

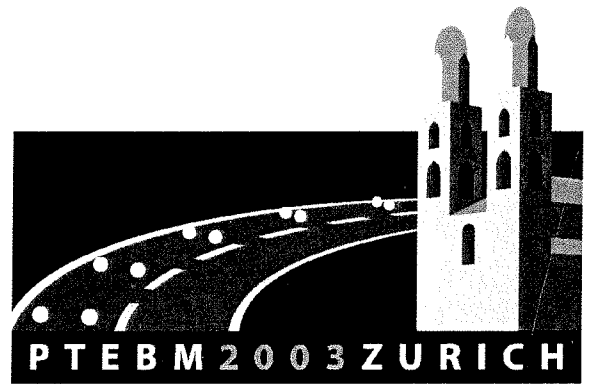
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“Mode of loading on flexural fatigue laboratory properties of conventional and asphalt-rubber mixes: a model validation”

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# Performance Testing and Evaluation of Bituminous Materials

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# Contents

<b>Preface</b>	XVII
----------------	------

## **SESSION 1: SPECIAL SESSION RILEM TC 182-PEB CONTRIBUTIONS**

**Moderator: Manfred N. Partl**

1. Activity of RILEM TC 182-PEB TG1 "Binders": 2 <sup>nd</sup> RILEM round robin test on binder rheology D. Sybilski and A. Vanelstraete	3
2. Fatigue of bituminous mixtures: different approaches and RILEM group contribution H. Di Benedetto, C. De La Roche, H. Baaj, A. Pronk and R. Lundström	15
3. RILEM - Interlaboratory tests on performance prediction of pavements H. Piber and M.N. Partl	39

## **SESSION 2: CHARACTERIZATION OF BITUMINOUS BINDERS AND MASTIC**

**Moderator: Ilan Ishai**

4. A new high-frequency torsional rheometer for bituminous binders L.D. Poulidakos, M.B. Sayir and M.N. Partl	59
5. Dynamic and transient testing of asphalt binder and paving mix L. Zanzotto, O.J. Vacin and J. Stastna	66
6. Precision of bituminous binder rheology tests in the 2 <sup>nd</sup> RILEM round robin test D. Sybilski and A. Vanelstraete	74
7. Performance evaluation system for bituminous binders A. Vanelstraete and W. Teugels	81
8. Rheological characterisation of some (polymer modified) bitumen and bitumen-filler system at compaction and in-service temperatures M. van de Ven and K. Jenkins	88
9. The use of direct tension tests for the assessment of low temperature properties of bituminous binders S. Largeaud, H. Raffegaud, B. Simaillaud, B. Eckmann, E. Sauger, S. Ollier, G. Hervé, L. Wendling, J. Pascot, J.C. Vaniscote and D. Chabert	95
10. Empirical and fundamental rheological properties of polymer modified bitumens G.D. Airey and B. Rahimzadeh	102

- |     |  |     |
|-----|--|-----|
| 11. | Evaluation of fatigue properties of bituminous binders<br>J.-P. Planche, D.A. Anderson, G. Gauthier, Y.M. Le Hir and D. Martin         | 110 |
| 12. | Rheological characterization of bituminous binder to predict pavement rutting<br>Y. Le Hir, D.A. Anderson, J.-P. Planche and D. Martin | 117 |
| 13. | Practical test methods for measuring the zero shear viscosity of bituminous binders<br>J. De Visscher and A. Vanelstraete              | 124 |

### **SESSION 3: AGING**

**Moderator: Hussein Bahia**

- |     |  |     |
|-----|--|-----|
| 14. | Accelerated aging tests for asphalt concretes<br>Y. Hachiya, K. Nomura and J. Shen   | 133 |
| 15. | Testing of performance properties of asphalt mixes for thin wearing courses<br>J. Judycki and P. Jaskuła   | 141 |
| 16. | Effectiveness and durability of rejuvenating agents<br>I. Schiavi, M. Nunn, C. Nicholls and P. Chambers  | 148 |
| 17. | Development of a new methodology for characterization of polymer modified bitumens ageing by infrared microspectrometry imaging<br>V. Mouillet, J. Lamontagne, F. Durrieu, J. Kister and D. Martin | 153 |
| 18. | Development of an accelerated durability assessment procedure for high modulus base (HMB) materials<br>G.D. Airey, Y.K. Choi, A.C. Collop and R.C. Elliott   | 160 |
| 19. | Short- and long-term ageing of bituminous binders - Simulation with RCAT method<br>A.F. Verhasselt   | 167 |

### **SESSION 4: BITUMINOUS BINDER-AGGREGATE INTERACTION**

**Moderator: Dariusz Sybilski**

- |     |   |     |
|-----|---|-----|
| 20. | The influence of aggregate on moisture susceptibility in terms of asphalt-aggregate interactions<br>S.-C. Huang, J.F. Branthaver and R.E. Robertson | 177 |
| 21. | Adhesive activity of bitumen with adhesion agent and its influence on asphalt concrete water-resistance<br>V.A. Zolotarev and A.A. Pissanko         | 184 |
| 22. | Causes of premature ravelling failure of porous asphalt<br>J.L.M. Voskuilen and P.N.W. Verhoef  | 191 |
| 23. | Predicting the early life skid resistance of asphalt surfacings<br>W.D.H. Woodward, A.R. Woodside and J.H. Jellie                                   | 198 |

24. Comparison between tensile, stiffness and fatigue life test results  
H.M.R.D. Silva, J.C. Pais and P.A.A. Pereira 205
25. Investigation of problems in binder extraction from conventional and rubber modified asphalt mixtures  
O. Sirin and M. Tia 212

## **SESSION 5: MIX DESIGN**

**Moderator: Yves Brosseaud**

26. Influence of curing on cold mix mechanical performance  
J.-P. Serfass, J.-E. Poirier, J.-P. Henrat and X. Carbonneau 223
27. Evaluation of improved porous asphalt by various test methods  
S. Takahashi, L.D. Poulidakos and M.N. Partl 230
28. Study of the aggregate gradation for the pervious asphalt concrete  
L. Momm, E. Meurer Filho and L.L. Bariani Bernucci 237
29. Gyratory compaction: influence of angle on stability and stiffness characteristics  
N. Ulmgren 244
30. Comparison of Marshall and SUPERPAVE design methods, evaluation of wheel tracking test of asphalt mixtures designed by both methods  
M. Varaus 250
31. Semi-circular bending test to asses the resistance against crack growth  
R. Hofman, B. Oosterbaan, S.M.J.G. Erkens and J. van der Kooij 257
32. The spatial approach of hot mix asphalt  
M.F.C. van de Ven, J.L.M. Voskuilen and F. Tolman 264
33. Expression de l'incertitude sur les résultats d'essais dans les laboratoires routiers  
M. Saubot 271
34. The influence of fine aggregate on the bituminous mixture mechanical behaviour  
J.C. Pais, P.P.A. Pereira and L.G. Picado-Santos 278
35. Effect of asphalt film thickness on low temperature cracking and rutting  
Y. Tasdemir, T.S. Vinson and E. Agar 285
36. New developments in the PRADO volumetric mix design  
L. Francken, A. Vanelstraete, D. Léonard and O. Pilate 292

## **SESSION 6: MODULUS**

**Moderator: Ann Vanelstraete**

37. Comparison of analysis techniques to obtain modulus and phase angle from sinusoidal test data  
T. Pellinen and B. Crockford 301
38. Evaluation of the indirect tensile stiffness modulus test  
X. Carbonneau, Y. Le Gal and P. Bense 308

39. Permanent deformation and complex modulus : two different characteristics from a unique test M. Neifar, H. Di Benedetto and B. Dongmo	316
40. Determination of viscoelastic properties from the indirect tensile stiffness modulus (ITSM) test A.C. Collop and G.D. Airey	324
41. Viscoelastic linearity limits for bituminous materials G.D. Airey, B. Rahimzadeh and A.C. Collop	331
42. Surface roughness of asphalt concrete and its mechanical behavior L. Momm, C. De La Roche and F.A.A. Domingues	339

## SESSION 7: FATIGUE

**Moderator: Hervé Di Benedetto**

43. Assessing the potential in fatigue of a dense wearing course emulsified bitumen macadam H.A. Khalid	349
44. Flexural beam fatigue properties of airfield asphalt mixtures containing styrene-butadiene based polymer modifiers K. Newman	357
45. Mode of loading on flexural fatigue laboratory properties of conventional and asphalt rubber mixes: a model validation J.B. Sousa, J.C. Pais, P. Pereira and G. Way	364
46. Analysis of fatigue performance of asphalt mixtures. Relationship between toughness and fatigue resistance F. Pérez Jiménez, R. Miró Recasens and J. Cepeda Aldape	372
47. Prediction of the intrinsic damage during bituminous mixes fatigue tests D. Bodin, C. De La Roche, J.-M. Piau and G. Pijaudier-Cabot	380
48. Determination of fracture parameters of asphalt mixes by the repeated indirect tensile test F.O. Martínez and S. Angelone	387
49. Fatigue of mixes : an intrinsic damage approach H. Baaj, H. Di Benedetto and P. Chaverot	394
50. Asphalt material fatigue test under cyclic loading: the lengthening of samples as a way to characterize the material damage experiments and modelling Y. Lefeuvre, C. De La Roche and J.-M. Piau	401
51. Fatigue and healing characteristics of bitumens studied using dynamic shear rheometer X. Lu, H. Soenen and P. Redelius	408
52. Influence of rest time on recovery and damage during fatigue tests on bituminous composites D. Breyse, C. De La Roche, V. Domec and J.J. Chauvin	416

53. New approach for the fatigue characterisation of bituminous binders  
S. Tóth and R. Perlaki 424

## **SESSION 8: TEMPERATURE INDUCED CRACKING**

**Moderator: Ulf Isacsson**

54. Influence of polymer modification on low-temperature properties of bituminous binders and mixtures  
X. Lu, U. Isacsson and J. Ekblad 435
55. Test methods for the behavior of bituminous binders at low temperature  
R. Gubler, M.N. Partl, M. Riedi and C. Angst 442
56. Properties of bituminous mixtures at low temperatures and relations with binder characteristics  
F. Olard, H. Di Benedetto, A. Dony and J.-C. Vaniscote 450
57. Performance indicators for low temperature cracking  
H. Soenen and A. Vanelstraete 458
58. Fissuration à basse température des enrobés bitumineux - essai de retrait thermique empêché et émission acoustique  
S. Cordel, H. Di Benedetto, M. Malot, P. Chaverot et D. Perraton 465
59. Thermomechanical analysis of aged asphalt pavements at low temperature  
T. Pucci, A.-G. Dumont, H. Di Benedetto 473

## **SESSION 9: PERMANENT DEFORMATION**

**Moderator: Chantal de la Roche**

60. Non-uniqueness of micro deformation of asphalt concrete  
L. Wang and C.S. Chang 483
61. Model for forecasting ruts in rutting tester  
A. Szydło and P. Mackiewicz 490
62. Simple performance test for permanent deformation evaluation of asphalt mixtures  
K.E. Kaloush, M.W. Witczak and B.W. Sullivan 498
63. Laboratory testing to develop a non-linear viscoelastic model for rutting of asphalt concrete  
F. Long and C.L. Monismith 506
64. Complex modulus and creep susceptibility of asphalt mixture  
J.M.M. Molenaar and A.A.A. Molenaar 513
65. Asphalt flow improvers -a new technology for reducing mixing temperature of asphalt concrete mixes with high resistance against permanent deformation  
K.-W. Damm 520
66. Evaluating creep compliance of asphaltic paving mixtures using a hollow-cylinder tensile tester  
W.G. Buttlar and G.G. Al-Khateeb 527

67. Comprehensive material characterization of asphalt concrete in tension based on a viscoelastoplastic model  
G. Chehab, Y.R. Kim, M.W. Witzczak and R. Bonaquist 534

## SESSION 10: FIELD AND ACCELERATED PAVEMENT TESTING

**Moderator: Jorge Sousa**

68. Hot mix asphalt design prediction and field performance, an Arizona study  
G.B. Way, J. Sousa and K. Kaloush 543
69. Evaluation of the effect of tack coats. LCB shear test  
R. Miró Recasens, F. Pérez Jiménez and J.M. Borrás Gonzalez 550
70. Validation and refinement of the transportek wheel tracking test in the South African guidelines for hot mix asphalt  
F. Long and B. Verhaeghe 557
71. Permanent deformation and fatigue evaluation of asphalt concrete mixes  
J. T. Harvey, I. Guada, D. Hung, C.L. Monismith, F. Long 565
72. Asphalt mix design for Cape Town International Airport using scaled APT and other selected tests  
K. Jenkins, F.J. Pretorius, F. Hugo and R. Carr 573
73. Permanent deformations in asphalt concrete layers in Brazil  
F.P. Gonçalves, J.A. Ceratti and L.B. Bernucci 580

## SESSION 11: STRUCTURAL PAVEMENT DESIGN AND MODELING

**Moderator: Herald Piber**

74. Harmonised European test methods  
J.P.J. van der Heide and J.C. Nicholls 589
75. Development and use of functional asphalt tender specifications  
R.C. van Rooijen and A.H. de Bondt 596
76. Performance – Related testing of asphaltic plug joint systems in Germany  
C. Recknagel 603
77. Damage analysis for flexible pavements at high and low temperatures using visco-elastic hybrid FEM  
A. Moriyoshi, M.N. Partl, H. Denpouya and S. Takano 610
78. Resistance to crack-growth and fracture of asphalt mixture  
J. Molenaar, X. Liu and A.A.A. Molenaar 618
79. Determination of constitutive model parameters to simulate asphalt mixture response  
G.D. Airey, S.T. Dunhill and A.C. Collop 626



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

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\*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.

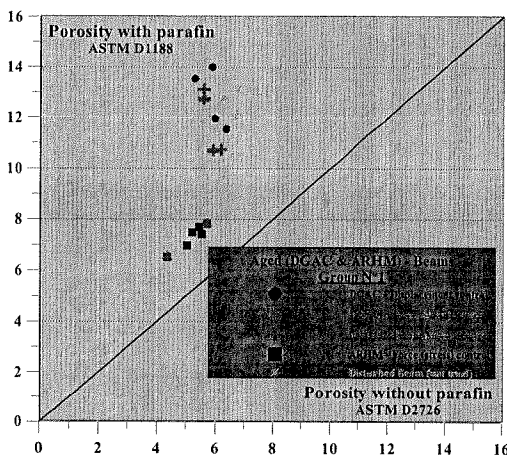
### **2 Material Properties**

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 then 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 than load control tests, as expected, for both types of mixes, the relative ranking 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.

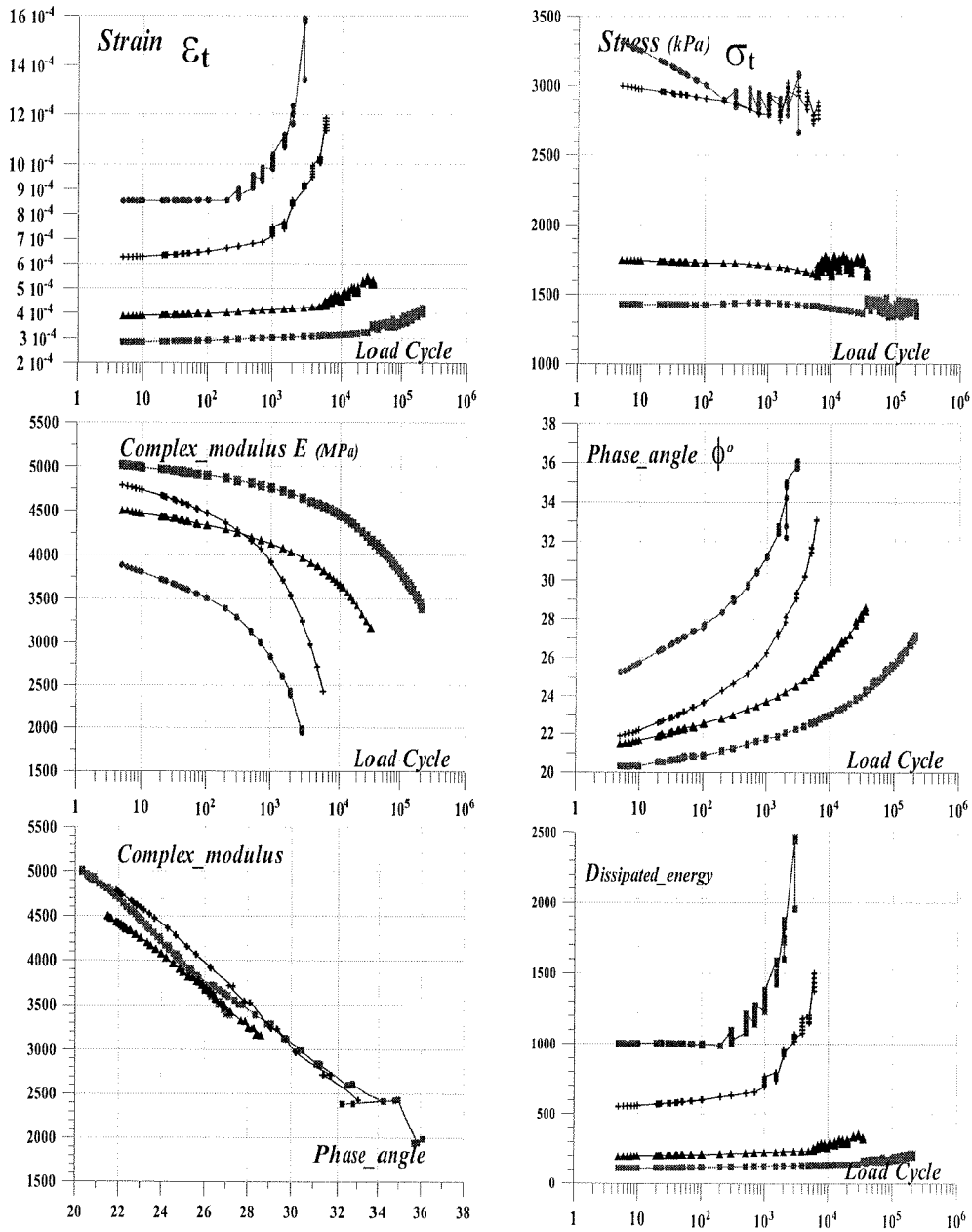
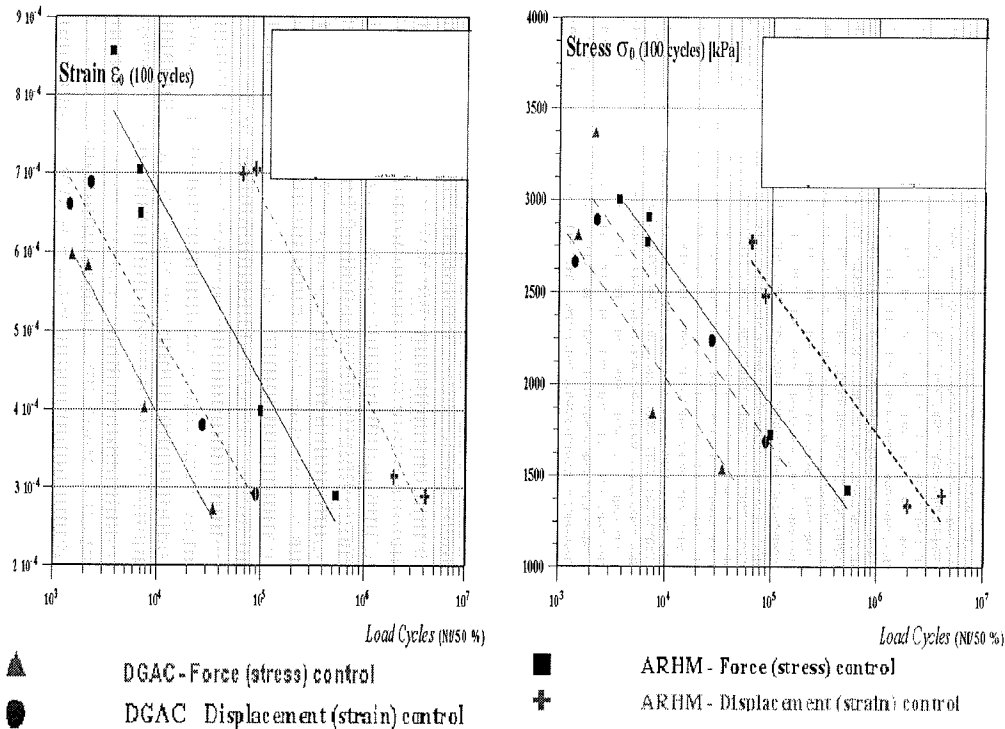


Figure 2 - Typical results of load controlled tests (AHRM)



**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  $a_0$  parameter is determined based on the variation of the E moduli. On the most recent methodology [Baaj, 2002] a  $a_F$  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.

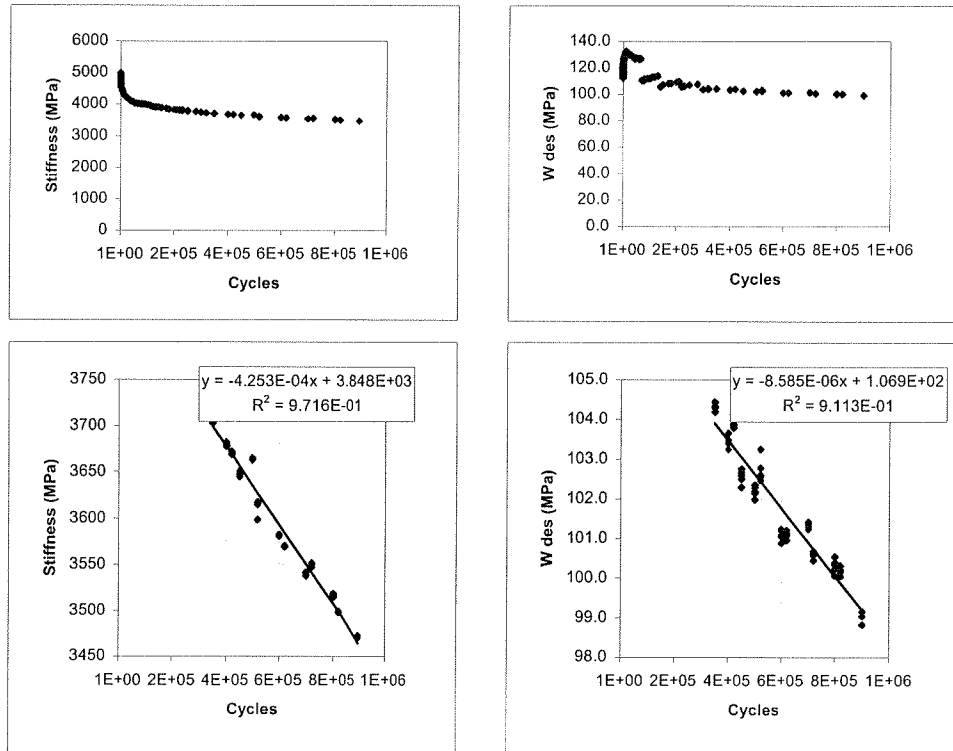


Figure 4 – Typical aspect of the linear range considered for the determination of damage

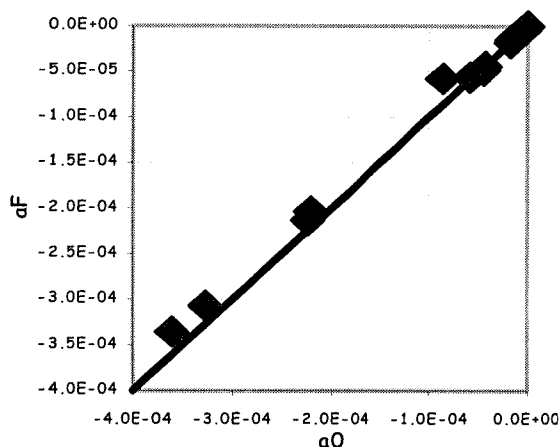
Based on the slopes of the best fit of those curves the  $a_0$  and  $a_F$  parameters were determined. From Figure 5 it can be identified that at low strain levels (low values of the parameter) both methodologies yield basically the same damage value. At lower higher strain values there are very small differences. As such in this analysis the latest approach proposed for the determination of  $a_F$  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  $a_F$  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  $a_F$  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  $a_F$  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  $a_F$  and  $a_0$



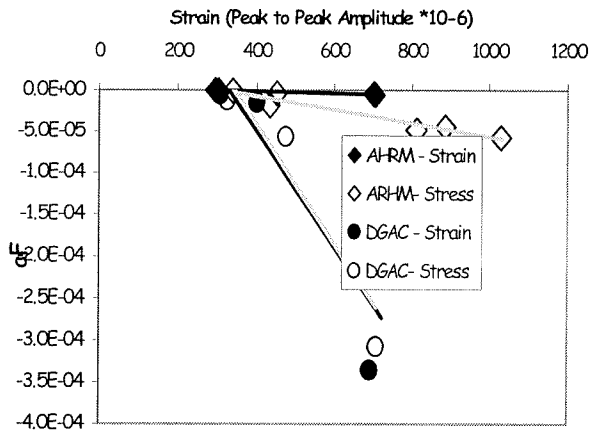


Figure 6 – Relationship between aF and peak to peak strain for all the tests.

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) ARHM 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 from 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.

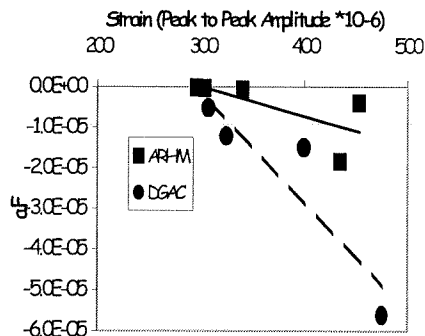


Figure 7 – Variation of aF with strain for low strain levels.

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.

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