Pais, J.C., Silva, H.M.R.D., Pereira, P.A.A., Picado-Santos, L.G.

“The influence of fine aggregate on the bituminous mixture mechanical behaviour”

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

Preface XVII

SESSION 1: SPECIAL SESSION
RILEM TC 182-PEB CONTRIBUTIONS
Moderator: Manfred N. Partl

1. Activity of RILEM TC 182-PEB TG1 "Binders": 2nd 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. Poulikakos, 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 2nd 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

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  
   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  
   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  
   J. De Visscher and A. Vanelstraete  
   124

SESSION 3: AGING  
Moderator: Hussein Bahia

14. Accelerated aging tests for asphalt concretes  
   Y. Hachiya, K. Nomura and J. Shen  
   133

15. Testing of performance properties of asphalt mixes for thin wearing courses  
   J. Judycki and P. Jaskula  
   141

16. Effectiveness and durability of rejuvenating agents  
   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  
   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  
   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  
   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  
   S.-C. Huang, J.F. Branthaver and R.E. Robertson  
   177

   V.A. Zolotarev and A.A. Pissanko  
   184

22. Causes of premature ravelling failure of porous asphalt  
   J.L.M. Voskuilen and P.N.W. Verhoef  
   191

23. Predicting the early life skid resistance of asphalt surfacings  
   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 Brosseauad

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. Poulikakos 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. Neifář, H. Di Benedetto and B. Dongmo

40. Determination of viscoelastic properties from the indirect tensile stiffness modulus (ITSM) test
   A.C. Collop and G.D. Airey

41. Viscoelastic linearity limits for bituminous materials
   G.D. Airey, B. Rahimzadeh and A.C. Collop

42. Surface roughness of asphalt concrete and its mechanical behavior
   L. Momm, C. De La Roche and F.A.A. Domingues

SESSION 7: FATIGUE
Moderator: Hervé Di Benedetto

43. Assessing the potential in fatigue of a dense wearing course emulsified bitumen macadam
   H.A. Khalid

44. Flexural beam fatigue properties of airfield asphalt mixtures containing styrene-butadiene based polymer modifiers
   K. Newman

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

46. Analysis of fatigue performance of asphalt mixtures. Relationship between toughness and fatigue resistance
   F. Pérez Jiménez, R. Miró Recasens and J. Cepeda Aldape

47. Prediction of the intrinsic damage during bituminous mixes fatigue tests
   D. Bodin, C. De La Roche, J.-M. Piau and G. Pijaudier-Cabot

48. Determination of fracture parameters of asphalt mixes by the repeated indirect tensile test
   F.O. Martínez and S. Angelone

49. Fatigue of mixes: an intrinsic damage approach
   H. Baaj, H. Di Benedetto and P. Chaverot

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

51. Fatigue and healing characteristics of bitumens studied using dynamic shear rheometer
   X. Lu, H. Soenen and P. Redelius

52. Influence of rest time on recovery and damage during fatigue tests on bituminous composites
   D. Breysse, C. De La Roche, V. Domec and J.J. Chauvin
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. Szydlo and P. Mackiewicz 490

62. Simple performance test for permanent deformation evaluation of asphalt mixtures
   K.E. Kaloush, M.W. Witzczak 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

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

69. Evaluation of the effect of tack coats. LCB shear test
   R. Miró Recasens, F. Pérez Jiménez and J.M. Borras Gonzalez

70. Validation and refinement of the transportek wheel tracking test in the South African guidelines for hot mix asphalt
   F. Long and B. Verhaeghe

71. Permanent deformation and fatigue evaluation of asphalt concrete mixes
   J. T. Harvey, I. Guada, D. Hung, C.L. Monismith, F. Long

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

73. Permanent deformations in asphalt concrete layers in Brazil
   F.P. Gonçalves, J.A. Ceratti and L.B. Bernucci

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

75. Development and use of functional asphalt tender specifications
   R.C. van Rooijen and A.H. de Bondt

76. Performance – Related testing of asphaltic plug joint systems in Germany
   C. Recknagel

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

78. Resistance to crack-growth and fracture of asphalt mixture
   J. Molenaar, X. Liu and A.A.A. Molenaar

79. Determination of constitutive model parameters to simulate asphalt mixture response
   G.D. Airey, S.T. Dunhill and A.C. Collop

Author Index
THE INFLUENCE OF FINE AGGREGATE ON THE BITUMINOUS MIXTURE MECHANICAL BEHAVIOUR

J.C. Pais, H.D. Silva & P.P.A. Pereira
University of Minho, Department of Civil Engineering, Portugal

L.G. Picado-Santos
Department of Civil Engineering of the University of Coimbra, Portugal

Abstract
The mechanical behaviour of a bituminous mixture is influenced by its composition. One of the compositional parameters that can change the bituminous performance in a pavement is the gradation of the fine aggregates. This paper presents the stiffness, fatigue and permanent deformation results of 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 less fine aggregates). All mixtures were produced and compacted in laboratory. Specimens for tests were obtained by cored and sawed from compacted slabs. For stiffness and fatigue, tests were executed on four point bending beam on controlled strain, whereas for permanent deformation tests were the repetitive simple shear test at constant height.

1. Introduction

One of main objectives of this paper is to understand in which way the fines gradation influences the bituminous mixture properties, namely the tensile fatigue and permanent deformation resistances of the whole bituminous mixture.

So, to evaluate the bituminous mixtures behaviour, standard fatigue and permanent deformation tests were executed on bituminous mixtures with different aggregate gradations.

2. Experiment design

2.1 Materials
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. Based on each aggregate gradation, more four mixtures were defined. 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 changing the amount of aggregates in the sieves #20, #40, #80 and #200.

Thus, the gradation curve proposed by the Portuguese normalization for wearing courses was used to produce mix number 1 (more fines) to 5 (less fines), as presented in Figure 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 Figure 2.
Figure 1. Aggregate gradation curve for wearing course bituminous mixtures

Figure 2. Aggregate gradation curve for base course bituminous mixtures

For each mixture studied, the optimum binder content was calculated using the formula based on the specific surface of the aggregates developed by Duriez (1950):

$$ t_b = \alpha \times k \times \sqrt[3]{\Sigma} $$

(1)

where $t_b$ = binder content; $\alpha$ = ratio between the bulk density of reference (2.5) and the real bulk density of the aggregates; $k$ = function of the binder content of the mixture and $\Sigma$ = depends on the grading curve of the aggregates. Table 1 presents the binder content for each mixture, given in percentage of aggregate weight.

Table 1. Binder content for the mixtures used in this study

<table>
<thead>
<tr>
<th>Mix</th>
<th>Binder content</th>
<th>Mix</th>
<th>Binder content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.0%</td>
<td>6</td>
<td>6.0%</td>
</tr>
<tr>
<td>2</td>
<td>5.8%</td>
<td>7</td>
<td>5.8%</td>
</tr>
<tr>
<td>3</td>
<td>5.8%</td>
<td>8</td>
<td>5.8%</td>
</tr>
<tr>
<td>4</td>
<td>5.4%</td>
<td>9</td>
<td>5.3%</td>
</tr>
<tr>
<td>5</td>
<td>5.2%</td>
<td>10</td>
<td>5.1%</td>
</tr>
</tbody>
</table>
2.2 Specimen preparation in the laboratory
To produce the specimens, the aggregates were heated at 178 °C and for the bitumen (PEN 50/70) the temperature was 150 °C. After mixing, the mixtures were placed in an oven at 135 °C during 4 hours to be subjected to the conditioning recommended by SHRP-A003A to simulate the aging during manufacturing (Tayebali, et al. 1994). The compaction was made with a lightweight vibratory steel roller. The air void content was measured in all specimens and the average for each mixture is presented in Table 2.

Table 2. Average air-void content for the mixtures used in this study

<table>
<thead>
<tr>
<th>Mix</th>
<th>Air-void Content</th>
<th>Mix</th>
<th>Air-void Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.3 %</td>
<td>6</td>
<td>4.9 %</td>
</tr>
<tr>
<td>2</td>
<td>2.9 %</td>
<td>7</td>
<td>7.4 %</td>
</tr>
<tr>
<td>3</td>
<td>1.2 %</td>
<td>8</td>
<td>4.0 %</td>
</tr>
<tr>
<td>4</td>
<td>5.0 %</td>
<td>9</td>
<td>6.6 %</td>
</tr>
<tr>
<td>5</td>
<td>7.7 %</td>
<td>10</td>
<td>10.8 %</td>
</tr>
</tbody>
</table>

3. Stiffness modulus and phase angle
The bituminous mixtures exhibit linear-viscoelastic behaviour as such that their response is time of loading and test temperature dependent. The material stiffness measures the ability to spread the traffic loads over an area.

The stiffness modulus and the phase angle were measured using a frequency sweep test. All the frequency sweep tests of this study were executed at a strain level of 150E-6, and at 10, 5, 2, 1, 0.5, 0.2 and 0.1 Hz.
In Figure 3 the stiffness modulus at 10 Hz is plotted to show 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 3. Stiffness modulus at 10Hz (temperature = 25 °C)
Figure 4 presents the phase angle at 10 Hz is plotted to show the ranking of studied mixes and it can be concluded that the increase of fines decreases the phase angle. The horizontal lines represent the average value for each type of mix.

![Phase angle graph]

Figure 4. Phase angle at 10Hz (temperature = 25 °C)

4. Fatigue life

One of the major modes of distress considered in the asphalt concrete pavement design is the fatigue cracking. When an asphalt pavement layer rests on an untreated aggregate base layer, the passage of a wheel load causes the pavement to deflect.

The resistance to fatigue of a bituminous mixture is the ability to withstand repeated bending load without failure. This form of distress manifests itself by the appearance of cracking in the pavement surface. The fatigue of a bituminous mixture has been directly associated with the repeated application of tensile stresses or strains and it is generally accepted that it can be very well evaluated by a four point bending test (Pais, 1999). Fatigue tests are performed imposing strain or stress repetitively until failure occurs. The fatigue life is characterized by the relationship between the strain level and the number of repetitions to reach the failure. The fatigue life of bituminous mixtures is influenced by several factors such as test temperature, frequency of applied loads. Aggregate gradation has an important effect on fatigue life as demonstrated by Sousa et al (1998).

To evaluate the bituminous mixture fatigue resistance, flexural fatigue tests were conducted according to the AASHTO TP8-94 (Standard Test Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending). They are intended to simulate pavement distress due to traffic loads during its expected design life. 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 25°C and at 10 Hz frequency rate of loading. Six fatigue tests were performed for each mix, three at a strain level of 800×10⁻⁶ and other three at 400×10⁻⁶.

The ranking of the bituminous mixes in the fatigue tests can be found in Figure 5 where the fatigue life at 100×10⁻⁶ (value obtained by extrapolation) is presented. The analysis of this figure shows
that the decrease of fine aggregates increases the fatigue life.

5. Permanent deformation

Permanent deformation in bituminous mixtures is primarily a plastic shear flow phenomenon at constant volume, occurring near the pavement surface, caused by the shear stresses occurring below the edge of the truck tires.

Also, intrinsically linked to this procedure is the assumption that most of the permanent deformation occurs on the hottest days with the heaviest trucks. This assumption stems from observations in the laboratory that bituminous mixtures exhibit strong plastic behaviour described by a plasticity function that exhibits kinematics hardening. This hardening seems to be associated with the capability of the mixture to develop better particle-to-particle contact as it develops shear strains, and with the capability of the aggregate skeleton to develop dilatancy forces that in turn are capable of developing stabilizing confining stresses (Sousa, 1994).

![Fatigue life at a strain of 100×10⁻⁶ (temperature = 25 °C)](image)

This phenomenon appears to be best captured by the RSST-CH executed at the highest 7 day pavement temperature at 5 cm depth. One of the advantages of this test is that it does not cause any change in volume in the specimen during testing. This is particularly important because a mix’s resistance to shear deformation should be measured with a test that does not cause any change in volume (densification or dilation) (Sousa, 1994).

The SHRP A-698 permanent deformation methodology to predict the accumulation of rut depth in asphalt concrete mixes was used and adapted, yielding the selection of adequate loading times, eventually to be used in the Repetitive Simple Shear Test at Constant Height for the prediction of rut depth.

RSST-CH testing was undertaken with 0.1 seconds loading times, plus a rest period of 0.6 seconds. For each bituminous mixture, 3 replicates were tested at 50°C. The magnitude of the loading pulse was set at 70 kPa. The test temperature was chosen to be representative of the maximum average seven day temperature at 5 cm depth.
A procedure to estimate the permanent deformation of asphalt concrete pavement based on the RSST-CH test was presented in the nomograph of the Figure 6. It is composed of four quadrants and it should be followed clockwise starting in Quadrant 1.

The procedure to estimate the permanent deformation starts by defining the rut depth level to be considered. The permanent shear strain, which is used to obtain the number of cycles in the RSST-CH, is calculated as following:

\[
\text{Rut depth (mm)} = 279 \times \text{Permanent Shear Strain}
\]  

The number of ESALs is calculated using the following model:

\[
\log (\# \text{ of cycles}) = -4.36 + 1.24 \log (\# \text{ of ESALs})
\]  

![Figure 6. Nomograph procedure to estimate rutting performance](image)

The permanent deformation results for all bituminous mixtures, expressed in number of ESALs to reach 12.5 mm rut depth, are presented in Figure 7. It can be concluded that, in this case, the permanent deformation was influenced by the air-void content. The increase of the air-void-content increases the permanent deformation.
6. Conclusions

This paper presented an evaluation of the stiffness, fatigue and permanent deformation performance of bituminous mixtures with different gradation of their fine aggregates based on the gradation proposed by the Portuguese normalization for wearing course and base courses.

From this analysis, the following conclusions can be made:

- The increase of fine aggregates increases the stiffness modulus and decreases the phase angle. So, the fines improve the performance and reduce the viscous behaviour of a mixture in the pavement.
- The decrease of fine aggregates increases 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 air-void content depends on the workability of the mixture. The binder and the fines contents change the workability properties of a mixture. So, the air-void, the binder and the fines contents are parameters very interdependent.

7. References