) was executed in order to determine air void content. The influence of paraffin on porosity for beam specimens is represented in Figure 1 for all mixes. The Hot Mix Asphalt (HMA) was submitted to short-term aging to simulate the pre-compaction phase of the construction phase, and the specimens were subjected to long-term aging to simulate the aging that occurs over the service life of a pavement (AASHTO PP2-94: Standard Practice for Short and Long Term of Hot Mix Asphalt (HMA)).

3. Mix Properties and Flexural Fatigue Tests

ARHM and DGAC specimens were submitted to the Long Term Oven Aging (LTOA) procedure, consisting of maintaining the specimens in an oven, at 85°C for a 5-day period. Flexural fatigue tests were conducted according to the AASHTO TP 8-94 (Standard Test Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending). Fatigue Life is defined as the number of cycles until a 50% decrease of the initial stiffness of the test beam is achieved. Tests were executed at 20°C and at 10 Hz frequency rate of loading.

Two types of testes were executed. One under controlled displacement where the amplitude of the displacement imposed is kept constant throughout the test. The other mode required a special modification to the ATS program (Automated Testing System from SHRP Corporation). If a test is executed under controlled load them the specimen is forced to accumulate permanent deformation (either in tension or in compression depending on the load). Because failure modes must be isolated, and in this case the investigation was based only on fatigue, it was necessary create a software control algorithm that would permit application of always the same load even when the fatigue damage was occurring while forcing the specimen to return to its original position. This was achieved by executing the test always under control displacement (therefore programming the sine wave to return always to the initial position) but the magnitude of the sine displacement was changed (increased) at each cycle to ensure that the amplitude of the load remained constant (as the modulus decreased). The typical results of the test are presented in Figure 2 for a DGAC mix. It can be observed that as the stress was maintained constant (with an acceptable tolerance level programmed into the software) the amplitude of the strain (displacement) was always increasing. It can be observed that the magnitude of the modulus decreased and the phase angle increased as expected.

4. Effect of Mode of Loading on Fatigue Performance

Figure 3 and 4 presents a summary of displacement-controlled tests and load controlled test plotted against the strain at cycles 100 (in displacement control tests that same strain was maintained while in the load control tests that strain was progressively increasing).

These results indicate that in this case the effect of mode of loading is not very prominent on the relative **ranking** of the mixes. Although displacement controlled tests actually lasted longer then load control tests, as expected, for both types of mixes, the relative raking was identical.

The effect of the air void content on these mixes must be considered when comparing these results with all others. The asphalt rubber mixes had extremely low air void contents while the dense graded mixes had high air void contents (see Figure 1).

However it is clear that asphalt rubber mixes out perform dense grades mixes in these testes by factors of 10 to 30 even at low strain levels (strain levels are reported from peak to peak amplitudes).

5. Fatigue damage function

A new method has been under developed to determine the fatigue damage of bituminous mixtures [Di Benedetto et al. 1996&1997], [Ashayer Soltani, 1998]. The method is based on the results of a sinusoidal cyclic loading test either in stress control or strain control.

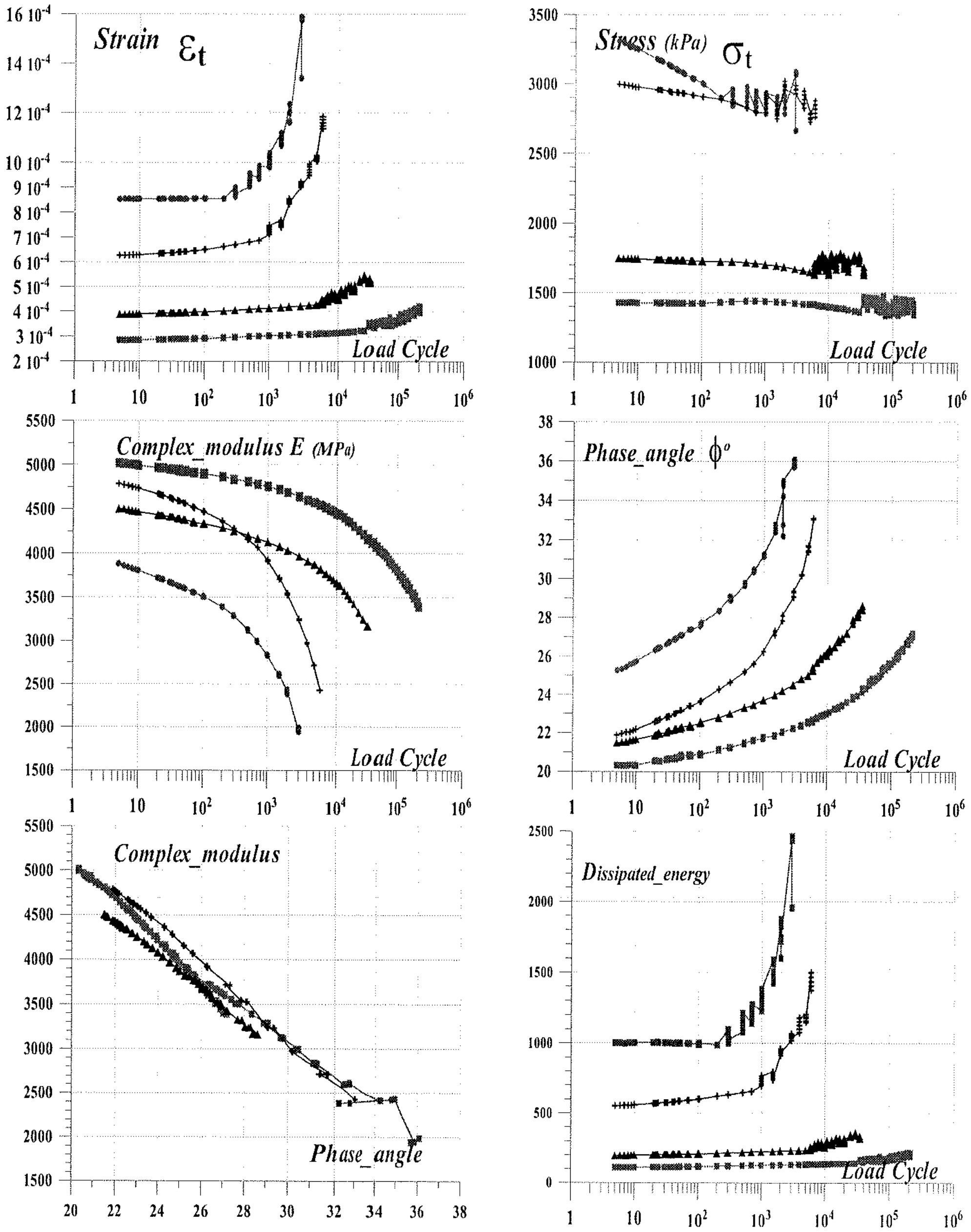

Figure 2 - Typical results of load controlled tests (AHRM)

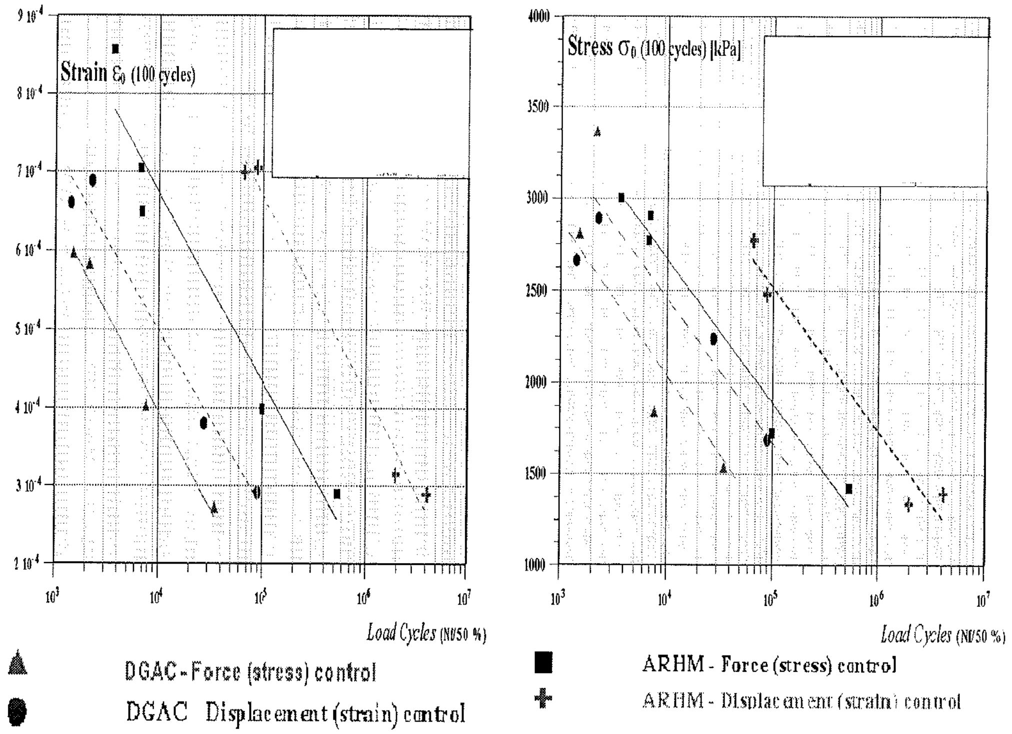

Figure 3 - Flexural fatigue results plotted against the initial strain and stress

The characterisation method is based on the computation of the rate of damage per cycle, which is corrected from the effects not related to fatigue (such as heating, thixotropy,...). It is expected to give, for each test, the true fatigue damage per cycle in function to the strain amplitude for a considered interval of cycles. These values are expected to give an intrinsic fatigue characterisation within that interval

The key aspect of this methodology is the determination of an intrinsic damage fatigue parameter, which is a function of the strain level, that determines the rate of moduli degradation with the number of cycles after taking into consideration that part of the rate of decrease in moduli that is a function of heat build up, healing, thixotropy etc). The purpose of this paper was to investigate the applicability of those concepts to the four point flexural fatigue tests executed under stress and strain control for dense graded mixes and for asphalt rubber mixes.

This approach has been evolving in terms of the methods by which the parameters are determined and the interval range where uniform (linear) rate of damage occurs. In the [Di Benedetto, 1996] paper a a0 parameter is determined based on the variation of the E moduli. On the most resent methodology [Baaj, 2002] a aF parameter is proposed computed taking into account the rate of energy dissipation variation with the number of cycles. The reader is invited to take advantage of the references to clearly understand how those parameters are computed. The reduced number of pages available for this paper does not permit the presentation of the formulas.

Figure 4 a and b show the typical evolution obtained of the moduli and energy dissipated for a strain control test. Figures 5 c and d identify the linear range considered for the test.

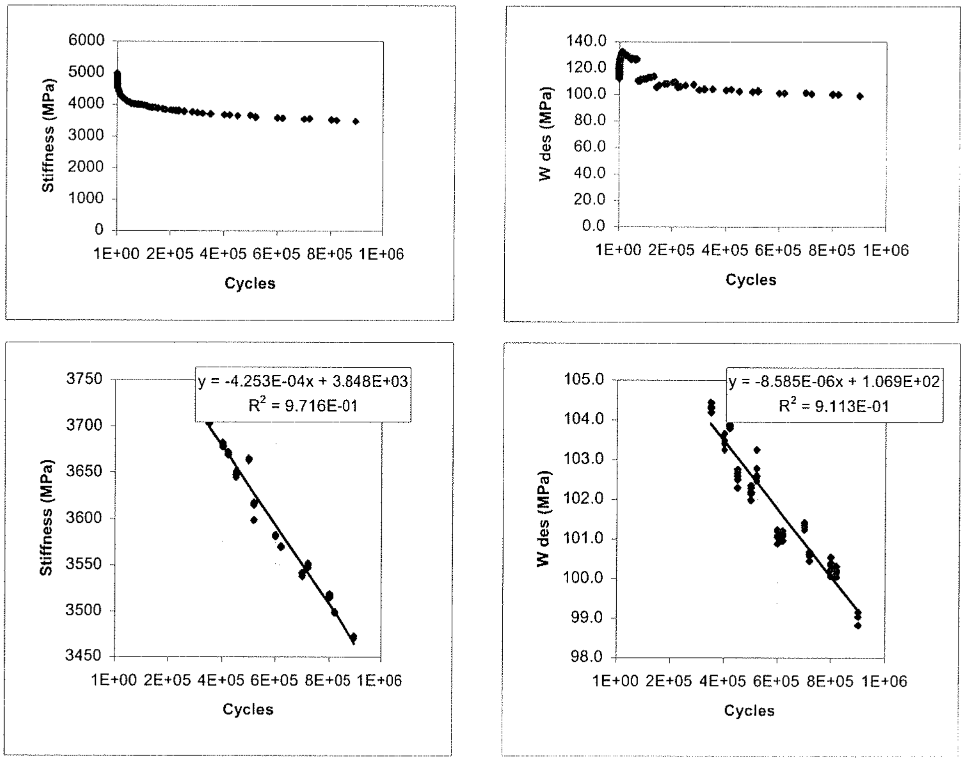

Figure 4 – Typical aspect of the linear range considered for the determination of damage

Based on the slopes of the best fit of those curves the ao and aF parameters were determined. From Figure 5 it can be identified that at low strain levels (low values of the parameter) both methodologies yield basically the same damage value. At lower higher strain values there are very small differences. As such in this analysis the latest approach proposed for the determination of aF was used.

The overall relationships obtained for stress and strain control for ARHRM and DGAC are presented in Figure 6.

It is clear that the aF parameter at high strain levels is very different for each type of mix. This is not surprising because AHRM has a much higher flexural fatigue life than the convectional mix and as expected the aF values are much lower indicating that at each cycle there is much less damage done to the mix. It is also apparent that globally the aF parameter from stress or strain tests are roughly identical (with some variability).

However the variability of the data may be caused by variations in air void contents on the beams tested.

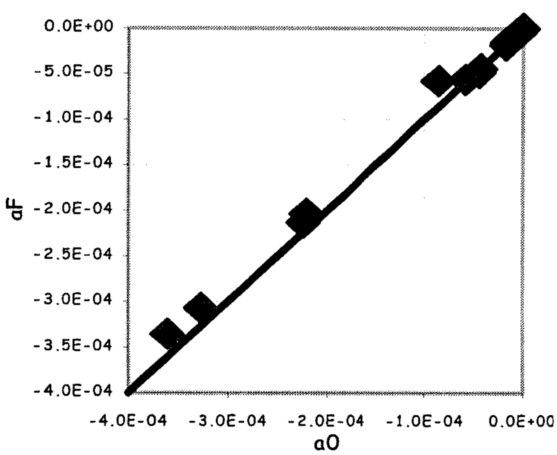

Figure 5 - Comparisons between aF and a0

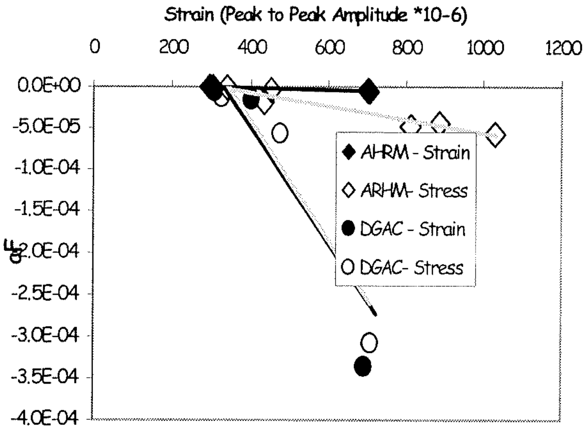

Figure 6 – Relationship between aF and peak to peak strain for all the tests.

However it was surprising to observe that around 270 micro strain (peak to peak strain). The aF parameters appear to become identical. If the values of aF are equal for two mixes at a given strain level it is to expect that they would have the same fatigue life at that strain level. It appears from this graph that at some point the two lines will cross indicating that at that strain level ARHM and DGAC would have the same fatigue life. However it is clear from Figure 3 that the trends indicate that even at a low strain levels (say 250 micro strain) AHRM would outperform DGAC. To investigate closer this aspect and assuming that the aF parameter from stress and strain test must be equal Figure 8 attempts to identify the trends of the lines based ONLY on low strain cycles (which lead to a high number of cycles before fatigue is reached therefore staying far form fast drop on moduli due to temperature effects). These results appear to confirm that in fact the values do **appear** to converge. However it is possible that the aF – Strain relationship may not be a linear function for each material and that the damage may not be linear with the number of cycles.

One of the apparent merits of this methodology was the possibility of defining the fatigue law of a material (reduction in E moduli) either in stress or strain modes of loading based on the equation aF-Strain.

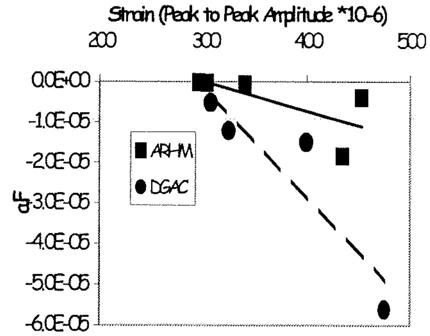

Figure 7 – Variation of aF with strain for low strain levels.

However if this relationship is not linear it will require extensive testing. Furthermore if the value of aF varies with the number of cycles (or the interval of cycles considered) this will require further fine tuning on the methodology before it becomes easy to use by practitioners.

6. Conclusions

Four point bending stress and strain control tests show that Asphalt Rubber mixes have 10 to 30 times better fatigue life than the conventional mixes tested. These results appear to indicate that further refinements need to occur in the damage concept before it can be made available for routine use.

7. Acknowledgements

The authors appreciate the help provided by Ad Pronk in the analysis process of the determination of the damage parameters.

8. References

Pais, J.C., Sousa, J.B., Way, G.B. and Stubstad, R.N. "An Overlay Design Method for Reflective Cracking", Asphalt Rubber 2000, Vilamoura, Portugal, 2000.

Sousa, J.B., Pais, J.C. and Stubstad, R.N. "Mode of loading in reflective and flexural fatigue cracking" *Fourth Internat. Conference on Reflective Cracking*, Ottawa, 2000.

Di Benedetto H., Ashayer Soltani M.A. and Chaverot P., "Fatigue damage for bituminous mixtures : a pertinent approach", Journal of the Association of Asphalt Paving Technologists (AAPT), 1996

Di Benedetto H., Ashayer Soltani M.A. and Chaverot P., "Fatigue damage for bituminous mixtures", RILEM, Mechanical tests for bituminous mixes, Lyon, may 1997, p263-270.

Baaj, H, Di Benedetto, H, Chaverot, P, "Fatigue of Mixes: An Intrinsic Damage Approach". RILEM 2002

Sousa, J.B, Pais, J.C., Rachid, S. "The effect of mode of loading on the comparison between asphalt rubber and traditional hot mixes laboratory performance", Asphalt Rubber 2000, Vilamoura, Portugal, 2000.