Maintenance and Rehabilitation of Pavements and Technological Control

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Edited by

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Preface

The sustainable maintenance and rehabilitation of pavements is becoming a key challenge in many countries in 21st century. It is well known that road and airfield pavement is the backbone of the economic prosperity and public welfare. But, the sustainability challenges pavement builders and managers to respond creatively to new and dynamic problems of rehabilitating and maintaining pavements in the most environmentally friendly manner by lowering energy cost, reducing traffic noise, and minimizing air and water pollution.

With sustainability as the main theme the **MAIREPAV5** (**MAI**ntenance and **RE**habilitation of **PAV**ements and Technological Control) conference was organized at the Canyons Resort in Park City, Utah, USA by the University of Iowa, from August 8-10, 2007. This is the **5**th International Conference in the series of conferences organized to allow researchers, government agencies, consultants and contractors to exchange technological advancements and innovations of building and maintaining longer-lasting road and airfield pavement. The first conference was held in São Paulo, Brazil by Mackenzie University in 1999, the second in Auburn, USA by the University of Mississippi in 2001, the third in Guimarães, Portugal by University of Minho in 2003, and the fourth in Belfast, Northern Ireland by the University of Ulster in 2005.

This book consists of papers presented at the MAIREPAV5 conference. The book includes two keynote papers on FHWA pavement and materials program and importance of good construction on reducing maintenance costs and eighty-eight peer-reviewed papers. Each paper was reviewed by at least two experts from the International Organizing and Scientific Committee. The final revised manuscripts were then reviewed by the editors to ensure compliance with the recommendations and suggestion made by the reviewers. The book is organized into fifteen sections based on the order of the technical sessions presented at the conference: asphalt pavement materials, concrete pavement materials, pavement construction, asphalt pavement performance modeling, concrete pavement performance modeling, pavement economic analysis, asphalt pavement rehabilitation, concrete pavement rehabilitation and recycling, pavement evaluation, asphalt pavement recycling I, pavement noise and safety, pavement management, asphalt pavement recycling II, sustainable pavement materials, and pavement preservation.

We would like to recognize the co-sponsors of MAIREPAV5: International Society for Maintenance and Rehabilitation of Transportation Infrastructure (iSMARTi), Federal Highway Administration (FHWA), Transportation and Development Institute (T&DI) of American Society of Civil Engineers (ASCE), Transportation Research Board (TRB), Korean Society of Road Engineers (KSRE), and Public Policy Center (PPC) and Civil & Environmental Engineering Department of the University of Iowa. We would like to record our indebtedness to distinguished members of International Organizing and Scientific Committee who have peer-reviewed papers and guided us to the success of this conference. Finally, we would like to thank authors who convened in Park City, Utah from all over the world to share their knowledge and experiences in building and maintaining pavements and their invaluable contributions to this book.

It was our honor and privilege to host MAIREPAV5 and edit this book.

Hosin "David" Lee / M. Asghar Bhatti

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Contents

CORRELATION BETWEEN MONOTONIC AND REPETITIVE TEST RESULTS IN BITUMINOUS MIXTURES

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Abstract: The pavement response to traffic repetitive loading is represented and evaluated more accurately in laboratory by using repetitive testing. However, the use of monotonic testing is very common to evaluate the behavior of bituminous mixtures and to control their quality when applied in pavements. Thus, the relationship between the results of monotonic and repetitive tests performed in this work is the main base of analysis of the accuracy of monotonic tests to assess the performance of bituminous mixtures *in situ*. Fatigue cracking and rutting are the main types of distress in flexible pavements in countries with warm temperatures. Initially, the behavior of several dense mixtures is determined by using normalized repetitive testing, namely bending beam tests in four points (fatigue) and repetitive simple shear tests at constant height (rutting). Then, similar mixtures are tested in a monotonic manner by using compression, tensile and shear testing. The monotonic tests are performed at different temperatures and strain rates, so as to reproduce a wide range of *in situ* conditions. The main conclusions result from the statistical comparison between the repetitive and the monotonic tests. Essentially, this work intends to evaluate the possibility of characterizing the performance of bituminous mixtures *in situ* by using the specific monotonic tests herein developed.

INTRODUCTION

The main objective of this work is to analyze the ability of the monotonic tests (tests carried out without load repetition, by applying a gradual and lineal increase of strength or deformation in function of time) developed in this work to evaluate the behavior of the bituminous mixtures, as well as some normalized tests which have already demonstrated their capability of evaluating the behavior of the bituminous mixtures *in situ*.

The requirement of "new" monotonic tests resulted from the specific conditions which must be represented, since the results of these tests were necessary as data entry for the numeric modelling of the behaviour of the bituminous mixtures. These tests also present other advantages, such as simplicity in the procedures and the low cost operations.

PROCEDURE FOR THE CHARACTERIZATION OF BITUMINOUS MIXTURES

The eight bituminous mixtures studied in this work (Silva, 2006) and the respective characteristics are presented in Table 1.

Table 1. Composition of the studied bituminous mixtures

Asphalt Mixture	HMA 1	HMA 2	HMA 3	HMA 4	HMA 5	HMA 6	HMA 7	HMA 8
% Passing #3/4”	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
% Passing #1/2”	83.7	83.7	83.7	83.7	83.7	83.7	83.7	83.7
% Passing #4	47.8	47.8	47.8	47.8	47.8	47.8	47.8	47.8
% Passing #10	32.5	32.5	32.5	32.5	32.5	32.5	32.5	32.5
% Passing #40	16.9	16.9	16.9	16.9	16.9	22.4	8.5	16.9
% Passing #80	9.4	9.4	9.4	9.4	9.4	13.3	4.9	9.4
% Passing #200	5.3	5.3	5.3	5.3	5.3	7.6	3.0	5.3
Binder content	5.2 %	4.4 %	5.9 %	5.2 %	5.2 %	6.5 %	3.2 %	5.2 %
Voids content	4.4 %	5.4 %	2.5 %	3.3 %	5.9 %	2.5 %	10.8 %	3.5 %
VMA	15.7%	15.0%	15.4%	14.7%	17.0%	16.5%	17.6%	14.9%
Binder pen grade	35/50	35/50	35/50	50/70	35/50	35/50	35/50	35/50
Filler source	Limestone	Limestone	Limestone	Limestone	Granite	Limestone	Limestone	Limestone
Aging	No	No	No	No	No	No	No	Yes

These mixtures were also used to analyse the influence of some parameters (aggregate gradation, binder content and penetration grade, filler source and aging) in the performance of a surface bituminous mixture (Silva, 2006), although it is not extensively presented here. In short, higher binder contents and softer binders increased fatigue life but reduced all other characteristics. The use of granitic filler is not desirable. The aging procedure improved the mixture performance. The “reference” grading curve for the dense mixture is the one with the greatest beaviour, and should not be changed for coarser or finner ones. Voids content values around 4 %, associated with VMA values around 15 %, are ideal for this surface bituminous mixture.

Monotonic Tests Developed in this Work

According to Airey et al. (2002), the response of a bituminous mixture depends on its stress state, and the straight relationship between a certain stress state and the respective response of the bituminous mixture must be determined by using tests carried out in a uniform stress state. Thus, it was determined that specimens of bituminous mixture with 5×5×8 cm^3 should be tested in a monotonic manner, in shear, tension and compression (Figure 1), by using a set of uniform stress states which allow the evaluation of the behavior of the bituminous mixture in several situations. These tests were carried out to obtain the minimum basic parameters required for the numeric constitutive modelling of the behaviour of the bituminous mixture.

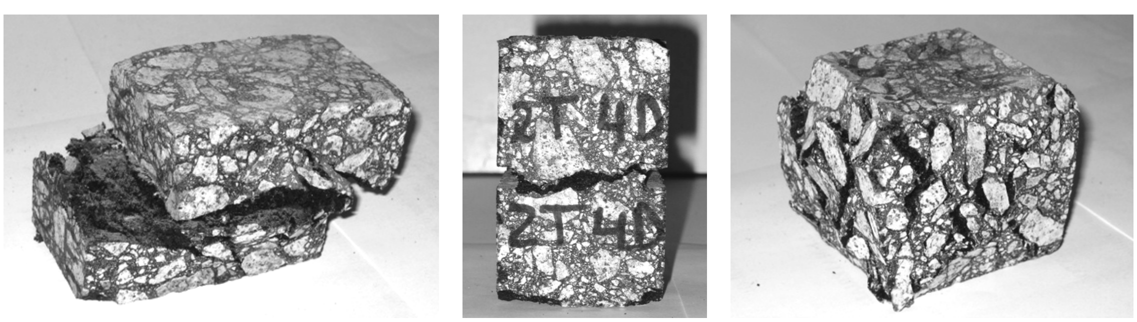

Figure 1. Specimens of bituminous mixture used in the monotonic tests

While tensile tests are related to fatigue cracking and compression tests to rut resistance, shear tests can be related to both phenomena. The main results obtained in the monotonic tests are the strength, the strain in rupture and the tangent modulus for the different tests configurations and bituminous mixtures. Figure 2 presents examples of the results obtained with the three types of monotonic tests used for the characterization of bituminous mixtures.

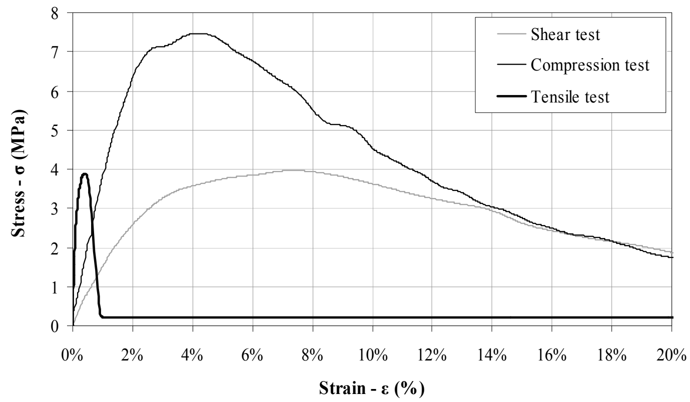

Figure 2. Stress-strain curves for the different types of monotonic tests carried out in this work

Repetitive Bending and Shear Normalized Tests

The normalized tests used in this work to verify the behavior of the bituminous mixtures analyzed previously with monotonic tests are the following:

- Repetitive four-point bending beam test for the evaluation of stiffness modulus (EN 12697-26) and fatigue resistance (EN 12697-24; Tayebali et al., 1994);
- Repetitive simple shear test at constant height (RSST-CH) to evaluate the shear modulus and rut resistance (AASHTO TP7-01; Sousa et al., 1994).

The 4-point bending tests were initially carried out at 15 ºC using frequencies of 10, 5, 2, 1, 0.5, 0.2 and 0.1 Hz to evaluate stiffness modulus. The procedures used in 4-point bending fatigue tests consisted of using cyclic loading at 20 ºC, in strain control (two strain levels of 300E-6 and 700E-6), by carrying out three repetitions for each strain level. Based on the number of cycles which caused the rupture of the specimen (reduction of the stiffness to 50%) and on the applied strain, six points related to the fatigue behavior of the bituminous mixtures are obtained. The best exponential fitting those points is the fatigue law of the bituminous mixture.

The shear modulus tests on the studied bituminous mixtures were carried out at 15 ºC by using frequencies of 10, 5, 2, 1, 0.5, 0.2 and 0.1 Hz. To obtain the rut resistance of the studied bituminous mixtures, RSST-CH tests were carried out by using repetitive loading at 50 ºC as it is stated in AASHTO TP7-01 provisional standard. The result of this test derives from the permanent shear deformation accumulated during the test and the number of equivalent ESALs.

RELATIONSHIP BETWEEN THE RESULTS OF MONOTONIC TESTS DEVELOPED IN THIS WORK AND REPETIVITE BENDING/SHEAR NORMALIZED TESTS

In this part of the work, the results of the monotonic tests (herein developed) are related to the results of the repetitive normalized tests in order to evaluate the confidence degree in the use of monotonic test results to study bituminous mixtures. Although all the results of the first group of tests can be crossed with those of the second group, this would not be logical because some tests evaluate completely different properties. Thus, comparisons were only established between tests which evaluate similar properties carried out on the same bituminous mixture. The relationships presented in this part of the work will assure the accomplishment of the objectives of this work.

Since the results to be compared were obtained by carrying out tests in very different conditions (monotonic tests and normalized tests with repetitive loading), the coefficients of correlation (R^2) will not be presented here, because they will be most likely low. Essentially, this work intends to verify if the monotonic tests herein developed can distinguish the behavior of different bituminous mixtures, like the normalized tests. Thus, the observation of the type of relationship between the results obtained in the two cases is enough for that purpose.

In Figure 3 it is presented the comparison between the shear strength of the studied bituminous mixtures, evaluated in monotonic tests at 15 ºC, and the dynamic shear modulus of the same mixtures, assessed in the RSST-CH at 15 ºC. An excellent relationship between both results can be observed. Thus, the monotonic shear tests developed in this work can accurately evaluate the behavior of bituminous mixtures in the pavement when submitted to shear loading.

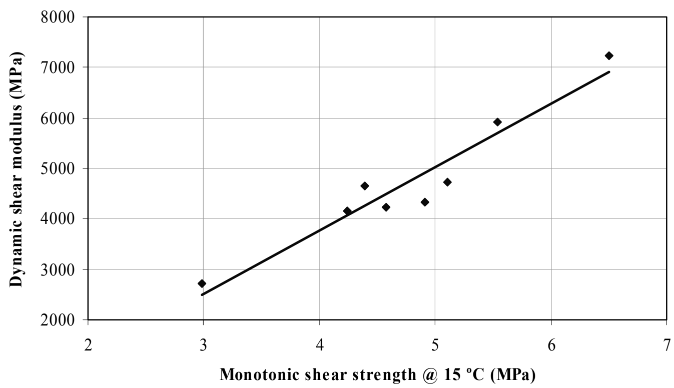

Figure 3. Monotonic shear strength and the dynamic shear modulus relationship

Figure 4 presents the relationship between the monotonic tensile strength at 15 ºC and the stiffness modulus of the studied mixtures obtained in 4-point bending beam tests at 15 ºC.

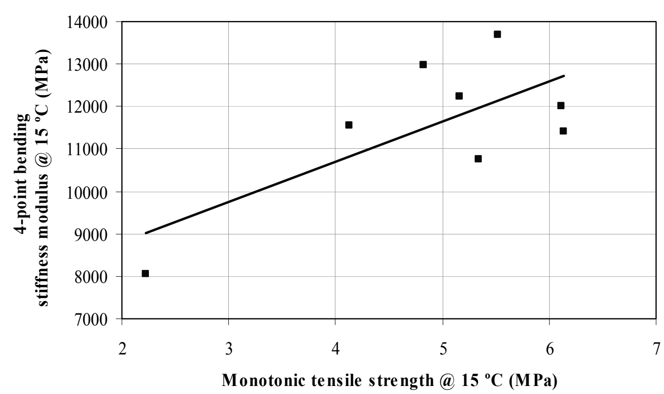

Figure 4. Monotonic tensile strength and stiffness modulus (4-point bending) relationship

Even without a high correlation between tensile strength and stiffness modulus, it is observed a direct relationship between the increase of the tensile strength of the studied bituminous mixtures and their stiffness. So, the monotonic tensile test is able to evaluate indirectly and in a fairly precise mode the behavior of mixtures submitted to tensile stresses *in situ*. The larger dispersion of the monotonic tensile test results derives from its greater sensibility to the strain rate used, thus justifying the development of this monotonic test in the future.

Next, the results of the monotonic compression and shear tests at 25 ºC are related to the results of the RSST-CH test at 50 ºC, in order to evaluate the rut resistance of the studied bituminous mixtures. The relationship between those results is presented in Figure 5. Although the monotonic tests have been carried out at a very low temperature to assess the rut resistance behavior of the studied bituminous mixtures, a good relationship can be verified between the monotonic tests and the RSST-CH test carried out at 50 ºC.

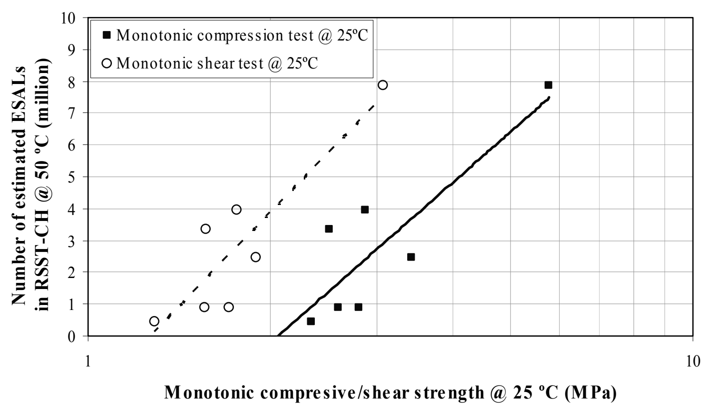

Figure 5. Monotonic compressive/shear strength and ESALs estimated in RSST-CH relationship

Concerning the two referred monotonic tests, the shear test had a better relationship with the RSST-CH test. This is easily understood, because of their greater similarity when compared with the compression test. Besides, direct relationships were observed between the increase of the compressive and shear strengths of the studied mixtures and the increase in the number of ESALs estimated in the RSST-CH test. Thus, the two monotonic tests carried out at 25 ºC can distinguish, approximately, the rut resistance of the bituminous mixtures studied in this work.

Finally, Figure 6 presents the relationship between monotonic tensile strength at 15 ºC and fatigue life obtained in 4-point bending beam tests at 20 ºC for the studied bituminous mixtures.

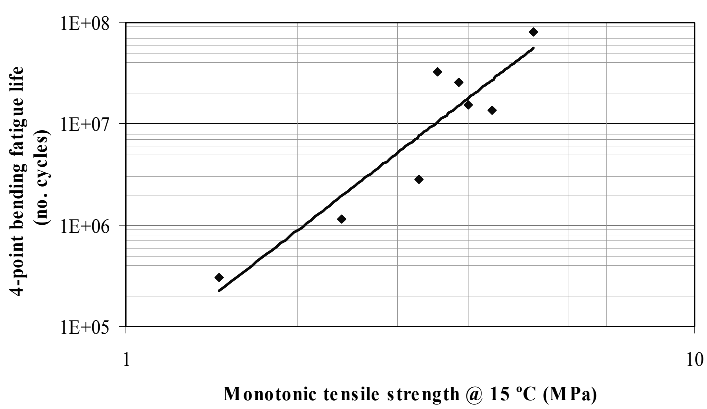

Figure 6. Relationship between monotonic tensile strength and 4-point bending fatigue life

The relationship between the tensile strength (the tensile strain/stress is the control parameter of the fatigue cracking phenomenon in the pavement design and in the study of bituminous mixtures) obtained in the monotonic test and the fatigue life obtained in the repetitive 4-point bending beam test is reasonable.

In fact, it is possible to establish a correlation between the results of these two tests, although some dispersion was observed. Thus, the monotonic tensile test developed in this work has some ability to distinguish the bituminous mixtures, concerning their fatigue cracking resistance.

CONCLUSIONS

In this work, normalized tests results were compared with results of monotonic tests herein developed, in order to validate the "new" tests implemented and their ability to distinguish bituminous mixtures with suitable or unsuitable behavior in the pavement.

Generally, a good relationship between the results of the monotonic tests developed in this work and the results of the normalized tests (repetitive 4-point bending beam test and repetitive simple shear test at constant height – RSST-CH) was observed.

It was concluded that the monotonic tests implemented in this work can accurately evaluate the behavior of the bituminous mixtures *in situ*, concerning the properties and the mixtures evaluated in this work. Thus, they can constitute a new test method to select the bituminous mixtures to be used in a pavement.

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